Main features and issues in the design of tall buildings in Bulgaria

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Abstract. In recent years, construction of tall buildings has been flourishing in many places around the world. In a considerable number of cases it is very much a matter of demonstrating financial and technological capabilities. Bulgaria is not isolated from these processes, mainly designing and building office, residential and hotel buildings with reinforced concrete structures. This requires systematization of information and experience in the design of tall buildings, as well as discussing the basic features and problems in the structural design of tall buildings and making recommendations based on existing experience and trends observed in the development of analysis methods and design. Basic issues related to height, architectural solutions, structural systems and other aspects that affect design solutions and problems related to these issues are discussed. The regulations related to the design of structures of tall buildings were commented on, with the main issues discussed mainly based on structural Eurocodes. The most important aspects of computer modeling of tall building structures and numerical analysis are discussed. Common problems related to the dimensioning and detailing of basic structural elements are commented. Finally, general recommendations are made for the research and design of tall buildings with reinforced concrete construction.

1. Introduction
Historically, the construction of tall buildings and facilities is not an end in itself. In the case of equipment - chimneys, towers, masts, the height is related to meeting certain technological requirements.

In the case of buildings, the construction of high-rise buildings is mainly related to the price of land in the center of large cities, and the implementation is also related to specific favorable conditions for construction - mostly appropriate geotechnical conditions. In all cases, it is necessary to have sufficient material and technical resources to carry out the construction. It is no coincidence that the very concept of skyscrapers for many years is associated mainly with cities in the United States. Even in the first few decades after World War II, very tall buildings were an exception, even in Europe's major cities.

In recent years, however, there has been a significant change in this regard. In many parts of the world, the construction of tall buildings is booming, becoming a kind of competition. In a significant number of cases, this is clearly a demonstration of financial and technological capabilities rather than a real necessity. Participation in such projects is a matter of prestige and a "business card" for investors, construction companies and design bureaus.

Bulgaria is not isolated from these processes. As a country with a relatively small population, which has historically been relatively evenly distributed in a large number of settlements, there was virtually no need to build tall buildings. Even in the capital Sofia until 20 years ago, there were very few tall
buildings. The very concept of a tall building has evolved over time. In the 1960s, 12-storey buildings were considered tall, then separate higher buildings began to appear. These were landmark buildings for the city, some of them with an experimental construction - the trade union house on Macedonia Square. In the 80s of the twentieth century, high-rise buildings in Sofia and other cities in the country can be specified – in Sofia these are the building of the trade unions, the Ministry of Transport, Energoproekt, Hotel Rodina, Park Hotel Moscow, Hotel Hemus. An iconic building is also the so-called then a "Japanese" hotel – New Otani designed by the famous architect Kurokawa. Three high-rise residential buildings have been built in the Iztok district for the needs of the diplomatic corps, three more at the beginning of Mladost district, as well as several other. In Varna these are the buildings of the Black Sea Hotel and the Municipality building, in Plovdiv - the Maritsa Hotel, in Burgas - the Bulgaria Hotel. Among the other tall buildings, the main examples are also hotels - "Kuban" in Sunny Beach, "International" in Golden Sands, "Dobrudja" in "Albena".

With the expansion of construction opportunities after the changes in 1989, there is a tendency to gradually increase the number of storeys of some newly built buildings, but until 2010 the criterion for a high-rise building remains in the range of 15-18 floors, i.e. up to about 50-60 m height.

2. Purpose of the paper
After 2012 and the revival of the real estate market after the economic crisis began the design and construction of buildings over 85-100 m, in some cases higher. It should be noted that the design developments in different phases of development of a project are probably currently about 10 times more than the buildings that are built or under construction. It should be noted the fact that some of these developments are adaptation projects developed in other countries and other conditions. The reasons for the lack of continuation and realization as construction of most of the project developments are complex, but the main ones are the following:

- difficult market realization with unclear prospects of properties in buildings of this size, whether for sale or rent;
- developer’s awareness of the scale of investment in the project development process;
- the relatively higher unit price of a built-up area in a tall building compared to that of "normal" construction, in some cases significantly higher;
- urban planning problems related to obtaining a construction permit for such buildings, especially in residential areas with high building density;
- problems related to transport access and maintenance of multi-occupant buildings;
- complicating and increasing the cost of installations.

The aim of the work is to systematize the information and experience gained in the design of tall buildings, as well as to discuss the main features and problems in the design of high-rise buildings and formulate recommendations based on experience and trends in the development of research methods and design.

3. Main aspects and factors that influence the design of tall buildings
The following main aspects are important in the design of tall buildings

3.1. Height
There is no clear and common definition of a tall building. Basic document related to urban planning [1] gives only general guidelines for building height. It defines as high construction all buildings taller than 15 m. As it is shown in [2] there are different criteria for the defining and measuring of tall buildings. One such criterion is the height relative to context that means that a building of given number of floors could be considered as tall in provincial city taken into account the local urban norm while the same building may not be considered a tall building in many big cities. Another criterion could be the aspect ratio. A slender building could give the appearance of a tall building even if it is not very high. The same source maintains that number of floors is not good indicator for defining if a building is tall.
because of different floor height in different buildings and due to different functions of floors. In spite of it a building of 50m or 14 or more floors could be considered as tall building [2]. The number of floors includes the main floors above ground, including the level of the ground floor and the floors of mechanical equipment and mechanical mezzanines with a significant area and does not include the floor levels with a significantly smaller area than the area of the main floors. Mechanical rooms above the general roof area should not be counted, too.

According to [3] tall buildings are those which height is 73 m (240 feet) or more. The Bulgarian Chamber of Engineers in Investment Design (KIIP) has created Technical counsel that works together with Sofia Municipality with the task for preliminary review and preparation of a technical statement about the structural design of tall buildings. As tall buildings are considered all buildings over 74m and those over 50m with irregular configuration in plan.

Heights and construction - in accordance with the traditional method of construction and height - heights from 90 to 130 m, and there are projects for 150, 180 and 200 meters of buildings.

3.2. Architectural designs

Experience shows that the main types of buildings that are designed in Bulgaria are office buildings and hotels. Those buildings are usually tower type.

Layouts of that type of buildings are presented on figure 1.

![Floor layouts of tower buildings](image)

Figure 1. Floor layouts of tower buildings.

Residential buildings are designed with more variety. Different layouts are presented on figure 2.
3.3. Structural systems

In high-rise buildings, it is necessary to make a clearer distinction than in conventional buildings of structural systems for resisting vertical and horizontal forces.

Usually in office buildings there is an aim for large bays as determined by the purpose, which implies a preference for flat slabs. Unfortunately such structures cannot be considered appropriate for tall buildings with regard to the horizontal loads.

The system resisting horizontal loads is of main interest when discussing the design of tall buildings. The height of buildings that are designed and constructed in Bulgaria so far defines the earthquake as the most important horizontal load. The main elements that provide the earthquake resistance of tall buildings are usually a combination of cores, shear walls (earthquake resistant walls). Some buildings do not include all those element types.

Floor structural layout of tower type of buildings is/are shown on figure 3
Figure 3. Floor structural layouts of tower buildings.

Floor structural layout of residential buildings is/are shown on figure 4.
Figure 4. Floor structural layouts of residential buildings.

Flat slabs are the floor structure, usually preferred by architects and developers for different reasons. All those reasons are not related to structural design considerations. On the contrary – from structural point of view flat slabs are not suitable for tall structures – they are thicker than slabs combined with beams and for that reason induce higher seismic forces at the floor level. Flat slabs are not ductile and they do not provide adequate stiffness, especially at the buildings’ contour. It should be noted that it is important to design beams at the facades, especially in tower type buildings.

The following key issues can be noted in this regard:

• application of traditional architectural solutions inconsistent with the height of the building
• insufficient peripheral stiffness associated with seismic behavior and building torsional stiffness
• application of prestressed slabs in order to reduce slab thickness.

Such design solutions are not recommendable because of structural and/or fire protection and durability considerations.

3.4. Legislation

Legislation is an important issue that affects the design of tall buildings.

In Bulgaria, as in most countries, there are no special regulations related to the design of tall buildings. Tall buildings usually fall into the category for which the design is required to be carried out in accordance with Eurocode system. The Eurocode itself was not developed with specifically for tall buildings. Rather, some specific guidelines in this regard can be found in Bulgarian norms [4]. For example buildings high "over 20 floors" or "over 30 floors" are considered in certain context. This is one of the reasons in practical applications to seek recommendations based on conclusions from comparisons of different standards, especially seismic ones, which are made in various literature sources, for example [5] it [6].

One of the tasks of the established Technical council to the Chamber of Engineers (KIIP) Sofia-city with the support of the Ministry of Regional Development and Public Works and Sofia Municipality is to deal with existing gaps in the legislation. A good example in this direction can be taken from [7].

It should be taken into account that the technical norms considering the design of tall buildings are not limited only to structural design. There are a lot of additional requirements that are imposed by architecture, greenery, roads, access to the building, fire protection, supply systems and other that can affect significantly the structure itself and shall be taken into consideration.
3.5. Computer modelling

There are a lot of important aspects of the computer modelling of buildings in general that are of particular importance for the modelling and analysis of tall buildings. Some of them are briefly mentioned below.

First of them is to choose the appropriate software. In spite of that not all the software for structural engineering is suitable for the analysis of tall buildings there are at least several popular commercial packages that are reliable and are used widely for the design of such structures. There are a number of important aspects of the creation of the computer model. It is important to start the modelling by carrying out thoroughly the regularity checks. The results from those checks as well the correct definition of the structural system of the building affect the value of the seismic forces that are used in the analysis.

Analysis and design of tall buildings must include developing a number of various computer models. In general, they can be described as follows:

- computer models for structural analysis of structures for vertical loads - these models are used for the design of slabs and for beams and columns that do not participate in the earthquake resistant system. It is recommended to develop and use both 2D and 3D computer models for the study of floor structures. This makes it possible to ensure the safety and the absence of defects in the elements of the floor structures, as well as to reduce the risk of damage due to deflections of slabs and / or beams.
- computer models for structural analysis of structures for horizontal loads - these models are used for the design of walls, cores and frames that create the earthquake resistant system.

The way the building is modeled in the computer model has a major impact on the obtained results. This applies to any building, but is very important in modeling the structure of tall buildings. Since the structure should be analyzed in consistent way a lot of important results and design checks need to be monitored simultaneously. Among the most important quantities to be controlled are the story drifts, the normalized axial forces in walls and columns and the quantities participating in the torsional flexibility checks. Design checks of at least the main structural elements should be carried out at every iteration.

The question of choosing a critical area remains open, especially in cases of lack of part of the basement walls.

The usual method for seismic response assessment, which is considered as reference analysis method, is by spectral response and modal superposition. In fact, a linear analysis is performed, which has many drawbacks.

The regulations recommend the use of various nonlinear methods, but in reality, the possibilities for using nonlinear analysis are limited. That application of nonlinear methods for the analysis of buildings is not sufficiently developed in the regulations from practical point of view, in particular with regard to the tall buildings. Anyhow it is highly recommended to carry out nonlinear analyses in order to compare the results that are obtained by different analysis methods and to compare those results in order to gain information and experience. Studies taking into account specific effects related to the calculation of structures of tall buildings and the application of appropriate nonlinear methods for them were performed in [8], [9] and [10].

3.6. General problems related to dimensioning and detailing

The problems related to dimensioning and detailing of the structural elements of high-rise buildings are the result of the high values of the internal forces in them, as well as the deficiencies or incompleteness of the technical norms.

Iterative analysis related to dimensioning and detailing of:
- reinforced concrete cores
- seismic resistant walls of rectangular, L, U and other complex cross section shape
- columns and beams as frame elements
is necessary in order to achieve compliance to the requirements of the regulations and to achieve safe and consistent design.
Foundation of tall buildings is another and relatively independent topic that is of particular importance for tall buildings, which goes beyond the scope of the article. Specific for tall buildings is the raft foundation, often combined with piles. There are a lot of specific issues regarding the computer modelling, detailing and construction of such foundations.

4. Conclusions and recommendations
Based on the observations and analysis, the following conclusions and recommendations could be formulated:

- tall building design and construction is area of intensive development;
- almost all tall buildings in Bulgaria are office or residential, and the structures are reinforced concrete. Specific studies and dissemination of knowledge about the analysis, design and construction of that type of buildings is important to improve the quality of engineering and buildings performance. Exchange of international and local experience and publication of recommendations based on scientific research and good practices is essential;
- there is insufficient experience in design and construction of tall buildings. The combination of local knowledge and traditions with modern methods of analysis, design and construction is the right approach to achieve better design and construction decisions. It is necessary to pay specific attention on right decision of the structural system, computer modelling and detailing;
- monitoring is important both in terms of the behavior of the building, and with regard to the accumulation of knowledge to enrich professional practice in the future;
- application of nonlinear methods for analysis should be expanded and comparison of the obtained results with those obtained by means of the reference methods should provide information both about the structural behaviour and also about the calibration of the parameters of the computer models used.

References
[1] Spatial Planning Act 2001 Republic of Bulgaria SG, amendments issue 21 2020
[2] Criteria for the defining and measuring of tall buildings 2016 CTBUH (Council on Tall Buildings and Urban Habitat) Illinois Institute of Technology Chicago, USA
[3] Moehle J, Bozorgnia Y and Yang T Y 2007 The Tall Building Initiative, Structural Engineers Association of California SEAOC 2007 Convention proceedings Squaw Creek, California, USA
[4] Ordinance № RD-02-20-2 of 2012 on the design of buildings and facilities in earthquake areas 2012 Republic of Bulgaria SG, issue 13
[5] Critical comparison of major seismic codes for buildings, Technical report 2013 fib Bulletin 69, CEB-FIP
[6] Santos S H C, Giarlelis C, Traykova M, Bucur C, Zanaica L and Lima S S 2017 Comparative study of a set of codes for the seismic design of buildings, 39th IABSE Symposium – Engineering the Future Vancouver, Canada
[7] Guidelines for performance-based seismic design of tall buildings 2017 TBI (Tall Buildings Initiative), ver. 2.03 PEER Report 2017/06, California, USA
[8] Traykova M, Boiadjieva-Marinova R and Traykov A 2015 Strengthening of existing RC frame in case of construction of additional floor, with account for the construction stages IABSE Conference, Geneva 2015: Structural Engineering: Providing Solutions to Global Challenges – Report pp. 1243-1247
[9] Traykov A and Boiadjieva R 2015 Computer Modelling of Structures with account of Construction Stages and Time Dependent Material Properties, J. of Civil Eng. Architect. Res. 2 (11) 1076-1085
[10] Bui D, Traykov A and Traykova M 2017 Shear lag effect and its effect on the design of high-rise buildings, High Rise Constructions 2017, Samara, Russia, E3S Web of Conferences 33, 02001