IOSUD - Universitatea Politehnica Timişoara
Doctoral School of Engineering Studies

OPTIMIZING THE SOLUTIONS AND TECHNOLOGIES USED FOR THE EXECUTION OF TALL BUILDINGS IN CONDITIONS OF HIGH GROUNDWATER

Doctoral Thesis - Summary
for obtaining the scientific title of doctor at
Polytechnic University of Timisoara
in the field of PhD Civil Engineering and Installations
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month 10 year 2022

The paper approaches at a theoretical and practical level the solutions found to solve the problems created by urban agglomerations, respectively the need to build tall buildings in order to minimize the built-up areas on the ground. In the practical case analyzed in this paper (the 20 floor block of the ISHO complex) it was mandatory to find a particular foundation solution beacuse of its height and considering the soil characteristics, respectively the presence of underground water.

Building A is currently the tallest residential building in Timisoara. Given that it is located in the vicinity of Bega river and the groundwater level is high, finding a foundation solution required increased attention and special customization. Duo to the field conditions resulted from the geotechnical study, but also to the other elements such as the height of the construction, its structure, etc., it was possible to establish one way to realize the foundation. The stiffnesses of the foundation system were analyzed as a whole, taking into account the cooperation and interaction between the infrastructure and the foundation land.

In **Chapter 1, "Introduction and general considerations"** of the thesis, a general presentation with the constructions progress in time was made. In this context, the tallest buildings in the world, in Romania and in Timisoara were presented. It was also described the way that materials evolution (durable materials such as: steel, iron or reinforced concrete) has allowed to create higher buildings (a chart with the tallest constructions over time is presented). This chapter also presents the need of vertical evolution on buildings (what impact does they have and how they influence people's everyday life). Currently, the tallest building in the world, located in Dubai (United Arab Emirates), is the Burj Khalifa, with a total height of 828 meters, but this trend is increasing because it has become a challenge to break this record.

Chapter 2 "General aspects related to constructions, buildings and structures" approach the importance of the building structural resistance, as well as the factors needed to be considered in order to choose a structural system. In this chapter, an introduction to constructions was made, in which was presented the 4 classes of constructions importance, the buildings were classified according to the way they behave in seismic actions, according to their plan shape, according to categories (residential buildings, social-cultural buildings, industrial buildings, respectively agricultural buildings).

A building is considered tall if it has more than 11 floors without a ground floor and very tall if the floor of the last level is at a minimum height of + 45 m.

Over time, structural systems have evolved and adapted to the needs of the population. In order to realize the buildings resistance structures, steel frameworks has began to be used, which allowed the development of the curtain glass walls, maximizing in this way the natural light from the office spaces and the homes becoming much brighter that in the cases of rooms with classic windows.

Depending on the purpose of the building, there are the following types of structural systems: structural systems in frames, systems with structural walls, respectively mixed systems (with reinforced concrete frames and structural walls).

In the 20 floor building studied in this paper, a dual structural system was used, consisting of the perimeter frames (formed of the closing beams and the facade pillars) and the structural walls of the central core (made of reinforced concrete). For the cast reinforced concrete elements, the respected work procedure (which was prepared previously) was presented, in which were related aspects about: making the formwork, mounting and checking the reinforcements, pouring and vibrating the concrete, concrete treatment after pouring. C30/37, C35/45 concrete classes and B500 reinforcement with B ductility class were used.

Chapter 3 "ISHO site analysis and synthetic presentation of geotechnical studies" presents the 2 site studies realized for the analyzed project located on the Bega river shore: a preliminary geotechnical study and a detailed geotechnical study.

In the case of the initial geotechnical study, the field research consisted of carrying out 6 dynamic cone penetration tests with a depth of 20 meters, 4 hydrogeological boreholes with depths between 10 - 25 meters and 4 geotechnical boreholes with depths of 20 - 50 meters. The analysis of the data from the field highlighted the fact that in the active area of the construction are soils with a medium to high compressibility. The purpose of the tests was to identify the stratigraphic sequences, to determine the physical and mechanical characteristics of the foundation land, but also to establish the execution and design conditions for the foundation works on the site. In the boreholes, groundwater was encountered at depths of 5.5-9.0 meters from the natural ground level. In this chapter was also presented the land stratification encountered in each individual drilling, together with the related topographical documentation.

The detailed geotechnical study was realized in order to be able to detail the geotechnical conditions from the site and to present the results obtained. As part of the geotechnical investigations, two Seismic Module Equipped Marchetti Flat Dilatometer Tests (SDMT), one Marchetti Flat Dilatometer Test (DMT) and eight Cone Static Penetration Surveys (CPT) were carried out. The stratification taken into account included the following seven representative layers: heterogeneous filler, dusty clay complex, sandy complex, clay complex, dusty sandy complex, dusty clay horizon, sandy horizon, clay complex. The conventional pressure value for layer I (dusty clay complex found between -2.66 m and -9.06 m) was chosen as $\bar{p}$conv = 150 kPa, based on NP 112-04.

Taking into account the geotechnical investigations realized, the foundation land was found to be in the "medium-difficult land" category. Due to the groundwater, the site was able to be classified as "with normal exhaustions". The detailed geotechnical study concluded that the analyzed site fit, in accordance with NP 074-2014, into geotechnical category 3 ("major geotechnical risk" class).

Chapter 4 " Using the exhaust systems in order to realize constructions in lands with a high groundwater level - general cases and particular case ISHO" approach the methods by which groundwater can be removed from the soil using an optimal exhaustion solution, but also the importance of executing a well-sized exhaustion system. The creation of an exhaustion system comes in the context of the need to lower the groundwater level in order to be able to carry out excavation work under safe conditions.

Choosing the most effective method of exhaustion is made according to: the dimensions of the excavation, the period of time in which the excavation remains open, the characteristics of the soil layers and the water pressure in each layer.

It’s mandatory to draw up a exhaustion project (which to contain at least a geotechnical study and a hydrogeological study) in cases where the underground water is higher than the lower level of the excavation.

In order to evacuate the water from the ISHO site, 13 boreholes were realized: 10 boreholes with a depth of 12 meters and 3 boreholes with a depth of 16 meters. Their positioning was represented schematically in figure 4.17.

Elaboration of hydraulic modeling using the specialized application PMWIN, in which the variants of the boreholes location, their number, as well as the necessary flow rates were studied, allowed to select the best variant in order to realize the exhaustion system for the presented case study, taking into account both of the execution possibilities from a technical and functional point of view, as well as taking into account the economic aspect (which was decisive in choosing the final option). By running the program, the levels and the transit flows in the studied location were obtained, which allowed the comparison of these data with the measurements actually made in the field. Obtaining similar results (from modeling with the values from the field) demonstrated the importance of realizing well-structured projects, drawn up with specialized modeling in advanced calculation programs prior to the execution of the works, since only in this way can optimization of costs be achieved and the most effective solutions found. The values obtained from the modeling coincided in 90% proportion with the values measured, which confirmed the fact that the model was well validated and calibrated.

Chapter 5 "Carrying out deep excavations in urban areas" defines the sources of risk that can arise when a deep excavation (bigger than 3 meters) is carried out in an urban area, but also how its execution influences neighboring buildings.

The first stage of any excavation is the design (in which the excavation dimensions in plan and its depth are established, the excavation solution is chosen and the exhaust system is determined), followed only later by the execution. During the execution, both the monitoring of the executed works and the following of the nearby constructions are mandatory.

In choosing the solution for excavation and protection of the earth bank, the characteristics of the foundation land, the site conditions, the neighborhoods and the climatic conditions of the area must be taken into account. The depth of the excavation is determined according to the number of underground levels that must be achieved and according to the foundation solution.

The shape of the 20 floor block in plan is an irregular trapezoid, with a built-up area of approximately 1,250 square meters. A depth of 4.30 meters (~+85.00 rMN) of the groundwater level compared to the elevation of the natural terrain was taken into account (it was also taking into consideration that ±1.00 m may vary depending on weather conditions). From the calculations, it turned out that an excavation depth of -8.00 meters from the excavation level and -8.58 meters in the area of the piles was required.

It was determined that the safe and stable execution of the excavation for building A should be carried out as follows: on the contour of the North, East and West sides, a slope with an incline of approximately 1:1 (protected with foil) should be created and on the South side, the protection should be ensured with the help of a Berlin support. The foundation system and the excavation realized under the protection of the Berlin support presented the guarantee that the resistance, stability and normal exploitation of the land massif adjacent to the support is not affected.

In this chapter were also described the stages of the excavation, as well as the way in which the monitoring works were carried out at block A.

Chapter 6 "Foundations" presents the types and the importance of the foundation solutions. The role of the foundations is to take over the loads from the superstructure and to transmit them to the good foundation ground. Thus, the category of land has an important role in choosing the foundation system. There are 2 categories of soils: cohesive (dusty soils and clay soils) and non-cohesive (blocks made from large pieces of rock, boulders, gravel and sand).

In order to establish the appropriate type of foundation, determinations are needed to reveal the characteristics and the mechanical properties of the foundation land. The type of foundation is directly influenced by the chosen structural system of the building.

The foundation depth is chosen depending on: the minimum constructive height of the foundation, the technological conditions of execution, the level of the underground water, the nature of the foundation land and the depth of the frost from the ground.

A foundation can be made from stone masonry, reinforced concrete or plain concrete.

There are 2 types of foundations: indirect foundations (for situations where the good foundation land is more than 6 meters away) and direct foundations (which can be under walls or under pillars; these foundations can be used only in good foundation lands which are at a shallow depth from the natural ground level). The types of indirect foundations are: foundations on columns, on caissons or on piles.

The foundation system chosen for the 20 floor block was a direct foundation on a 80 centimeter reinforced concrete raft in the area of the basement structure and an indirect foundation, on piles, placed under the 150 centimeter thick raft on the portion of the B+GF+20F structure (the stages of making the reinforced concrete raft can be seen in the photographic documentation presented in chapter 6.6). 34 piles (plus a test pile) were executed with a depth of 17 meters and a diameter of 108 centimeters. In the design of the piles, the soil-structure interaction of the foundation system was taken into account. The execution of the pilots was highlighted in the photographic documentation in subchapter 6.4.

Also within this chapter, a comparative calculation was made from a technical point of view, as well as from a cost (economic) point of view, which confirmed the fact that the execution of the foundation in the solution implemented in the construction site represented the optimal foundation option.

In order to verify the technology of making the piles according to the real situation in the field, a trial test was carried out on a pile with a diameter of d=1080 mm, additionally executed, with the same technology as the other piles. The bearing capacity of the foundation pile was verified through a test load at N2 level on an instrumented pile, test realized according to the NP 045-2000 standard. In subchapter 6.5, a photographic documentation is presented with the stages of making the test, as well as the values recorded by the pilot during the compression test.

This chapter also presents the solutions used for the foundation of the tallest building in the world (Burj Khalifa), respectively in Romania (Sky Tower). In these cases, similar to the ISHO situation, the buildings are located next to a watercourse. The foundation solution in the case of the 3 presented studies was based on the same principle, reinforced concrete raft and piles as a foundation solution, respectively an exhaustion system with boreholes used to lower the groundwater.

Uneven settlement of the land as a result of foundation solutions not adapted to the reality on the ground or the fact that the foundation did not reach the good foundation layer can lead to the appearance of cracks in the walls.

That is why, in the behavior of any construction, the foundation has a decisive role and no compromise should be made in design and execution. Special attention must also be paid to the protection of the foundation against various factors, but also to its waterproofing.

In the initial part of **chapter 7 "The importance of waterproofing works"** are presented the surfaces on which the waterproofings can be applied: on the infrastructure elements (foundations, floors, basements), respectively on the superstructure elements (wet rooms; balconies and loggias; terrace-type roofs) and the way in which they should be realized (certain provisions must be respected depending on the situation, provisions that are used in the case of overlaps or when the horizontal plan is joining with the vertical one). The following are used as waterproofing materials: bitumens, bituminous materials in rolls and bituminous masses prepared from bitumens. The types of materials used for waterproofing are: waterproofing materials in sheets, bituminous or polymeric.
The waterproofings used at block A are: temporary waterproofing on vertical elements used on the part of the building next to which, in the near future, another building will be built and so these temporary waterproofing will be replaced), permanent Armodillo waterproofing on vertical elements (on the basement walls) and waterproofing VOLTEX membranes used especially for foundations (for waterproofing the berline wall, under the raft of the building, under the raft of the pump house, for the waterproofing of drilled piles).
The quality of the waterproofing is obtained both by execution and by the way of maintenance. The condition of the waterproofing must be checked annually, usually at the beginning of summer. Maintenance is carried out whenever is necessary (once every 2-3 years for waterproofings that are up to 10 years old, at least once every 2 years for those that are 10-15 years old and annually if the waterproofings have been in operation for more than 15 years).

Chapter 8 "Description of the outer fire ring necessary for the operation of the A building from ISHO" analyzes the importance of creating an external fire system to serve the 20 floor building (without which the building wouldn't have received the approvals to be functional), but also the possibility of optimizing the system due to the fact that the block is located next to the Bega river.
It was necessary to find this solution for the pumping station because the water-sewage operator could not provide the necessary pressure and flow from the city's centralized system in order to supply the external fire hydrants and extinguish a possible fire.
The catchment basin for the fire ring works on the principle of communicating vessels: the water catchment system located on the right bank of the Bega canal leads the water through a sloped pipe to a basin that collects water. From this basin, in the case of a fire, water will be pumped using the pumping station. The hole intake water and the pipe used to transport water from Bega were sized for the flow rate of 25 l/s, in accordance with the P118/2-2013 standard. A metal grate was mounted at the intake to prevent vegetation debris or other debris to enter into the pipe and clogged it. The pumping station was built attached to the basement of block A, with the raft common, but it's an independent construction. The catchment outlet was made with the help of metal piles inserted into the Bega, from inside which the water was extracted with pumps and thus the execution was allowed. The photographic documentation from this chapter highlights the steps taken to create the fire system.

Chapter 9 "Urban planning to ensure the functionality of the ISHO development" aims to present the impact of the ISHO project on the neighboring area traffic, the recommendations which proceed from the traffic analyzes and the way to build the road in order to streamline the traffic.

For a rational circulation as a result of the residential development, it was necessary to build the access road network, as well as the bridge over the Bega, which is why this case study was also included in this paper.
For sidewalks and bicycle tracks, a resistance structure was adopted in accordance with the provisions of the NP 116-2005 Indicative ("Normative regarding the composition of rigid and flexible road structures for streets"). The arrangement of the sidewalks was carried out according to STAT 10144/2-91 and to Ind. P 132-93.
The importance category of the analyzed road section was "C" (works of normal importance), and the importance class III. The road was realized with four traffic lanes, bicycle tracks, sidewalks and has the purpose to ensure access between the European road Take Ionescu Boulevard and Splaiul Protopop Meleție Draghici street.
The concept for the bridge that will be later built over the Bega, which will connect the streets Splaiul Protopop Meletie Draghici and Splaiul Nistrului, was also presented.

Chapter 10 "Geotechnical monitoring of newly designed construction and nearby buildings" describes the importance of monitoring a construction over time so that it maintains its stability and safe operation throughout its design life. Monitoring over time is a periodic action that is carried out by: measurements of the settlement of the construction (using topographical methods), inclinometric measurements (through which displacements of the land massif are determined), measurements of the deformations of the foundation land (with the help of tasometers), measurements for determination of groundwater level (using exhaustion wells and piezometers). The measurements made during the execution period, but also those made during the construction's existence period must be kept in the Construction Technical Book. Within this chapter, the sketch with the location of the geotechnical monitoring works of the 20 floor block is also attached.

As a general conclusion, a building can be functional and safe only with adequate foundation solutions because, in addition to the related components that make the exploitation take place in optimal conditions, the foundation is the essential element of the resistance structure. Thus, for large-scale projects, the optimization of foundation solutions is the key to successful realized works. As was the case with the tallest buildings in the world, in Romania and in Timișoara, tall buildings can be obtained only by customizing the foundations to the situation on the ground.
Each construction and implicitly foundation element must satisfy a set of technical-economic requirements / main technical conditions regarding durability over time and structural robustness of the construction. For this reason, it’s a complex process to design and dimension each element of the resistance structure of a building.
The foundation is the support base of the constructions. It is the main element that makes up the infrastructure of the building and only with its help is it possible to settle on the ground. Since the ground in which the foundation is made has inferior mechanical characteristics compared to the construction materials used in the execution of the foundations, solutions must be found to compensate for the shortcomings of the land.
In many situations, due to the characteristics of the foundation lands (high swells, high humidity, reduced physical-mechanical characteristics), soils are classified as "unsuitable".
To optimize a foundation system, the nature of the foundation land must be taken into account and the loads brought by the building must be calculated. Only later it can be determined the type of the foundation, the geometric dimension of the foundation sole, the depth of foundation (established according to the elevation where the good foundation land is found) and characteristics of the materials that must be used to ensure the safety and integrity of the building. Possible subsequent intervention works on the foundations are difficult and

expensive (at the time of the intervention, it must be taken into account that the stability of the soil should not be affected).

Within the 3 buildings presented (the fully detailed ISHO case study and the 2 tallest buildings in the world, respectively in Romania schematically presented for comparison), due to the fact that the construction loads were high, the base of the building was secured through the piles, a deep foundation that allowed buildings to penetrate into the good foundation soil and transmit there the loads, providing in this way stability to the entire construction.

In order to carry out foundation works safely, it’s important that related issues to be also managed properly (in addition to soil characteristics and methods of groundwater evacuation for safe excavation).

The desire and ambition to build buildings as high as possible leads to the need to adopt new and more complex technologies, to use high-performance materials and highly qualified workforce.

The optimization of foundation solutions leads to projects executed with minimal consumption of materials and technology, but which ensure at the same time resistance and safety in operation.

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