Practical aspects of construction of high-rise buildings in Russia

Sergey Sinenko, Arthur Ahmetgaliev and Alexey Slavin

Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

E-mail: hr@mgsu.ru

Abstract. The article describes the process of construction of a multifunctional complex of Eurasia tower in MIBC "Moscow-city". The project which situated in the sector number 12 is office and recreation complex, consisting of 305 meters building with the square 207 542 sq.m. that is on the three-story podium, in which there are gym center, entertainment centers, restaurants and shops. Another areas will be distributed in the following way: 106 231 sq.m. will be given to offices of class A, and 21 185 sq.m. – to apartments. On the low levels there will be car park for more than 1000 cars. The first 29 floors will be given to nonresidential premises. Describes the best practices for engineering and monitoring, work performance conditions, factors constrained conditions, organizational aspects, technological sequence of construction of high-rise building constructions, as well as the variant of construction of the object using a 3 in lift cranes. According to the variant LLC "Liebherr-Rusland" after the end of erection of high-rise building part tower crane No 2 removes tower crane No 1 and then crane Derrick removing tower crane No 2. The project of construction is created with the use of CAD on the base of technical task for development, given by the company CJCS "Techinvest". Architecture-planning solutions are made by use of AutoCAD 2014, building calculation are made by use of programs Plaxis and SAP - 2000 Nonlinear. Given unexpected situations that affected the progress of construction, shows the new design methodology, which was implemented as a standard functionality of the systems, allowing to support not only new functions but also a methodological decision as a whole.

1. Introduction

MIBC “Moscow-City” is the largest investment building project in the sphere of immovables not only in Moscow, but as well in Russia nowadays. In 1992 JCS “City” was founded to manage creation and development of project, at the same time General Contract of management of creation and development of project MIBC “Moscow-City” was signed by JCS “City” and Moscow Government. The construction of Moscow International Business Center (MIBC) “Moscow-City” is situated on the Krasnopresnenskaya embankment, on the territory having acreage about 100 ha, 60 ha from which are subject to new building. Allotted territory is a single place in the center of Moscow where business district of such size could be created (figure 1).

The localization of MIBC “Moscow-City” in the center of the capital allows to provide easy and convenient access to the complex. The program of creation of modern transport system that was signed by The Moscow Government includes [1]: built pedestrian bridge over Moscow-river; reconstruction and development of existing roads; creation of new multi-lane highways, connecting MIBC with the main transport ways of the city (especially, part of the 3rd road ring with the ten-lane
bridge and public-transportation hub “The West entry”); construction of two new subway stations, station of mini-subway with interchange hub in the central core of MIBC; creation of new speed outstreet transport system “Sheremetyevo-CITY”; creation of especially new, effective and safe system of cargo delivery to MIBC by railway, car and river transportation systems.

Nowadays MIBC “Moscow-city” is (figure 2): 2.5 million sq.m. area of offices, hotels, trade and recreations; unified integral information space, modern telecommunication systems and technology; resource-saving technology, independent systems of electricity and heat supply; modern transportation system, including created subway stations and high-speed ground transport; active multilevel and multifunctional use of area.

![Figure 1. Area of MIBC “Moscow-city” construction](image1)

![Figure 2. Nowadays MIBC “Moscow-city”](image2)

2. Methods

As an example will be considered the tower “Eurasia”– the project which situated in the sector number 12 is office and recreation complex, consisting of 305 meters building with the square 207 542 sq.m. that is on the three-story podium, in which there are gym center, entertainment centers, restaurants and shops. Another areas will be distributed in the following way: 106 231 sq.m. will be given to offices of class A, and 21 185 sq.m. – to apartments. On the low levels there will be car park for more than 1000 cars. The first 29 floors will be given to nonresidential premises (figure 3).

External design of the building is the combination of classic and a part of modern style. It is planned to place panoramic lift outside the building. Building common data: the construction start: 2004; the construction finish: 2011; height: 309 m; the amount of floors: 70; square: 207 542 sq.m.; office square: 106 231 sq.m.; apartments square: 21 185 sq.m.; amount of car places: 1000; the sum of investment: 250 billion dollars.

CJCS “Promstroproekt” made project of construction’s organization and supported project with the adaptation of technical solutions of engineering system and nets.
3. Results
The process of construction of multifunctional complex in the sector number 12 of MIBC “Moscow-city”, consisting of high-altitude part (70 floors) and stylobate (3 floors). Independence of their foundation sediment is provided by sedimentary seam between these parts of the buildings. Constructive system of high-altitude part consists of building stiffening core and external building frame in the low office part of the building, and also of system of reinforced concrete shear walls in the high apartment part [8, 9].

The building stiffening core of office part consists of reinforced concrete shear walls that are about 500 mm thick with steel columns, placed in the cross of walls axis. External building frame in the office part consists of the supporting steel columns and wind truss. The building stiffening core and external building frame are connected by outriggers on the 2nd and 46th floors (technical levels) aimed to increase stability and stiffness of the tower.

The system of shear walls in the apartment part consists of reinforced concrete walls that are about 300 mm thick with steel columns, placed in the cross of walls axis. Additional stability and wind load resistance are provided by stiff frames of structural steel, working with “weak” direction in the areas, where there are no shear walls.

The connection between concrete walls and steel columns is provided by use of stud-bolts, welded on the steel columns. Besides, horizontal reinforcing bars of walls are attached to the steel columns by joint couplings if it's necessary.

The frame of the floors in the all parts of the tower consists of steel beams and concrete slab of floor on corrugated metal sheets, working as unified composite system.

The connection between concrete floor and steel beams is provided by use of steel stud-bolts. In the walls of building stiffening core beams of floor are connected with steel mounting beams for perception of construction loads.

The fencing of pit on the perimeter of building’s underground part is made by the method “wall in the ground”. It allows to “cut” pit from the groundwater.

For perception of soil and hydrostatic pressure by “wall in the ground” during the construction there were made ridgepoles that are anchored in bores drilled in limestone and clay on the different levels, and the shoring system, that was used inside the pit in such places where it’s impossible to use ridgepoles. During exploitation “wall in the ground” will be supported by slabs of floors.

The base of slab is limestone of middle and low strength. The foundation of high-altitude part of building is the plain 3.5 m thick slab.

Figure 3. Construction of tower "Eurasia" by cranes, attached to the side of structure

Figure 4. The Derrick crane is dismantled manually
The columns of stylobate are based on the single foundations, which sizes vary from 900x900 mm to 2700x2700 mm, their thickness is 3.2 m.

The project provides drainage system. Monolith concrete slab of stylobate's floor is put over drain layer by thickness from 300 mm to 450 mm with perforated pipes, connected with discharge pumps. This solution will allow to decrease the hydrostatic pressure of ground waters in case of their possible appearance [2, 3]. It’s not necessary to decrease hydrostatic pressure of water under the foundation of high-altitude part, so there are no drainage pipes in this part of foundation.

Inside drain layer it is planned installation of drain pipes, used for removing filtrated ground waters. Wall drainage must be arranged along the building perimeter near outer basement walls from the foundation base to planned mark. Drain should be made of clear macadam or washed gravel with the size that is not more 40 mm. The use of recycled materials, such as crushed concrete, is impossible.

The floors of stylobate’s underground part are beamless plain monolith reinforced concrete slabs by thickness 300 mm. It is based on the monolith reinforced concrete columns, placed by step 8.0x8.0 m. The floors of underground part of the tower consists of steel beams that are placed in a distance of 3.0 m and concrete slab by thickness 150+75 mm on corrugated metal sheets, working as unified composite system [3,4].

The sizes of columns vary from 400x400 mm to 500x1800 mm, and for steel columns the profile 60K3 is used that is poured by concrete with the use of fine grid. Thickness of walls is 500 mm.

High-rise part consists of two parts: apartment part – in the high quarter of building, and office part – in the low three quarters of building.

The floors and coating in the high-rise part of building are complex reinforced concrete slabs on corrugated metal sheets by height 75 mm, that are on the steel beam systems of collar beams and secondary beams.

Constructively office space is presented a box frame, consisting of steel frame, monolithic building stiffening core and perimeter “pipe”, forming “pipe in pipe” system that is progressive design for high-rise objects. The perception of horizontal loads and stability of construction is provided by monolith reinforced concrete stiffening core.

According to the construction project, building stiffening core (internal pipe) is extensional bounded system, consisting of steel columns placed by step 9x18 m, collar beams and vertical diagonal connections, using for stability of constructions during advanced installation.

Additional stiffness to constructions of office part is provided be perimeter stiffness “pipe” (outer pipe). It is created by line of columns, connected in every floor by high steel sill beams-lintels.

Transfer of vertical and horizontal loads from apartment part of building to constructions of office part is provided with outriggers that are located on the technical floor that is on the top of office part of the building. These outriggers also connect building stiffening core with the perimeter pipe, providing their cooperative work.

On the technical floor there is one more group of outriggers that are redistribute loads because of change of columns step on the perimeter of lower floors for arrangement of entrances in the lobbies of the building.

The floors are monolith reinforced concrete slabs on the corrugated metal sheets that are put on the steel beam systems of collar beams and secondary beams.

The outer facades. The building is coated by hinged colored panels, made of aluminum and glass. In the office part glasses are clear, and window apertures are not opening. The same hinged panels are used also in the apartment part, but there are opening window frames for natural ventilation in every apartment. Glass pack with the stainless steel frames are used in main office and in the lobby of apartment part, and also in the premises of the retail in the podium. Stamped metal panel system is used under roof of podium and cooling stacks.

According to the technical task of CICS "Promstroyproekt", LLC "Liebherr-Rusland" prepared variant of object's construction by 3 tower cranes model 280 ES-N16: crane No1 with arm 51.6 m, and capacity from 5.2 to 16.0 t and crane No 2 with arm 55 m, and capacity from 4.41 to 16.0 t - for
construction of high-altitude part of building and part of stylobate (podium); crane No 3 with arm 45.0 m and capacity from 6.1 to 16.0 t - for construction object's stylobate part (picture 3).

Attached tower cranes No 1, 2, 3 are self-installed and self-removed to mark of podium coat. Then removing is made by truck crane Liebherr LTM1800 or by static tower crane Derrick.

For building erection according to individual project it is necessary to build 59 sections of tower for crane No 1 and 57 sections of tower for crane No 2, that are attached to the constructions of building at the level of floor on the special marks (8 pieces of attachments).

The tower cranes are self-installed and are set behind building stiffness core, for what it is necessary to set temporary beams on each floor for arrangement of mounting aperture, in which walking crane will be situated. The size of lift shafts according to the project is not enough for installing such crane there. Tower crane has the height of hook lifting about 54 m and can make mounting works at 10 floors, than moves vertically through 16 m.

After erection of high-rise building part elements of crane Derrick are taken on the roof (max weight of element is 140 kg) by tower crane. Then crane Derrick is installed, set near the tower crane and make its removing. The 2nd tower crane is removed the same way [10]. Then crane Derrick is removed by hand and with the help of cargo-and-passenger elevator or lift is moved down to the mark 130, 00 (figure 4).

According to the variant LLC "Liebherr-Rusland" after the end of erection of high-rise building part tower crane No 2 removes tower crane No 1 and then crane Derrick removing tower crane No 2.

The project of construction is created with the use of CAD on the base of technical task for development, given by the company CJCS "Techinvest". Architecture-planning solutions are made by use of AutoCAD 2014, building calculation are made by use of programs Plaxis and SAP - 2000 Nonlinear.

The use of modern design tools showed its effectiveness and allowed to reduce time and costs of designing, primarily due to the re-use of accumulated information in the design process, providing of necessary information support during the whole project life cycle and, most important, quality and timeliness of technical solutions forming. The implementation of new design methodology is partially set as a standard functionality of system, partially achieved by institutional progress, partially provided by means of systems customization, allowing to support not only new functions, but methodological solutions as a whole [5, 6, 7].

The section "The project of organization of underground and overground parts of building's construction" is developed according to laws, norms, rules, instructions of building design and state standards that are applicable on the territory of the Russian Federation, initial data, technical conditions, requirements, given by the state control and interested organizations during agreement of initial-permit documentary, and includes events in the part of construction's organization, providing abidance of ecological, hygiene standards, fire and explosion security, and also safe working conditions, security of populations and object's stability due to accidents during building and construction works [1, 5, 6, 8, 9].

Initial data for the development of the section "The project of organization of underground and overground parts of building's construction" was: project documents, developed by the company "Summa A.S." and its subcontracting organizations; report of engineer-geological research, made by SPA "NOAKS"; expert conclusion of the section "Foundations" of the project of multifunctional business complex, made by SRIFUC of N M Gersevanov.

The project of construction's organization was developed, including preparatory period and the "wall in the ground", technological schemes of construction of sheet pile wall, construction of anchorage of pit's fence, tiered development of the pit to the level of the bottom of monolith reinforced concrete slabs for high-rise part of building including a berm and ramp wit 120 degrees slope for movement of construction transport on the bottom of the pit. In the PCO there are constructive solution of underground and overground parts of building's construction, also the variants of setting of tower cranes for the object's construction are shown there [1, 3, 4, 5].
In connection with the presence of buildings near the construction, it was recommended to make engineering examination of these objects, including geodesic research of draft, of cracks appearance in the main constructions with the installation of beacons, as well as the deformation of construction buildings. To avoid following claims before the construction start, it was necessary to make a defect list of the condition of the nearest buildings with the help of maintenance service. And also, it was necessary to monitor the process of high-rise building erection, for which it was necessary to determine the location of slab and wall marks to monitor vertical movements of foundations and main load-carrying structure. Also, the measuring of vertical loads in the ground under the bottom of the foundation and the measuring of horizontal movements of building under construction were organized [10].

4. Discussion
The working conditions of construction site are characterized as constrained. Constrained conditions in the built-up part of the city are explained by the following facts: branched nets of utility lines and area of mini-subway; existing and building objects near the construction site; constrained conditions of allocation of materials and constructions.

For underground and overground parts of buildings construction, including podium (stylobate) the principal scheme was created (figure 5). Due to absence of information about the Contractor and existence of definite models of tower cranes that should be used by the contractor on the design phase, three additional variants of cranes installation were developed. For the object construction it was recommended to use the following models of cranes: LLC "Stroynemtech" offers Italian tower crane CTT 331-16 (attached or lift); CJCS "Rentakran" recommend to use cranes "Potain" (attached crane - MD265B or MD 185A and lift crane - MD 175A) with constructive rework. LLC "Liebherr-Rusland" recommend to use German lift tower cranes 280EC-H16 [1, 5, 8].

![Figure 5. The scheme of tower cranes installation for the building construction](image)

CJCS "Promstroysprojekt" offered some variants of tower cranes' installation on the example of tower cranes, produced in Italy by the company Terex-Comedil (figure 6):

The first variant - 3 attachment cranes Comedil CTT 331-16; crane No 1 with the arm 50 m, and capacity from 6.2 to 16.0 t for construction of high-altitude part of building and part of stylobate
(podium); crane No2 with arm 60 m, and capacity from 4.6 to 16.0 t - for construction of high-rise part of building and part of stylobate (podium); crane No3 with arm 45.0 m, and capacity from 7.3 to 16.0 t - for construction object's stylobate part.

The second variant – 1 lift and 2 attached cranes Comedil CTT 331-16. Lift crane No1 and attached crane No2 – for construction of high-rise part of building and part of stylobate (podium); attached crane No3 – for construction object's stylobate part.

The third variant – 2 lift and 1 attached canes Comedil CTT 331-16; 2 lift cranes No 1, No 2 – for construction of high-rise part of building and part of stylobate (podium); attached crane No 3 – for construction object's stylobate part.

During construction building was divided vertically in three tiers [5, 6, 8]:
- the first tier – from 05 underground floor to 25 floor;
- the second tier – from 26 to 46 floor;
- the third tier – from 47 to 68 floor.

The technological sequence of building construction: construction of steel columns and beams of building stiffening core, then steel columns and beams along perimeter on the five floors; mounting steel constructions on the next 5 floors and concrete pouring of construction and floors on the lower 5 floors; mounting of outer hinged panels from the first floor, in 7 days after concrete pouring on the second floor and etc. – in 7 days after concrete pouring on every following floor.

The installation of metal constructions, delivery of reinforcement, formwork and shuttering was carried out by tower cranes (lift or attached cranes depending on contractor). The concrete delivery in the shuttering was carried out by concrete pump Shwing BP 2000 HDR. Truck cranes KC-3577 were used for handling operations.

Also on the tiers there were organized sanitary-engineering and electro-engineering works, improvement works were carried out at the final stage of construction.

![Diagram](image.png)

**Figure 6.** The installation scheme of tower cranes Terex-Comedil

5. Conclusions
According to the solution of Moscow Government, directive construction time is 4.3 years, including preparing period – 1.5 months, base construction period – 4.2 years (installation of pioneer pit, “wall in the ground”, sheet pile wall, anchors, ground works in the pit by tiers with ramp for construction
transport to the bottom of the pit – 9.5 months, tower cranes installation, construction of underground and overground parts of building, improvement works – 40 months or 3.3 years).

As real situation showed, construction of tower “Eurasia” was not finished during directive time. In spite of high preparation level of contractor and subcontractor organizations and the use of modern means of projection, some unexpected situations were appeared that influenced on the process of construction [7]. For example: according to constrained conditions for tower cranes it was necessary to increase the construction territory in amount of technical zones between sections No 12 and No 16. For this purpose it was necessary to make with JCS “Moscow-City” temporary allotment of this territory during the period of underground and overground parts of building’s construction, to displace temporary fence and put slabs on the sand base. Also it was necessary to organize place for handling works; on the 20th of August the construction was frozen on 48 level on the mark 221.7 m. At this time the trial in the case of tower “Eurasia”. There were question of ownership of the tower and the bankruptcy of the contractor; case of contractor bankruptcy was finished on the 25th of November 2011; new contractor’s waiting for opening credit line of “Sberbank” for 500 billion dollars.

Only by 8th of February 2012 construction works restarted, tower glazing was started on the 18th floor.

It should be said that high-rise buildings construction is technically complex and extremely expensive activity, so this article is focused on the accumulation of experience of high-rise building construction, increasement of standard of design and organizational and technological solutions, and aims to help in the project design and construction of future high-rise buildings.

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