Deck method of erecting buildings and embedded structures in the space-limited urban environment

Aleksandr Afanasiyev
Moscow State University of Civil Engineering, 129337, 26, Yaroslavskoye Shosse, Moscow, Russia
E-mail: 7450688@gmail.com

Abstract. The decle method of the buildings and embedded structures erection in confined spaces of urban development is dwelt upon. The structural and technological characteristics and combined methods of the works performance when erecting the under- and aboveground parts of buildings according to the closed and semi-closed technologies are described. The fundamental principles on the technological processes optimization are developed: piles installation, ditch sheeting using the method "diaphragm wall", soil excavation under floorings and their erection in terms of maximum saturation with the mechanical aids and continuous organization of works performance. The primary advantages and a complex of the organizational-technological solutions for this technology implementation are described.

1. Introduction
Erection of buildings and embedded structures in confined spaces of urban development is a relevant objective, including a series of scientific problems relating to provision of reliability within the period of erection and operation. Designing and erection technologies of aboveground parts of the buildings requires arrangement of deep excavation pits and represents a complex geotechnical task that requires permanent monitoring.

The annual growth of motor transport (up to 350 thousand cars) results in an evident demand for underground parking lots.

The technology of deckle method in housing construction accelerated erection of multi-storey underground parking lots with the release of adjacent territories for play and sports grounds, recreation areas, etc.

2. Methods
The erection technology of the buildings and embedded structures is the most commonly encountered in Canada, France, England, Germany and other countries.

In the Russian Federation construction according to this technology was started in 2001. In Moscow they have erected: multipurpose centers "Arbat-Center" and "Tsarev sad"; hotel "Ritz Carlton", a series of multi-purpose buildings with the embedded part up to 5 floors [1].

When designing and constructing they use the new organizational and technological solutions that find an application in high-rise construction [1].

Starting from 2016, the works for erection of subway station "Nizhegorodskaya" of Kozhukhovskaya line of the Moscow subway using the "from top to bottom" method are being performed.

This technology use decreases consumption of metal due to the absence of spacing systems, reduces the works intensity for soil excavation, arrangement of monolithic floorings and a foundation slab [2].
3. Results
This technology finds a wide application when constructing buildings and embedded structures in confined spaces of urban development and is based on technological processes combining of the under- and aboveground parts erection (“down-up”).

The closed and semi-closed methods of the works performance are applied (fig.1). In the closed method, interfloorings bridge over fully the embedded space leaving process-oriented openings for works performance for soil excavation and transportation, supply of reinforcement, formwork systems, fixtures, concrete mixture etc.

![Technological schemes of closed (a) and semi-closed (b) works performance.](image)

- fence (of diaphragm walls)
- bearing piles
- flooring above the first embedded floor
- interfloorings
- foundation slab

The dimension of openings is accepted with due regard to the dimensions of the excavation equipment operating in the respective horizons.

Works performance according to the closed technology consists in arrangement of fences using the method "diaphragm wall" in consecutive erection of floorings of the embedded part "from top to bottom" with the use of the preliminarily installed piles that, in the course of digging, are united by the monolithic floorings system between themselves and the fencing wall of the excavation pit. Subsequently piles serve as columns and in combination with the floorings create the system with high spatial rigidity, what makes it possible to erect underground parts and embedded objects with the minimum influence on the adjoining development with small dependence on the engineering and geological factors.

As a result of the works performance combination of the zero cycle and underground part, the total duration reduction by 17-22 % [1,2] is achieved.
At the same time, the complex sequence of the technological operations and a higher cost are worth noting.

Works performance for arrangement of the underground part [1] is regarded to be one of the most difficult types of the construction processes from the geotechnical point of view and requires the use of the integrated monitoring program for a construction period.

The semi-closed method provides for, beside process-oriented openings at grasps, open planes arrangement for the high-rise part of the building.

In this case bearing piles placed on contour, are united with monolithic floorings of perimeter zones, what ensures achievement of the required spatial rigidity of the underground part. Erection of the high-rise part of a building is implemented by the "open" method, using the traditional methods of floor-by-floor building up.

Most often the semi-closed method is used when erecting buildings having the deep foundations and multilayered system of embedded floors. [4].

Technological peculiarities of works performance according to the closed technology.

The primary technological stages of the works performance of the zero cycle are:
- arrangement of external walls using the method of "interlocking piles", "diaphragm wall" or their combination in a curved plan of the embedded part;
- complex of the construction processes for arrangement of bearing piles (drill strings);
- erection of monolithic flooring with uniting of pile heads and arrangement of process-oriented openings;
- complex of excavation and concrete works for arrangement of interfloorings;
- performance of reinforcing and concrete works for erection of a foundation slab.

The peculiarity of the deckle technology is the maximum saturation of a facility with construction machinery and labor resources when combining the technological processes.

So, when performing works for installation of drill strings and fences according to the method "diaphragm wall", the following machinery is concentrated at a construction site: drilling devices for bearing piles installation, two grab excavators, a self-propelled crane and a set of dump trucks and concrete mixers for works performance for installation of a "diaphragm wall". The following is placed in the area: a site for reinforcement cages enlargement with an automobile crane; clay mixing unit for bentonite slurry preparation with the pipework, sets of fittings for concrete mixture pouring using the method of vertically movable tube etc. (fig.2). Breaking of a facility area into technological zones makes it possible to organize the technological processes combining on basis of continuous methods of works performance. Such solution makes it possible to reduce operational downtimes, to use more rationally the mechanical aids and to reduce the overall work duration.

Erection of the embedded parts "from top to bottom" requires solution of a series of the organizational and technological issues in terms of lack of space of a construction site. So, monolithic flooring of zero floor can be a site for placement of self-lifting and attachment cranes, concrete pumps, the zone of construction materials storekeeping, semi-finished products and structures. [3, 4]

At the same time, the deckle technology implementation requires a higher organization of labor, use of the modern excavating and excavating-transportation machinery, special fittings and attachments for performance of earth and concrete works in confined spaces of the underground space.

When developing the technological documents (project for implementation of construction operations, operation chart flowsheets and regulations), the significant attention should be paid to: works performance safety, gas pollution exclusion of the underground space, operating method use of quality control, appraisal and prediction of intensity of strength development by concrete, terms determination of stripping and loading of structures, assessment of the organizational and technical reliability on basis of continuous works performance and technological processes combining.

Works performance for installation of drill strings.

Depending on the engineering and geological factors and loads, drill strings in form of metal pipes are used, filled in with concrete (steel tube confined concrete); made of rolled section, concreted after
floorings erection; of the two-stage system composed of cylindrical reinforcement cage for the lower stage and in form of a metal pipe for the upper one; made of reinforcement cages of the cylindrical form with a uniform cross-section etc.

Figure 2. Technological schemes of the processes combination of arrangement of “diaphragm wall” and drill strings with breakdown into technological zones and sequences of pile works.

The technological regulations for installation of drill strings provides for accuracy of boreholes drilling with deviations within the limits 1:100 of the depth and placement in a plan with tolerances ±5 cm. It is achieved by use of the special guide walls and modern drilling machinery. To install reinforcement cages, special conductors with hydraulic jacks are used, that ensure alignment in the plan and in depth. The pivot anchorage of the top of a reinforcement cage ensures its vertical position according to the principle of "plumb", and vertical movement creates the conditions of its bottom clamping in a position near to final position (fig.3).

Taking into account the huge dimensions of drill strings, they are manufactured at reinforcement enterprises or steel production plants of separate brands united into the whole at a construction site with the use of conductors and welding.

Reliability of connection joints is controlled by the ultrasonic, electromagnetic or other nondestructive methods and are confirmed by test certificates. [6]

To install drill strings they use the boreholes drilling technologies with borehole casings and under the layer of bentonite slurry.

The technological regulations for works performance is developed for each case, which take into account not only the technological sequence and quality control of works, but also regulates the length of stay of a bore hole before its concrete pouring.
The drilling method with the use of borehole casings is regarded to be the most commonly encountered and more cost-effective. It provides for the needed parameters of the geometrical position of piles and physical and mechanical characteristics of concrete.

To preserve the final position of a pile: space between a borehole casing and the top part of a pile (fig.3) is filled in with ballast of broken stone, in doing so the final position after a conductor removal is ensured.

Figure 3. Technology of a reinforcement cage installation (a, b) of a drill string and alignment with a conductor use (c).

Upon completion of the drill strings erection, arrangement of flooring above the first embedded floor is implemented. It includes the works for vertical planning, arrangement of upfilling and separation layer made of self-aligning mixture with the antiadhesion coating. In the course of reinforcing works performance, the connection of cap piles with the reinforcement of the flooring is made. Works are carried out on technological grasps with arrangement of cast formwork for process-oriented openings for soil excavation.

Works performance for arrangement of the first flooring and gain in strength of 70% and more serves the beginning of erection of the underground and aboveground parts of a building. Fig.4 shows the first stage of the works performance which consists in soil excavation under a flooring and beginning of the aboveground part erection. As far as the interfloorings are arranged, the second stage is implemented which consists in sequenced building up the frame of a building with the simultaneous works performance for arrangement of the embedded part.

The "down-up" technology is based on the fact that the pile foundations take up from 40 to 60 % of the load from a building being erected, and a foundation slab – 40-50 %, what makes it possible to combine the technological processes of zero cycle and the aboveground part. As a rule, upon the works completion for piles installation, erection of the frame of a building to the height to 50 % from the projected height is allowed.
Erection works of the aboveground part are performed upon the design strength achievement of monolithic flooring. The complex of the preparatory works is fulfilled, that include the installation of attachment cranes, the distribution boom of a concrete pump, concrete conveying pipes, sites for concrete mixtures acceptance and concrete pumps placement.

![Erection of a foundation slab](image)

**Figure 4.** Combination of technological stages of soil excavation under flooring and erection of the aboveground part. (tower cranes and other mechanical aids are omitted for clarity).

Panel formwork systems, reinforcement cages with hand-knitted bars and small tools and equipment are used for the works performance.

Intensification of gain in strength is achieved both by use of the heatup technology with heating wires and thermos curing of high-strength concretes of class B35-B40, with calculation of temperature gradients excluding crack formation and other destructive processes. For acceleration of gain in strength of concrete of embedded floorings, heat treatment in summer time is allowed.

Control of gain in strength is made on the temperature characteristics of the concrete layers with due regard to underground space temperature, ventilation effects and thermal insulation techniques of open surfaces. The actual strength of concrete is estimated by "nondestructive" methods or by direct tests.

The work production plan, operation chart flowsheets and schedules are developed in relation to the works performance for monolithic structures erection.

Erection of a foundation slab includes technological processes for preparation of a base, arrangement of concrete bedding and horizontal waterproofing, reinforcing. Each technological stage is exposed to instrumentation control and drawing up an act.

Concrete pouring of massive foundation slabs is made by the method inclined concrete pouring with the mixture transportation by concrete pumps with branched system of concrete conveying pipes. Mixture supply to a laying-in point is made through tremie pipes or flexible hoses of concrete conveying pipes with the compulsory sealing with spud vibrators. As a rule they accept a continuous scheme of concrete mixture supply, what does not require arrangement of construction joints.

The technological regulations are being developed in relation to mixture placing, that include, beside a layout scheme of pipeline transportation, placement of thermocouples to control temperature fields of hardening concrete. Depending on the temperature conditions, upon concrete pouring completion, a slab surface is insulated from heat or moistened.
Figure 5. Technological cycles of the processes combination of the underground and aboveground parts erection of the building: a) - soil excavation of the 4th layer; b) - arrangement of floorings; c) - erection of a foundation slab.

1 - grab excavator; 2 - excavating-transport machinery; 3 - truck mixer; 4 - concrete pump; 5 - concrete conveying pipe; 6 - tower crane; 7 - distribution boom of concrete.

4. Discussion

The results of the study are given on example by semi-closed technology of erection of a multifunctional complex.

The complex is composed of five united structural elements (fig.6):
1 - a high-rise part with the height of 129.0 m, including 28 elevated floors with stepdown descent of the area on height with a placed spire with the height of 10 m;
2 - three towers with the height of 59.4 m;
3 - substructure with the variable, with the height from 17.6 to 11.6 m.

All volumes are united between themselves, including the central high-rise tower. A frame-beam structural scheme is used.

Each tower is equipped with the vertical transport system (lifts). The fire safety measures are provided for.

The underground part represents the six-level frame volume with the dimension in the plan 128.4x87.7 m with flat interfloorings and drill strings made of rolled metal.

The technology of the works performance is similar to that dwelt upon earlier. So, to fence an excavation pit, a “diaphragm wall” is arranged, drill strings are installed, on which caps an armored floor is arranged. Four process-oriented openings are left for soil excavation and installation of interfloorings of the embedded part. An opening for a high-rise part amounts to 52.0x50.2 m. The
thickness of the foundation slab for a high-rise part amounts to 2.2 m. For the rest part the slabs’ thickness varies from 1.0 to 1.6 m (fig.7). The works are carried out on grasps with the materials supply (fittings, cast formwork, concrete mixture) through process-oriented openings.

Figure 6. Layout plan on the building elements in vertical direction.

To perform the works for foundation slab installation, automobile cranes for fittings supply and truck-mounted concrete pumps for laying concrete mixture are used. Compulsory sealing with spud vibrators is provided for. When performing concrete works at winter time, sealing of open surfaces and peripheral heatup with heating wires is implemented. The temperature control is made judging by which an estimation of a degree of gain in strength is made.

After concrete pouring of a foundation slab, the erection process of a high-rise part of a tower is made by the building up method. This method was applied when erecting the aboveground part of all the building elements. The continuous method of the works performance is used, based on a facility breakdown into technological grasps and performance of separate kinds of works by the specialized teams and brigades (fig.8). Such solution has made it possible to reduce time of works performance by 18-24%.

A translucent fence installation should be regarded as the most time-consuming cycle of the works. Special glass panels with the treated surface were used, that is capable of reflecting thermal rays. To exclude cold bridges, special thermal-insulation blankets were used, placed on the vertical reinforced-concrete guiding rails. Installation of the wall envelope was made with the use of tower and boom-type cranes.
5. Conclusions
Finally it is important to note the technological efficiency of a complex facility construction with the underground space development ensuring more than 1000 car places.

Due to the technological processes combining, reduction of the construction duration and prime cost of the works is achieved.

Technologies have a big practical relevance, make it possible to erect facilities in immediate proximity to real estate development, don’t require additional areas for technological equipment placement.

Stability of the underground part is achieved by the horizontal loads accommodation by rigidity discs (floorings).

More than ten-year experience of the operation of buildings and embedded structures has shown a high maintenance reliability and safe-keeping and integrity of an adjoining real estate development.
Figure 8. The facade of the building and a section along the towers 59.6 m high.

References
[1] Katsenbach R. Designing of excavation pits and foundations in terms of urban development. Modern high-rise construction. M., 2007, pages 169-177.
[2] Afanassiev A A. The deckle method of high-rise buildings erection. Modern high-rise construction. M., 2007, p.396-408.
[3] Faronkhniya M, Lapshina O. Concerning the system TOP&DOWN. High-rise buildings, No. 2, 2009, p.102-104.
[4] Afanassiev A A. The deckle method of buildings and embedded structures erection. /Construction materials, equipment, technologies of XXI century/M., No. 9, 2010, p.30-33.
[5] Moscow City Construction Regulations 2.07-01. “Bases, foundations and underground structures”.
[6] Combined piled-raft foundations. The guideline for high-rise buildings. JSC TSNIEPZhilische, 2006, p.206.
[7] Rashendarfer R, Afinogekov A. The technology of carrying out underground works. /High-rise buildings/. 2008, No. 10, p.84-88.