Geotechnical Aspects of Underground Construction in Soft Ground, Kastner, Emeriault, Dias, Guilloux (eds)
© 2002 Spécifique, Lyon. ISBN 2-9510416-3-2

Construction of the underground part of the Turkish Trade Center in Moscow.

V.P. Petrukhin, O.A. Shuljatjev, O.A. Mozgacheva
The Research Institute of Bases and Underground Structures (NIIOSP), Moscow, Russia

ABSTRACT: Underground construction in towns is carried out in the constrained conditions. One of the necessary conditions at such construction is to make surrounding buildings and structures safe. In so doing, non-uniform settlements of the building foundations shall not exceed the permissible values specified by the Codes.
In accordance with the predictions a number of buildings in vicinity to the construction site of the Turkish Trade Center in Moscow are bound to considerable settlements in excess of the permissible values. In this connection work on monitoring of the guard structure, soil massif and surrounding buildings has been carried out to mitigate construction adverse effects.
The article gives the monitoring results and estimates the effect of the arrangement to decrease deformation of the surrounding buildings.

1 INTRODUCTION

The Turkish Trade Center (TTC) site is to be located the center of Moscow, at a distance of not more than 1 km from the Moscow Kremlin. Fourteen buildings mainly 2 or 3 stories (see Fig.1) are adjacent to the site, including two buildings of a great architectural & historical value (No. 2, the 17th century Church Chamber; No. 3, The Mansion of the 2nd half of the 19th century). Five buildings (Nos. 1-5) are practically located border of the diaphragm wall (the distance up to the guard structure does not exceed three meters).

The TTC features a complex building with plan dimensions 120x60m, of six storeys above the ground level, underground parking place deepened up to 12,57m (3 floors).

The diaphragm wall 27.0m deep and 0.6m thick has been made as a retaining (curtain) structure. The diaphragm wall is arranged all around the underground structure and has an overall length 314m. Fixing of the retaining structure is effected by three rows of injection prestressed temporary anchors 20m (the first and the second levels) and 16 m long as well as by struts (where it is possible) (Fig. 1, 2). The length of the anchors roof parts is 8m, diameter -150mm.

The Turkish «Kasktas» Co. has developed the diaphragm wall excavation over clamps with a grab crane made of Casagrande Co. (the Turkish "Ekingiler" Co. as the general contractor). The excavation has been run under bentonete slurry, concreting is effected by a tube vertically moved.

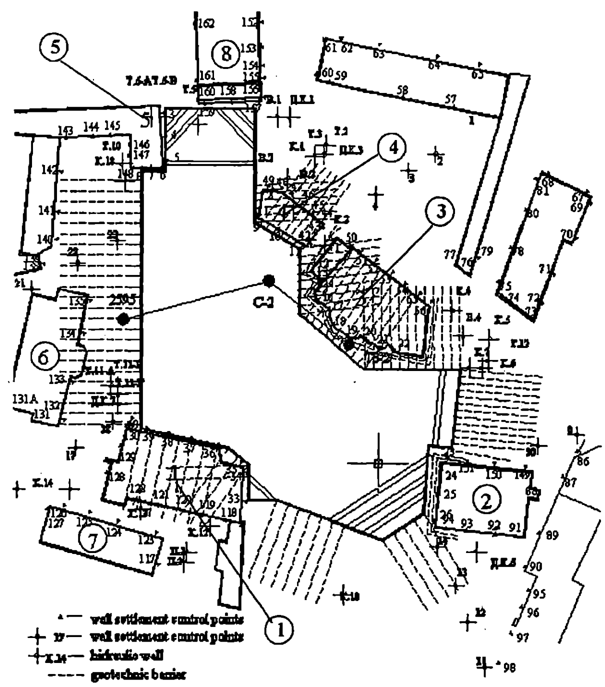

Figure 1. Layout of the buildings, ground and wall brands and the diaphragm wall layout with anchors & struts

2 THE GEOLOGICAL CONDITIONS OF THE CONSTRUCTION SITE

According to the geotechnical investigation the construction site is a relatively flat surface with absolute elevations 123,4-125,0 m. The following deposits are encounted to a depth of 35 m from top to bottom (Fig. 3):
modern technological deposits (1) cover completely the construction site. The deposits consist mainly of

clay soil, sand of different sizes with building debris (10-20%);

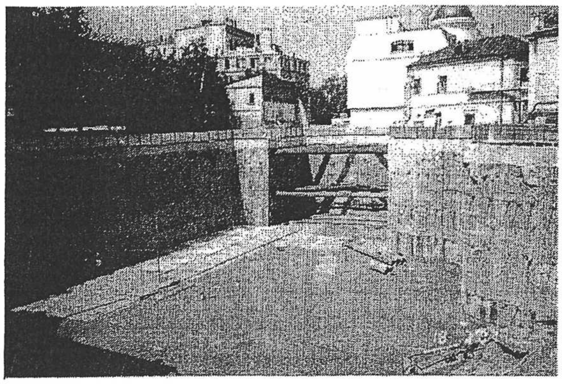

Figure 2. Photo of the construction site.

modern alluvial deposits of the Moscow River bottom land (2) are directly underneath the technological deposits. They mainly contain medium to coarse sand of medium density. As showed by the drilling some loose sands lenses have been found in its upper part;

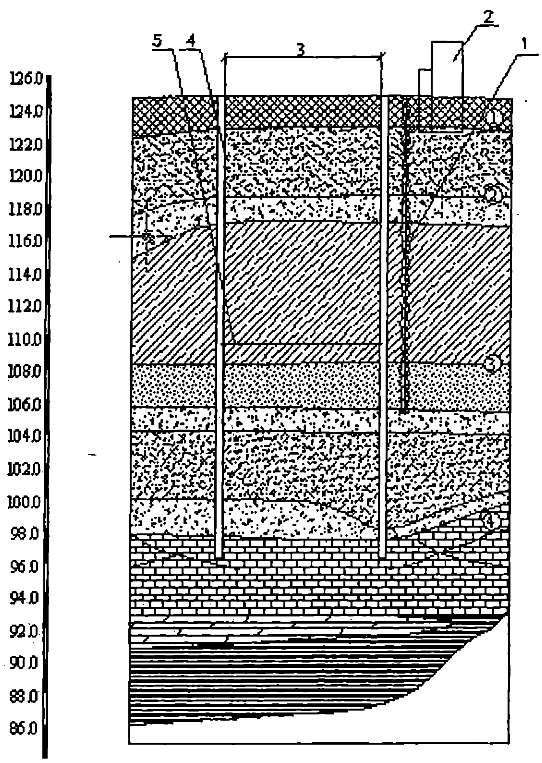

Figure 3. Geological sectional view.
1 - geotechnic barrier; 2 - existing building; 3 - subsurface outline; 4 – diaphragm wall; 5 – excavation level .

medium quaternary deposits (3) are found underneath the alluvial ones. The upper part of the section is sandy loam with saturated sand layers of different sizes, with gravel and crushed stones. The sandy loam possesses thixotropic properties. The lower part of those deposits is of sand.

carboniferous system (4). The ancient valley of the Moscow River belonged to the massive carboniferous deposits.

Hydrogeological conditions. Underground water at the investigation site represents an aquifer of the quartenary alluvial, alluvial-fluvioglacial and carboniferous deposits. The water bearing soil are sandy loam, medium, course and gravel sand occurred on lime stones and dolomite fractured, frequently cracked to lumps, and broken stone. The free surface of the underground water was encounted when drilling at a depth of 5,8-6,0m from the ground surface.

The foundations of the buildings surrounding the TTC are not deeply laid, i.e. 1.5 to 4.5 m from the ground surface. Modern alluvial deposits are mainly lying under the foundations.

3 ARRANGEMENT EDDITIONAL SETTLEMENTS OF THE BUILDINGS

In accordance with the preliminary calculations (using the Plaxis Program with the Mohr-Coulomb model) the additional settlements of the buildings close to the diaphragm wall (buildings Nos. 1-5) exceed the allowable limits for the extra settlements values as established by the Moscow construction Codes [1].

The extra settlements are divided into two groups: the "technological" ones occurring at arrangement of the retaining structure and anchorage; and the "structural" ones resulted from the changes of the stress-strain condition of the foundations base caused by the movement of the retaining structure during the soil excavation.

As is known, if the " structural " settlements may be defined more or less accurately and may be evaluated at the design stage, the "technological" settlements depend upon a kind of a retaining structure, equipment used, geological and hydrogeological conditions of the construction site, work execution quality. It is difficult to calculate "technological" settlements, yet they can be estimated on the basis of the construction experience under the similar conditions.

As has been previously noted in accordance with the premilinary calculations settlements of the buildings close to the retaining structure exceeded the permissible values (Table 1) specified by the Moscow Codes [1] even with the "technological" settlements. In this connection the necessity has arisen to take proper arrangement to decrease both "technological" and " structural" settlements.

First, according to the design to reduce the "technological" settlements the clamps length, when arranging the diaphragm wall near the buildings, have been decreased from 5 to 3m. Second, for buildings 2 and 3 cementation of the foundations and the "foundation-soil" contact have been carried out; the base soil reinforcement by a so called "geomassive" method (only building 3) have been made; a geotechnical barrier between the buildings and the diaphragm wall by a injection of cement grouting through the injection system to a deep of 18m (Fig.3) have been provided. Two processes take place while cement grouting is being injected: compaction of the surrounding soil massive and correspondingly change of its stress-strain state; soil reinforcement resulting from formation of lenses of cement grouting. Injection took place under pressure of up to 0.5 MPa, grouting consumption per running meter is about 0.3 m^3, the injectors are staggered with a place 0.5m.

To decrease the "structural" settlements in place where it was possible acc. to the structural requirements anchors have been changed for the struts (Fig. 1).

If the use of the struts has been found impossible so in order to reduce the "structural" settlements under the anchors two strain layout have been used which may allow to control over changes of the stress-strain state of soil behind the diaphragm wall.

The first layout (close to the buildings) have suggested effort of tension of P=420 kN and effort of blocking of 0.9 P. As per the second layout (beyond the buildings) P=400 kN and effort of blocking is 0.8P. The displacement of upper part of diaphragm wall reduced at 30% as a result of stress- strain state change of the soil.

4 MONITORING RESULTS

For an entire construction period the monitoring program on-site has been suggested as follows:

- tool measurement of the vertical & horizontal displacements of the diaphragm wall, soil massif and also foundations of buildings surrounding the site ;
- visual observations of the state of the diaphragm wall and surrounding buildings;
- tool & visual observations of the state of the underground communications;
- tool & visual measurement of underground water stages at the territory adjacent to the construction site.

In this given work the results of the only tool measurement for vertical & horizontal displacements of the diaphragm wall, soil massif and also the surrounding buildings foundations have been presented.

The values of the buildings foundations settlements being monitored at various construction steps and the values being correlated to the ultimate settlements limits as regulated by the Moscow Codes may be seen in Table 1.

In the column 2 one can see the foundation settlements occurred whilst the diaphragm wall ("technological") arrangement. When being reviewed those items it may be clear that the settlements of the buildings 2, 3, where arrangement on elimination of the "technological" settlement have been taken, are minor (1,5...3,3 mm). The settlements of the buildings 1and 5 for which these arrangements were not carried out, came to 6,6...14,4 mm. Thus due to the above arrangement the settlement have been decreased two...ten times.

Table 1. The maximum settlements of the buildings through various construction steps.

Building No. (Brand No.)	Max. settlement, after construction of diaphragm wall, mm	Max. settlement upon excavating the 1st anchors level, mm	Max. settlement upon excavating the 2nd anchors level, mm	Max. settlement upon excavating the 3rd anchors level, mm	Max. settlement upon excavating the excavation up to design elv., mm	Max. allowable Extra settlements as per the Moscow norms, mm
1 (36)	14.3	15.3/25.6	25.8	36.2	36.9	30.0
2 (24)	1.5	1.8/5.4	9.6	19.6	19.6	5.0
3 (19)	3.3	3.4/4.6	8.7	26.9	28.1	5.0
5 (6)	6.6	6.8/6.9	9.5	14.2	15.5	30

The values of the "technological" settlement of the diaphragm wall as well as the settlement whilst the anchors construction and foundations excavated as per percentage ratio to the entire extra settlement have been presented in the Table 2.

Table 2 "Technological" settlements of the buildings

Building No	Settlement part of the "wall ground", %	Settlement part of the 1st level, %	Settlement part of the 2nd level, %	Settlement part of the 3rd level, %	Settlement part of the ground excavation from the 3rd level to design elv., %
1	39	30	1	28	2
2	8	20	21	51	0
3	12	4	15	65	4
5	42	3	16	31	8

As seen from Table 2 the part of settlement as per percentage to the entire settlement whilst the diaphragm wall construction in case of non-fulfillment of the measures to reduce its values should be 40% approx.
The mostly settlement per level has occurred during the work on anchoring which correlates to the results of R. Katzenbach et al. [3].
The maximum settlement has resulted upon the works of the 3rd level.

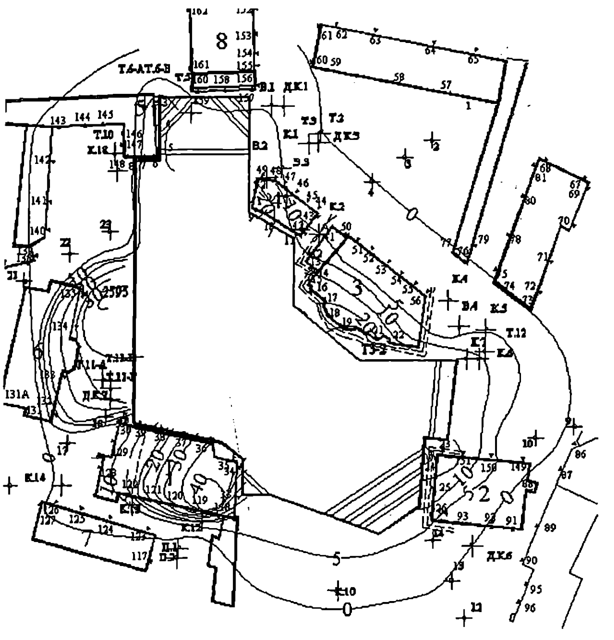

Figure 4. Isolines of the identical settlements at the moment of final construction.

The general settlement values ("technological" & "structural") at final construction have been presented in Fig. 4.
Upon the settlement values being reviewed it is obvious that the influence zone for the soil massif and, consequently, for the buildings is 25-30 m approx. or 2…2,5 times more than the excavation depth (12,57 m).

The maximum measured settlement values of the foundations have been occurred for the buildings with anchors. The settlements of the buildings, which are in an immediate close to struts, is three-four times less. It must be noted that distance from the buildings with struts to the diaphragm wall is not more than 2 meters, i.e. they are on the edge of the diaphragm wall.
Apart from the measuring the vertical displacement of the buildings the horizontal displacements has been also measured as per the buildings, ground marks, upper part of the diaphragm wall and communications.
Upon its review the largest horizontal displacements of the diaphragm wall upper part has been occurred in the place of anchors. The maximum values (about 20 mm) have been registered as per marks close to the buildings №№ 1 and 6.
As it has been mentioned above, whilst the anchoring process two strain layouts have been approved as allowable to control over a process of changes for the initially stress-strain state behind the diaphragm wall. The maximum horizontal displacements of the diaphragm wall in the places of anchoring with effort of tension of P=420 kN and effort of blocking of 0.9 P is 14 mm at average (close to the building 1). In the places of anchoring with effort of tension of P=400 kN and effort of blocking of 0.8 P (beyond the buildings) the same value is 20 mm at average (between the buildings 1 and 5). Thus the projected extra ground compression behind the diaphragm wall has been considered as an efficient one and allowable to reduce the displacement of the diaphragm wall upper part at 30%.
As reviewed upon the wells displacement the maximum values of it have been measured as 23 mm on the marks, located between the diaphragm wall and building 6. The displacement of the rest wells is not more than 10 mm mostly. The received values of the horizontal displacement for hydraulic lines are correspond to the values of the horizontal

displacement of the "diaphragm wall" and also to the displacement of the ground marks with maximum values as registered per marks at the maximum displacement of the diaphragm wall and wells (marks between the buildings 5 and 6 with displacement was 12,6-24,8 mm as on 28.08.01). The marks displacement as per other sections is less and, as a rule, not more than 10 mm.

Within anchoring the distribution area of the horizontal displacement is 25…30 m; in the places of braces the horizontal displacement of the massive ground to the foundation side has not been practically registered (or not more than 3 mm).

5 CONCLUSIONS

The following conclusions can be drawn on the bases of the monitoring analyses:

1. At the places of anchorage of the diaphragm wall the influence of the anchorage and the excavation on the stress-strain state of the surrounding soil massif is 25 to 30m, that in 2 to 2,5 times more than the excavation depth.
2. At places of the struts arrangement, soil horizontal movements towards the excavation are practically absent (not in access of 3mm) and vertical ones – 3 to 4 times less than in the excavation guard anchorage places.
3. The "technological" settlement as a result of the diaphragm wall arrangement can reach 40% of the summary extra settlement values. Approximately the same value refer to the "technological" settlements at anchorage.
4. Use of special arrangement (reduce the length of "the clamps", arrangement of the geotechnical barrier, cementation of "foundation – soil" contact, the soil reinforcement by "geomassive" method) has enabled to decrease "technological" settlements in process of the diaphragm wall arrangement by 2 to 10 times .
5. Additional soil compression outside the diaphragm wall accepted in the design at the expense of the increase of the effort of tension and effort of blocking has enabled to decrease horizontal movements of the diaphragm wall. This has led to decrease of the soils movement and reduction of the building settlements and water bearing communications.
6. The following measure have been taken to decrease the "structural" settlements along with the measures pointed out in item 4:
   - Regulation of stress-strain state of soils outside the diaphragm wall by changing effort of tension and effort of blocking;
   - change of anchorage of the retaining structure for a strut one;
   - structural arrangement (metal tie rods, metal bandage and others).

Use of the above arrangement at the construction of the underground part of the TTC has enabled to preserve the surrounding buildings. The monitoring thorough system made it possible to monitor the change of stress-strain state of the surrounding soil massif and the retaining structure, that, in its turn, has enabled to introduce changes in the design decisions and, finally, to perform trouble-free complicated geotechnical work to which construction of deep excavations within the existing buildings refer.

REFERENCES

1. Recommendations on reviewing and monitoring for the technical terms of the serviced buildings close to the sites of newly buildings or reconstruction. M., 1998.
2. Manual on monitoring the strains of the basements & foundations for the buildings and constructions. M., 1975.
3. R. Katzenbach, U. Arslan & Chr. Moormann, 1999. Soil-structure of deep excavations in urban e nvironment. Proc. Int. Symposium held at Tokyo Int. Exh. Centre, Tokyo, Japan, 19-21.07.1999.