Analysis the results of calculating the monolithic wall in the soil with anchor fastening without distribution beams based on the solution the spatial problem with various topology the element of fencing

V Znamenskiy, E Morozov, D Chunyuk and D Pekin

1 Moscow State University of Civil Engineering, Moscow, The Russian Federation
2 “INV-STROY” LLC, Moscow, Russia

Abstract. The article analyzed the results of the calculation of the monolithic trench "wall in soil" (WIS) with fastening attachment anchors without the use of distribution beams based on solving a spatial problem with the different topology of the fence elements. In practice, when solving such problems in a flat arrangement, it is assumed that the WIS is a solid construction in the longitudinal direction, vertical concreting joints are not taken into account, formed between grabs, rupture along horizontal longitudinal reinforcement between adjacent spatial frames, reduction of the rigidity of the WIS structure due to the formation and opening cracks in two directions, as well as inelastic operation of the compressed zone concrete. Analysis of stress-strain state (SSS) of the fence construction structure based on the results of spatial calculation with different topology (flat and volumetric) of finite elements (FE) showed the need to correct the calculation methodology. Based on the results of the calculations, it was found that the values of internal forces in the design obtained using flat FE are significantly overestimated. Based on the numerical method of studies, recommendations on the selection of the design scheme of the monolithic reinforced concrete structure of the pit's fence are proposed and the calculation methodology is corrected. The subject of the study, the results of which are presented in this article, was the specifics of the operation and calculation of the WIS with anchor attachment without distribution beams and the analysis of the calculation results based on the solution of the spatial problem with different topology (flat and volume) of the FE structure of the fence.

1. Introduction

The traditional calculation of the filler structure of the pit without distribution beams in different software complexes does not take into account important features of design solutions and used in calculating theories of plate bending, which in aggregate can lead to incorrect determination of SSS of WIS at different stages of construction and subsequent selection of incorrect solutions for reinforcement of the structure.

2. Methods

Such a design situation was considered in the design of the pit fence in Moscow. The pit enclosing structure was represented by monolithic reinforced concrete WIS of trench type with a thickness of 600 mm, depth of 21.5 m, with the use of concrete of class В40 and reinforcement with spatial frames
made of rods of class A500C. The lower end of the WIS was placed in a water-resistant layer for 3.85-5.95 m, which allowed considering it as an anti-filtration veil of the perfect type. The WIS surface was provided with a cross-section of the binding beam 600 × 700 (h) mm.

Stability of WIS during pit development was ensured by its deepening into the ground below the pit bottom by 5.95 m and by the arrangement of 3 levels of temporary pre-tensioned injection ground anchors installed with a pitch of 1.5 m in the horizontal direction.

The WIS was arranged on a site folded by modern soil formations, modern man-made sediments, upper quaternary cover deposits, mid-quaternary fluvioglacial deposits of the Moscow horizon, and Middle quaternary moraine deposits of the Moscow and Don horizons.

Modern soil formations are represented by soil-plant layer up to 0.2 m thick.

Modern man-made deposits (EGE-1), opened from the surface to a depth of 0.3-3.2 m, are represented by bulk soils: loams refractory clay with inclusions of construction debris up to 5%, not packed.

Upper Quaternary cover deposits are represented by layered, semi-solid loams, with interlayers of hard and refractory clay loam (IGE-2), 0.4-3.2 m thick.

Mid-Quaternary fluvioglacial deposits of the Moscow horizon are represented by loams and sands:
- dusty sand, medium density, medium degree of water saturation and water saturated, with interlayers of soft-clay loam and sandy loam plastic, with rare gravel inclusions, highly clayey, with a power of 0.5-3.7 m (EGE-3);
- sandy loam, soft plastic loam with inclusions of up to 10% gravel, gruss (EGE-4), capacity 0.6-5.2 m;
- sandy loam, refractory with layers of semi-solid loam, with inclusions up to 10% of gravel, gruss (EGE-5), capacity 0.4-6.5 m.

Mid-Quaternary moraine deposits of the Moscow horizon are represented by loams and sands:
- sandy loam, semi-solid, with hard loam layers, with semi-solid clay layers, with inclusions of up to 10% gravel, gruss (EGE-6b), 0.5-9.5 m capacity;
- Gravel sand, dense, water-saturated, with layers of pulverized sand, with pebbles inclusions (EGE-7b), capacity 0.3-6.0 m.

Mid-Quaternary moraine deposits of the Don horizon are represented by hard loam, with inclusions of up to 30% gravel, gruss of carbonates, lime (EGE-8), with a capacity of 3.5-18.6 m.

The hydrogeological conditions of the site were characterized by the presence of three aquifers - inter-moraine and Jurassic. The inter-moraine aquifer was opened of 5.5-13.9 m, and the Jurassic was opened at a depth of 28.0-31.7 m.

The design diagram of the WIS on the geological section of the construction site is shown in Figure 1.
The influence of the above factors on the results of the WIS calculation was evaluated using the PC Midas GTS NX 2018 (Figure 2) in a spatial design using flat 4-node and volume 8-node FE simulating a monolithic reinforced concrete structure.

First of all, the calculation of the WIS was carried out according to the traditional method, according to which the design was modeled by flat FE based on the theory of calculation of Kirhgo-Liav plates and taking into account the reduction of the initial modulus of elasticity of concrete due to formation and opening of cracks and non-elastic operation of concrete in the compressed zone, resulting in a reduction of bending stiffness and distribution capacity of the design of the fence. Dimensions of the design model together with soil are adopted 41 × 36 m taking into account the minimum influence of boundary conditions on the calculation results. The WIS design was made in the form of flat FE with a size of 0.25 × 0.25 m, rod finite elements were used to model anchors. The width computational model was along the fence - 9 m.
The spatial settlement scheme (Figure 3) with use of volume FE dimensions of $250 \times 250 \times 60$ (t) mm on sides and $250 \times 250 \times 240$ (t) mm in the section of monolithic reinforced concrete WIS is executed with similar parameters corresponding to the previous model.

3. Results and Discussion
Thus, the SSS of the system "anchors - fence - surrounding ground mass" was considered taking into account the spatial work and the main stages of pit development. Izopols of displacements and normal vertical and horizontal stresses on the faces of the structure after the development of the pit are given in Figures 4-6.

The normal stresses obtained from the calculation results on the faces of the WIS structure in both vertical and horizontal directions due to the absence of distribution beams confirmed the need to simulate vertical working joints of concreting and the impossibility of correct determination of SSS of the fence structure when using flat FE.

Figure 4. Izopoles of SVG displacement
Figure 5. Isopole of vertical normal stresses on the faces of the SVG: a) from the ground; b) from the side of the pit.

Figure 6. Izopols of horizontal normal stresses on the faces of SVG: a) from the ground side; b) from the pit side.
Figure 7. Izopols of SVG displacement: a) horizontal movements; b) vertical movements.
Figure 8. Isopols of vertical normal stresses on the faces of SVG: a) from the ground side; b) from the pit side.
The maximum horizontal movements of the WIS during modeling with volumetric FE were 14 mm (Figure 7a), which is almost twice less than the similar movements during modeling with flat FE - 27 mm (Figure 4a), besides, the zones of maximum horizontal movements do not coincide in height. By comparison of normal tension to the application of flat FE in fig. 5, 6 and volume FE in fig. 8, 9 essential quantitative and qualitative differences are also received that confirms according to items 5.1.13 and 3.15 of the joint venture 63.13330.2012 need of realization of special approach for the calculation of massive reinforced concrete structures – 1 sq.m/0.6 m$^3$ = 1.67 ≤ 2.

In this case, when calculating normal sections of reinforced concrete structures by bending strength, it is necessary to use normal stresses obtained on the basis of spatial calculation in extreme volumetric FE to determine actual values of bending moments:

$$M_{3D} = \frac{\sigma_{bt} - \sigma_{bc}}{1 + \frac{1}{W_t} + \frac{1}{W_c}} = \frac{I_{el}}{z_t} \cdot \frac{\sigma_{bt} - \sigma_{bc}}{z_t + z_c} = \frac{I_{el}}{h} \cdot \frac{\sigma_{bt} - \sigma_{bc}}{h}$$

(1)

where $\sigma_{bt} = \frac{N}{A} + \frac{M_{3D}}{W_t}$ and $\sigma_{bc} = \frac{N}{A} - \frac{M_{3D}}{W_c}$ is the system of equations of the off-center loaded section for the determination of bending moments $M_{3D}$.
\[ \sigma_{bt} = \frac{\sigma_{bt,1} + \sigma_{bt,2} + \cdots + \sigma_{bt,n}}{n} \quad \text{and} \quad \sigma_{bc} = \frac{\sigma_{bc,1} + \sigma_{bc,2} + \cdots + \sigma_{bc,n}}{n} \]

are the maximum tensile and compressive stresses of concrete in extreme volumetric KE, respectively, obtained from spatial calculation.

\[ W_t = I_{el} \quad \text{and} \quad W_c = I_{el} \]

are the moments of resistance of stretched and compressed faces, respectively;

\[ I_{el} = I_b + \alpha \cdot A_s \cdot (z_t - a)^2 + \alpha \cdot A_s' \cdot (z_c - a')^2 \]

is the moment of section inertia without consideration of cracks and non-elastic deformations of concrete;

\[ I_b = \frac{b \cdot h^3}{12} \quad \text{is the moment of inertia of concrete}; \]

\[ \alpha = \frac{E_s}{E_b} \quad \text{is the reinforcement reduction factor to concrete}; \]

\[ A_s \quad \text{and} \quad A_s' \]

are the area of stretched and compressed reinforcement, respectively;

\[ z_t = \frac{S_b + \alpha \cdot A_s \cdot a + \alpha \cdot A_s' \cdot (h - a')}{A_{red}} \]

is the distance from the center of gravity of the section to the stretched face;

\[ z_c = h - z_t \]

is the distance from the center of gravity of the section to the compressed face;

\[ S_b = \frac{b \cdot h^3}{2} \quad \text{is the static moment of concrete relative to the bottom face}; \]

\[ E_s \quad \text{is the module of elasticity of steel}; \]

\[ E_b \quad \text{is the module of elasticity of steel}; \]

\[ a \quad \text{and} \quad a' \]

is the distance from the center of gravity of the stretched and compressed reinforcement to the stretched and compressed facets of the section, respectively;

\[ h = z_c + z_t \]

is the section height; \( b \) is the width section;

\[ A_{red} = A_b + \alpha \cdot A_s + \alpha \cdot A_s' \]

is the specified cross-sectional area.

Which are further compared to the limit bending moments perceived by the reinforced concrete sections:

\[ M_{3D} \leq M_{ult}, \quad (2) \]
where $M_{ult}$ the ultimate bending moment is is based on the solution of the equilibrium equation of the sum of moments of internal forces relative to the neutral axis.

Comparison of the results of the calculation of the reinforced concrete structure of the pit fence based on the solution in the spatial arrangement using flat and volumetric FE is a very relevant task and will be further considered following the proposed methodology.

Conclusions

1. Calculation of monolithic reinforced concrete “wall in soil” without the use of horizontal distribution beams should be carried out in spatial setting with the use of volumetric FE simulating the enclosing structure and the proposed methodology for determining the actual bending moments.
2. The values of normal stresses on the faces of the enclosing structure in vertical and horizontal planes depend significantly on the topology of FE simulating the “wall in the ground.” Assumptions adopted in the theories of plate bending (static and kinematic hypotheses), when using flat FE, significantly distort the SSS of the enclosing structure. Also, consideration of geometrical nonlinearity in the calculation of the pit enclosure according to the deformed scheme based on the sequence of construction of the structure and physical nonlinearity of concrete taking into account formation and opening of cracks may have a significant impact.
3. In the considered structure of the pit fence, SSS in the places of installation of soil anchors when solving the spatial problem with the use of volumetric FE indicates the occurrence of above-support bending moments (to a greater extent the 2nd tier and a lesser 3rd tier) or markedly decreasing values of moments near the anchors, unlike similar values obtained with the use of flat FE.

References

[1] Ilichev V A, Znamenskiy V V, Morozov E B, Chunyuk D Y, 2010 Opyt ustroistva kotlovanov v gorode Mockve Sb. trudov nauchn. texn. konf. “Aktualnye voprosy geotexniki pri reshenii sloznyx zadach novogo stroitelstva i rekonstrukcii 33
[2] Znamenskiy V V, Chunyuk D Y, Morozov E B 2012 Zhilishhnoe stroitelstvo, Ustroistvo ogorazhdavushhix sistem kotlovanov v stesenenny’x gorodskix uslovijax 9 p 60
[3] Pekin D A Arxitektura i stroitelstvo Rossii, Plitnaya stalezhelezobetonnaya konstrukciya 8 p 20
[4] Trekin N N and Pekin D A Promyshlennoe i grazhdanskoie stroitelstvo, Skrytye metallicheskie kapiteli bezbalonnych monolitnyx perekrytiy 7 p 17
[5] Willam K J, Warnke E D 1975 Constitutive Model for the Triaxial Behavior of Concrete, Proceedings, International Associations for Bridge and Structural Engineering, ISMES, 19 Bergamo, Italy
[6] Osipov V I, Filimonov S D and Kail E V 2002 Compaction and reinforcement of weak soils using the “Geocomposite” method Base, foundations and soil mechanics No 5 pp 15-21
[7] Vlasov A N, Merzlyakov V P, Ukho S B 1990 Effective characteristics of the deformation properties of layered rocks Construction properties of soils pp 19-21
[8] Vlasov A N, Merzlyakov V P 2009 Averaging of deformation and strength properties in rock mechanics Publishing house DIA p 208
[9] Gryaznova E M, Gavrilov A N, Borschev K S and Chunyuk D Y 2018 Geotechnical monitoring in construction (textbook) 2nd edition revised MGSU publishing House p 80
[10] Kopteva O V, Kozimodemianskii B G, Chunyuk D Y 2017 Engineering surveys for the design of foundations of structures near sources of vibration impacts Journal of Industrial and civil engineering No 10 pp 54-58

[11] SP 20.13330.2011 Foundations of buildings and structures

[12] Chunyuk D Y, Reduction of risks during the development of underground space of cities in the collection IV DENISOVSKAYA READING. Problems of ensuring environmental safety of construction pp 113-119

[13] Chunyuk D Y 2011 Reducing geotechnical risks in constructing deep excavations in congested urban situations with non-numeric methods of statistics Actual problems of design and construction of buildings using energy saving technologies and modern construction methods of the international scientific-practical conference pp 270-274

[14] Chunyuk D Y 2015 Assessment of accident-prone deformation zones of buildings close to deep foundation pits 15th International multidisciplinary scientific geoconference/ SGEM 2015 Science and Technologies in Geology, Exploration and Mining/ Conference proceedings. Vol II pp 97-103

[15] Chunyuk M S 2019 Application of soil-cement piles for strengthening the foundations of existing buildings in the zone of influence of deep pits Prospects of science No 3 (114) pp 208-210

[16] Abelev M Y, Averin I V, Kopteva O V, Chunyuk DY 2018 Study of the Processes of Consolidation of a Thick Mass of Water-Saturated Clay Soils when Erecting Unique Structures Soil Mechanics and Foundation Engineering Vol 55 Issue 5 pp 333–339

[17] Selviyan S M and Chunyuk D Y 2020 Performance evaluation of the effectiveness of the use of coredrivers in the construction of base plates Modelling and Methods of Structural Analysis, IOP Conf. Series: Journal of Physics: Conf. Series 1425 012079 IOP Publishing doi:10.1088/1742-6596/1425/1/012079.

[18] Kurilin N O Chunyuk D Y 2020 Characteristics of the plastic zones of the large-scale buildings soil foundation Modelling and Methods of Structural Analysis IOP Conf. Series: Journal of Physics: Conf. Series 1425 012138 IOP Publishing doi:10.1088/1742-6596/1425/1/012138.

[19] P Jia, W Zhao, X Du, C Zhang, Q Bai, Z Wang 2019 Study on ground settlement and structural deformation for large span subway station using a new pre-supporting system. ROY SOC OPEN SCI 2019 (6) 181035

[20] P Jia, W Zhao, Y Chen, S Li, J Han, J Dong 2018 A Case Study on the Application of the Steel Tube Slab Structure in Construction of a Subway Station Applied Sciences 8(9) 1437