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INCREASING THE STABILITY OF EXTRACTION PITS WHEN BUILDING HIGH-RISE HOUSES WITH MULTI-LEVEL UNDERGROUND CAR PARKING UNDER CONDITIONS OF HIGHLY DEFORMED SOILS

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ABSTRACT

The article presents the calculation of the pit construction and possible settlement from the buildings erected in the conditions of compact city development in St. Petersburg. The analysis of the most effective types of shoring walls for support of excavation pits under complex engineering and geological conditions is performed.

Geotechnical investigation of the construction site was implemented using the software complex "Plaxis 3D" on the Hardening Soil model, which allowed calculating by the method of multistage construction. A numerical analysis made it possible to more accurately predict the settlements due to improved soil models, considering its nonlinear behavior under the load actions.

Using the numerical methods of calculation, the stress-strain behavior of the system "soil massif –sheet piling wall – surrounding area" was determined.

Calculation of the building settlement was carried out with the software LIRA-SAPR Soil, which allowed establishing that the bearing structures of the designed building meet the regulatory requirements of strength and deformability.

Keywords: Megacities, Construction, Model Engineering, Deformable Subsoil, Excavation Pit, Setting Of Ground.

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1. INTRODUCTION

Due to the active growth of megacities, it is important to build constructions intended for the disposition of various types of establishments inside them, such as multifunctional centers, public service centers, business offices, etc. The complexity of the construction is that such objects are built in a compact city environment. The most important stages are a geotechnical investigation of the construction site, excavation pit and monitoring of surrounding buildings and construction, otherwise, the construction of the proper quality is not feasible.

Problems of stabilization of soft soils were studied by Yu.M. Abelev, Yu.A. Gotman, B.I. Dalmatov, G.N. Zhinkin, V.F. Kalganov, M.N. Pershin, B.A. Rzhanitsin, A.N. Sokolovsky, V.E. Sokolovich, A.N. Tokin in Russia, and by A. Dobson, L. Casagrande and others abroad [1-4].

Numerous works of Dashko R.E. are devoted to the feasibility study for construction under the complex engineering-geological and hydro-geological conditions of St. Petersburg [5-6].

An example of a construction under the complex engineering-geological and hydro-geological conditions is a construction of a multifunctional center in a compact city development located on the territory of St. Petersburg (Russia).

St. Petersburg is located in the northwestern part of the Russian plate, which has a two-level structure. The lower level is made up of gneisses, diorites, granite and other magmatic and metamorphic rocks. The upper level is deposits of a sedimentary cover. A sedimentary cover is divided into two strata - the lower and upper. The upper stratum is sandy and clay rock of the Quaternary period; these are the softest deposits. The lower stratum is represented by stronger deposits that have passed through several stages of lithification. Bedding rocks are not water-saturated and have a high density.

The studied object is located in the Primorsky district of St. Petersburg near the metro station Pionerskaya and is a sixteen-story monolithic building. The construction site is within the limits of Prinevskaya lowland geomorphologically.

Quaternary (technogenic deposits, lacustrine-glacial deposits of the Baltic glacial lake, glacial deposits of the Luga stadial) and sediments of the Vendian's Kotlin suite are taking part in the geological structure of the territory within the depth of drilling (35-40 m) [7].

In hydrogeological terms, the considered area is characterized by the presence of groundwater with a free surface and headwater.

Groundwaters with a free surface are confined to filled soils and sandy and pulverescent interlayers in lacustrine-glacial loams. Glacial deposits are a confining layer.

At the construction site, there are soil formations, as presented in Table 1.

Table 1 Types of soils at the construction site

№	Soils	Layer thickness
I	Filled soils of EGE 1 are represented by sand, sandy-clay with fragments of bricks, break stones, and gravel, and contain plant residues	1.0 – 2.9 m
II	light pulverescent weathered ferruginated stiff loam (stiff according to C_v) EGE 2	0.8 – 3.9 m
	heavy pulverescent banded fluid-plastic loam (high-plastic according to C_v) EGE 2a	
	light pulverescent gray bedded fluid-plastic loam (high-plastic according to C_v) EGE 3	

№	Soils	Layer thickness
III	pulverescent soft sandy loams (high- and low-plastic according to C_v) - EGE 4 and 5	20.6 – 23.4 m
	pulverescent solid loam (semi-solid according to C_v) EGE 6.	
IV	pulverescent bluish-gray faulted solid clay, with fragments of sandstone EGE 8	9.5 – 15.7 m
	pulverescent bedded solid clay EGE 9	

During the drilling period (September 2013), the groundwater line was recorded at depths of 0.2 - 1.3 m, at absolute marks of 3.1 - 2.1 m.

The well stocks, drilled in December 2007 and July 2008, recorded the groundwater line at depths of 1.9 - 2.0 m, at absolute marks of 1.5 - 1.1 m.

According to the data of long-term observations of the SZ GGP "Sevzapgeologiya" on the regime well 155 located in the considered region under similar hydrogeological conditions, the maximum position of the groundwater line is expected during the periods of snowmelt, active precipitation near the surface, absolute mark ~ 3.0 m. The average annual level is assumed to be at a depth of ~ 1.0 m.

The headwater is confined to gravel sand IGE 7, penetrated at a depth of 7.2 - 10.2 m, the absolute marks minus 4.0 - minus 7.1 m. The piezometric level was established at depths of 3.7 - 4.5 m, on the absolute marks minus 0.2 - minus 1.3 m, water pressure was 3.1 - 6.3 m. The coefficient of filtration of filled soils can be taken equal to 1-3 m/day, of loams in the horizontal direction - 0.1 m/day and less.

2. METHODS

Currently, in practice the following types of enclosures are used for excavation support:

- waler systems - fastening in a slope or a spread, applicable in cohesive soils working together with timber, shield or metal inventory shoring structures, when a trench width of a cutting or a digging is not more than fifteen meters;
- a piling barrier - reliable, inexpensive, easy to execute and reduce the cost of zero works. They can be used in complex solid dense or fluid soils and on uneven terrain surfaces. For fixing, prefabricated concrete piles, metal pipes or profiles are used, arranged in a staggered order in one or two rows. With a step of 1.5 or 0.5 m, with free space or with filling. They are immersed by pressing, impact or vibration methods by means of shovel attachments: pneumatic punches, diesel hammers, and vibratory mechanisms. It is advisable to use this kind of shoring later as a bearing structure of the object;
- trench walls are used in open pits, limited conditions and for the construction of underground structures (underground levels of buildings, car parking, tunnels, dikes). The main feature: the depth of the shoring is up to 40 meters;
- ground anchors are an anchor system of the excavation walls against collapse, which compensates the ground tilting moment. There are injectable and self-drilled anchors. Ground anchors affect the sedimentary processes of buildings in the immediate neighborhood of the excavation pit;
- mesh trench shield is used as portable all-metal modular sections. It is made of wire and pipes of various diameters made of high-strength steel, for temporary shoring of the pit walls and trenches while laying of communications, excavations and for short periods of work. It is reusable, inventory;
- sheet piling is used at a pit depth of up to 8 meters with soft, water-saturated soils (e.g. sand, clay), where the groundwater level is high. The tongue serves as a curtain and filter and receives the lateral and hydrostatic pressure of the ground and underground waters. The

tongues have a flat and cross section, for fixing with each other in an upright position they have locks at the edges. The Larssen sheet piling is the most common protection option for excavation and trenches.

For a given pit depth and engineering-geological conditions, it is advisable to use a sheet piling (Tongue Larssen), since there is a relatively high level of groundwater in the construction site and soft soils (in the first two layers) [8-14].

Geotechnical investigation of the construction site was carried out by means of the software engineering complex "Plaxis 3D" on the Hardening Soil model. The three-dimensional model gives an overall picture of the stress-strain state of the construction site, including a 30-meter influence area.

"Plaxis 3D" allows calculating by the method of multistage construction. At the initial stage, a natural stress-strain state is formed. After each stage of construction work, a new stress-strain state is formed, corresponding to changes in the design model.

The numerical analysis makes it possible to more accurately predict the settlements due to improved soil models, considering its nonlinear behavior under the load actions.

The excavation pit is located on a built-up and well-maintained part of the block. The existing buildings fall into the 30-meter influence area.

According to the technical statement, the buildings belong to the category II of a technical condition. In accordance with SP 22.13330.2011, the maximum deformation of the foundations of surrounding buildings and structures located in the influence zone of a new building construction of the category II of a technical condition is 30 mm, irregularity of the settlement 0.002.

The excavation pit anchoring device is supposed to be made of metal tongue VL-606A.

In a plan, the excavation pit is a rectangle measuring 59x55 m. The absolute mark of the day surface with which the tongue will be drilled is about +3.000. The absolute mark of the bottom of the excavation taking into account the preparation is -1.800. Thus, the depth of the excavation is about 4.8 m. The required depth of the tongue penetration is determined by the presence of a solid layer. The required depth of the sheet piling wall, which ensures the sealing of the tongue in a solid ground, is 12 m (pulverescent loams IGE-5).

Since the tongue cut the layer of sand gravel and sandy loam with a high percentage of large particles and sand pockets, including the ground. According to the hydrological nature, the excavation is an imperfect type - water filtering into the pit during its excavation is possible [15, 16].

Preliminary calculations of sheet piling showed the need to introduce additional shoring elements in the construction of sheet piling since the deviation of the sheet pile wall according to the cantilever operation scheme will be 18 cm.

The corners of the excavation pit are spread out by walers, installed in two belts (pipe 377x12) at a distance of 4 m and 8 m from the pit corner. Struts of 370x12 pipes with a pitch of 8-9 m are also provided. Excavation of the pit is carried out under the protection of ground berms. The building of berms is carried out by sections, and a step-by-step excavation with concreting of the mattrass after each step of excavation is recommended.

The layout of the excavation site is conducted by the DZ-42 bulldozer, the development of the ground for the building construction - by the KOBELCO 250LS excavator, with V_k = 1,2 m^3, with the loading of soil onto KamAZ-53215 cars.

Work activities for the excavation pit construction:

- penetration of the tongue on the design mark on the pre-planned territory to the absolute +3.000 mark;
- penetration of the tongue is allowed to lead by the technology of high-frequency vibration;
- after the formation of a closed loop – there are piling works;
- the initial excavation of the foundation pit to a depth of not more than 2 m (to the absolute mark of +1.000), then the device of the binding beam (I-bar 40SH1) and the system of angular and struts at a depth of 1.5 m (absolute mark +1.500);
- excavation of the first section in the central part of the pit at the mark (-1.800), followed by concreting the mattress;
- along the sheet pile wall, a ground berm with a height of 2.8 m is left along the contour with a slope of 1: 2. The width of the upper platform of the berm is 5 m;
- stage-by-stage development of grips of ground berms with concreting of the grill plate after each stage of excavation. Preliminary, the installation of struts is being carried out within the grip;
- the mounting of the struts is carried out in specially prepared trenches without the development of the main body of ground berms. Only after the inclusion of the slopes in the work further works on the excavation in possible.

4. RESULTS

By using the numerical methods of calculation, the stress-strain state of the system "soil massif - sheet piling wall – surrounding area" was determined. The boundary conditions were the limiting values of the additional settlement of the surrounding building, the bearing capacity of the anchoring elements of the excavation and the overall stability of the structure.

The main stages of the calculation, modeling sequence of work are:

- Determination of existing stresses in the soil massif considering the existing buildings;
- works on the construction of sheet piling;
- stage-by-stage excavation of the pit to the design mark.
- the effect of a uniformly distributed technological load of 3 t/m2 from construction equipment or storage of materials, as well as in the area of driveways at a distance of 2 m from the edge of the excavation is taken into account. The load on the foundation of existing buildings was calculated on the basis of the bulk weight of the structures 0.5 t/m^3.

The results of the calculation are presented by the deformation patterns of the "soil massif – shoring elements of the excavation pit - surrounding buildings" system, horizontal displacements, forces in the sheet pile, struts and corner walers (see Figures 1-5).

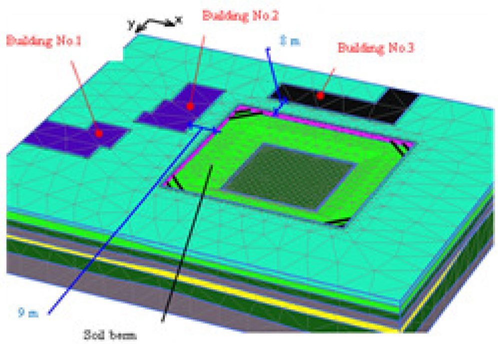


Figure 1. The overall view of the calculation model at the initial and final stages of work

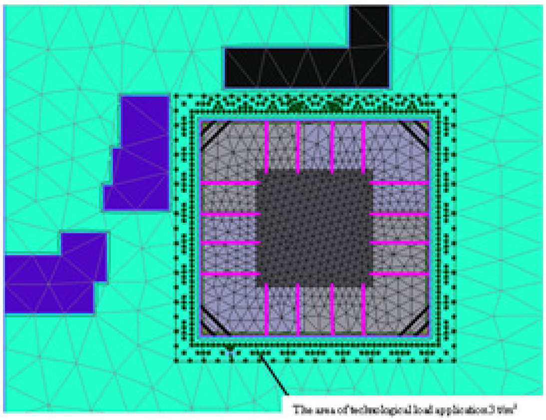


Figure 2. The scheme of technological load application

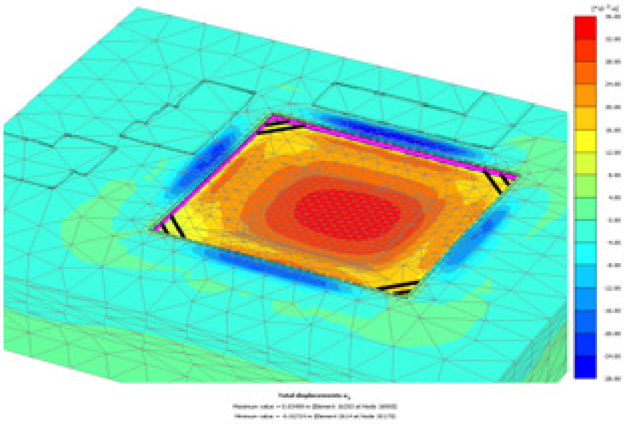


Figure 3. The preparatory stage of the foundation pit construction. Building soil berms. Vertical displacement isopoles

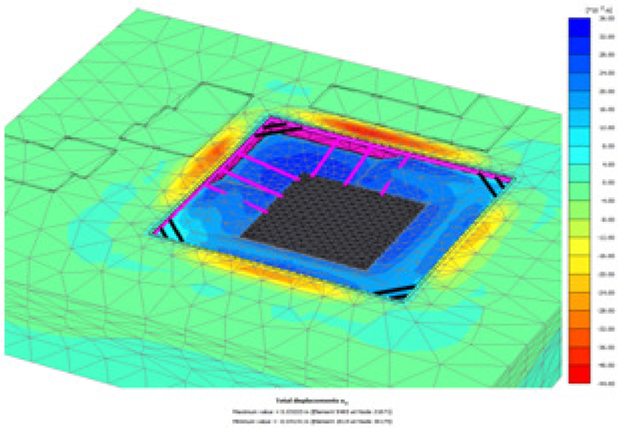


Figure 4. Vertical displacement isopoles. The main stage of the foundation pit construction. Development of sectional grip berms, consecutive incorporation of struts

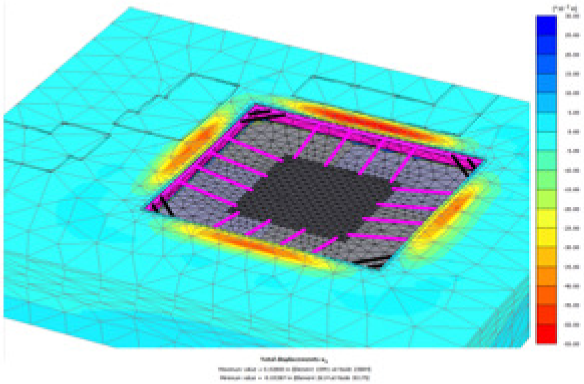


Figure 5. Final stage. Vertical displacement isopoles

The calculations allowed to obtain the following values:

The maximum force in the corner waler is 130 tons, in the struts - 70 tons.

The tongue VL-606A with a length of 12 m with the reinforcement of the pit corners and the arrangement of the struts meets the requirements for strength and deformation.

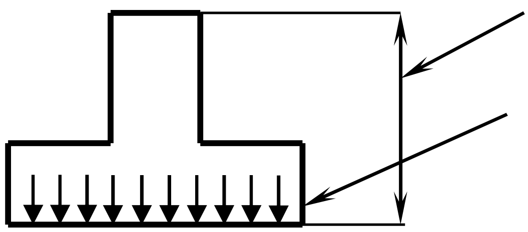
For these construction conditions, it is recommended for the corners of the excavation to be unfolded by two rows of corner walers at a distance of 4 m and 8 m from the pit corner. The cross-section of the corner walers is a 377x12 pipe. As a strut, it is recommended to use a pipe 377x12. The strut step 8-9 m, the steel grade - St20.

It is allowed to apply an additional temporary load along the edge of the excavation. The value of the load is 3 t/m^2 at no closer than 1 m from the edge of the excavation.

The maximum movement of the sheet piling, obtained by calculation, is 6 cm. The maximum additional settlement of existing buildings is 0.3 cm <3 cm. The tilt of buildings does not exceed 0.002. Loads in the walers and struts do not exceed the breaking strength of the material.

Calculation of the settlement of the building was carried out in the computer-aided complex LIRA-SAPR Soil. The piling foundation is the EGE №6 (engineering-geological element). The source data for determining the foundation settlement are presented in Figure 6 [17].

Pulverescent brownish-gray loams with gravel, pebble up to 20%, with boulders with sand pockets, solid with characteristics: E = 300 kg / cm^2, φ = 28, IL = -0.21, c = 47 kPa.



d=0.00 m – height from the buttom to the level of upfilling;
γ^1=0.00 t/m^3 – density of soil above the bottom;
P=29.5 t/m^3 – average pressure under the bottom;
L = 39 m – length of the foundation;
b = 19 m – width of the foundation.

Figure 6. Source data for determining the foundation settlement

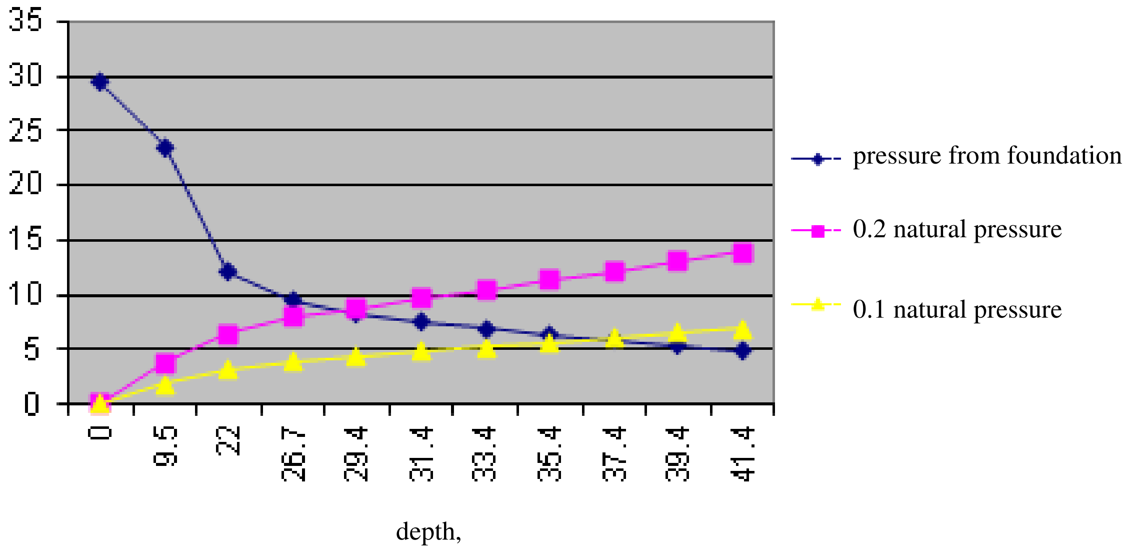


Figure 7. Results of calculations of the foundation settlement

Table 2 Results of calculating the foundation settlement over the soil strata

Stratum	h_i,m	$E_{i,}$ t/m^2	γ, t/m^3	Estimated depth, z	2 z/b	α
1	19	250000	1	0	0	1,0000
2	6	3000	2,25	9,5	1	0,7982
3	3,40	2800	2,11	22	2,3158	0,4114
4	2	3500	2,13	26,7	2,8105	0,3215
5	2	3500	2,13	29,4	3,0947	0,2833
6	2	3500	2,13	31,4	3,3053	0,2578
7	2	3500	2,13	33,4	3,5158	0,2353
8	2	3500	2,13	35,4	3,7263	0,2154
9	2	3500	2,13	37,4	3,9368	0,1974
10	2	3500	2,13	39,4	4,1474	0,1820
	42,4			41,4	4,3579	0,1676

The maximum settlement from the design load was 5 cm, which does not exceed the maximum permissible value. The maximum permissible settlement was determined according to Table 72 of the Manual SP 22.13330.2011 and was 8 cm (Figure 7, Table 2).

5. DISCUSSION

Based on the calculation results, it can be concluded that the bearing structures of the designed building meet the regulatory requirements for strength and deformability.

Since the construction of the multifunctional center was carried out under conditions of compact city development, in highly deformable soils, the condition of buildings and structures near the construction site was monitored during the construction process. The monitoring was carried out in accordance with the "Recommendations for the inspection and monitoring of the technical condition of operated buildings located near a new construction or a reconstruction" [17].

The monitoring allows determining the settlements, tilts and horizontal displacement of the structures under construction and surrounding buildings and the structures located in the influence area, the condition of the structures, the operation of the measuring systems, and other characteristics of the construction site in accordance with Table. 4.2 TSN 50-302-2004.

Under the studied construction conditions, it was important to determine the settlement of buildings located near the object under construction. Figure 8 shows the maximum settlement of buildings in the initial and final stages of construction.

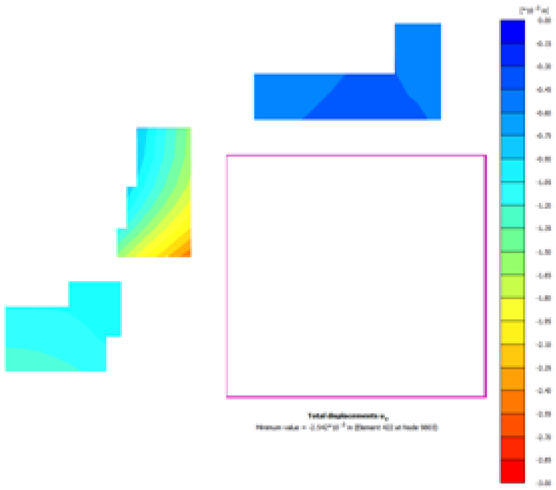


Figure 8. Settlements from the construction of a service center

Another important element is the determination of the settlement of surrounding buildings; the maximum settlement calculated is 0.3 cm, which is ten times less than the permissible value according to TSN.

As a result, the most suitable type of excavation pit shoring for conditions with highly deformable soils was defined, the dimensions of the bearing structures of the pit, namely the tongue VL-606A, walers and struts of 377x12 pipes made of St20 steel were calculated and numerically determined. The necessary values of the surrounding buildings settlement were determined. The calculated settlement values turned out to be less than the permissible for the given construction region. Therefore, the buildings and structures near the construction site will not lose stability and their operation will not be disturbed.

Based on the calculations performed and the measures taken to strengthen the foundation, it can be concluded that, under the conditions of compact city development, and on highly deformable soils, it is possible and not dangerous to build such structures (high-rise buildings).

6. CONCLUSIONS

In the modern world, with a global growth of megacities, when building new constructions or performing reconstruction within an urban development on soft grounds, in difficult engineering and geological conditions, it is important to understand, that the smallest mistake in design can lead to the destruction and, consequently, the dispersal of surrounding residential buildings. To ensure the reliability and safety of buildings (structures) during construction and reconstruction, as well as the security of neighboring buildings, it is necessary to carry out comprehensive geotechnical support for the construction.

Due to the complex and multi-factor tasks of geotechnical support, the solution in most cases is possible only with the use of modern numerical methods that implement physically and geometrically nonlinear models.

The results of the studies and calculations presented in this article are of a practical nature and can be used by organizations involved in the design, construction, and monitoring of buildings and structures in similar engineering and geological conditions.

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