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STRESS STRAIN STATE ESTIMATION OF UNDERGROUND PARKING BY NUMERICAL MODELLING

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Abstract. There is a big problem with parking places in the cities with conditions of dense buildings. This article is devoted to the problems associated with road traffic and construction of parking lots. Also, the article offers a solution for construction of massive underground parking.

Keywords: massive underground parking (MUP), stress stain state, traffic, slurry wall, numerical methods modeling

Relevance of the theme

During the last decade, the Europe faced a rapid increase in motorized transport, especially in road and air transport. This increase is expected to continue in the near future. Despite the growth of traffic, people should be able to park their cars in safe and accessible places. But in the absence of parking places people left their cars on carriageways or pavement. Often this problem leads to traffic jams.

According to the REPORT OF THE HUNDRED AND TENTH ROUND TABLE ON TRANSPORT ECONOMICS number of vehicles increases each year and due to this, situation with parking lots become worth. According to the statistics and forecasts, by 2020 the number of vehicles will double. That’s why it is relevant to take into account during construction of underground parking such factors: traffic volume, dense building accommodation and technogenic factors [1, 2].

Growing number of European cities have led the world in changing the direction of parking policy. European citizens grew tired of having public spaces and footpaths occupied by surface parking. Each parking space consumes from 15 m^2 to 30 m^2, and the average motorist uses two to five different parking spaces every day. In dense European cities, a growing number of citizens began to question whether dedicating scarce public space to car parking was wise social policy, and whether encouraging new buildings to build parking spaces was a good idea. No matter how many new parking garages and motorways they built, the traffic congestion only grew worse, and as much as 50% of traffic congestion was caused by drivers cruising around in search of a cheaper parking space. For example, to provide European standards by 2025 it is required to rebuild every year up to 230 thousand cars storage, as well as 170000 parking spaces, for a total of approximately 400000.

As we already know, majority of European cities have situation with dense buildings. Those buildings are cultural heritage and some of them are under protection of UNESCO. That’s why demount of such construction is impossible. The government tries to invent most innovative approaches of parking for improving the economic, social, and environmental quality of city centers. In such a way choosing the right policies depends on a city’s goal-whether it is to reduce CO_2 emissions, to relieve traffic jams, to remove vehicles because they are a nuisance, or any number of other reasons - and certain policies fit certain goals better than others. But the problem remains the same. It means that amount of cars growth up year by year but area of city centers remains the same.

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Analyzing dilemma related to accommodation of parking lots there was proposed an idea of massive underground parking construction. Such kind of parking will solve majority of problems.

There are some advantages of massive underground parking:

– parking lots will be situated directly below the city most replete traffic zones;
– underground parking will free cultural and touristic places of the city;
– there will be provided direct access to local railway and metro stations;
– MUP will have access to main transport junctions;
– there will be intense decreasing of traffic jams.

This article is devoted to the underground parking construction. There are proposed methods of designing and calculation of MUP in the cities with dense buildings.

Formulation of the problem

Before designing of massive underground parking it is rational to consider major problems which will appear during construction process. In this way the aim of successful construction is estimation of stress strain state.

As erection of parking will be deep underground there are such influence factors to be considered:

– pressure from soil and nearby buildings;
– vibrations that are connected with movement of underground and surface transport;
– flooding and erosion by the ground water;
– influence of underground construction on the foundation of nearby constructions.

For better understanding let's consider each factor separately.

During taking a decision on a steep, potentially prone to landslide soil masses, it is important to know the distribution of stresses in the ground during discharge and slope stabilization:

– Under any circumstances, there is a limit stress, which results in the destruction of the soil skeleton and redistribution of particles;
– Forecast conduct soil masses under the influence of external and internal influences, changes the equilibrium conditions for a variety of natural and man–made causes such as pressure from buildings and constructions that are situated near area of construction.

The sources of vibration in residential and public buildings are engineering and plumbing, as well as industrial plants and vehicles (subway shallow, heavy trucks, trains, trams), created with the work of high dynamic loads, which cause the spread of vibration in the ground and building constructions. These vibrations are often also cause noise in the building.

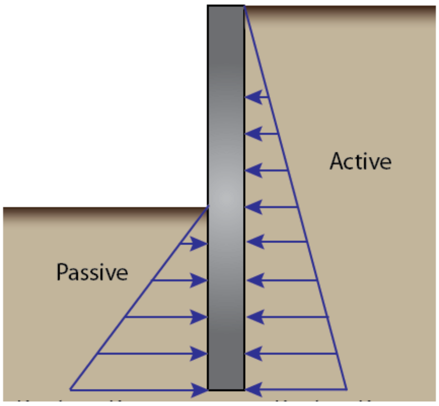

Fig. 1. Distribution of pressure in the soil

The next one factor is groundwater. It includes all water of earth crust beneath the surface of the soil and the bottom of the surface water bodies and streams. Due to the impact of groundwater on bearing capacity of soil and underground construction or foundations it is important to take into account the possibility of changes in the hydro-geological conditions of the site during construction and operation facilities.

The adverse factors of ground water include: the natural seasonal and long-term fluctuations in the groundwater level, changing of the water level due to technical reasons, an increase in the aggressiveness of groundwater in relation to the content of underground structures and increased corrosivity of soils, imposed by the technological features of production.

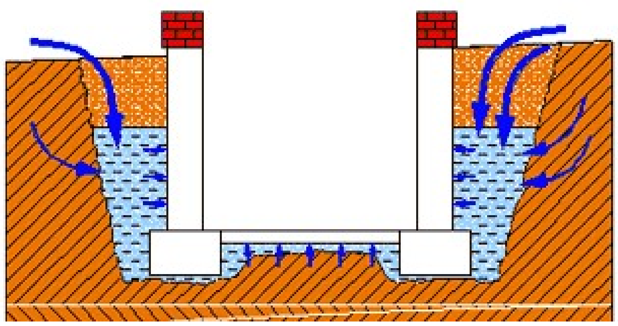

Fig. 2 Ground water distribution

The last but not the list parameter is influence of underground parking on the foundation of nearby constructions. Before construction it is necessary to explore the depth and condition of foundation of nearby structures. It is also necessary to take measures to strengthen the foundations which are in close proximity to the construction area. Vibrations from underground constructing can lead to destruction or creaking of some building elements. Also all works need to be performed in a day time for normal existing conditions of citizens.

After analyzing of all factors which will influence on further construction we can estimate stress strain state of main bearing elements of underground parking. The task is to provide reliable method of erection and to select most useful construction elements.

Solution of the problem

First of all we decided to provide the list of main constructive elements and their characteristics.

Overlapping of underground parking can be beamed or monolithic. In the beam–type ceilings, there is used steel or reinforced concrete beams. Reinforced concrete beams in the best use of frame stand with reinforced concrete columns and small spans. Metal beams can span a much greater overlap and are used in frame buildings – both concrete and the metal columns. Overlap on the steel beams is made of large- and small-sized concrete slabs. Using the latest to reduce the slab thickness, and reduce the cost of construction and installation work. Monolithic slabs are thinner compared with the teams and allow the building to block the complex configuration in the plan.

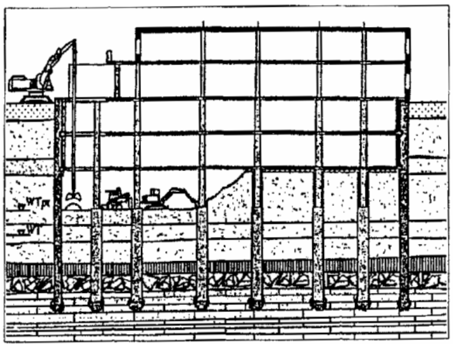

Fig. 3. Construction of underground structures

Creating a high quality shield and tunnel formwork made use of reinforced concrete in the construction of the walls of the underground car park one of the most commonly used solutions. Monolithic concrete structures are cheap enough. Their advantage is also the possibility of building space is limited. The use of these structures allows to build parking with parameters (grid columns, floor height), exactly matching the dimensions of the storage and driveways. Applied and finished concrete structures, but their use is hampered by a small selection of board options, suitable for the module and the technical specifications for the construction of underground parking.

Parking ramps can be isolated for passing only just entering or leaving vehicles and combined to skip the counter flow. This option eliminates the need for ramps, saving space, but it is much more complicated construction. Bearing walls and floors concrete ramps operates.

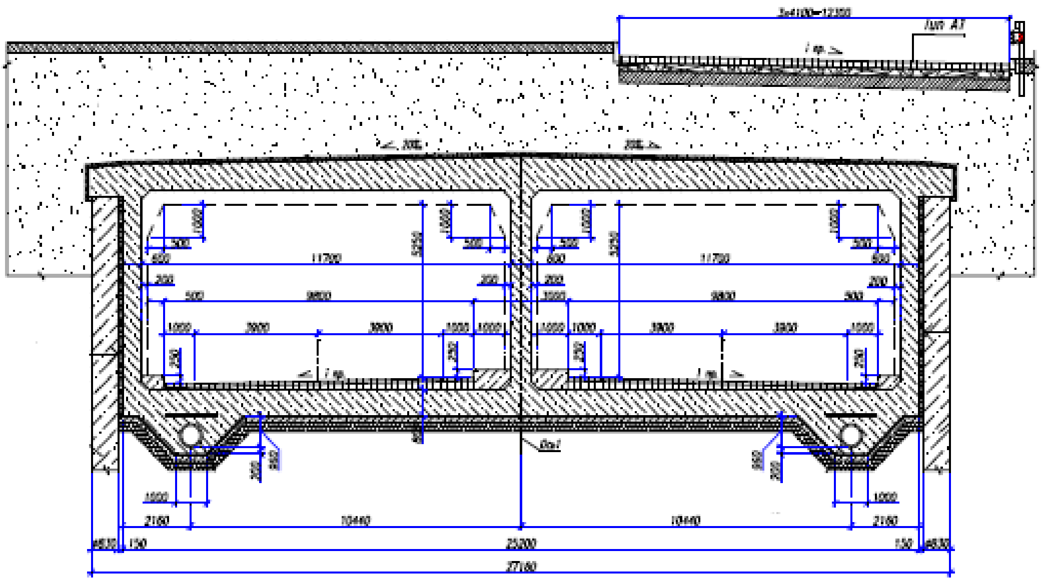

Fig. 4. The cross section of the tunnel

Floors of underground parking today often arrange concrete with reinforced top layer or liquid bulk mastic coating. The advantages of such floors: simple technology, low labor costs, high shock-, water- and oil-resistant, dust-free − made them very popular solution.

Also the waterproofing is very important. Therefore, quality waterproofing of underground parking − it is a matter of security and durability of the structure. Typically it is used lots cast and impregnating waterproofing walls.

In recent years, there are new and effective supplements that greatly improve the density of concrete, waterproofing materials and new technology, which improves the quality and reduce the cost of waterproofing works. Among these technologies include injection waterproofing injection binder in adjacent soil. For its devices are increasingly used new polymers. Of great importance is waterproofing expansion joints. In addition to waterproofing, sealing joints should have a high degree of flexibility, so they can easily follow the deformation structures.

During the construction of underground parking emphasizes fire safety, which in turn is reflected in the higher requirements for a fire resistance of reinforced concrete slabs, beams, columns, ventilation and smoke removal.

So we decided to calculate the most loaded element of underground structures, which is called "slurry wall".

The method of "slurry wall" is intended for the construction of underground structures in the ground for various purposes. The essence of it is that the walls of buried buildings erected in the narrow and deep trenches, vertical sides are kept from collapsing by clay suspension, which creates excessive hydrostatic pressure on the ground and act as a fitment. After that the trenches of required size are filled (depending on the design and purpose structures) of reinforced concrete, or precast concrete elements.

This method is appropriate to apply in complex hydro-geological conditions, in the cramped conditions of the existing building, under the conditions of big cities, with very high density of built-up. This method is effective at building in built up areas of small underground structures at considerable depths (typically 20 m) − transport tunnels, car parks, pedestrian crossings, underground highways, etc.

By the material most common "slurry wall" are:

– reinforced concrete wall bearing wall structures, which receive vertical and horizontal loads;
– concrete, which receive vertical loads, as well as serving both anti-filtration diaphragms;
– clay subsoil, which are anti−filtration, which are made of natural or artificial waterproof materials.

By construction, the "slurry wall" can be:

– drilled one;
– reinforced concrete, consisting of individual dense coupled with each section;
– reinforced concrete, consisting of individual dense coupled together sections with continuous horizontal reinforcement;
– prefabricated single-stage − of flat panels, ribbed and box with vertical joints between them;
– prefabricated consisting of columns with lateral grooves;
– combined multilevel with tiers of different materials.

Calculation method

The program complexes LIRA−SAPR and ESPRI is used to calculate the strength of flexible retaining walls and to assess the stability of the soil around the recessed portion of the wall.

Methods of calculating the strength of the enclosing structure is based on the numerical solution of the problem of bending beam, clamped at one end and held plastic ground connections (anchors, struts). To model the elastic bending of the wall using the finite element method.

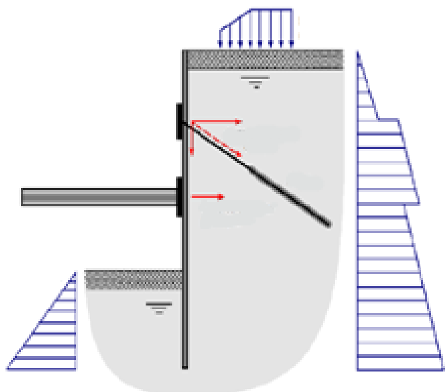

Fig. 5. Design scheme

During the solution of the problem we perform the following calculations:

1. Calculation of active and passive earth pressure on the fence.

2. Calculation of plastic response and stability of the soil around a buried wall (fence).
3. Calculation of longitudinal forces in the anchors and braces.
4. Finite element solution of the problem of elastic bending of the wall under the pressure of soil from the side of the pit.
5. The calculation of the pit enclosure for durability.

Calculation of earth pressure

In the case of the free surface of the load horizontal $\sigma_{\alpha h}$ and vertical $\sigma_{\alpha v}$ components of the differential pressure for cohesion less soils at depth z are given by:

$$\sigma_{\alpha h} = y \cdot z \cdot \lambda_{\alpha} ;$$

$$\lambda_{\alpha} = \left[\frac{\cos\varphi}{1 + \sqrt{\dfrac{\sin(\varphi+\delta)\sin(\varphi)}{\cos\delta}}} \right] .$$

Under uniformly distributed load on a horizontal surface q σ_{ph} and vertical σ_{pv} components of passive pressure at depth z from the surface are given by:

$$\sigma_{\alpha h} = (q + yz)\lambda_{ph} + \frac{c}{tg\varphi}(\lambda_{ph} - 1);$$

$$\lambda_{ph} = \left[\frac{\cos\varphi}{1 - \sqrt{\dfrac{\sin(\varphi+\delta)\sin(\varphi)}{\cos\delta}}} \right]^2 .$$

Solution of the elastic bending of the wall

Bending problem is solved numerically by the finite element method using a variational formulation. Cover only the longitudinal component of the strain and stress. Variational formulation of the problem is as follows. Find displacement v, and minimizes the function:

$$f(v) = \frac{1}{2}\int_a \sigma(v)\varepsilon(v)dz + \frac{1}{2}\int_{S_c} C_n \omega^2 dS_C + $$
$$+ \frac{1}{2}\int_{S_C} C_\tau u_\tau^2 dS_C - \int_{S_p} Pvdx.$$

Longitudinal strain will emerge from the compressive strain (stretch):

$$\varepsilon_x(u) = \frac{du}{dx}$$

and deformation of the bending:

$$\varepsilon_x(w) = -y\frac{d^2w}{dx^2} .$$

Stresses and strains are related by Hooke's law:

$$\sigma_x = E\varepsilon_x .$$

Bend fence is modeled as an elastic beam bending section, to the one-step guard.

Due to the fact that the structure is linear, estimation of the stress-strain state can be carried out using a flat design scheme. Each design scheme is a flat cross-sectional model of the pit with a fence and concrete structures of the tunnel. The scheme consists of finite elements that define the configuration and properties of the surrounding natural ground, construction of bored piles, as well as specific properties of contact surfaces.

Dead weight of concrete piles and construction is taken into account by the program automatically according to certain characteristics. Also as permanent loads in the calculation schemes considered dead weight of the soil and the hydrostatic pressure of the water. Hydrostatic pressure is applied on the already formed construction to the final stage of the calculation on the outer edges (from the soil in its natural state) [3].

The temporary load is taken: the load of a moving vehicle on the roadway above the tunnel ceiling. The calculation is performed in two stages with two software systems.

Calculation in ESPRI. Slurry wall:

– Initial data for calculation we can see at the Fig. 6.
– The geometrical dimensions of the pit.
– Physical and mechanical properties of the soil.
– The geometrical dimensions of rabbet.
– Stiffness characteristics are defined for rabbet as piles D 830 mm.
– The geometrical dimensions of the anchors (conventional braces.)
– Stiffness characteristics for anchors are set infinitely large.
– Construction load sliding wedge q = 3,5 t/m^2.
– Reference mark phasing excavation of the soil.

The results of calculation are shown at the Fig. 7.

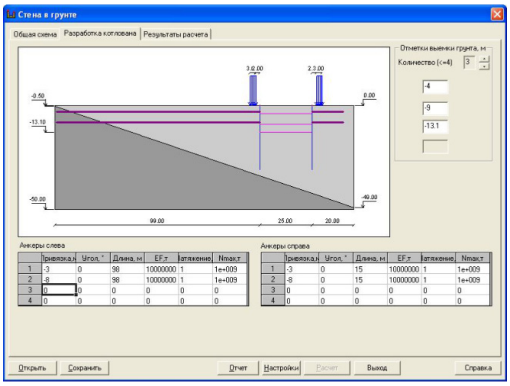

Fig. 6. The initial data for calculation

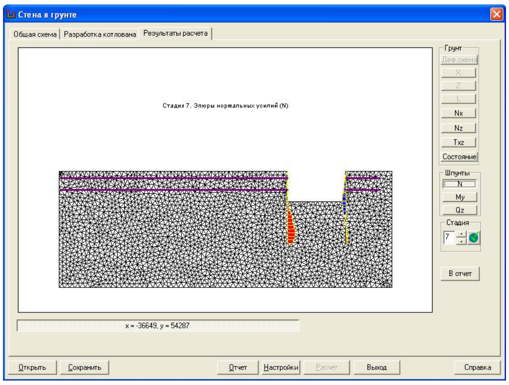

Fig. 7. The destruction in the soil

The calculation in the LIRA SAPR based stepwise installation closed tunnel:

- soil is modeled 51 FE (single-node finite element elastic coupling);
- between the pile and the wall of the tray are set friction elements 264 FE (two-node unilateral frictional element.) Coefficient of friction $f = 0.6$ (concrete to concrete);
- during dismantling of braces foundation pit the effort are transferred to the solidified part of the tunnel and is modeled with application corresponding reaction braces.

Stage of installation:

1) Installation of bottom part of the tunnel on the level – 8 m.

2) Dismantling of braces on the level – 8 m (application loads from conventional anchors).

3) Installation of the tunnel to the top (to the level – 3.5 m).

4) Dismantling of braces on the level – 3 m (application loads from conventional anchors).

5) Dismantling of the top (to the level − 3.5 m), backfilling soil.

6a) Apposition to the pile lateral earth pressure on the load НК, located on the sliding wedge.

6b) Hydrostatic water pressure.

7a) Instead stage 6a and 6b application load НК above the tunnel.

7b) Hydrostatic water pressure.

8a) instead stage 6a and 6b, 7a and 7b application load НК in the tunnel.

8b) Hydrostatic water pressure.

The can see at the Fig. 8 the bending moments of the final stage of installation.

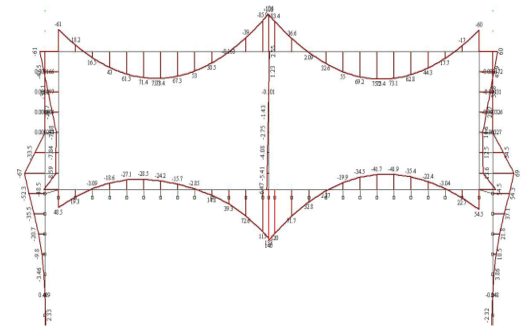

Fig. 8. Bending moments on stage 8b of installation

Conclusions

Considered and reviewed the construction decisions, taking into account the adverse factors for underground parking, it can be concluded that their erection is a complex process, from an engineering point of view but at the same time, economically and socially profitable product that will greatly improve transport accommodation in urban areas with existing buildings. Estimations of stress strain state demonstrate that during construction of underground parking in areas with existing buildings it need to be considered combination of factors that negatively influence on erection process and further functioning of parking. In result there was proposed method of calculation and selection of constructive materials.

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