Garage complexes as the infrastructural basis of a modern city

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Abstract. The problem of the effective organization of parking spaces, the need for the construction of a multi-storey garage complex located in the transport-service system of the city investigated. The requirements of the existing federal law and regulations governing the conditions for placing the garage complex and car maintenance areas in relation to residential, public and business buildings located in the immediate vicinity have been worked out and considered. The construction site of Autohall garage complex, having weak, water-saturated clay soils, has been investigated. A constructive solution is considered and the advantage of using reinforced concrete column piles as supports reinforcing the soil is revealed. MONOMACH software complex solves a wide range of problems and has a number of advantages over other automated systems. The program implements a wide range of possibilities for inter-program communication. The construction of a monolithic frame of the complex, its volumetric model in COMPONOVKA program was consistently performed. Program GRUNT determined spatial modeling of the soil body according to the given engineering and geological surveys, the physical and mechanical characteristics of the soil, the bed coefficient. A monolithic foundation slab on a pile foundation was imported into PLITA program and the calculation of the optimal thickness of the slab, reinforcement of the lower and upper zones, numerical modelling of the work of the stress-strain state, i.e. an optimal design solution was chosen that excluded uneven deformations of the base, i.e. the design solution excludes ultimate deformations of the base.

1. Introduction
In modern urban conditions, the road transport network is often congested and the traffic is partially or completely halted. Among the problems generated by the high level of motorization of the urban population in large cities, architects and urban planners are aware of the urgent need to build parking lots, considering them to be the most important elements of the city’s infrastructure. Optimizing the vehicle storage has changed enormously over the past century. Research of the problem of effective organization of parking spaces and the accumulated experience in design and construction makes it possible to distribute the space of urban areas effectively, to accommodate cars belonging to citizens has been investigated [1, 2]. The traffic performance of Ryazan is decreasing from year to year, due to cars parked along streets and squares, and the problem of the lack or insufficient number of organized parking spaces is actualized [3-5].
The construction site of the garage complex, the construction of which is directly associated with a decrease in the traffic performance of streets, has weak, water-saturated clay soils. The use of a foundation slab is not enough, since displacements obtained when calculating exceed the maximum permissible standard values. The calculation of the slab-pile foundation with the support of column piles on the rocky soil-limestone is carried out with the help of MONOMAH software package, which includes a wide range of functions agreed with regulatory documents. The software determines the bed coefficient by analyzing the stratification of the soil body, calculates deformations that occur both during construction and operation, taking into account the overall work of the complex frame.

2. Materials and methods
When speaking about multi-storey garage complexes, one means highly specialized structures designed for the organized parking of as many vehicles as possible. For this purpose, tiers located one above the other, various types of ramps, inclined floors, elevators, parking equipment and a complex of infrastructure (fire safety systems, ventilation, etc.), as well as maintenance workshops and other types of services are designed for the driveway. However, the purpose does not determine the shape of the transport structure, as well as the sum of the most important elements forming its basis. All the rest depend on the professionalism of design specialists: architects, designers and competent engineers. They conduct architectural and engineering research, choose the proportions and appearance of the building, its division, exterior, interior decoration and so on. Like any issue, when designing there should be the unity of form and content, including technical aspects [6, 7].

The garage complex is determined by some features and, first, by the multifunctionality of the use of the first floors. Garage users are divided into two large groups: those in need of short-term or long-term car storage. Storage areas with a relatively short duration of stay of vehicles should be located within walking distance. The needs of such users can be satisfied by low garages from one to four floors. In higher garages, parking spaces for them should be allocated on the lower floors. Usually the first floor is of multifunctional use and serves for the maintenance. Parking spaces are located on adjacent sites and on the ceilings above the first floor. In this case, the length of the path for everywhere or at the exit is small, the road in front of the car is free. There are no special difficulties in meeting the requirements of fire safety, ventilation, environmental friendliness and other requirements of Russian standards [8]. The structure of such a building is open to external observation from all sides. Therefore, its proportions, details, materials and even the color should be chosen with great care. Those who need long-term storage of cars usually use large multi-storey car parks. In both cases, the main factor influencing the choice of a garage complex is the attractiveness of the construction site and its involvement in the city's infrastructure.

The urban development situation in Ryazan determined the choice of the construction site for the Autohall garage complex (Fig. 1), being a area free from buildings and located in Kalnaya Street, 3A (Fig. 2). Optimization of design and architectural solutions took place at the stage of developing the design assignment and influenced the appearance of the entire structure.

![Figure 1. Model of garage complex Autohall](image1)

![Figure 2. Microdistrict Kalnoe, Ryazan region (garage complex Autohall)](image2)
The important role in design and construction is played by the foundation, as one of the main elements of the building. The longevity of the entire structure will depend on the quality and reliability of it, since it perceives the loads from the walls of the building and overlying structures and transfers them to the base soils, counteracting the lift forces of the soil.

3. Results and discussion
A monolithic reinforced concrete slab was designed for the entire building on a solid pile foundation in garage complex Autohall to redistribute loads, eliminate uneven deformations of the base and ensure joint work. On the basis of the calculation, reinforced concrete piles 6 m long with a section of 30x30 cm were taken as supports reinforcing the soil. The depth of the foundation was 1.350 m from the ground surface.

The program interface MONOMACH is intuitively accessible, since when creating a design model, work is carried out with familiar objects: axes, beams, ceilings, columns, floors and other structural reinforced concrete elements. The basis for calculating building structures is the finite element method.

A volumetric model for the garage complex was created with the help of KOMPONOVKA program, which is included in the main module of MONOMACH software package (Fig. 3). The software has a wide range of functions and allows predicting the influence of design factors. The load-bearing structures of the complex are monolithic reinforced concrete columns on which the monolithic reinforced concrete floor slabs are supported.

According to Table 8.3 [9] the dead load of all structures, obtained in automatic mode, when forming a volumetric model of the complex and setting temporary loads (for multi-storey garages - 4 kPa) were taken as constant loads (Fig. 3).

![Figure 3. Volumetric design model of the garage complex](image1)

![Figure 4. Stages of building a 3D model of a soil body for engineering and geological surveys](image2)

The issues of engineering and geological phenomena on the territory of the building, the relief and the results of the physical and mechanical characteristics of soils were determined by the results of drilling wells and their desk study by specialists of RYAZANGRAZHDANPROEKT CJSC. Weak, water-saturated soils were exposed under the base of the foundation slab.

Hydrogeological conditions of the construction site are as follows: soils to a depth of 8.0 m have a high degree of corrosiveness towards steel and soils to a depth of 2 m are moderately aggressive to concrete of normal permeability.

The next step was the spatial modeling of the soil body according to the data of engineering-geological wells located within the building area. Having set the absolute elevation of the mouth, using GRUNT program, a spatial model of the soil base was formed according to the specified engineering and geological conditions of the construction site, vertically reinforced with rigid elements (Fig. 4).
After placing the piles in the plan, their total number was 250 (Fig. 5). To check this technical solution, a numerical simulation of the work of the stress-strain state was carried out in universal software package MONOMAH, certified in the Russian Federation.

Based on the simulation results, it has been established that the use of a monolithic foundation slab on a solid pile foundation, on weak clay soils, provides regulatory requirements for the deformability of the foundation (Smax<Su). One of the most important tasks of calculating a pile-slab foundation is to find the dependence of the zones of influence for the second group of limiting states.

A slab on a pile foundation was imported into PLITA program. Column piles were used to support on the rocky limestone soil, which was load-bearing. The material for the foundation slab is heavy concrete of class B25 and reinforcement of class A 400 [10]. The slab thickness depended on the loads and the pile pitch (Fig. 5-6). The foundation slab was at the same time the floor of the garage complex.

The analysis of the calculation results in the software and hardware, made it possible to draw the following conclusions: the maximum displacement was 24.5 mm, which was less than the permissible value of 180 mm according to Appendix D, SP 22.13330.2016 Foundations of buildings and structures. Updated edition of SNiP 2.02.01-83* (Fig. 6); the optimal slab thickness was 500 mm (Fig. 8); the foundation slab was reinforced in the lower zone with separate rods with a diameter of 20 mm and a pitch of 200 mm and in the upper zone the ones with a diameter of 16 mm and a pitch of 200 mm, reinforcement of class A400 (Fig. 7-10). Technically, exceeding the permissible yielding (according to the second group of limiting states) led to a complete or partial loss of serviceability.

![Figure 5. Distribution of displacements (yielding) in the foundation slab, S=100cm, h=60cm](image1)

![Figure 6. Results of calculating the optimal slab thickness, S=100cm, h=60cm](image2)

Isofields of reinforcement in PLITA program are presented in Figures 7-10. At the end of the design process, a complete model of the complex is obtained. The results of the calculation made it possible to substantiate a variant of the optimal design solution for a multi-storey garage complex, considering the complex engineering and geological conditions of the construction site.

![Figure 7. Top reinforcement along X axis, S=50cm, h=60cm](image3)

![Figure 8. Top reinforcement along Y axis, S=50cm, h=60cm](image4)
4. Conclusion
The foregoing allows concluding that universal program complex MONOMACH is aimed at sequential computer-aided design of buildings in conjunction with the created 3D model of the soil body based on engineering and geological data.

The program requires not only time to build a computational model of the inter-program data transfer and the calculation itself, as well as the availability of professional, construction knowledge that allows interpreting the results obtained and qualitatively prepares a reasonable choice of design.

As a result of the analysis of calculations carried out at the modern technological level and their interpretation, the following design decisions were made: the thickness of the foundation slab is 500 mm with heavy concrete of class B25; reinforced concrete piles have a section of 30x30cm and are 6m long; slab foundation is reinforced in the lower zone with separate rods with a diameter of 20 mm and a pitch of 200 mm and the rods in the upper zone with a diameter of 16 mm and a pitch of 200 mm, reinforcement of class A400.

The selected optimal design solution is the erection of the foundation slab uniting column piles resting on rocky soil that is the most technologically advanced and reliable when weak, water-saturated clay soils. These findings can be used when designing similar buildings.

This direction of design is relevant and in demand. The construction of multi-level garages in densely built-up Ryazan will help solve the problem associated with storage of vehicles, traffic and expansion of the road network and a high level of motorization of the urban population.

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