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# Overall stabilization of underground workings in limestone-shells

**Mitinskiy Vasiliy[1]*, Chepelev Valentyn[2], Vynnykov Yuriy[3], Lartseva Iryna[4], Aniskin Aleksej[5]**

[1] Odessa State Academy of Civil Engineering and Architecture https://orcid.org/0000-0003-3976-2531
[2] Collective enterprise «Budova», Odessa
[3] Poltava National Technical Yuri Kondratyuk University https://orcid.org/0000-0003-2164-9936
[4] Poltava National Technical Yuri Kondratyuk University https://orcid.org/0000-0003-0133-5956
[5] University North, Varazdin (Croatia) https://orcid.org/0000-0002-9941-1947
*Corresponding author: *mitinskiy.v@gmail.com*

The characteristic properties of limestone-shell used as the base of foundation are described. Using the example of multi-storey residential building design, comprehensive solution has been proposed for plugging workings in an array of limestone-shell for the subsequent construction of slab-pile foundation, which includes engineering and geological surveys, geotechnical design, the choice of mortars and their compositions, as well as continuous monitoring plugging conditions. It is stated that two types of cement-sand mortar are used for plugging workings: the first is with the addition of superplasticizers, which provide high solution mobility, low water loss and non-shrinkage after hardening; the second is without adding superplasticizers with fluidity high degree. The results of laboratory studies to select the composition of soil-cement are given.

**Keywords:** limestone-shell, underground working (catacomb), plugging, injection, soil-cement, bearing capacity

# Комплексне закріплення виробок у вапняку-черепашнику

**Митинський В.М.[1]*, Чепелев В.Т.[2], Винников Ю.Л.[3], Ларцева І.І.[4], Аніскін А.[5]**

[1] Одеська державна академія будівництва та архітектури
[2] Колективне підприємство «Будова», м. Одеса
[3] Полтавський національний технічний університет імені Юрія Кондратюка
[4] Полтавський національний технічний університет імені Юрія Кондратюка
[5] Північний університет, м. Вараждин (Хорватія)
*Адреса для листування: *mitinskiy.v@gmail.com*

Описано характерні властивості вапняку-черепашнику, який використовують як основу фундаментів. На прикладі проектування багатоповерхового житлового будинку в м. Одесі запропоновано комплексне розв'язання задачі тампонування виробок (катакомб) у масиві вапняку-черепашнику для подальшого влаштування плитно-пальового фундаменту; воно включає в себе проведення робіт з інженерно-геологічних вишукувань, геотехнічного проектування, вибору розчинів і їх складів, а також виконання робіт з постійним моніторингом умов тампонування. Виробки розташовано на глибині близько 30 м від денної поверхні, вони складають понад 26% площі забудови будинку. Викладено, що для надійного тампонування виробок на першому етапі використовувалися два типи цементно-піщаних розчинів: перший – з додаванням суперпластифікаторів, що забезпечують високу рухливість розчину, низьку його водовіддачу та безусадочність після твердіння; другий – з високим ступенем розтікання. На першому етапі розчин подавався у свердловину як наливом, так і насосом, що дозволяв створювати тиск до 2 МПа; на другому етапі виконувалося ін'єктування розчину в зону виробок з використанням манжетних колон. Для ін'єкції використовувався цементний розчин з добавками-пластифікаторами, а на окремих ділянках – ґрунтоцемент. Наведено результати лабораторних досліджень для вибору складу ґрунтоцементу. При цьому встановлено, що раціонально приймати витрату суглинку як відходу виробництва і найдешевшого матеріалу в кількості 1 м$^3$ за насипною густиною на 1 м$^3$ ґрунтоцементу. Витрати цементу призначено у діапазоні 100 – 200 кг/м$^3$ розчину з урахуванням необхідності отримання марок розчину М25.

**Ключові слова:** вапняк-черепашник, підземна виробка (катакомба), тампонування, ін'єктування, ґрунтоцемент, несуча здатність

**Introduction.** Increase in the pace of construction and reduction in the number of construction sites with a relatively simple geological structure makes geotechnical engineers to develop areas with complex geological conditions, including those complicated by the presence of underground workings (the so-called «catacombs»).

Therefore, in the design and construction of high-rise buildings in terms of a dense urban development in the area of underground workings, the issue of accumulation and analysis of experience in building effective and reliable bases and foundations, as well as geotechnical monitoring of the construction of such objects, is relevant [1, 2].

**Analysis of resent research and publications.** The experience of foundations in the area of underground workings is given in [1 – 6].

From the analysis of these studies aimed at solving the problem of bored piles installation in areas of underground workings, the most popular is the technology of rib control by plugging the cavity with its subsequent piles construction [5, 6].

**Identification of general problem parts unsolved before.** The problem of rocks stratum possible forcing by the weight of a building, and methods for solving these problems, in particular the use of plugging workings in an array of limestone-shell for the subsequent construction of multi-storey buildings on slab-pile foundations, has not been adequately investigated in geotechnical design practice.

T**he aim of the work** is to develop an effective complex of works on overall stabilization of underground workings in an array of limestone-shell for the subsequent construction of multi-storey buildings on slab-pile foundations.

**Basic material and results.** At the construction site of a 24-storey residential building in Odessa, Gagarin Avenue, 19, workings are located at a depth of about 30 m from the surface and account for more than 26% of the built-up area of the building (Fig. 1, a).

At the site in question, the workings were previously tamped with sand filling by injecting water-sand pulp. The search work performed in the process of engineering-geological prospecting enabled clarifying the planned-altitudinal position of the workings and the quality of the plugging performed.

As a result, it was defined that the workings are not filled with sand to the full height and measures for their additional stabilization are required. The complexity of the plugging is that, due to insignificant height of the identified voids (0.4 ... 0.8 m), access to them through the vertical holes that have to be arranged beforehand, is difficult to implement, and the mine survey of workings has not been performed.

The project, considering geotechnical conditions complexity, provides for a plate-pile foundation of prismatic piles with a section of 35x35 cm, length 14.0 m, with their bottoms stop in the Strata-8 – light red-brown clay. The grating is designed as a solid monolithic slab, 1.8 m thick. Below the sole of the clay layer there limestone-shell array lies, in the sawn difference of which the underground workings are revealed (Fig. 1, b). Thus, to ensure the base operation reliability, it was necessary to fill all the voids in terms of the lack of their exact location and the quality of the filling that was previously performed

Work reliable tamping was provided by the gradual injection of mortars into the zone of their distribution. At the first stage, cavities connected both with each other and with previously drilled exploration wells were filled, which is shown in Fig. 1

To solve the problems, two types of cement-sand mortars were used, namely: the first type with the addition of superplasticizers, which provide high solution mobility, low water loss and non-shrinkage after hardening; the second one is without adding superplasticizers with a high degree of fluidity.

Depending on the voids height in each well and the identified production slopes in the interval between the wells, a sequence of filling them with a solution, alternation and injection volume of each type of mortars were developed. The mortar was fed both in bulk into the well, and with a pump that enabled to create pressure up to 2.0 MPa. The control of the cavities filling degree with the mortar was carried out with the help of a flap, which was lowered both into the filled and control wells.

At the second stage, the solution was injected into the area of workings using cuff columns (Fig. 2). In the plan the cuff columns were arranged in the interval between the wells for the injection of cement-sand mortar (first stage), the height of production in 80 cm starting from its bottom. The injection was carried out as follows: a cuff column of pipes with a diameter of 86 mm was installed into a pre-drilled injection well with a diameter of 168 mm, and the gap between the cuff tube and well walls was filled with casing mortar to prevent the injection mortar from escaping to the surface.

After the casing mortar developing its strength from 1 to 2 MPa (one day), cementation began. The packer was sequentially installed over each cuff and cement mortar penetrated the soil under pressure, breaking the created casing.

Injection was performed using a double packer, which ensured mortal penetration into the soil exclusively at a given site. For the injection, cement mortar with plasticizing additives was used, and in some areas it was soil-cement. The injection of the mortal through the cuff was made sequentially from the bottom to the top within the height of the working.

Laboratory studies were performed to select the soil-cement mix. Content of loam, as a waste of production and the cheapest material, was taken in the amount of 1 $m^3$ in bulk density per 1 $m^3$ of soil-cement.

The intergranular pores in the loam are filled with mixing water and grains of Portland cement. Cement content was allocated in the range of 100...200 $kg/m^3$ of the mortar according to the reference sources recommendations [7, 8] and taking into account the need in obtaining M25 grades of mortar.

The mixtures were put into 4×4×16 cm forms, after 3 days the formwork was removed and stored in baths with water until the required age. The day before the strength test, the samples were removed from the bath and stored in air-dry conditions. The age of the samples was 7, 14 and 28 days. Some part of the samples was left to study the durability for a longer period of hardening. Samples were weighed to determine the average density after molding and before each strength test.

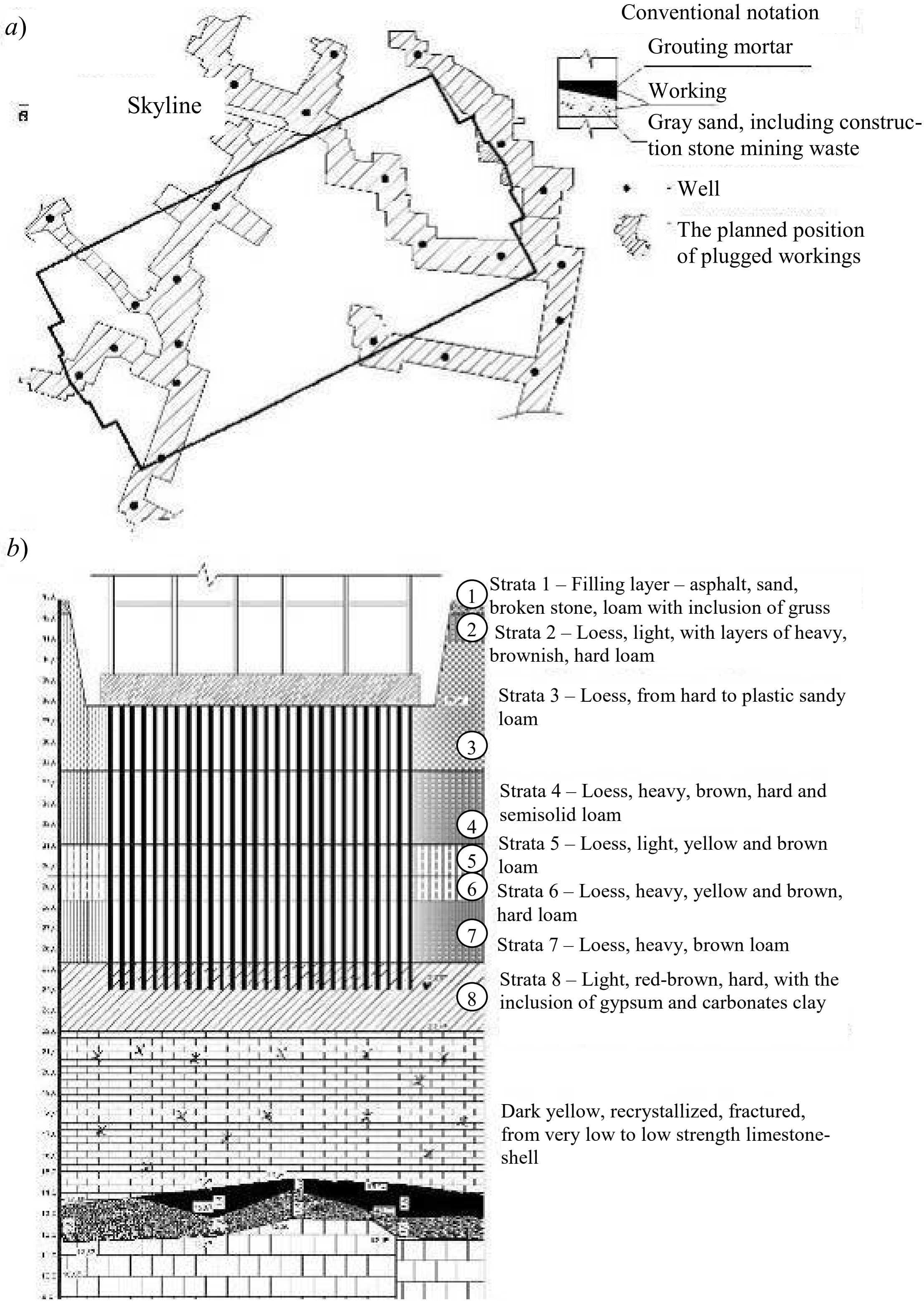


**Figure 1 – The location of the underground workings in the plan (a) and on the combined section (b)**

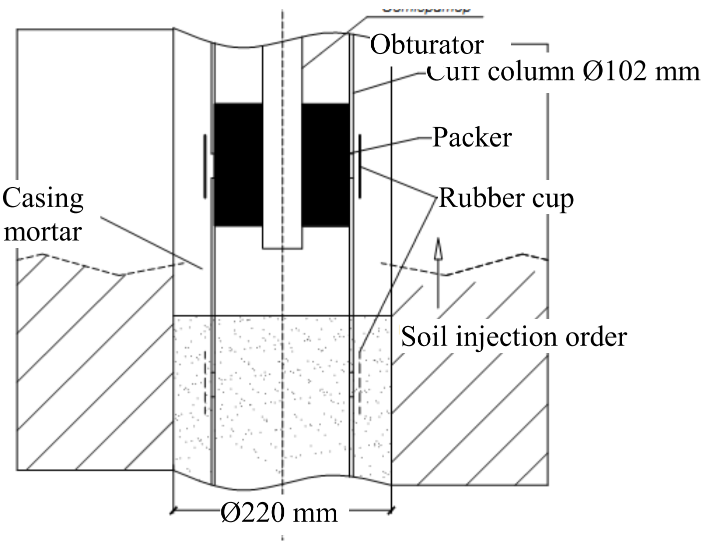


**Figure 2 – The cuff column bottom**

Compressive strength was determined on a PG-10 press. The value of strength was taken as the average result for the three sample beams. Sample marking was performed in series, nine sample beams in each series. The effect of cement content on the strength of soil-cement at the age of 28 days is presented in Fig. 3.

The effect of cement content on strength is considered at its age of 28 days. The intermediate 7 and 14 days have the same regularity and are lower than the grade strength by 50 and 30%. Increased cement content leads to increase in mortar strength.

Therefore, on the curves (Fig. 3), by means of interpolation, economically profitable cement content for each grade of soil-cement have been found.

The results of the experiments enabled to find a relation between soil-cement grade (M) and cement content:

| | | | | | | |
|---|---|---|---|---|---|---|
| Soil-cement grade | 5 | 10 | 15 | 20 | 25 | 35 |
| Cement (C), kg/m$^3$ | 50 | 85 | 115 | 150 | 165 | 200 |

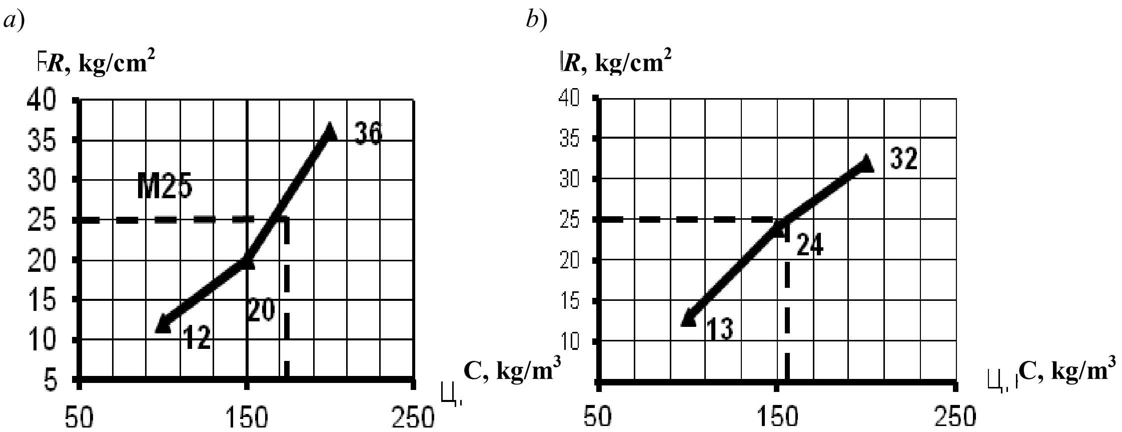


**Figure 3 – The effect of cement content on the strength of soil-cement from mushy consistency (a) and low-slump (b) mixtures**

The ratio between cement and loam, that is C / C : Loam / C = 1 : X (Fig. 4), is an important characteristic. It shows the uniformity and homogeneity of the distribution of cement grains in the intergranular space of loam and in the volume of its filling, determines the strength of soil-cement, its depending on the strength of the actual clay grains.

The curve nature at the age of 28 days indicates two general patterns in changing soil-cement strength from the C: Loam taken. There is slow influence of C: Loam in early terms – up to 14 days and accelerated – in the range of 14-28 days. The greater the ratio between cement and loam, the higher the soil-cement strength in the range of content C = 100 – 200 kg/m$^3$. This curve enables to choose the necessary ratio C: Loam for the range of soil-cement obtained grades by us using the example of M25 (there are dotted lines in the figures. Each soil-cement grade meets the only C ratio: Loam = 1:X: M10→1:10; M20→1:7; M25→1:6; M35→1:5.

The average density of soil-cement (Fig. 5) at the age of 28 days varies between 1560 – 1820 kg/m$^3$. The difference is 260 kg/m$^3$, which is 17%. Increase in the density of soil-cement by 1% leads to increase in its strength by 19%. This means that density is primary and strength is secondary.

Than density is higher, than cement content (not even water) is higher, since during samples testing (destruction) at the age of 28 days, it is noticed increasing amount of non-evaporated water to the sample center. And only a layer of 2 – 4 mm from the surface of the samples is dried. The inner zone of the samples is still wet and as they dry and hydrate, their strength should increase.

The strength of soil-cement over time (Fig. 5, b) increases with increasing cement content (Table 1).

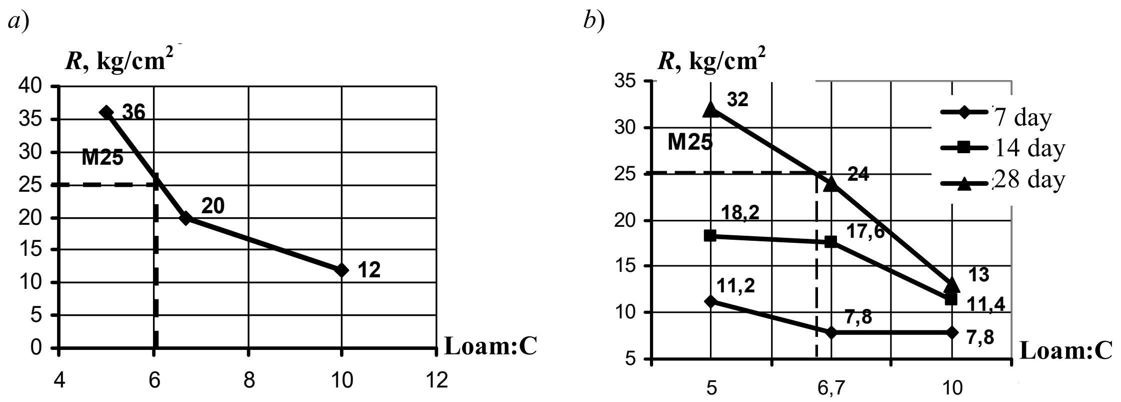


**Figure 4 – The effect of soil and cement ratio on the strength of soil-cement from mushy consistency (a) and low-slump (b) mixtures**

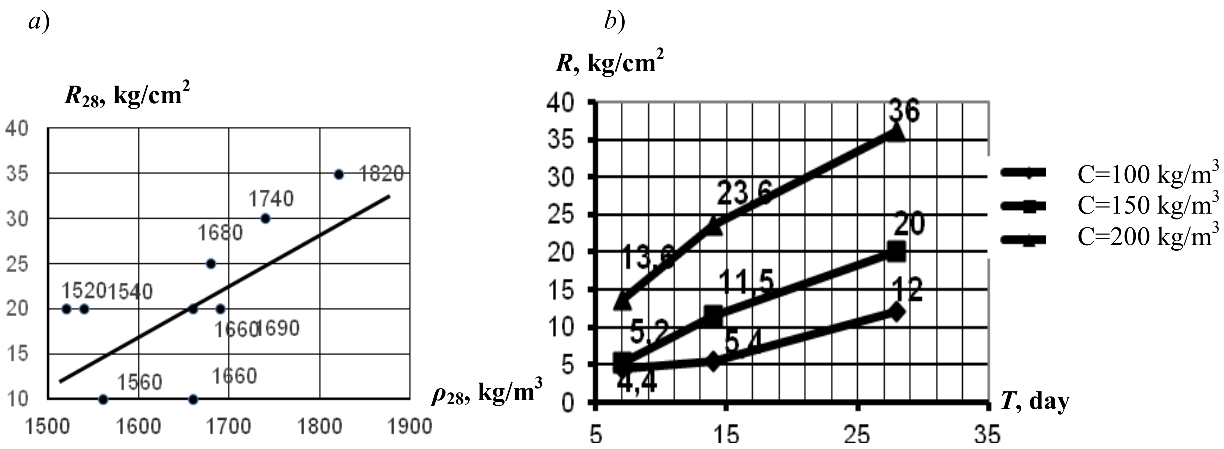


**Figure 5 – The strength variation of soil-cement depending on its average density (a) and age (b)**

**Table 1 – Soil-cement mix for grades 10 – 35 from mushy consistency mixtures**

| Grade of soil-cement | Content of components for soil-cement, kg/m$^3$ | | | |
|---|---|---|---|---|
| | Portland cement M400 | Water | W/C | Loam |
| M10 | 85 | 460 | 5,4 | 1000 |
| M15 | 110 | 470 | 4,3 | 1000 |
| M20 | 150 | 495 | 3,3 | 1000 |
| M25 | 165 | 495 | 3,0 | 1000 |
| M35 | 200 | 500 | 2,5 | 1000 |

**Conclusion.** Thus, using the example of a 24-storey residential building design, comprehensive solution has been suggested for plugging workings (catacombs) in an array of limestone-shell rock for the subsequent construction of high-rise buildings on slab-pile foundations, which includes engineering and geological surveys, geotechnical design, selection of soil-cement grouts and their compositions, as well as works implementation with the constant monitoring of plugging conditions.

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