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LONG-TERM SUBSIDENCE OF A MULTISTORY BUILDING ON THE BASE REINFORCED WITH SOIL CEMENT ELEMENTS

The methodology and results of long-term geodetic observation at subsidence of nineten storey building with a strip cast-in-place foundation on sandy and peaty base reinforced with soil cement elements at the process of its construction and exploitation are presented in the article. The correctness of elastic-plastic model use with Mohr Coulomb strength criterion and planar task finite element method for the evaluation of the deformed state «strip foundation – reinforced soil layer – the natural basis» system are substantiated.

***Keywords:** soil cement element, strip cast-in-place foundation, settlement, geodetic observation, modulus of deformation, method of ultimate elements.*

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ТРИВАЛІ ОСІДАННЯ БАГАТОПОВЕРХОВОГО БУДИНКУ НА ОСНОВІ, АРМОВАНІЙ ҐРУНТОЦЕМЕНТНИМИ ЕЛЕМЕНТАМИ

Наведено методику та результати багаторічних геодезичних спостережень за осіданнями дев'яти-десятиповерхового будинку зі стрічковими монолітними фундаментами на піщаній і заторфованій основі, посиленій ґрунтоцементними елементами, в процесі його зведення та експлуатації. Обґрунтовано коректність використання пружно-пластичної моделі з критерієм міцності Мора-Кулона та плоскої задачі методу скінченних елементів для оцінювання деформованого стану системи «стрічковий фундамент – армований шар ґрунту – природна основа».

***Ключові слова:** ґрунтоцементний елемент, стрічковий монолітний фундамент, осідання, геодезичні спостереження, модуль деформації, метод скінченних елементів.*

Introduction. The territory of Ukraine is characterized by the following difficult geotechnical conditions: collapsible and peaty soils, silts, poured soils, hydraulic fills, flooded area, dense housing. Soil cement element (SCE) and piles (SCP) are performed by stream and drilling-mixing technologies directly on building site. They are efficient in the soft soils strata with thickness up to 30 m [1].

Analysis of recent sources of research and publications. The material for their production is the ground, cement, water. A special bit of soil foundation from the bottom of the pit within the area of the bit is loosened, soaked with a water cement suspension, mixed to a condition of a mobile homogeneous cement mixture. If necessary, the spatial framework of steel fittings is immersed in a mixture. The stability of the well walls is unequivocally ensured by the presence of a mobile soil cement mixture in all soils, including floodplains. After of the soil cement mixture, the SCE or SCP of the design diameter and laying depth is formed [1 – 7].

The world experience of using the drilling-mixing method of cementations disperses soils showed that there is a complexity of soil cement mixture consolidation and its high water-cement ratio (in particular, below groundwater level). This leads to the fact that a significant portion of the water of the mixture is superfluous in the process of hydration of cement and forms its additional porosity. Such a phenomenon reduces the strength of soil cement, which leads to a decrease of bearing capacity of SCE and SCP on the material. In many cases, their bearing capacity on the soil is higher than the material. This reduces the efficiency of SCE and SCP and requires additional steps in the manufacture of such elements and piles [3 – 7].

It is also set that cement content increasing from 5% to 50% lead to the soil-cement mechanical properties increasing by linear dependence, so, structural strength of soil-cement is possible to regulate by cement content even for the complete replacement of soil by cement in mortar; in soil with lower content of clay grains is higher mechanical characteristics, for production of strong soil-cement sand with low content of clay grains is most effective; additives (sands, tails) using lead to soil-cement strength and deformation modulus increasing, so we recommend to use additives, tails using are more efficiency; soil-cement piles reinforced by steel frame allows to increase the carrying capacity by material to a value that exceeds the value of their carrying capacity by the soil [7].

Identification of general problem parts unsolved before. In massive of weak soils, due to their small deformation module, significant settlement of the base foundations of buildings and structures is possible, even under the condition of reinforcement of the SCE of a part of the compressive layer. Therefore, in order to expand the normative base of the design of SCE and increase its reliability, the method of determining the settlements of objects with strip foundations on the base of reinforced needs further improvement. The most reliable option for solving this problem is comparing the calculated and measured long-term geodetic observations of the values of settlements of natural objects.

That is why the **goal** of this article is to analyze the results of geodetic observations in time for the settlements of buildings with strip foundation on the basis of the reinforced SCE and the substantiation of the most reliable method of forecasting settlements of such objects.

Basic material and results. The platform for a residential building (sections I, II, IV, V – nine stores, III – ten) with a basement on the Panianka street, 65-b in Poltava, is made up of flood plains and stream-laid deposits of the Vorskla River, which are covered with 2.5 – 2.7 m of filled soil. For sections I – III, a layer (up to 2 m) of silty sand with impurities of organic substances is located under the filled soil. For IV and V there is a layer (also up to 2 m) of light silty clay, from slightly plastic to soft, with impurities of organic substances, as well as a layer (0.3 – 0.6 m) of clay heavy, fluid, strongly peaty. Under these layers is a three-meter thick of silty and fine sand of medium density. The ground water level is 2.3 – 2.5 m from the surface of the site.

Under the project of OJSC «Poltavtransbud» two-meter layer under the fill was reinforced with vertical SCE, which were made by drilling-mixing technologies (fig. 1, a). SCE was executed by the firm «Fundamentbud-3» using the drill machine BM-811 on the basis of the car «Ural». At the top of the SCE, a 0.5 m thick gravel pillow was poured into it, which erected monolithic reinforced concrete strip foundations 2200 mm wide under external longitudinal bearing walls and 3200 mm – under the median longitudinal bearing wall (Fig. 1, b). According to the project, to increase the overall rigidity of the building, monolithic reinforced concrete belts were installed and brick walls were reinforced.


a b

Figure 1 – The bottom of the foundation pit (sections IV and V) after reinforcing the SCE of the base (a), the gravel pillow, sprinkled on top of this base, and the strip monolithic foundations (b)

To determine the actual values of settling of the reinforced bases of the building, the observation of its settlements is organized by means of geometric leveling of the III class of accuracy by the method of Professor M. Zotsenko [8]. For this purpose, in the characteristic places of all sections at the level of the socle of the bearing walls, surface marks are installed: metal plies with a diameter of 20 mm, laid in the wall at a depth of about 130 mm, which protrude from the wall by 20 mm (Fig. 2). Immediately with the construction of the socle of the building, they arranged the wall marks, laid a leveling line and performed a zero-cycle observation. The following cycles were carried out after the construction of each storey, the acceptance of the building for exploitation, as well as its settlement. In the first two – three years of operation of the building measuring performed 2 – 3 times a year, and now approximately once a year.

Fig. 3 contains a scheme of placing leveling deformation marks on the object of research and connecting points. The modern look of the object is shown in Fig. 4


a b

Figure 2 – Wall siege marks at the research object:
a – at the time of their arrangement; b – at the time of leveling 01.10.2017

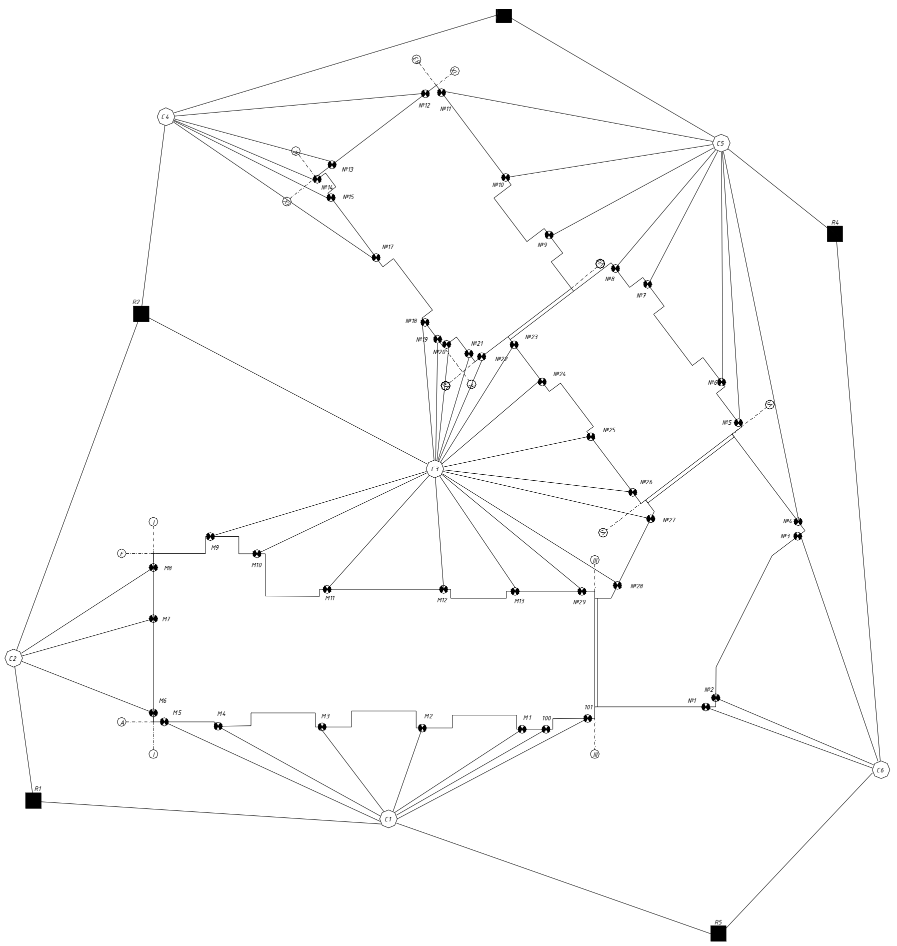


Figure 3 – Scheme of geodetic leveling deformation marks established at the research object and the connecting points between them

Figure 4 – Modern observations of the object – a house on the Panianka street, 65-b in Poltava (01.10.2017)

The results of field observations of the building were the following: the scheme of its leveling with the placement of marks and connecting points; diagrams settlements marks on the subject during its construction and exploitation (Fig. 5); graphs of development of minimum $S_{min}(t)$, average $\overline{S}(t)$ and maximum $S_{max}(t)$ settled marks in time, combined with the schedules of the construction of stories and the exploitation of buildings (Fig. 6); absolute and relative magnitude of settlements of buildings at the time of the last cycle of observations.

First, we note that the settling sections I and II are less than the other three. In addition, the conditional stabilization of deformations in this section can be traced more clearly than in the other three. This can be attributed to the following factors: the construction of section I-II began and ended earlier than others, and, consequently, the time span from the application of the last significant load on the building is less; the soil conditions under section I-II are better, while the constructive solutions and dimensions of the foundations are the same.

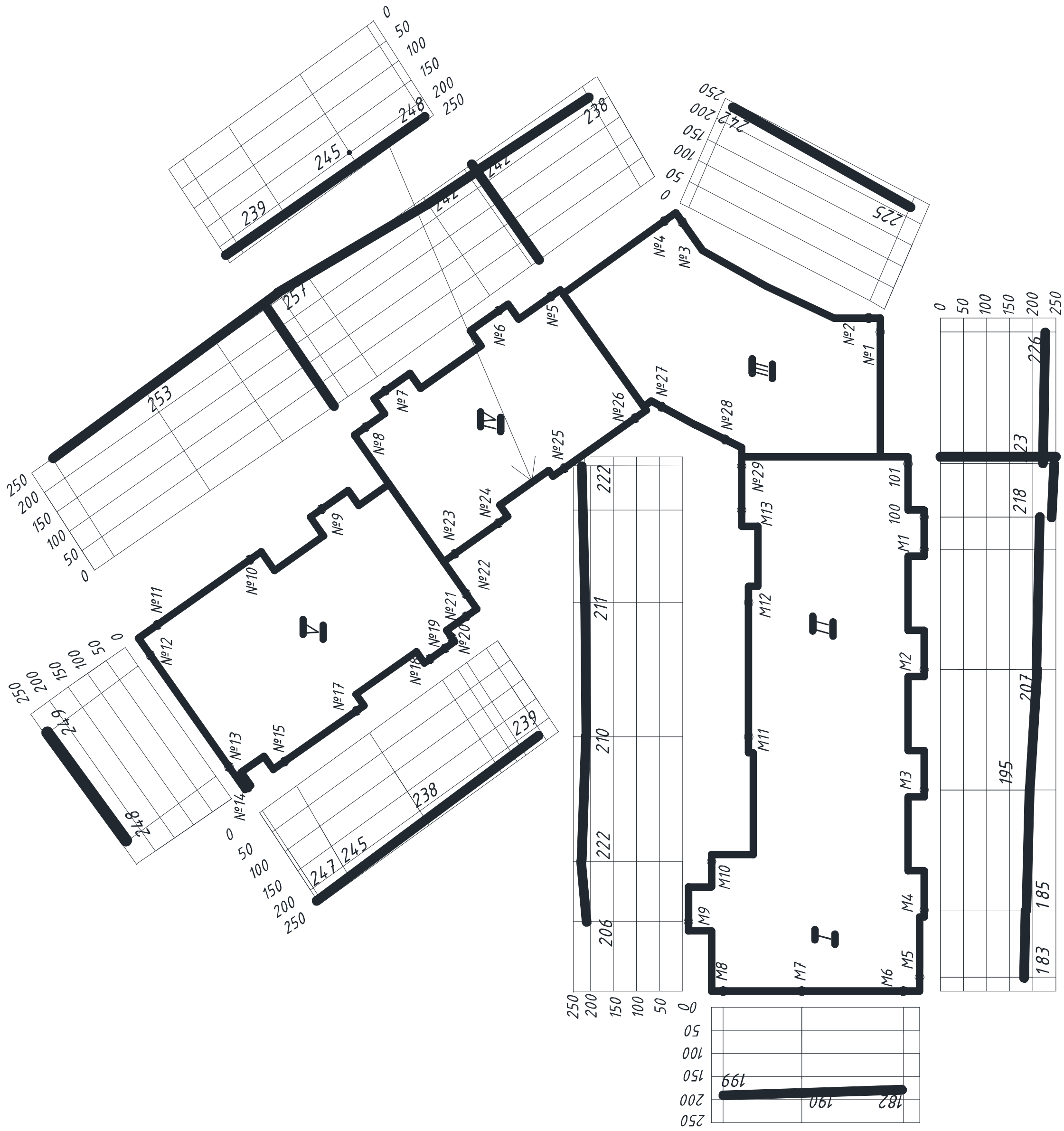
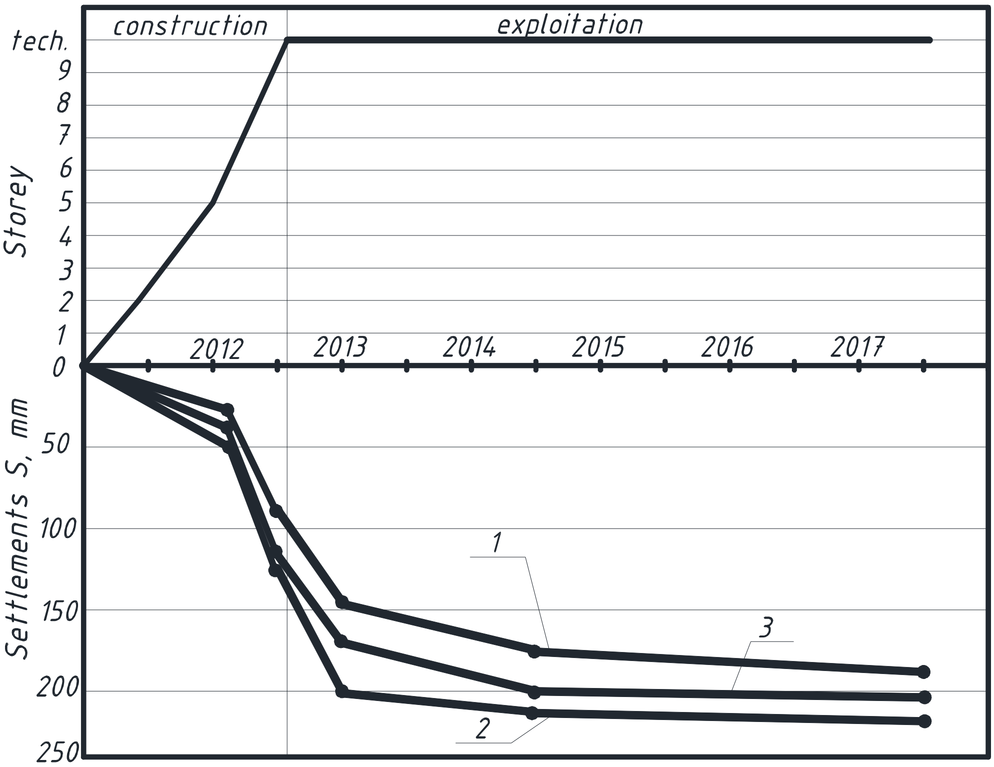


Figure 5 – Diagrams settlements of marks at research object at 01.10.2017

a)



b)

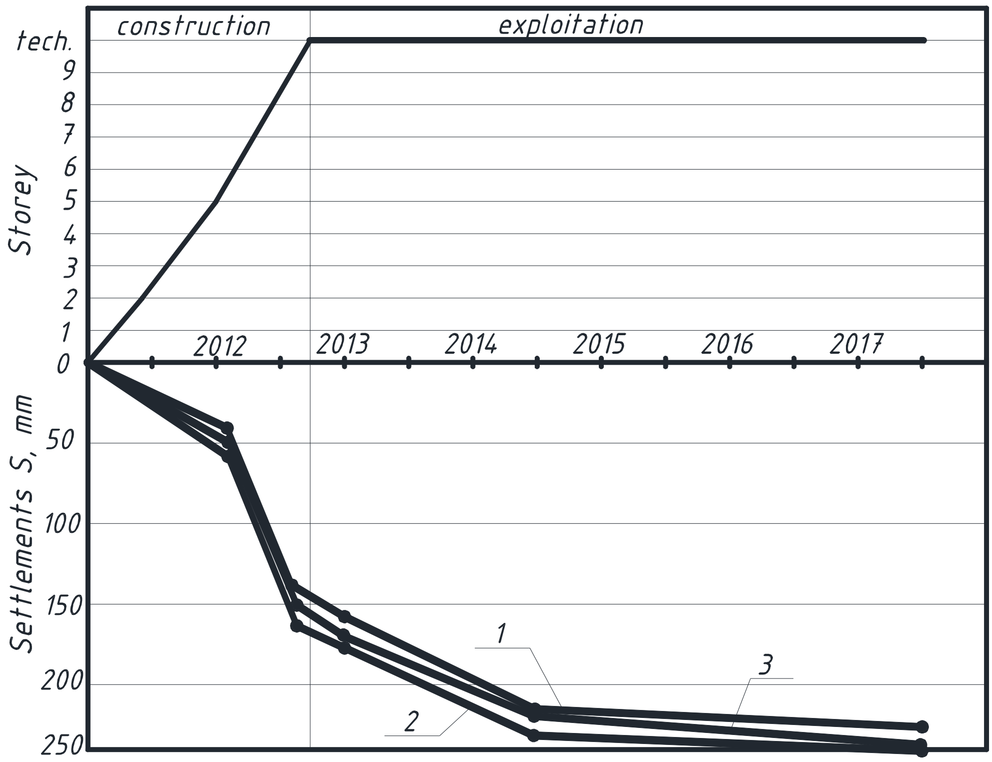


Figure 6 – Graphs of the development of maximum, minimum and average settlements marks in time at the research object:
a – section I i II; b – section IV

In particular, it was found that at 1.10.2017:

– the minimum settlements of the wall marks of section I-II building was 182 mm, average – 204,5 mm, and maximum – 223 mm; similar data are for section III – 225, 235,8 and 248 mm respectively; for section IV – 239, 245,7 and 257 mm respectively; for section V – 238, 245,6 and 253 mm respectively;

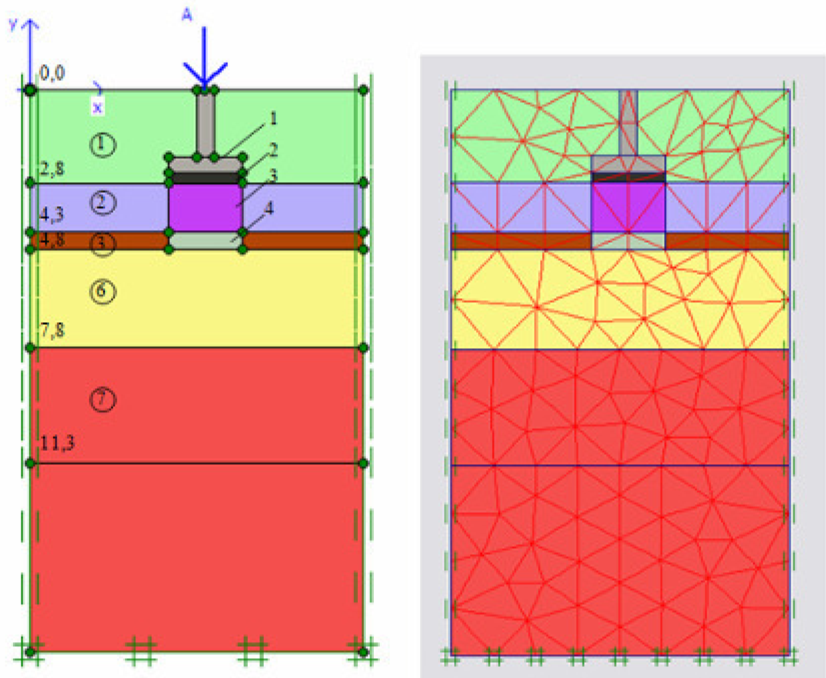
– the average values of settlements exceeded the maximum allowable values for all sections of the building Su = 180 mm, but the relative differences in settlement; ΔS/L did not exceed the maximum permissible values of the magnitude ΔS/L = 0,004 [2];

– cracks and other visible defects or deformations in the building were not revealed, and its technical condition is defined as the state I – normal;

– there is a tendency towards stabilization of settlements (conditional stabilization – 1 mm / year) basis of the foundations of the building, especially for section I-II.

After this, the settlements bases of the foundations of section IV are calculated by normative methods (layered summation and I.O. Rosenfeld) [2]. They turned out to be more than twice as small as the actual values.

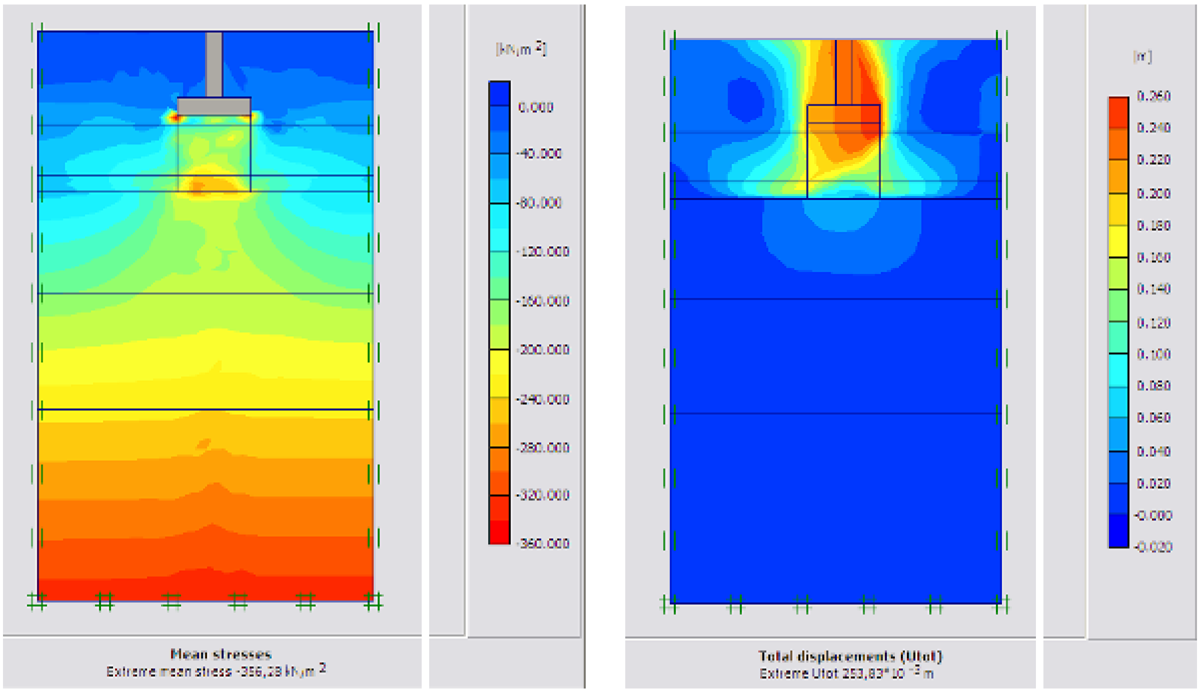
Therefore, in the future, the analysis of settlement of the reinforced bases of strip cast-in-situ foundations was performed by modeling the flat (2D) version of the Finite Element Method (FEM) using an elastic-plastic soil model. At the same time, the value of the deformation modules of soils within the reinforcement mass was determined as a weighted average depending on the percentage of reinforcement. The values of unit cohesion soil in the reinforced mass were also taken as weighted average, and the angle of internal friction – as for soils in the natural state. In fig. 7 shows the calculation scheme of the base of the building.



a b

Figure 7 – Estimated 2D (a) deformed (b) scheme o
f the base of the foundation of section IV:
1 – foundation; 2 – gravel pillow; 3 і 4 – zones of soil layers, reinforced by SCE

Fig. 8 shows the general vertical stresses and deformations of the base of the section IV after applying the load to it F_V = 650 kN.



a b

Figure 8 – General stresses (a) and deformations (b) of the base of the section IV

In particular, for the system «reinforced GCE base – strip foundation» the corresponding settlements were about 250 mm, which has a high convergence with the results of field observations.

So, **conclusions**, as a result of geodetic observations of the settlements of nine to ten storey buildings with strip cast-in-place foundations on the basis of compiled soils containing organic matter and hardened SCE. New experimental data on the development of actual deformations of such bases in time have been obtained. The high reliability of the FEM modeling of the «reinforced base – strip foundations» system with the use of the flat version of the PLAXIS complex has been confirmed. Application of an elastic-plastic soil model with a strength criterion for Mohr-Coulomb is useful in determining the settlements of reinforced SCE weak bases of strip cast-in-place foundations.

The strengthening of the base only within the layer of weak soils (its capacity is even less than the width of the foundations) for the strip cast-in-place foundations was not sufficient. In order to comply with the norms for limiting sediments, the reinforcement of such bases within a short layer must be carried out at a much higher depth, which should be established by simulation. The same method of reinforcing the bases of SCE has confirmed its effectiveness for soils with high content of organic substances.

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