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MONITORING OF THE SOIL-CEMENT PILES BUILDINGS SETTLEMENTS

In the paper it is discussesed new experimental and theoretical developments on soil-cement pile produced by drilling-mixing method. The biggest focus were made on field samples and full scale tests of the soil-cement piles, long term geodetic observations of the constructions settlements. Those experiences were implemented in Ukrainian normative documents. Geodesic monitoring of nine-ten storey building (with soil-cement piles length 6 m and diameter 500 mm in wet loess foundations) have shown that the settlements of its sections is much smaller than the ultimate values in national requirements.

Keywords: *wet loess soil, pile, soil basement, foundation, soil-cement, mixing technology, strength, settlement.*

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МОНІТОРИНГ ОСІДАНЬ БУДІВЕЛЬ НА ҐРУНТОЦЕМЕНТНИХ ПАЛЯХ

Розглянуто нові експериментально-теоретичні розробки авторів з питань бурозмішувального методу виготовлення ґрунтоцементних паль, дослідних натурних виготовлень і випробувань ґрунтоцементних паль, тривалих геодезичних спостережень за осіданнями будівель на ґрунтоцементних палях, які було враховано при складанні сучасних Державних будівельних норм України. З’ясовано, що ґеодезичні спостереження за дев’яти-десятиповерховим житловим будинком на ґрунтоцементних палях довжиною 6 м і діаметром 500 мм за умов замоклих лесових основ показали, що осідання всіх його секцій значно менші за допустиму нормами величину.

Ключові слова: *замоклий лесовий ґрунт, паля, ґрунтова основа, фундамент, ґрунтоцемент, бурозмішувальна технологія, міцність, осідання.*

Introduction. Volume of piles using in modern construction is constantly increasing. Therefore, using of new ways to improve its construction and manufacturing methods is important problem for today. Boring piles are the most commonly used type of piles in the world because of its technological efficiency and production convenience at the construction site. But, concrete boring needs additional technical measures to use it in different geotechnical conditions. For example, when the soil does not hold borehole walls then casing pipes are used, but even those measures does not fully protect the well from breakthrough by movable soil. Then drilling should be protected by clay mud which circulates in the well, brings out ruined soil, and at the same time supports walls in a stable position.Such measures are complicating production of the boring concrete piles, there additional time and costs are required.

Development of the soil cementation boring-mixing method during last few years has led to the new boring piles arising – soil-cement piles. It has all advantages of the bored piles, but in the same time problem of the borehole walls stability is completely excluded in the any kind of the geotechnical conditions [1 – 7].

Analysis of recent sources of research and publications. Known data [2 – 12] indicates that physical and mechanical properties of the soil-cement piles in the different places are quite clos for piles in the same soil conditions and with the same cement percentage content.

Experimental data of the Poltava geotechnical school [5 – 8, 13] show that mechanical properties of the soil-cement depend from lithology of dispersed soils; pH index of the water and of the water-soluble salts; cement percentage content and its quality; cement quality; water-cement ratio (W/C) and degree of soil-cement mixture compaction; presence of the steel reinforcement in the soil-cement; presence of the chemical additives.

In particular, laboratory and field researches and statically tests of the soil-cement physical and mechanical characteristics have shown that:

– cement content increasing from 5 to 50% leads to the soil-cement mechanical characteristics 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 there arehigher mechanical characteristics, for production strong soil-cement sand with low content of clay grains is most effective;

– additives (sands and tails) using leads to soil-cement strength R and deformation modulus E increasing, so it is recommended to use additives and tails more efficient;

– soil-cement piles reinforced by steel frame allow to increase the carrying capacity by material to a value that exceeds the value of their carrying capacity by the soil.

Identification of general problem parts unsolved before. In weak soil massive, for example wet loess soil, due to their small deformation module, significant settlement of the buildings and structures base foundations is possible, even under the condition of the soil-cement piles use.

Therefore, in order to expand the normative base of the GCE design and increase its reliability, the method of objects settlement determining with strip rafts on the soil-cement piles. The most reliable option for solving this problem is comparing the calculated and measured long-term geodetic observations of the natural objects settlements values.

That is why the **goal** of this article is the geodetic observations results analysis in time for the building with strip rafts settlements on the soil-cement piles and the substantiation of the most reliable method of forecasting settlements of such objects.

Basic material and results. Soil-cement piles were used during house construction in the str. V. Kozak, 14 in Poltava (Fig. 1).

Building is placed on the territory with dense housing (Fig. 2). Because there are a lot of close buildings, pile driving is impossible.

Figure 1 – General view of the three-sectioned nine-ten storey house in the str. V. Kozak, 14 in Poltava (order of sections – left – right)

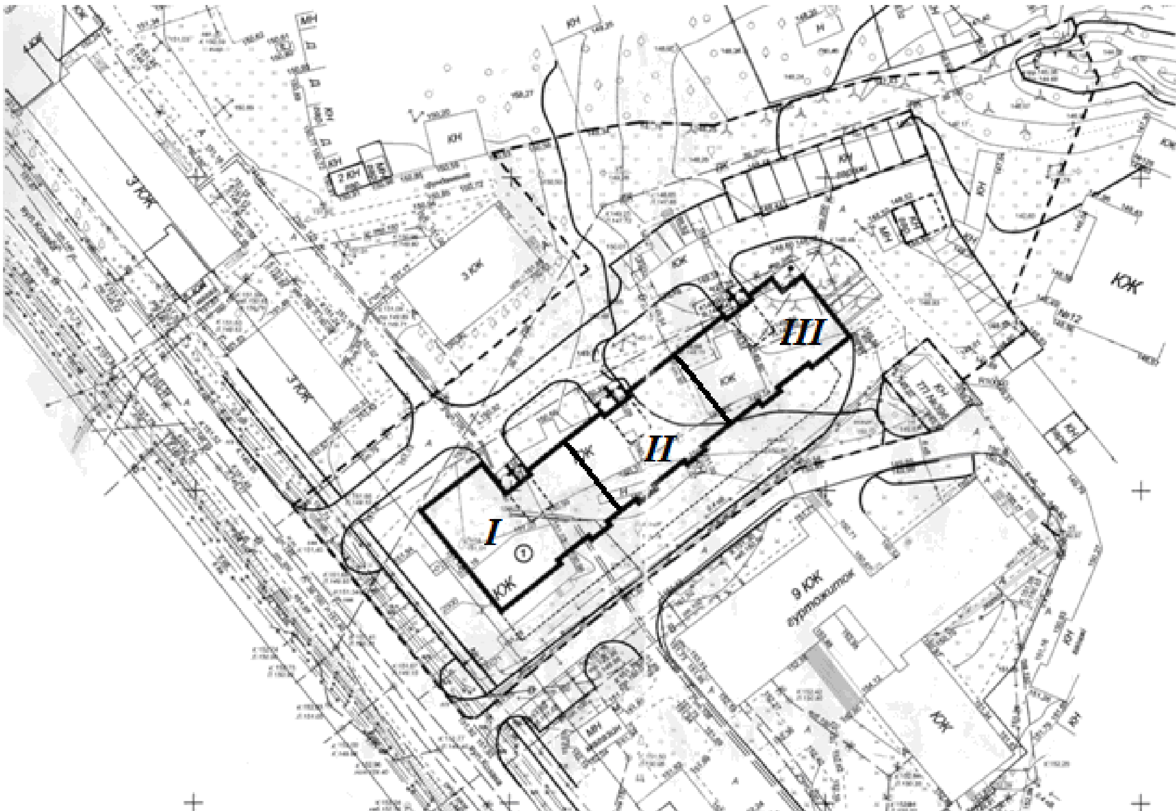

Figure 2 – The site of the three-sectioned nine-ten storey house on the str. V. Kozak, 14 in Poltava

In terms of geomorphology site is dedicated to Poltava loess plateau. Engineering-geologic section of the building site is on the Fig. 3.

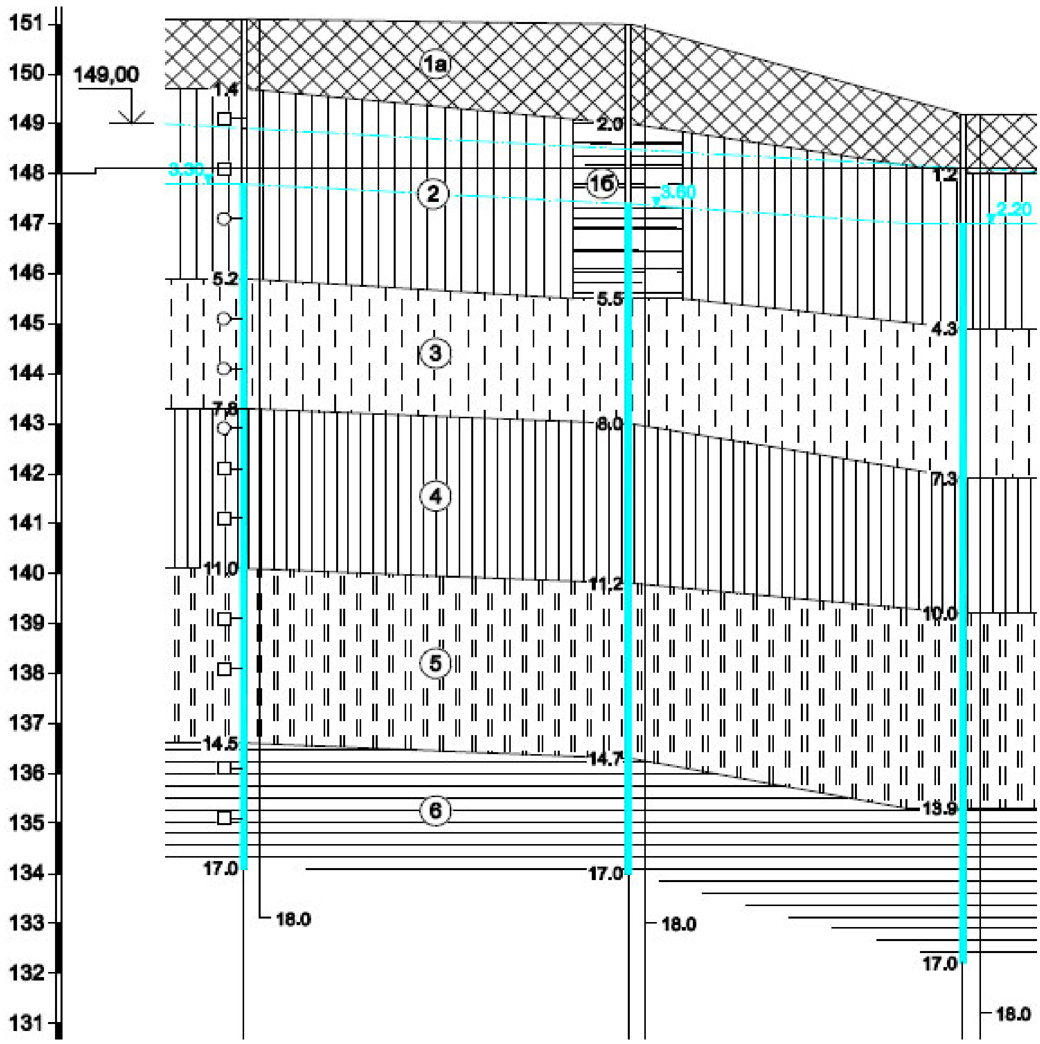

Figure 3 – Engineering-geologic section of the construction site

At the construction site normative values soils physical and mechanical characteristics are presented in the Table 1.

Soils 2 – 6 can serve as the natural foundations, their calculated physical and mechanical characteristics are given in the Table 2.

The level of the ground water is 2.2 – 3.6 m underground so bore-mixing technology efficient method of pile arranging use is possible in such conditions. As pile is almost below the groundwater level, hydro geological conditions are also favourable for normal soil-cement strength increasing.

Soil for piles is soil 3 (Tables 1 and Tables 2).

For sections I and II there were constructed reinforced soil-cement pile with length 6 m and a diameter 500 mm. Welded reinforcement space frames was used for piles reinforcement.

Piles in three rows are performed under the middle wall of the building, distance between the rows axes is 1000 mm, and distance between the piles axes in the one row is 1000 mm.

Piles in three (distance between rows axes is 1000 mm, distance between piles axes in row is 1100 mm) and two three (distance between rows axes is 1000 mm, distance between piles axes in row is 1000 mm) rows are performed under external walls of the building.

Under section III root piles were arranged. Separating screen between the sections was not found.

Table 1 – Normative physical and mechanical soils characteristics of construction site

Characteristics	Soil number					
	1	2	3	4	5	6
Moisture on the liquidity point W_L		0.37	0.32	0.36	0.30	0.43
Moisture on the border of plasticity W_p		0.21	0.20	0.21	0.19	0.23
Plasticity number I_p		0.16	0.12	0.15	0.11	0.20
Natural moisture w	0.18	0.24	0.30	0.28	0.25	0.24
Moisture at full water saturation W_{sat}		0.32	0.30	0.28	0.25	0.24
Liquidity index I_L		0.19	0.83	0.47	0.55	0.05
Water saturation ratio S_r		0.75	0.89	0.92	0.93	0.88
Gravity weight of the soil particles Y_s (kN/m³)		26.56	26.46	26.56	26.46	26.66
Gravity weight of the soil Y(kN/m³)	14.80	17.64	18.01	18.63	19.16	18.98
Gravity weight of the dry soil Y_d (kN/m³)		14.23	13.85	14.55	15.33	15.30
Gravity weight of the water saturated soil γ_{sat}		18.78	18.01	18.63	19.16	18.98
Gravity weight of the pushed soil in water γ_{sb}		8.98	8.72	9.18	9.65	9.68
Porosity n		0.46	0.48	0.45	0.42	0.43
Porosity ratio e		0.87	0.91	0.82	0.73	0.74
Filtration coefficient of m/day	0.40	0.20	0.40	0.20	0.50	0.10

Table 2 – Calculated physical and mechanical soils characteristics

Characteristics	Measur.	Soil number, values				
		2	3	4	5	6
Gravity weight of the soil, γ_n	kN/m³	17.54/18.68	17.91	18.53	19.06	18.88
Specific cohesion, c_n	MPa	0.015	0.010	0.016	0.011	0.054
Angel of the internal friction, φ_n	deg	23	28	25	28	19
Deformation modulus, E	MPa	8.5/4.5	7.0	12.0	11.0	21.0

Permanent monitoring of building by geodesic leveling settlements was used to determine actual settlements of the building foundations. On the building sections there were installed leveling marks in special places. Observation of building settlements started in June 2013 after the construction of the building cap, where geodetic marks had been established.

Observations continue by present. Building is taken in the exploitation on 1.02.2015. Scheme of the geodetic leveling marks is shown on the Fig. 4.

During the observations volumes of work were measured (masonry, floors, loads presence on the floors and so on). Behind them linear load on grillage and unit pile were expected.

Graphics of the minimum, medium, maximum settlements in time for building marks are shown on the Fig. 5.

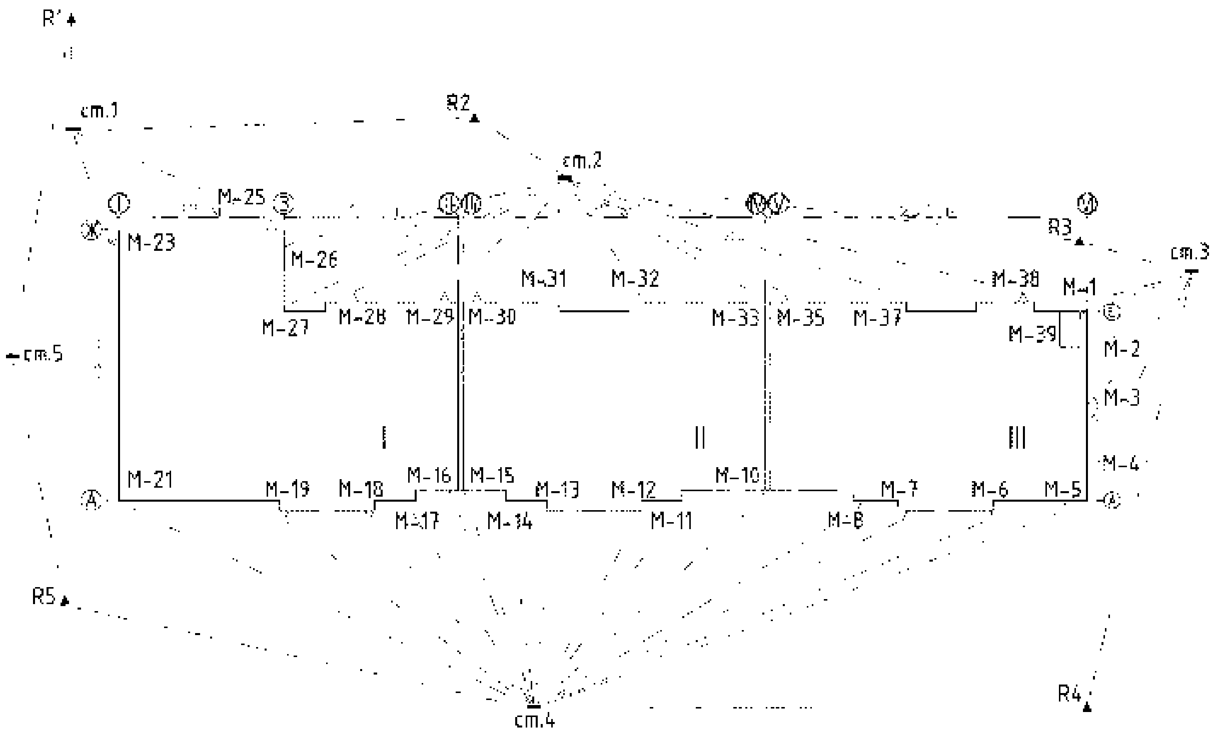

Figure 4 – Scheme of the geodetic leveling marks of nine-ten storey house on (str. V. Kozak, 14 in Poltava) I-III – building sections; M-1…M39 – wall leveling marks; R-1…R-5 – bench marks; st. 1… st. 5 – leveling intermediate stations

As a result of field tests were found that on 02.01.2015 settlements are:

– first section marks minimum settlement – 29 mm, average – 38,9 mm, maximum – 60 mm;

– second section marks minimum settlement – 32 mm, average – 45,8 mm, maximum – 67 mm;

– third section marks minimum settlement (with root piles) – 40 mm, average – 54 mm, a maximum – 70 mm;

– absolute settlement of all sections, and their relative uneven subsidence are less than the ultimate values in national requirements [1];

– there is tendency to pile foundation settlement stabilization;

– sections mutual influence that caused their uneven deformation is not recorded.

Conclusions. Thus, geodesic monitoring of nine-ten storey building (with soil-cement piles length 6 m and diameter 500 mm in wet loess foundations) has shown that the settlements of its sections are much smaller than the ultimate values in national requirements.

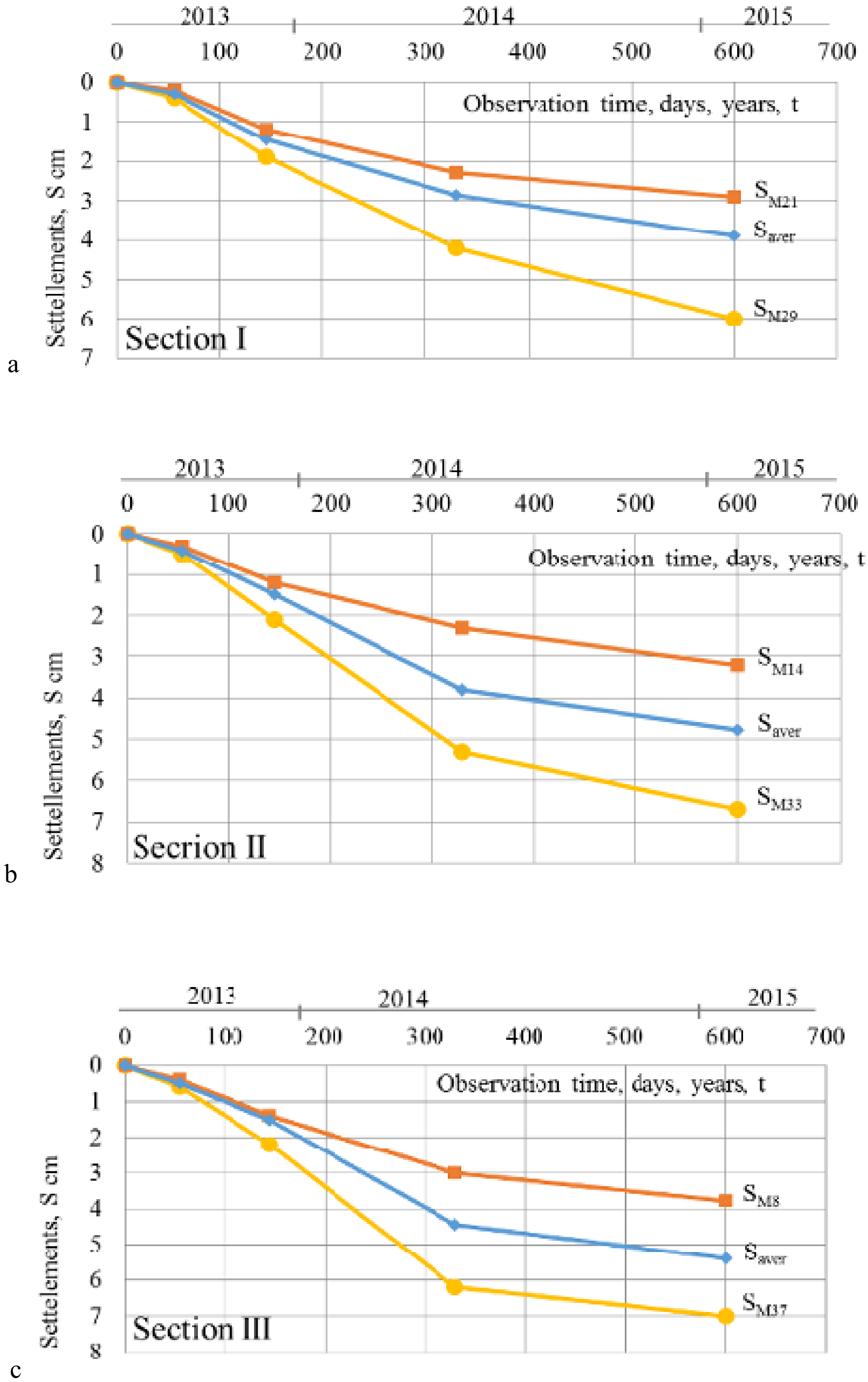

Figure 5 – Graphs of the geodetic marks minimum, average and maximum settlements in time (apartment building str. V. Kozak, 14: a – section I; b – II; c – III)

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