Innovative solutions in the field of geotechnical construction and coastal geotechnical engineering under difficult engineering-geological conditions of Ukraine

Solutions innovantes dans le domaine de la construction géotechnique et de la géotechnique côtière dans des conditions géotechniques complexes en Ukraine

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ABSTRACT: This paper contains the research findings of reinforced soil cement properties manufactured by drilling mixing method. Application of soil cement for solution of specific geotechnical problems is considered herein in terms of specific examples In the field of coastal geotechnical engineering the hybrid coastal hydraulic engineering structures and sheet pilings using reinforced concrete semi-shells have been developed. Full-scale physical simulation of pressing-in and removal of steel piles is carried out using a modular coordination pile-pressing system.

RÉSUMÉ : Cet article présente les résultats de l'étude des caractéristiques de matériau renforcé sol-ciment fabriqué par forage et mélange en place. L'utilisation de mélange sol-ciment pour la résolution de certains problèmes géotechniques est considéré à partir d'exemples précis. Dans le domaine de la géotechnique côtière, des ouvrages mixtes côtiers et maritimes ont été construits, ainsi que des pieux à rainures, fabriqués en utilisant des demies coques en béton armé. La simulation physique à grande échelle des processus d'enfoncement et d'extraction des pieux en acier est réalisée par application d'un système de coordination modulaire d'enfoncement des pieux.

KEYWORDS: soil cement, drilled pile, roll displacement of buildings, pile-pressing system.

1 DRILLED PILES IN UNSTABLE SOILS

Drilled piles installation in unstable soils is specified by conditions to secure wellbore stability prior to concrete placing. We know some well-drilling methods in such soils under protection of well casing being removed at concrete placing or under drilling mud protection followed by underwater concreting. SOLETANCHE METHOD of drilled piles installation is now very much in evidence as well. It involves the cored screw dipping into the soil to the projected drilling depth and feeding of concrete mixture through such screw under pressure with simultaneous screw lifting.

However the aforesaid methods have their faults, specifically:

- application of well casings results in considerable increasing of works costs, and in some cases it's not possible to remove well casings. Moreover floated soil may escape from drill hole into the well casing thus damaging neighboring buildings and constructions;
- the way to install reinforcement cage into the piles manufactured by SOLETANCHE technology seems rather problematic, whereas drifting sand penetration to the drill hole at drilling is not improbable;
- drilling under the drilling mud and underwater concreting prevents floated soil escaping into the well casing, but on the other hand, makes material quality control more complicated and increases labor intensity.

Mixed technology of drilled piles manufacturing provides primarily manufacturing of soil-cement elements (SCE) with dia. 0.8-1.2 m using drilling mixing method or jet method (Van Impe 2005, Bruce 2000, Larsson 2003). As soon as the soil concrete reaches 30% of its rated capacity, a well hole shall be drilled along the element's center line up to the projected drilling depth, so that the width of a soil concrete shell around it amounted to 150 mm. It serves to protect a drill hole against ingress of water and/or unstable soil for a specific period. Reinforcement cage is mounted in a dry drill hole and the concreting is performed.

The soil cement shells also provide increasing of bearing capacity of composite drilled piles at vertical and horizontal load actions owing to SCE which provide the contact surface between a pile and the soil.

The development works for manufacturing of 8 meter long composite drilled piles were carried out in conditions of bedding of water-saturated loess clay soils.

The following factors were determined in process of the research conducted:

- prism strength and concrete content in soil cement in the samples taken from the pile shaft after 28 days of concrete damp curing (σ, mPa),
- SCE diameter (D, mm),
- drill well cross section in SCE (D′, mm),
- availability of loose soil cement in drill hole bottom
- drill hole water flow 2 hours prior to surveillance (h, mm),

- concrete content in soil cement using method of estimation of part of hydrated cement as for the time of research conducting (Δ, %),
- visual inspection of reinforcement cage mounting,
- testing of concreting sampling.

Four average piles were selected from a pile field consisting of 256 piles, which data are specified in Figure 1 (1 – fill-up ground, 5-6 – flow loamy soils, 7 – semisolid clays) and in Table 1.

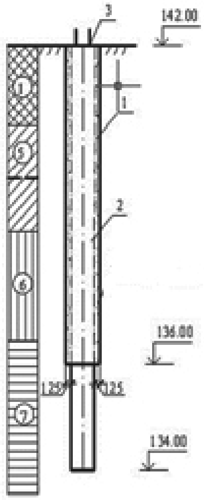

Figure 1 – Composite pile diagram: 1 – soil cement shell, 2 – cast-in-place reinforced concrete pile, 3 – reinforcement cage.

Table 1. Test piles installation indices

№	σ, mPa	D, mm	Δ, %	D′, mm	h, m
1	3.4	801	22	512	0.1
2	3.7	786	21.4	524	0.05
3	3.2	790	20	518	-
4	3.5	793	20.6	510	0.1

Findings of pilot works related to installation of composite drilled piles in soil cement shells testifies the following:

- soil cement elements buried in the clay-pans correspond to the design size and properties. In 7 days after their installation they can be lightly drilled and hold wellbore walls in flow clay-bearing soils;
- up to 10 cm of loose soil cement remains in drill holes and can be compacted using earth rammer and impregnated with fluid soil cement;
- drill hole water flow makes ca. 20*l* per hour, what just insignificantly influences the results of drill hole concreting;
- reinforcement cage mounting and drill hole concreting can be easily performed.

2 SOIL CEMENT PILES

Prism strength of soil cement manufactured by drilling mixing method or jet method without using of reinforcing chemical additives makes 1,5…4 mPa depending on water and cement content (M. Zotsenko, Yu. Vynnykov, 2011). In many instances such material strength seems insufficient for manufacturing of underground supporting frames, so there is a necessity to increase the soil cement strength.

This problem can be solved having applied reinforcing of soil cement structures with steel reinforcement. Correspondence of thermal-expansion coefficients of these materials apart from rather high grip of reinforcement on soil cement as well as its high waterproofing capacity is deemed to be the ground for collaboration of soil cement and steel reinforcement.

Effect of reinforcement on soil concrete strength was studied in vitro by testing of pile models of scale 1:4. Models dimensions made up 100 x 100 x 400 mm (Fig. 2). 4 series each per 6 samples were investigated. Samples of the first series were not reinforced, while the samples of the following series were reinforced 1,13%, 2,03% и 3,14% (P_f,%) correspondingly. End surfaces of reinforcement cages were equipped with supporting plates with longitudinal reinforcement bars rigidly fastened thereto. Reinforcement protective coating made 20 mm.

Figure 2. Axial compression testing of test samples

Soil cement was produced in vitro using the drilling mixing method, i.e. no stabilization of loess soil-water-cement mixture was carried out. M400 Portland cement content amounted to 20% by weight of soil skeleton. The soil-water-cement ratio with consideration for soil natural humidity made up W/C (Water/Cement) = 2.7. At that its slump of concrete cone flowability amounted to 11 cm.

Properties of constructive materials used in the above experiment are shown in Table 2.

Table 2. Materials mechanical properties

Reinforcement properties		Soil cement properties	
E_s, mPa	R_{sc}, mPa	E_s, mPa	R_b, mPa
210000	225	2000	1.12

All samples were subject to the axial compression test, during which the average values of their bearing capacity were determined, see Table 3.

Table 3. Values of bearing capacity of soil cement prisms

Series No.	Section reinforcement percent μ, %	Average values of bearing capacity N, kN	Coefficient of variation, v
1	0.00	11.20	0.21
2	1.13	42.50	0.19
3	2.01	62.70	0.17
4	3.14	84.00	0.18

Definition of bearing capacity of steel soil cement prisms by materials was performed using two methods to select the most acceptable one for calculation of structural analysis of steel soil cement structures.

The first method of testing the axially loaded elements' strength with given dimensions, reinforcement quantity and loads is equated as

$$N = \varphi(R_b A + R_{sc} A_{s,tot}), \qquad (1)$$

where N is a required axial force; φ – coefficient equal to 0,92 in this case; R_b – prism strength of soil cement; A – normal prism section area of 0,01 m^2; R_{sc} – reinforcement rated compressing strength equal to 225 mPa ; $A_{s,tot}$ – total area of main reinforcement.

Rated values of abovementioned indices, as well as model bearing capacity and expected bearing capacity of full-scale piles are shown in Table 4.

Table 4. Bearing capacity of soil cement prisms and piles by materials (using the first calculation method)

Series No.	ρ_f, %	A_s, mm^2	*N*, kN	*N*, kN full-scale pile
1	0.00	0	11.20	179
2	1.13	113	33.70	661
3	2.01	201	51.91	1019
4	3.14	314	75.30	1478

The second method constitutes the method of calculation of oblique loaded reinforced concrete elements in accordance with deformation model in the stress-strain state in its supercritical stage. Axial compression figures its special case. Dynamic pile formula for definition by material of standard cross-section is given by

$$N_U = A_b \left[A R_b \eta_U + \frac{R_b \eta_U (K - \eta_U)}{1 + (K-2)\eta_U} \right], \qquad (2)$$

where A, η_U, K are bearing capacity coefficients.

Table 5 illustrates the bearing capacity of steel soil cement prisms and expected bearing capacity of soil cement piles.

Table 5. Bearing capacity of soil cement prisms and full-scale piles (determined by the second method)

Series Nos.	A	η_u	K	N_u, kN	*N*, kN, full-scale piles
1	0	1	1.70	11.20	179
2	1.54	1.40	1.70	32.20	635
3	2.73	1.60	1.70	52.41	1033
4	4.27	1.79	1.70	81.68	1616

Figure 3 contains relationship: bearing capacity of steel soil cement samples – ratio of standard cross-section reinforcement. It also contains relationships determined analytically according to the aforementioned methods.

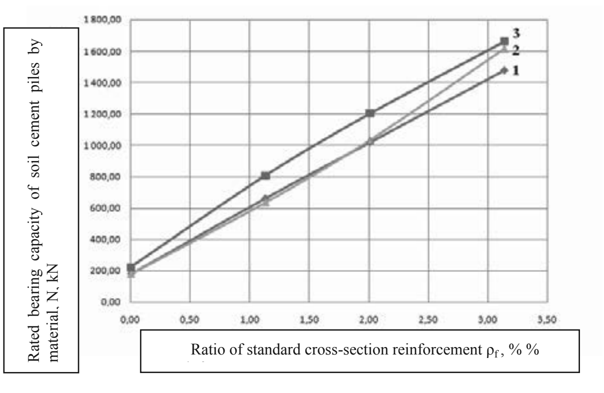

Figure 3. Relationship between bearing capacity of soil cement piles by material N and ratio of standard cross-section reinforcement ρ_f based on the following data: 1 – calculation by the first method, 2 – calculation by the second method, 3 – according to in vitro data.

On basis of the research performed it may be concluded as follows:

- Application of longitudinal reinforcement enables to considerably increase the soil cement strength;
- Comparison of data of analytical calculations of soil cement strength with in vitro data showed that the described methods of reinforced concrete structures calculation can be used for calculation of steel soil cement structures strength;
- As for the two above calculation methods the calculation according to the deformation model shall be given preference, since it is aimed at calculation of structures at combined loading. Moreover this method seems to be less sensitive to soil cement parameter variability.

3 USE OF SOIL CEMENT FOR REGULATION OF SETTLEMENT SPEED OF BUILDINGS AT RECTIFYING THEIR ROLL DISPLACEMENT

The method of soil drilling out from bottom of less subsided foundations for rectifying of roll displacement of buildings is widely used in Ukraine. For this purpose underworking of the bottom with help of horizontal drill holes of variable diameters is usually performed (V. Shokarev, V. Shapoval, 2009).

Technological parameters calculation for underworking of soil under foundation (diameter and pitch of drill holes) is carried out by formula

$$S = d \cdot t, \qquad (3)$$

where S is the required settlement for rectifying of roll displacement of a building; d – drill hole diameter; t – pitch of a drill hole.

Possessing the research findings related to changing of zero-air dry unit weight (ρd) under bottom of foundation and experimental data on critical density of soil (ρsr.) – vertical pressure relationship we can determine the soil layer depth, where drilling of horizontal drill holes and soil structure destruction will be carried out

$$h = \frac{S}{1 - \rho_d / \rho_{кр}}. \qquad (4)$$

Time of conditional stabilization of building's settlement shall be determined by formula

$$T = \frac{tg\rho}{V}, \qquad (5)$$

where V is the value of conditional stabilization equal to 0.143 cm per day.

Influence coefficient tgρ shall be determined by quotation

$$tg\rho = \frac{S - S_1}{\ell n t / t_1}, \qquad (6)$$

where S, S_1 means the value of building's settlement received according monitoring data; t, t_1 means time interval between monitoring stages.

If stabilization of building's settlement during rectifying of its roll displacement takes place prior to fulfillment of required settlement, additional breaking up of soil under foundation bottom shall be necessary. In order to forecast the time of stabilization of building's settlement after fulfillment of required settlement the soil cement mortar using drilling mixing technology shall be fed to the foundation bottom. It allows to reduce the building's settlement speed and to achieve the required value.

4 INNOVATIVE SOLUTIONS FOR COASTAL HYDRAULIC ENGINEERING

A new structure of the retaining wall has been worked out to provide, firstly, resistance to heavy loads stipulated by soil pressure behind the coastal sheet piled wall and, secondly, simplifying of construction technology for deep water quay wall due to absence of traditional anchor devices. Retaining wall (Fig. 4) includes steel sheet piles installed along the structure, soil backfilling behind the wall and transversal sheet piled rows (counterforts) connected with axial wall. Counterforts are made of sheet piles of different length and have a shape of rectangular trapezoid. The length of the sheet piles in counterforts is decreased according to the distance from the axial wall and width of the transversal rows is increased downwards. Sheet piles' heads are joined by the cap. In such structure the idea of counterforts is not only to increase a rigidity of the retaining wall while withstanding the applied loads but also to reduce effectively soil pressure behind the wall.

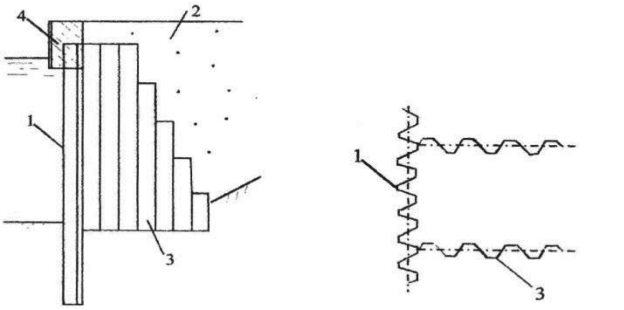

Figure 4. Sheet piling wall with counterforts: a – cross-section; b – plan. 1 – axial sheet piling; 2 – soil backfilling; 3 – sheet piled counterforts; 4 – cap.

A new construction of the bulkhead is worked out to increase the bearing capacity of the coastal protection wall or quay wall as well as to reduce their material consumption (Fig. 5). The structure incorporates the front wall and soil backfilling behind it. Anchor bearers are made of "comb" type as several small anchor plates fixed along the rigid core. Anchor force is taken by all plates of the comb simultaneously. It provides increasing of the bearing capacity both of the anchorage and of the structure in whole (keeping the same material consumption for the anchorage as at the traditional solutions with one large anchor plate). On the other hand proposed structure may provide decreasing of the material consumption (keeping the same structure's bearing capacity as at the known facilities).

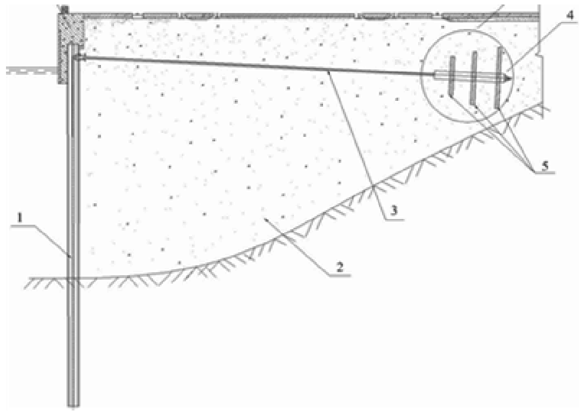

Figure 5. Anchored bulkhead with anchor bearer of new "comb" type: 1 – sheet piling; 2 – backfilling; 3 – tie-rod; 4 – rigid core; 5 - anchor plates.

The basic research for full-scale physical modeling on press-in and extraction equipment was based on the Modular Piling System. This multifunctional equipment has been developed with the intended purpose of implanting prefabricated construction elements using the press-in method. The piling system is equipped with the original hydraulic piling machine (Fig. 6) with wedge-operated clamps (testing devise) and a modular coordinating skidding system (MKS).

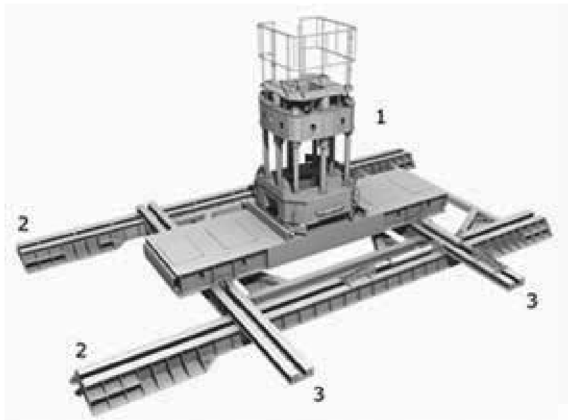

Figure 6. Modular section of the piling system MKS: 1 – press-in piling machine; 2 – longitudinal guides (skid tracks); 3 – transverse guides (cross slide).

In terms of its impact capability the piling machine is completely quiet and vibrations in the ground are at an absolute minimum allowing for the machine to work on certain highly sensitive ground areas, extremely small spaces, and in historical preservation areas. The strategic technological advantages of the piling system are high productivity, precision and quality control.

Depending on the features of the project, location of the piles in terms of engineering and geological conditions of the site, pressing construction elements into the ground could be provided with the flow-line and coordinating installation methods.

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