Geotechnical survey in soft soils for reconstruction purposes

Accompagnement géotechnique de sols meubles pour le but de reconstruction

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ABSTRACT: The causes of emergency deformations of buildings on soft soil are analyzed in the report. The pecularities of works in soft clay on constructed foundations and reconstructed buildings are also considered. The kind of nonlinear elastic model of deformation of soft clay is proposed. There is also a numerical analysis of the influence of different foundation techniques on the soil massif and existent buildings. All calculations are proved by corresponding practical examples.

RESUME: En article il fait l'analyse de cas de depennage pour la deformation de bâtiments sur le sol léger. Il fait venir la particulier de travail pour la reconstruction de bâtiments sur le sol argileux léger pour le fordemtnt de bâtiments en reconstruction. Il examiner le non ligne elastique modele de deformation de le sol argileux léger. Il fait venir le numerique analyse de l'influence de la different technolodie de l'organisation de le fondement sur le massif de sol et la position de bâtiments. Les calcul est suivre de la pratique examples.

During construction and complicated reconstruction of buildings in the borders of a town a complex of technogenic influence appears. These influences are rather unfavourable for buildings subjected to considerable settlements for long period of utilization. Due to that geotechnical forecast becomes of great importance. It allows to estimate the possible deformations of buildings from technogenic influences of new construction and reconstruction, to choose the most harmless techniques of construction works and optimum design solutions and to erect in advance the necessary reinforcement of existing buildings in the zone of risk.

The analysis of emergency cases in Saint Petersburg and other cities of the world shows that in many cases the emergencies were caused by insufficient geotechnical preparation of projects. For example, during construction of several buildings in Lyons the excavation of foundation area caused shifting of soil and damage of neighbouring buildings. The geotechnical inadequacy of the project was recognized as the cause of damages [1]. The list of similar emergencies in Saint Petersburg is rather wide in comparison with the total volume of construction and reconstruction in the city. The main causes of emergencies are based on the lack of proper taking into account of pecularities of weak clay, the layer of which of 10...30 m thickness is actually under the whole historical centre of Saint Petersburg. So it seems to be reasonable to research into the pecularities of this soil.

As it is known, weak clay is water saturated strongly compressed deposit, that loses its strength at ordinary velocities of load application [2]. According to up-to-date view the weak clay is disperse structurized system that may be transferred from the state of solid body into the state of liquid medium under the action of usual construction activities. In other words it is structurally unstable medium. Weak clays of Saint-Petersburg region are characterized by coagulating bonds and have strongly pronounced structure. The value and type of destructurizing limit depends on the type of external action that caused the damage. For example the following parameters may be considered: structural strength of single-axis, compressing and three-axis compression or shear, gradient of filtration start or of filtration consolidation. All these parameters are naturally interconnected because they reflect the same phenomenon - destructurizing (breaking of structural bonds).

Numerous nature investigations show that the strength of structural bonds has one special property: in general case it is invariant relative to the natural stress state and is actually constant within the limits of the layer of one genesis. The influence of the dead load is recognizable only in porous soil (e.g. in Baltic loam with n>0.6), structural strength of which is not very high. So it is evident that in laboratory tests it is not necessary to make natural stess state in a sample because in this case the residual (after sampling and transporting) structure disappears and humidity of soil is changed.

Constant structural strength in weak clay shows the necessity to use unconsolidated characteristics in calculations. The natural research allows to state that in some cases the process of soil packing doesn't mean its strengthening. The process of strengthening is rather long and it's not interesting for construction on natural foundation because the reduction or loos of carrying capacity takes place in the process of loading or soon after the end of loading when the soil strengthening has not appeared yet.

Since weak clay initially has nonconsolidated characteristics of strength and the graph $\tau=f(\sigma)$ is not a horizontal line, in different tests (single-axis compression and three-axis compressing and shear) destructurizing takes place at the same value of maximum tangent strength. Consiquently, at static loading of natural soil full destructuring appears in conditions when actual tangent strength exceeds the value of unconsolidated shear strength (yield condition of Tresk - Sen Venan). The degree of destructuring can be estimated by the coefficient of lateral thrust ξ at loading. It is obvious that the closer ξ to 1, the more similar to viscous liquid the soil is. Clay soils of hard and semihard consistency are known to be chardcterized by the coefficient of lateral thrust $\xi<0.25$ and that of fluid consistency $\xi>0.7$. Laboratory tests showed that during loading the coefficient of lateral thrust also changed; increased from ξ_0, which corresponds to the state of rest, to ξ_1, which is close or equals 1 (ref. fig. 1). the process of ξ changing is described by monotonously increasing function:

$$\xi = \frac{1}{\tau' \sqrt{2\pi}} \int_{-\infty}^{\tau} e^{-\frac{1}{2}\left(\frac{\tau - \tau^{*}}{\tau'}\right)^{2}} d\tau . \qquad (1)$$

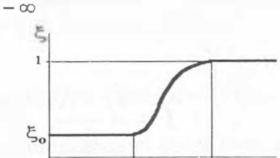

Fig. 1 Graph of dependence of the coefficient of the pressure on tangent stresses

This equation is formally analogous to the function describing the properties of loess soil when its humidity is changed. In the equation (1) τ' and τ^* are:

$$\tau' = \frac{\tau_f - \tau_r}{6}, \qquad \tau^* = \frac{\tau_f - \tau_r}{2},$$

where τ_r and τ_f are the yield paint and of structurizing for cohesive soils, respectively. At $\tau < \tau_r$ soil dots as a solid body, $\xi = \xi_o$. At $\tau_r \leq \tau \leq \tau_f$ the bonds are broken and at $\tau > \tau_f$ soil becomes fluid medium, $\xi \rightarrow 1$.

In symbols ξ and m_v (m_v is the coefficient of relative compressibility) the equations for volume and shear moduli will be represented as follows:

$$K = \frac{1 + 2\xi}{m_v}; \qquad G = \frac{1}{m_v} \frac{1 - \xi}{2} \tag{2}$$

It is clear that at constant coefficient of relative compressibility (without drainage) and when the coefficient of lateral thrust tends to 1, the volume modulus tends to a constant value, while shear modulus tends to zero. So the soil is appeared to be uncompressed in volume, but it doesn't resist to the form deformations, i.e. it becomes liquid.

To describe numerically the above mentioned mechanism of soil behavior, the dependence between deformations is represented in matrix $\{\sigma\} = [D]\{\varepsilon\}$, where $[D]$ is the matrix of hardness. The total differential, with taking into account variability of the matrix of hardness, will be:

$$d\,\{\sigma\} = d\,[D]\,\{\varepsilon\} + [D]\,d\,\{\varepsilon\}. \tag{3}$$

Then the matrix of hardness in conditions of the plain deformation and in symbols m_v and ξ will be:

$$[D] = \frac{1}{m_v}\begin{bmatrix} 1 & \xi & 0 \\ \xi & 1 & 1 \\ 0 & 1 & \frac{1-\xi}{2} \end{bmatrix} \tag{4}$$

If we transform equation (3) taking into account equation (4) at m_v = const we shall get the following equation in increments:

$$d\{\sigma\} \approx \frac{1}{m_v}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 1 \\ 0 & 1 & \frac{1}{2} \end{bmatrix}\left(\{\varepsilon^i\} - \{\varepsilon^{i-1}\}\right) + \frac{\xi_i}{m_v}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & -\frac{1}{2} \end{bmatrix} - \frac{\xi_{i-1}}{m_v}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & -\frac{1}{2} \end{bmatrix}\{\varepsilon^{i-1}\} \tag{5}$$

Index i means the step of loading (step of problem solution). Equation (5) is interesting because it allows to get the stable solution even at $\xi = 1$.

The coefficient of relative compressibility will be variable if the gradient of a head is more than starting limit of filtrating consolidation. The coefficient m_v is the function of the gradient of a head I:

$$m_v = \frac{1}{I'\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{I-I^*}{I'}\right)^2}, \quad I' = \frac{I_f - I_r}{6}, \quad I^* = \frac{I_f - I_r}{2}.$$

The graph of this function is similar to the graph $\xi = f(\tau)$, and the same characteristical points I_r and I_f can be marked on it (see fig. 2) [3].

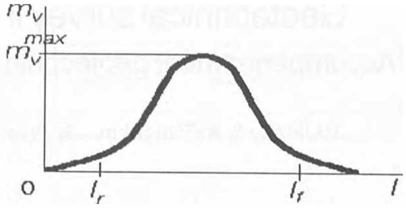

Fig. 2. Graph of dependance of the coefficient of relative compressibelety on the gradient of a head.

The proposed model is kind of the model of nonlinear-elastic medium and is analogous to the deformation theory of plasticity in which an experimental operator ψ (obtained in stretching test of a rod) is used instead of variable modulus G.

To describe the deformation of soft clay, the function $G = f(\xi, m_v)$ in the form (2) looks more preferable because it has clearer physical sense than an operator ψ.

Computer realization of the given model enabled us to solve a series of practical problems.

1. Influence of Pile Pressing-in on the Soil Massif.

Since the speed of pile driving and the speed of water wringing-out are nearly equal, the local soil massif is subjected to working in the sand soil.

In clay soil during pile pressing-in the deformation of forms mainly takes place and it leads to destructurizing of the soil. In the areas of massif where the gradients of a head are higher than the gradients of the starting of filtrating consolidation, the consolidation of soil will take place. The statement of problem concerning the influence of pile pressing-in on the massif of soil may be limited to the determination of horizontal shear per the pile radius. The absence of dynamic influences during pressing-in allows to use the proposed static model.

The solution of a series of problems made it possible to conclude that sand packing (dusty, fine and medium grained sand of medium density) takes place around a pile in radius *(3...5)d*, where *d* is the reduced diameter of a pile. Destructurizing of the strong clay soil ($I_L \leq 0.75$; τ = 20...40 kPa; τ_f = 50...70 kPa) is observed in the zone of radius *(12...14)d* and in soft clay (($I_L > 0.75$; τ_r = 5...10 kPa; τ_f = 15...20 kPa) - in the zone of radius *(20...30)d*.

An effective technique to reduce the zone of destructurizing is preliminary loosening of soil by a screw with diameter 1,2...1,5 times more than the pile diameter. It is obvious that in the zone of loosening deformations are concentrated and due to that the radius of destructurizing is reduced. Bv loosening the clay soil is not only smashed (as a result its strength is also reduced) but it also gains the higher (air) porousity. So during pile pressing-in the clay soil gets the ability to be compressed. So the radius of destructurizing zone is reduced to 5d in the strong clay and to 10d in soft clay.

The safe distance from the place of pile pressing-in should be estimated on the following condition: after a pile pressing-in the additional settlements of the nearest foundations must not be higher than permissible critical values (2...4 cm), and relative nonuniformity of settlements of adjacent foundations must be within limits depending on the building state [4].

It is evident that the safe distance must be estimated taking into account the thickness of the sand layer *h* between the bottom of the foundation and the roof of soft clay. The calculations show that at *h* ≤ *3,0 m* safe distance coincides with the zone of destructurizing of soft clay and at *h* ≥ *5,0 m* the place of pile pressing-in can be as close to the existing building as 5d.

The above safe distances are proved by the data of nature observations. In figure 3 there are the settlements in adjoining Saint-Petersburg. The nearest raw of piles is 1,7 m from measuring wall of the house № 15. Piles were pressed-in without preloosening of soil. The works were carried out in 1992. During

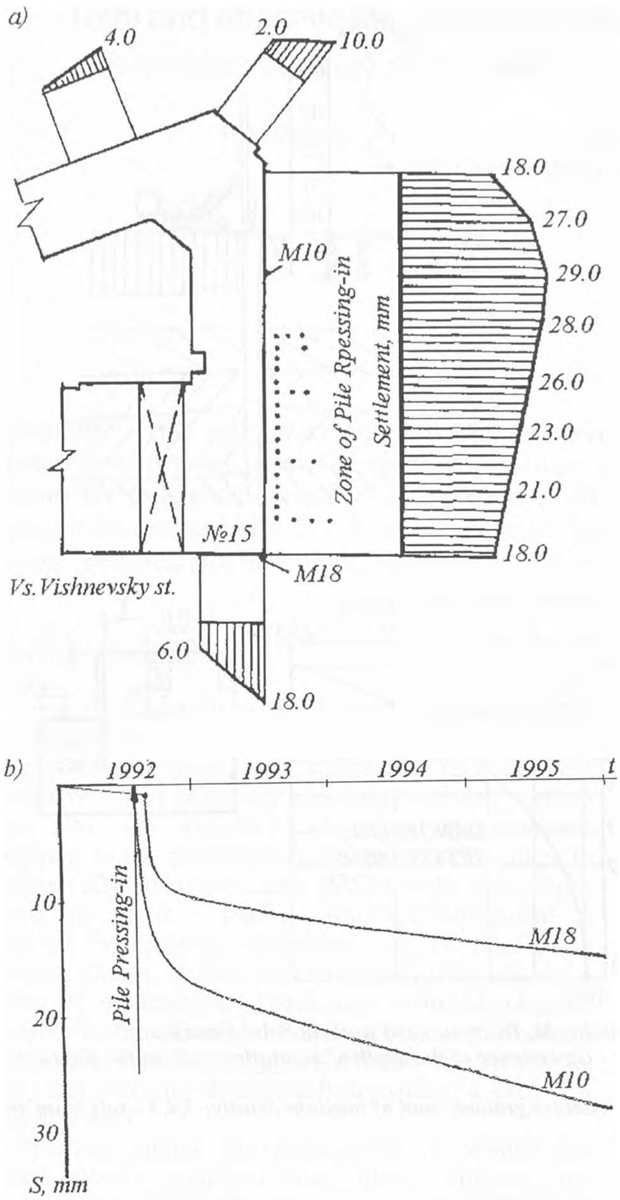

Fig. 3. Influence of pile pressing-in on old buildings in Vs.Vishnevsky street in Saint Petersburg.
***a** - plan of the site and diagram of settlements of house № 15; **b** - graph of settlements of house № 15 with time.*

pressing-in the house № 15 was damaged in 10 m adjoining zone of the pile field. The measuring wall was subjected to the most significant settlements - 17 mm. After that the works were suspended until February 1996. To this date the settlement of the house № 15 was 30 mm. Calculations according to the proposed model showed that the development of settlement would continue and the measuring wall would be settle by 50 mm.

2. On Application of Electro-Graphical Effect (EGE) to Piling within City Boundaries.

It is known that during EG-discharge elastic compression of soil takes place under the action of shock wave induced by the discharge. At the end of outline breakdown the pressure of a vapour-gas hole, induced by the discharge, is intensively decreased pile widening may be initially approximately modeled in calculations by specifying forced shifts in the soil in the direction from the discharge center. These shifts cause the appearance of additional statical stresses in a massif and, as caculations showed, the destructurizing of soft Baltic loam in large zones which are 10 times more than forced shift. It is notable that the development of widening becomes possible only to the sides and upward due to the deformations of forming. In the period of action of a shock wave clay and sand soils dot as practically nonconsolidating media. The effect of foundation consolidation is a consequence and results from the dead load of soil itself and of exciting buildings.

So even without taking into consideration the dynamic effects at EG-discharge and considering only the static problem, in which widening is modelled by specifying the forced shift, we inevitably conclude that EGE can not be recommended for reconstruction and new construction within city limits. The dynamic influence at EG-discharge on unstable structure soil needs special research [5]. This rather interesting technique should have definite limits and conditions of application. It is necessary to carry out special research in order to develop such kinds of piling technique.

3. Stability of the Hole in the Process of Boring for Piles.

Considering stability of a hole it is usually assumed that there is a sphere of radius R which limits the moving zone of plastic failure [6]. the medium pressure onto a hole F is described by the degree function of relation of Boring radius to the radius R. The radius R takes into account that the soil structural accepts part of the natural pressure onto a hole.

In soft clay along the surface of a well casing plastic deformations take place and they are not followed by the strengthening of soil. Consequently considering the stability of the boring hole it is necessary to use uncnsolidated characteristics of strength. In this case the degree function becomes constant:

$$F = \gamma H, \tag{6}$$

where γ is the specific weight of soil,

H is depth from mouth of the borehole.

Stability of the hole is provided when pressure F is less than the backpressure P_1

$$F \leq P_1 \tag{7}$$

$$P_1 = (H-h)\,\gamma_w + h\,\gamma + 2\,C\,h\,/\,r\,, \tag{8}$$

where γ_w is the specific weight of water or mixture in a hole;

h is the height of soil plug which is left in a hole during boring;

C is the specific cohesion of soil.

Taking into account the condition (6) and the equations (7) and (8) it can be easily found that the face of the boring hole, drilled with housing pipes of diameter 1,2 m and length 23 m, and a plug 2,0 m, filled by water upto the mouth, is unstable in soft Baltic loam. This simple calculation clarifies the cause of emergency deformation of the house № 16 on street Malaya Dvoryanskaya in Saint-Petersburg, when wall of similar piles was built close to it. The house has got nonuniform settlements (See Fig. 3a) and cracks 80 cm wide.

Realization of the proposed model in final deformations allows to observe the hole filling up by soil. Calculations show that in soft Baltic loam the stability of vertical boring may be provided only by application of heavy clay mixture, processing well pronounced tiksotropy or viscous polymeric clay mixtures.

4. Adjacency of Foundation Pit to the Building.

During construction in dense town area it is quite often a problem to find out the optimum variant of a foundation design for a new building in combination with the problem of foundation reinforcing in neighbouring buildings. An example of solving such problem can serve a geotechnical survay of foundation

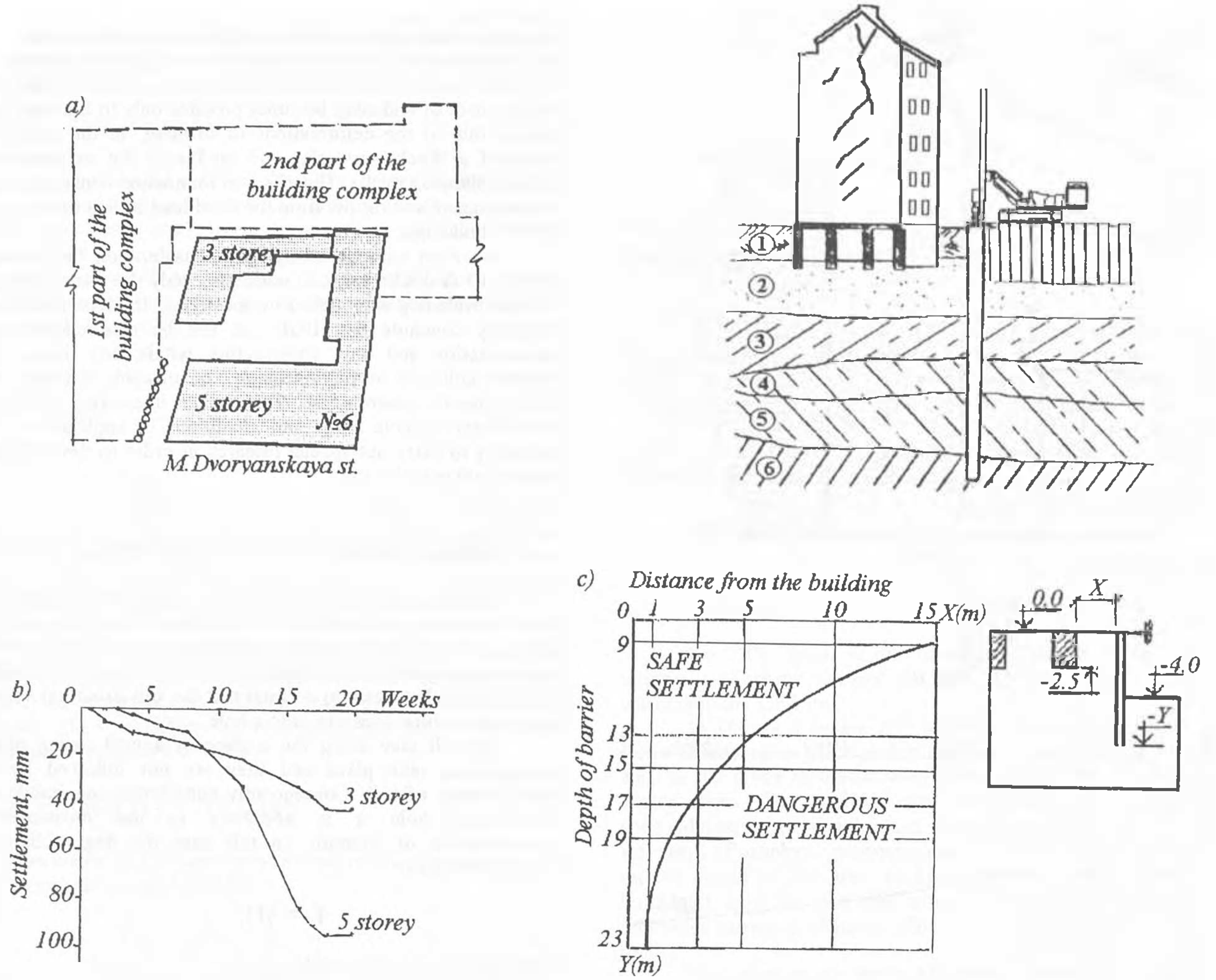

Fig. 4. Adjacency of new building complex to the old building M. Dvoryanskaya street in Saint-Petersburg
a - plan of the site; b - graph of settlements of house№6 with time; c - dependence of the depth of separation wall on the distance to building.
Notations in the geological column: 1 - technogenic layer; 2 - medium-grained sand of medium density; 3,4,5 - soft loam and fluid sandy loam; 6 - medium hard moraine loam.

construction for the 2nd part of the building complex in adjoining the yard wing of house № 6 in Malaya Dvoryanskaya street.

The main building of this complex was deformed during construction of the above separating wall for the 1st part of the complex. Calculations on the basis of the proposed model made it possible to choose the necessary in the given geological engineering conditions design of the barrier of the foundation area and possible distance to the existing building (see. Fig. 3b).
The criterion of the choice (including preventive reinforcing of the building) was to prevent the development of additional settlements of the building exceeding 2 cm. In particular it was found that in case of the barrier pressing-in in soft soil the difference between pressures on both sides of the barrier can cause the destructurizing of soft clay and loss of the wall stability.

In order to choose the technique of constructing foundation in conditions of dense urban development it is necessary to have the geotechnical forecast of the risk zone and recommendations for choosing safe techniques or regimes of works with preliminary reinforcing of existing foundations.

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