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Stress-strain state of the system “base-strip foundation” at elimination of excessive tilts of buildings

État des déformations de la “base - ceinture de base”, tout en éliminant le déploiement de bâtiments supplémentaires

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ABSTRACT
The classification of technologies of tilts elimination of buildings and constructions is carried out. It is offered the geomechanical and design models corresponding to physical state of soil under strip foundation underworked by horizontal cylindrical boreholes. The structural diagram of the device for control of parameters of the system “foundation soil – strip foundation with tilt” is presented.

RÉSUMÉ
Implementé éliminer déploiement des technologies de classification des bâtiments et des structures. Un modèle géomécanique et du design, un bon état physique des sols dans le cadre de la fondation de la bande, un souléagements cylindriques horizontaux. Une ébauche de l'appareil de contrôle les paramètres du système «saleté foundation - une fondation avec le rouleau de ruban adhésif».

Keywords : strip foundation, tilt, soil underworking, model, control of parameters

1 INTRODUCTION
The tilt of foundation is one of the basic criteria determining operational serviceability of building object. The allowable values of buildings and constructions tilts are restricted by normative documents. However in many cases the tilt of foundation exceeds allowable values and sometimes limiting values at different stages of life cycle of building object (Maffei, 2001, Shokarev, 2006). It is necessary to choose and realize optimum technology of elimination of excessive tilt for the further safe operation of such building. At carrying out of the given kind of works it is necessary to provide the adequate forecast of geomechanical processes in the system “base-foundation - superstructure”.

2 CLASSIFICATION OF ELIMINATION TECHNOLOGIES OF BUILDINGS AND CONSTRUCTIONS TILTS
Elimination of tilts of buildings and constructions is made by engineering influence on their subsystems “foundation – superstructure” or “base-foundation” (Krivoshheyev, 2005).

Influence on subsystem “foundation-superstructure” is usually made by rise of the superstructure by piston or flat metal, rubber jacks. Jacks are established in special niches in basement part of building and united in the single-line or modular systems. It is also used lowering of superstructure with help of the active constructive systems placed at construction in socle bearing elements. Constructive systems include thermoplastic elements (asphalt concrete, polymers, etc.) or regulating devices in which sand or water is frequently used in quality removed working environment.

Influence on subsystem “base-foundation” is carried out by change of geotechnical soil parameters or its underworking. It is used the following technologies: adjustable wetting (sweating) of soil, loading of base by additional static loading, loading (unloading) of base by tension devices, electroosmosis for change of physomechanical characteristics of soils, with the purpose of realization of foundation settlement less collapsible part of building.

Underworking of soil in foundation bed is made vertically, inclined and horizontal concerning foundation base thus the following kinds of drilling can be used: machine drilling, machine with casing, hammer drilling, hydromechanical and also infinite circuit.

High-pressure injection in foundation soil is used with the purpose of foundation rise of collapsible part of buildings.

It is possible to execute classification of elimination technologies of building tilts of the system “base-foundation-superstructure”:

1 The device of adaptable systems (jack systems, Constructive systems)
2 Change of soil properties of foundation soil (by wetting, by steam, by loading, by electro osmosis, by injection)
3 By under working of foundation soil (horizontal, vertical, inclined)

The technology of elimination of building tilts based on local horizontal underworking of soil foundation by cylindrical boreholes is widely used at present time.

Works of local horizontal underworking of foundation soil is usually made in the following technological sequence (fig.1):

- earth excavation from the side of less collapsible part of building;
- drilling out of necessary quantity of soil from the base of building object by the device of horizontal cylindrical boreholes executed with help of settlement parameters (length, step, diameter of boreholes);
- local humidifying of a ground around of a contour of cylindrical chinks;
- regulation of technological settlements of foundations by humidifying (loosening) of soil around the boreholes and restoration of vertical position of building object;
- performance of excavation backfill.
The main problem is maintenance of geotechnical safety of building object at development of design decisions for elimination of building tilts by local horizontal underworking of foundation soil. Forecasting of technological settlements and tilt of building is carried out with use of modern methods of theoretical and applied geomechanics, and also in view of features of the device of excavation, boring of boreholes and etc.

For increase of reliability of the forecast of stress-strain state of the system “base-strip foundation with tilt” it is necessary:

- to execute engineering - geological researches in necessary volume;
- to choose settlement geomechanical model of soil corresponding to physical state of underworked soil and design features of foundations;
- to determine parameters of deformability and durability of soils which are taking into account features of drilling of horizontal cylindrical boreholes;
- to use adequate methods of numerical modeling of stress-strain state of foundation soil allowing to take into account character of structural state of soil including during manufacture of works.

The general law of deformation of underworked foundation soil and contour of cylindrical boreholes were investigated for development of geomechanical and design models of system “underworked soil massif (base) – foundation with tilt. For this purpose numerous natural experiments have been executed during elimination of excessive tilts of buildings (tab.1).

### Table 1. Experience of elimination of tilts of buildings with use of technology of horizontal underworking of foundation soil by cylindrical boreholes

<table>
<thead>
<tr>
<th>Type of object</th>
<th>Quantity, pieces</th>
<th>Quantity of floors</th>
<th>Deviation from verticals, mm</th>
<th>Elimination of tilt, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel buildings</td>
<td>30</td>
<td>4-14</td>
<td>200-560</td>
<td>95-106</td>
</tr>
<tr>
<td>Brick buildings</td>
<td>8</td>
<td>3-14</td>
<td>95-540</td>
<td>92-100</td>
</tr>
</tbody>
</table>

The following assumptions are accepted at development of geomechanical model of soil massif and design model of underworked foundation soil (fig.2):

- destruction of soil under strip foundation base occurs in local areas (pillars) between proximal cylindrical boreholes;
- the mechanism of soil destruction is connected to the shift deformations occurring, at loadings more than limiting resistance of soil.

The geomechanical model of the system “underworked soil massif – strip foundation with tilt” which allows allocating the basic physical processes of formation of stress-strain state in the given system is offered on the basis of the executed researches.

Figure 1. Underworking of soil in base of building by mechanical boring of horizontal cylindrical boreholes: 1 – excavation; 2 – slope of excavation; 3 – foundation of building; 4 – boring rig; 5 – horizontal cylindrical borehole; 6 – bored soil.

Figure 2. Geomechanical model of stress-strain state of underworked soil massif under strip foundation base with tilt: 1 – foundation soil; 2 – strip foundation; 3 – slope of excavation; 4 – bored soil; 5 – boring cylinder; 6 – characteristic arc of contact between borehole and soil.
physical model of system “underworked foundation soil-strip foundation with tilt”. The suggested variant of the design model of the researched system taking into account physical thickness of compressed layer of soil is presented on fig. 3.

Figure 3. The design circuit of system “underworked foundation soil – strip foundation with tilt”: 1 - contour of development of plastic areas; 2 - area of soil in which boreholes are bored; Dp - diameter of circle of development of plastic areas; b0 - width of the foundation; B - width of soil massif in the form of rectangular; H0 - physical thickness of compressed layer of soil; P - the distributed loading.

4 CALCULATION OF PARAMETERS OF SYSTEM “UNDERWORKED FOUNDATION SOIL – STRIP FOUNDATION WITH TILT”

The suggested geomechanical model of soil massif and design circuit of underworked foundation soil allows defining the basic physicomechanical, strength and geometrical parameters of system “underworked foundation soil – strip foundation with tilt” which are necessary to control during elimination of tilt of building object.

The thickness of the foundation soil, thickness of soil wall between strip foundation and excavation, depth of excavation, depth of foundation, step, diameter of cylindrical boreholes, width of the plastic ring areas arising around of cylindrical boreholes after their boring are accepted as the basic design parameters.

Let’s define physical thickness of the foundation soil with tilt of building on the basis of technique used at the decision of Renkin tasks (Harr, 1971):

$$H_0 = \frac{P}{\gamma \sin(\alpha - \varphi)} \cdot \sin(\alpha - \varphi)$$

where $H_0$ - physical thickness of the foundation soil; $\alpha$ - angle of foundation inclination; $\Delta$ - angle between normal to a surface of the foundation soil and a direction of action of external strip loading $P$; $\gamma$, $\varphi$ - specific weight and angle of internal friction of soil.

The width of soil wall is defined under the formula:

$$b_\ell > \frac{D_0 + b_0 - b_\ell}{2},$$

where $D_0$ - diameter of circle of development of plastic areas; $b_0$ - width of plastic area in soil in zone of footing excavation; $b_\ell$ - width of the foundation.

Orthographic epure of strip foundation settlement is the initial value for calculation of diameter of horizontal cylindrical boreholes; it is received by results of geodetic survey of high-altitude position of a building to the beginning of works on elimination of its tilt.

Technological parameters of system “underworked foundation soil – strip foundation with tilt” are interconnected among themselves by the following basic ratio:

$$d^2 = st,$$

where $s$ - required technological settlement; $d$, $t$ - diameter and step of horizontal cylindrical boreholes.

For exception of interaction of the ring plastic areas generated around bored horizontal cylindrical boreholes, they should be divided by site of soil (pillar) working in an elastic phase. Width of pillar is selected from condition, that stresses should be no more size of settlement resistance of soil at external loading in it.

The step of boreholes in line is defined from condition:

$$t \geq d + 2\Delta + l_y,$$

where $d$ - the varied diameter of boreholes; $\Delta$ - width of plastic ring area of soil around of boreholes; $l_y$ - width of an elastic site of soil pillar in direction of vertical axis of asymmetry.

It is possible to define necessary diameter of boreholes from (3) knowing step of boreholes and required value of technological settlement:

$$d = \sqrt{S(d + 2\Delta + l_y)}$$

and accordingly to choose necessary diameter of screws for mechanical boring.

Depth of foundation of horizontal cylindrical boreholes is accepted proceeding from a condition that they should be located in very compressed layer of soil but thus should not cross the initial plastic areas generated at edge of foundation (fig.2):

$$h_\ell > H_1,$$

where $h_\ell$ - depth of boreholes location; $H_1$ - height of initial plastic areas formed at edge of foundation.

We shall enter factor of identification for definition of the current character of stress-strain state of underworked foundation soil:

$$K_i = \frac{V'}{V},$$

where $V'$ - total volume of areas in the foundation soil taking place in an elastic condition; $V$ - also in plastic.

Foundation soil works according elastic - deformable linear model (Ter-Martirosyan, 2005) at performance of condition $K_i \geq 10$ and therefore loss of stability of the base is impossible at manufacture of works on elimination its excessive tilt.

The algorithm of definition of width of plastic zone around contour of cylindrical boreholes is developed for practical realization of identification method of stress-strain state of underworked soil. The analytical decision of tasks about distribution of stresses and deformations around of round aperture in ideal elastic - plastic environment with criterion of plasticity of Tresk is received earlier (Fadeev, 1987). This analytical decision is one of the most exact; therefore it can be used on a site of the strip foundation where loading is less than value of limiting resistance of soil. The numerical method of definition of width of plastic zones around of cylindrical boreholes is used at the big loadings.

One or several lines containing 1 … n of boreholes of different diameter are bored at elimination of foundation tilt. The volume of plastic areas in foundation soil will be equal:
\[ V^\circ = (d + 2\Delta c)n \]

where \( d \) - diameter of cylindrical boreholes; \( \Delta c \) - width of ring plastic area around of boreholes; \( 1, n \) - length and quantity of boreholes.

The total volume of soil, proceeding from the suggested design model, is limited by physical depth of the foundation soil, length of boreholes and length of foundation. We will write for total volume of soil:

\[ V_0 = H_0l/l, \]

where \( H_0 \) - physical depth of the foundation soil; \( l_1 \) -length of foundation; \( 1 \) – length of boreholes.

We will get for elastic-deformed volume of soil taking into account formulas (8), (9):

\[ V' = V_0 - V^\circ = H_0l/l - (d + 2\Delta c)n/l. \]

5 CONTROL OF PARAMETERS OF DESIGNED MODEL OF UNDERWORKED FOUNDATION SOIL AND FORMATION OF ADMINISTRATIVE INFLUENCES

There are divergences in values of actual and predicted parameters at elimination of excessive tilts of buildings, for example, technological settlement and tilt of building object. Therefore it is necessary to provide engineering actions in the project: monitoring in mode of real time, technological receptions of settlement regulation on triangular epure, etc. It allows providing equality of predicted and actual deformations of system “underworked foundation soil -strip foundation with tilt” at all stages of performance of works of elimination of building tilt.

For the suggested design model of the system “underworked foundation soil – strip foundation with tilt” the basic controllable parameters are:

- thickness of soil wall between foundation and excavation, depth of excavation;
- depth of foundation, diameter. Step of cylindrical boreholes;
- character of change technological settlements and tilt of foundation;
- factor of identification of underworked foundation soil;
- value of soil whistler in zone of strip foundation.

The structural diagram of automated control is developed for monitoring the above-stated parameters (fig.4).

Figure 4. The structural diagram of the automatic device for the control of parameters of design model and identification of character of stress-strain state in foundation soil: 1- building with tilt; 2 - the block of measurement and processing of signals; 3 - the block of calculation geometrical, physic mechanical parameters of the foundation soil and its identification on stress-strain state; 4 - the block of formation of managing influences \( YB_1, \ldots, YB_4 \) for correction of technological process of tilt’s elimination; 1.1…1.n; 2.1…2.n; 3.1…3.n; 4.1…4.n; 5.1…5.n accordingly measuring converters of thickness of soil wall, diameter of boreholes, settlement, tilt of foundation and whistler of soil.

The electromagnetic non-contacting measuring converters are used at construction of the structural diagram of the control of the current parameters of design model. It allows defining both absolute size of tilt and its direction. The non-contacting through passage electromagnetic gauge combined with a ferromagnetic float is used at the decision of the task connected to the control technological settlements of soil reaching several tens centimeters, during alignment of foundation tilt. The non-contacting inductive gauges of displacement consisting of two ferromagnetic parts, fixed accordingly on surface of soil and on a lateral surface of the strip foundation are used in design of the indicator of the control of the of occurrence moment of soil whistler. Accommodation of such gauges on length of the foundation allows supervising the initial moment of soil whistler which corresponds to transition in a plastic state.

The universal structural diagram includes the block of continuous calculation of stress-strain state in technological process of elimination of foundation tilt, and also the block of formation of the current administrative commands. It allows defining local zones of soil demanding administrative influence, for example, changes of correction of technological settlements under strip foundation base, etc.

6 CONCLUSION

1) The most rational method of underworking of foundation soil “mechanical boring of horizontal cylindrical boreholes is chosen on the base of the executed classification of technologies used at elimination of building and construction tilts.
2) Geomechanical and design models of the system “underworked soil massif (base) - strip foundation with tilt” allowing taking into account physical depth of foundation soil are suggested.
3) It is realized the method of identification of stress-strain state of the system “underworked foundation soil – strip foundation with tilt” on the base of the factor of the identification which is taking into account a ratio of sizes of elastic and plastic volumes of the deformed soil.
4) It is developed the structural diagram of automatic system of management of technological process on the basis of formation of administrative commands, taking into account the current control and calculation of key parameters of design model and results of identification of stress-strain state of the sys tem “underworked foundation soil-strip foundation with tilt”.

REFERENCES