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Investigation of the bored pile work with thermochemical broadening in the basis

Etude du travail de pieu foré avec élargissement thermochimique de la base

A. V. Glushkov, L. A. Hinkanin

Volga State University of Technology, Yoshkar-Ola, Russia

N. S. Sokolov

Chuvash State University, Cheboksary, Russia

I. V. Glushkov

Perm National Research Polytechnic University, Perm, Russia

ABSTRACT: The article presents the experimental investigation results of the broadening effect at the bored pile bottom on its bearing capacity. To determine the effect of thermochemical broadening (TCB) on the bearing capacity of bored piles, investigations on models of piles on the experimental site were carried out. A complex comparison of the model experimental studies results and calculations by the finite element method of the stress-strain state of piles with thermochemical broadening in the face is carried out. For the deformation zone analysis of the basis, the development of plastic points distribution along the main stages of load application is presented. Modelling of thermodynamic processes passing at the bottom of the well during thermochemical broadening of a bored pile are strongly considered. The temperature gradient is determined in the course of a numerical experiment by the finite element method in the ANSYS software complex. As a result of calculations, it has been established that piles with TC-broadening show an increase in the zone of deformation of the basis around the pile due to the created elliptical form of broadening. Experimental studies indicate a significant increase in the bearing capacity of bored piles with the use of thermochemical broadening.

A well-developed combination of analytical and numerical methods for calculating the optimal shape and mass of the charge allows to select the required amount of the initiating mixture. The article is intended for specialists in the field of industrial and civil engineering and geotechnics.

RÉSUMÉ: L'article présente les résultats des recherches expérimentales sur l'effet d'élargissement au fond du pieu foré sur sa capacité portante. Pour déterminer l'effet de l'élargissement thermochimique (TCB) sur la capacité portante des pieux forés, des études sur des modèles de pieux sur le site expérimental ont été effectuées. Une comparaison complexe des résultats des études expérimentales sur modèle et des calculs effectués par la méthode des éléments finis de l'état de contrainte-déformation des pieux avec élargissement thermochimique du visage est réalisée. La modélisation des processus thermodynamiques passant au fond du puits lors de l'élargissement thermochimique d'un pieu foré est fortement prise en compte. Le gradient de température est déterminé au cours d'une expérience numérique par la méthode des éléments finis du complexe logiciel ANSYS. À la suite de calculs, il a été établi que les pieux avec élargissement TC montrent une augmentation de la zone de déformation de la base autour du pieu en raison de la forme elliptique créée d'élargissement. Des études expérimentales indiquent une augmentation significative de la capacité portante des pieux forés avec l'utilisation de l'élargissement thermochimique.

Une combinaison bien développée de méthodes analytiques et numériques permettant de calculer la forme et la masse optimales de la charge permet de sélectionner la quantité requise du mélange initial. L'article est destiné aux spécialistes du génie civil et industriel et de la géotechnique.

Keywords: bored piles, thermochemical broadening, FEM, geotechnics.

1 INTRODUCTION

Bored piles are one of the most frequent constructions applied to transfer the load on the basis. The use of bored piles begins with rather small diameters and lengths at cottage, low construction, construction of small architectural forms and reaches considerable sizes (tens of meters in length, to several meters in the diameter) at construction of high class buildings, bridges and unique constructions (Mangushev, 2013; Kupchikova, 2015). Practice of construction shows that bored piles can be used effectively at reconstruction of buildings and constructions in the sphere of strengthening of the structure foundations, underground parts of the building and constructions interacting with the basis (Prnozoin, 2014).

Thus, the singular value is gained by the scientific researches aimed at the development of the interaction theory of bored piles with the basis and technologies of increase in their bearing capacity (Bogomolov, 2015).

Broad application of bored piles technology opened a class of problems which builders face at their realization: formation of sludge at the bottom of the well; a small bearing capacity (compared with other technologies); high deformability of the uncompacted basis zone (the process of their work is complicated at strengthening of the foundations).

2 EXPERIMENTAL INVESTIGATIONS

The purpose of the research is to study the work of board piles with thermochemical broadening in the basis.

To determine the effect of thermochemical broadening (TCB) on the bearing capacity of bored piles, investigations on models of piles on the experimental site were carried out. As models of piles, models of monolithic concrete bored piles with a length of 700 mm ($L=700$ mm) and a diameter of 130 mm ($d=130$) were used. As thermochemical mixture, the thermite mixture is used, providing at the exit a high combustion temperature in an oxygen-free environment. Distant initiation of thermochemical mixture was made according to the principle of "electric matches". The technology of the creation of bored pile models and the structure in them by means of thermochemical mixture of broadening is shown in fig. 1.

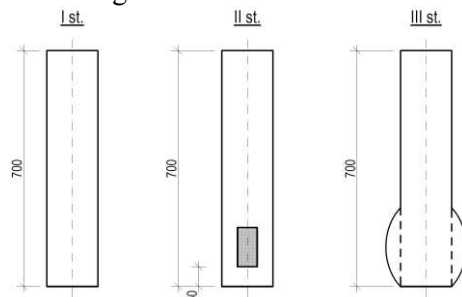


Fig. 1. Technology of creation of the bored pile with thermochemical broadening in the face on stages: 1 st. – the well structure in the basis; 2 st. – fixation of thermochemical mixture in the well face with the subsequent laying of concrete mixture; 3 st. – distant

initiation of thermochemical mixture and receiving broadening in a pile with the creation of the compacted zone in the basis.

In the engineering-geological terms, the experimental platform is evenly put by soft loam from the surface up to the depth of 2,8 m, which is the qualitative homogeneous basis within the investigated deformation zone of the bored pile and thermochemical broadening (Suvorov, 2016).

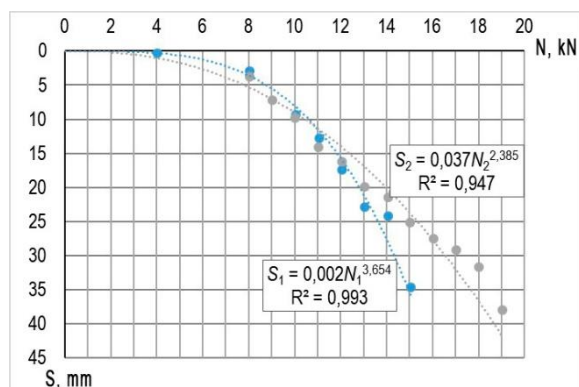


Fig. 2. The graph of the foundation settlement dependence under the load of a board pile in experimental investigations in a cohesive basis:

$S_1=f(N_1)$ – a pile without thermochemical broadening; $S_2=f(N_2)$ – a pile with TCB

After a full set of concrete strength, tests of bored pile models with the static pressing load were carried out in accordance with GOST 5686-2012 "Soils. Methods of field test piles". The vertical static load was given step by step on 0,1-0,2 kN (100-200 kg) by means of a hydraulic jack DG-5, registration of pile movements was carried out using two Maximov flexometers PM-3.

When processing the results of experimental investigations, the classical solution of approximation of power functions by the method of least squares was used (fig. 2).

As a result of the carried-out testing, it is possible to note that when the settlements are more than $S=30$ mm the bearing capacity of piles

with TCB exceeds the bearing capacity of piles without broadening by $N_2/N_1=1.2$ times.

3 NUMERICAL MODELLING OF THE STRESS-STRAIN STATE

At the initial stage of testing the hypothesis about the influence of initiating a thermochemical mixture at the bored pile bottom, numerical physical modelling was carried out with the use of the geotechnical complex – Plaxis 2D (Ilyichev, 2014). Further experimental studies confirmed the accepted geometric parameters and physical models accepted in calculations (Ponomaryov, 2016).

As a calculated model, the axisymmetric model of the bored pile was used, the calculated area was accepted by the sizes of $5d \times 2.5L$, where d is the diameter of the bored pile on top, L is the length of the pile. The breakdown of the calculation area into finite ones is shown at Fig. 4.

Let us consider the main calculation results of the stress-strain state of bored piles with thermochemical broadening (TCB) in a cohesive soil. Studies have established that the load-bearing capacity of piles with TCB is more than 1.2 times higher practically in the entire range of settlements (Figure 3). The calculated graphs of the settlement dependence on the load of $S=f(N)$ for piles with broadening have a high correlation with the approximations of the experimental data. So it confirms the correctness and conditionality of the chosen geometric and physical design model.

The presence of broadening obtained with the aid of using a thermochemical mixture has a positive effect on the work of a bored pile in the basis.

Fig. 5 shows isolines of vertical stresses σ_y in a cohesive basis for a bored pile using thermochemical broadening and a test pile without TCB. The greatest increase in the diameter of the pile in the face was made by 10-15%, which provides decrease in the maximal

vertical stresses σ_y to 15%, giving the inclusion of a larger volume of soil in the basis away from the center of the pile and above the plane (the level) of the point.

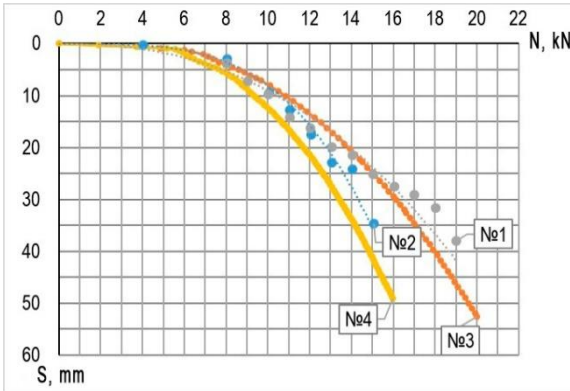


Fig. 3. The graph of the foundation settlement dependence under the load of $S=f(N)$ of a board pile in a cohesive basis:

1,2 – tests of a pile model in a cohesive soil without TCB and with TCB respectively;

3,4 – modelling of a bored pile by finite element method without TCB and with TCB respectively.

Fig. 6 (a) shows vertical displacements of U_y in the basis of the pile without TCB (on the left) and with thermochemical broadening (on the right). For piles with TCB (on the right), an increase in the deformation zone of the basis around the pile by 1.10-1.15 times is noted due to the created elliptical form of broadening, which redistributes the load on the pile. In the current example, with equal settlements of $S_2=S_1$, the loads on the pile differ by $N_2/N_1=1.25$ times.

For the given applied loads in fig. 6(b), horizontal displacements of U_x for the bored pile and its analog with the use of the thermochemical mixture are shown. The horizontal component of soil displacements in the basis as a result of the load application becomes more pronounced due to a change in the direction of forces transfer from a predominantly vertical one. Therefore, the maximal horizontal displacements of $U_{x,max}$, localized mainly in the area at the bottom of the well, for piles with broadening of 30-40% more than for piles without broadening.

To analyze the deformation zone of the basis in Fig. 7 the development of zones of plastic deformations in the main stages of the load application is presented. For both pile constructions, a relatively equal volume of soil is noted, which has passed to the plastic stage at the appropriate stages. Differences consist in the appearance of plastic deformation zones in the area around and aside from broadening, which means that the surrounding part of the basis starts working actively and has a positive effect on the final bearing capacity of the pile.

4 NUMERICAL MODELLING OF THERMODYNAMIC PROCESSES

Thermochemical broadening is caused by a phase transition of free moisture (an unrelated physicochemical reaction of mixture making from the liquid state into the vaporous state (Hinkanin, 2014). To describe this phase transition, it is necessary to consider the free enthalpy of steam-and-water mixture in a small time scale (Russian code of rules, 2012).

Let us consider the thermal balance of the system "pile with TCB – soil". In the first approximation is taken a heat flux on system borders (at a distance of 2.0 metres from a pile axis of symmetry) equal to 0 W. Thus, the entire thermal energy of a charge is absorbed by the concrete mixture, the enthalpy of the water-vapor transfer and the surrounding soil (1).

$$Q_{charge} = E_{water} + E_{vapor} + Q_{concrete} + Q_{soil} \quad (1)$$

The ground conditions described above make it possible, with sufficient accuracy; give a set of equations for the thermal balance of the system.

$$Q_{soil} = c_{soil}(t, \varphi) \cdot m_{soil} \cdot \Delta t_{concrete-soil} \quad (2)$$

$$Q_{concrete} = c_{concrete} \cdot m_{concrete} \cdot \Delta t_{charge-soil} \quad (3)$$

$$E_{water} = f(p_{water}, \Delta t_{charge-soil}) \quad (4)$$

$$E_{vapor} = f(p_{vapor}, \Delta t_{charge-water}) \quad (5)$$

The temperature gradient is determined in the course of the numerical experiment by the finite element method in the ANSYS software complex. The applied model of non-stationary heat-and-mass transfer makes it possible to

estimate both the duration of the heating process of a concrete mixture and the process of the transition of disconnected water from the liquid into the vaporous state. The processes of convective heat exchange in non-Newtonian liquid (concrete mixture), which were not considered in the first approximation, are estimated as unimportant. Breakthroughs of gaseous combustion products along the pile body from the charge to the wellhead have little effect on the heat transfer process due to the low heat capacity of the gas.

As can be seen from Fig. 8, the process of heating the concrete body to the boiling point of water passes between the first and second minutes. The warming up zone between the wall "soil/pile" and the charge is heated above 100°C (minimum temperature in the heating zone) in 126 seconds. At the same time, it should be noted that at comparable energy consumption of the combustion process, it is more effective to use mixtures with a low combustion temperature, but a longer chemical reaction time, which will provide a long uniform heating, increasing a specific enthalpy of the concrete mixture.

Additional investigations are required to determine thermophysical properties of the concrete mixture in the boundary state (from liquid to solidified state).

The use of charges with the ratio "diameter / height" more than 1:10 can not be recognized as effective, because of the increased influence of convective processes of heat-and-mass exchange in the pile body.

During numerical simulation, the temperature distribution in the pile with TCB was obtained in the time interval from 0 sec to 3600 sec. Fig. 9 shows the temperature dependence (in logarithmic scale) from the time at different points of the horizontal section of the pile with TCB at a distance of 115 mm from the plane of the point (along the horizontal plane of the charge symmetry).

The peak of the combustion temperature of the charge is 60 seconds from the start of the burning

reaction of the mixture (1636.82°C). The full-scale experiment shows that the volume of the broadening zone is higher, when the burning time of the mixture is longer and its combustion temperature is lower.

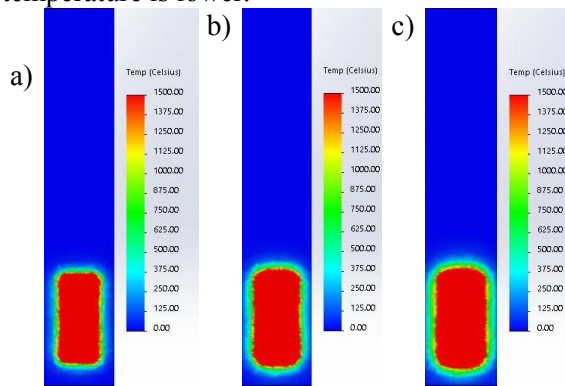


Fig. 8. The process of heating of the pile body with TCB. From left to right: thermogram a) at 10 sec., b) at 50 sec., c) at 100 sec. of heating.

At the "charge-body pile" interface (25 mm), the temperatures also reach a maximum at 60 seconds (1623.48°C), which is explained by the low thermal inertia of the charge material (in the model it is accepted as an alloy of iron and aluminum).

At the "pile-ground" interface (65 mm), the temperatures reach a maximum (148.039°C) at 660 seconds from the start of the combustion reaction.

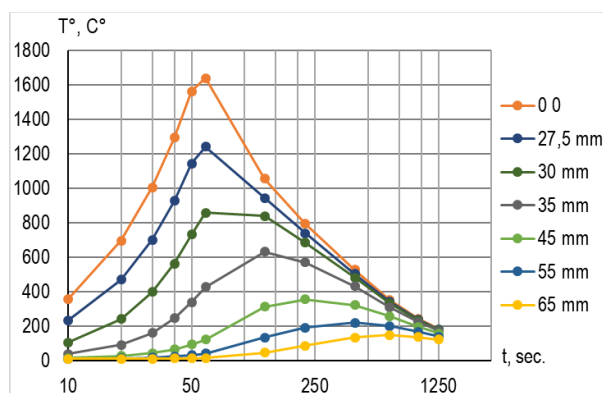


Fig. 9. Temperature distribution in horizontal plane from the charge center to the pile wall in time

B.1 - Foundations, excavations and earth retaining structure

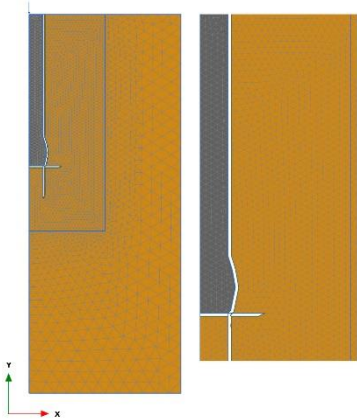


Fig. 4. The breakdown of the calculation area into triangular finite elements

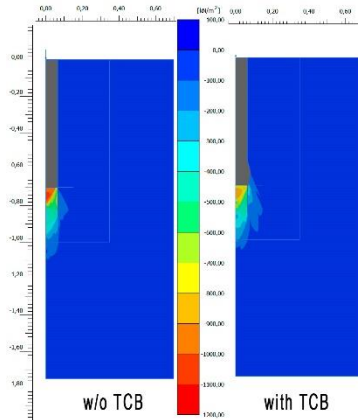


Fig. 5. Vertical stresses of σ_y in the basis of the bored pile

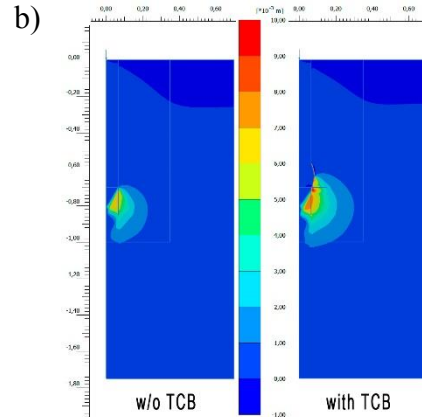
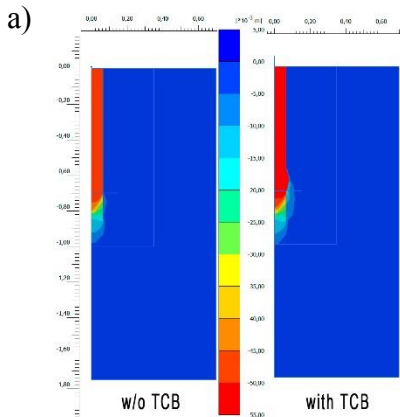


Fig. 6. Vertical U_y (a) and horizontal U_z (b) displacements in the basis of the bored pile

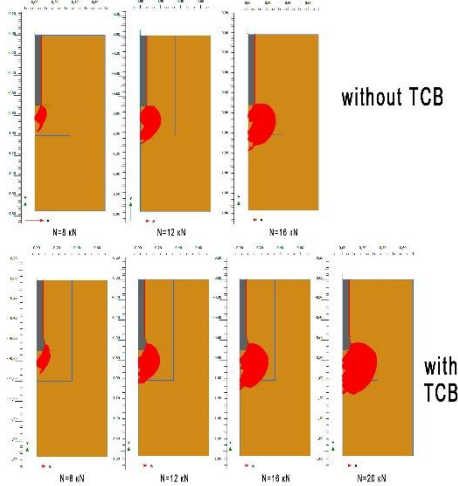


Fig. 7. Plastic deformation zones in the basis with the increment load N for the bored pile without broadening and with broadening (TCB)

5 RESEARCH CONCLUSIONS

1. According to the results of experimental studies in a cohesive soil, when the settlements are more than $S=30$ mm, the bearing capacity of bored pile models with TCB is higher than the bearing capacity of piles without broadening by $N_2/N_1=1.2$ times.

2. Numerical modelling of the bored pile work with broadening got as a result of the initiation of a thermochemical mixture can be carried out using geotechnical complexes of the finite element-analysis and obtain an adequate picture of the component distribution of the stress-strain state (Fig. 4-7). As a result of calculations, it has been found that piles with TCB show an increase in the deformation zone of the basis around the pile by 1.10-1.15 times due to the created elliptical form of broadening, which redistributes the load from the pile to the basis.

3. The process of heating the concrete body in a pile with TCB to the boiling point of water passes between the first and second minutes. The zone of warming up between the wall "soil/pile" and the charge is heated above 100°C (minimum temperature in the heating zone) in 126 seconds. Thus, it is more effective to use mixtures with a low combustion temperature, but with a longer duration of chemical reaction.

4. Numerical modelling showed that the charge extension in proportions more than 1:10 (the diameter to the charge of its height) does not have a significant positive effect. On the contrary, in this case, an increase in the convective heat transfer system is inevitable, and it will reduce the effectiveness of piles with TCB.

5. The ratio of the body volume of the pile to the charge volume for the considered technical solution was 23%. An indicator of the effectiveness of a technical solution for piles with TCB can be the ratio of the volumes of the charge and piles to the bearing capacity of the pile, and is expressed in a separate criterion.

The conclusions confirm the high potential for using pile structures with TCB in industrial and civil engineering, as well as in the reconstruction

of buildings and structures if to study thoroughly the technology of production.

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