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NUMERICAL ASSESSMENT OF CARRYING CAPACITY AND ANALYSIS OF PILOT BARETT BEHAVIOR IN GEOLOGICAL CONDITIONS OF VIETNAM

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Abstract: The article provides an analysis and comparison of the bearing capacity of barrett piles in difficult geological conditions at a construction site in Hanoi - Vietnam based on the results of analytical calculations using various methods. In particular, it contains calculation results according to Building Code of Russian Federation SP 24.13330.2011 "Pile foundations" [1], by numerical modeling of the pile operation under load using the PLAXIS 3D and MIDAS GTS NX software package, based on the results of field tests with piles (static load method). It is noted that the bearing capacity of bored piles and barret piles, according to the results of full-scale static tests with a limiting settlement of 40 mm, is in good agreement with the numerical solution (with the adopted soil model Hardening Soil (HS)) and with the calculation by the analytical method according to the strength characteristics of the soil base

Keywords: pile-barrett, settlement-load dependence, bearing capacity, FEM, analytical solution, mathematical modeling

ЧИСЛЕННАЯ ОЦЕНКА И АНАЛИЗ РАБОТЫ НЕСУЩЕЙ СПОСОБНОСТИ СВАЙ-БАРЕТТ В ИНЖЕНЕРНО-ГЕОЛОГИЧЕСКИХ УСЛОВИЯХ ВЬЕТНАМА

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Аннотация: В статье приводится анализ и сопоставление несущей способности свай-баретт в сложных инженерно-геологических условиях на строительной площадке в г.Ханоя - Вьетнам по результатам аналитических расчетов по различным методикам, в частности, по СП 24.13330.2011 «Свайные фундаменты» [1], путем численного моделирования работы сваи под нагрузкой с использованием программного комплекса PLAXIS 3D и MIDAS GTS NX, по результатам полевых испытаний сваями (метод статических нагрузок). Отмечено, что несущая способность буронабивных свай и свай-баррет по результатам натурных статических испытаний при ограничении предельной осадки 40 мм, хорошо согласуется с численным решением (с принятой моделью грунта Hardening Soil (HS)) и с расчетом аналитическим методом по прочностным характеристикам грунтового основания.

Ключевые слова: свая-баретта, зависимость осадка-нагрузка, несущая способность, МКЭ,аналитическое решение, математическое моделирование

INTRODUCTION

Currently, high-rise buildings are being actively erected in large metropolitan areas of the world [4]. At the same time, the constructive safety of these structures is largely ensured by a reliable foundation, including during construction on soft soils [14]. The choice of the type of foundation is a very important stage, and it is made at the design stage on the basis of geological survey documents. The foundation structure requires a significant part of the cost of a high-rise structure.

Features of geotechnical conditions define special requirements for the design of zero cycle structures for such facilities [5]. In this regard, barrett piles are increasingly used as deep foundations, which can perceive significant longitudinal and transverse forces due to the increased bearing capacity both in material and in soil compared to alternative types of pile foundations [6].

To calculate the bearing capacity of bored piles on the ground and before testing the piles with a static load, one should assign the main structural parameters of the underground structure and apply various calculation methods of analytical and numerical calculations for limit states [4] at the stage of preliminary design of pile foundations.

In this regard, it is important to carry out a comparative analysis of the results of numerical modeling of the interaction of the bearing capacity of barrett piles in soft soils using various soil models (MC and HS) in the PLAXIS 3D, MIDAS GTS NX software systems and analytical calculations in accordance with the results of field tests [one].

Many scientists have dealt with the design and operation of barrett foundations, including in conditions of soft soils [8–13]. At the same time, it should be taken into account that a special approach is required to calculate the bearing capacity of piles, taking into account the stress-strain state of the enclosing soil mass [9,13,14].

Such a comparative analysis was carried out during the construction of a high-rise building with a developed underground part in the city of Hanoi, Vietnam where, as foundations, barrettes with a section of 800x2800 mm and a length of 37 meters were designed.

MATERIALS AND METHODS

According to the results of geological surveys, the explored depth of the foundation at the construction site in Hanoi - Vietnam has a depth of 61 m and consists of 9 soil layers. Physicomechanical and strength characteristics of soils are shown in Table 1.

Table 1. Physical and mechanical properties of soils

Layer Number	Soil	h, m	γ, kN/m^3	I_L	e	φ, degree	c, kPa	E, MPa
1	Bulk packed soil	1.6	16.00	-	-	-	-	-
2	Fluid clay	16.1	17.00	1.408	1.246	6.30	7.00	1.50
3	Fine sand	5.1	19.00	0.350	0.771	30.00	-	13.5
4	Fluid-plastic clay	10.2	17.20	0.811	1.171	18.00	9.10	15.0
5	Fine sand	3.0	19.20	0.350	0.746	30.00	-	13.5
6	Soft-plastic loam	3.4	17.80	0.695	1.002	7.40	9.60	5.00
7	Fine sand	1.0	19.10	0.035	0.755	30.00	-	13.5
8	Fluid-plastic loam	4.8	17.50	0.930	1.082	8.00	9.50	3.00
9	Gravel and pebble soil	>15.8	20.10	0.300	0.524	38.00	2.00	50.0

The barrette pile operates under indentation load within a depth of 37.00 m, from an elevation of -14.90 m to -51.90 m.

In accordance with Russian standards [1], the bearing capacity of hanging piles is determined depending on the physical and mechanical properties of the foundation soil and the depth of the pile. In accordance with paragraph 7.2.6 [1] it is presented in the following general form:

$$F_d = f(I_L, e, D, L), \quad (1)$$

where I_L is a soil flow rate;

e is soil porosity coefficient;

D is pile trunk diameter, m;

L is pile-laying depth in the ground, m

The correct choice of the base soil model and its input parameters is of particular importance [7] In numerical geotechnical modeling.

We performed mathematical modeling of the test step by step in several stages:

1. Formation of the initial stress-strain state of the soil mass;
2. Development of the foundation pit;
3. Arrangement of barret piles;
4. Loading of the barrette (see Fig. 1).

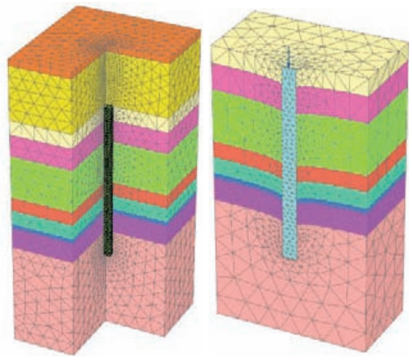
A gradual application of a vertical indentation load to the experimental barrette was carried out by 2500 kN at each stage.

Mathematical modeling of changes in the stress-strain state of the soil mass in the process of virtual testing of the experimental barrette pile was carried out using the geotechnical software PLAXIS 3D and MIDAS GTS NX in a spatial setting.

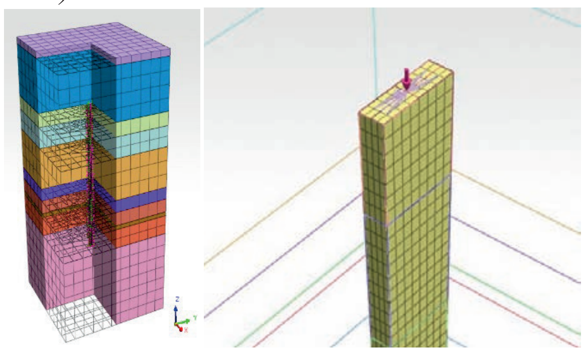
The software package implements several soil models, in particular: Mohr-Coulomb model (MC, Coulomb-Mohr model), Soft Soil Model (soft soil model), Hardening Soil Model (hardening soil model), Soft Soil Creep (soft soil model with taking into account creep), Hardening Soil with Small Strain (model of hardening soil taking into account the stiffness of small deformations), Modified Cam-clay (modified model of Cam-clay, MCC), etc.

It is known that each of these models has its own advantages and disadvantages. In more detail, we considered two models most often used in geotechnical design:

- ideal-elastoplastic model Mohr-Coulomb;
- Elastoplastic model of the hardening soil Hardening Soil.



a)



b)

Figure 1. FE model:
a) PLAXIS 3D; b) MIDAS GTS NX

After assigning the parameters of the pile foundation, full-scale tests with the vertical static load of a single barrette with a section of 800x2800 mm and a length of 37 meters were made and carried out at the construction site. The tests were carried out in accordance with Standard of Rusian Federation GOST 20276-2012 [3] using hydraulic jacks using the Top-Down method up to a maximum load of N = 30 MN.

TEST RESULTS AND COMPARISON

Based on the results of full-scale tests, we construct graphs of the dependence of settlement on time for each stage of the load [14]. The condition of the maximum settlement of the pile head under a load of 40 mm is achieved at a vertical load $F_{d,site}$ = 27500 kN (see Fig. 2). This value is taken as the bearing capacity of the barrette on the ground.

Analytical calculations have shown the value of the total bearing capacity of this barrette equal to $F_{d,calc1}$ = 27285 kN. At the same time, 77% fell on the heel of the pile and only 23% on the side surface.

Considering the significant thickness of weak soils with a low modulus of deformation within the barrett trunk, we note that the pile settlement under load will play a significant role in the formation of its overall bearing capacity. Therefore, it was decided to limit the bearing capacity on the ground by the maximum settlement of a single pile, equal to 40 mm, similar to field and numerical tests in accordance with the provisions of the Russian Geotechnical Construction Standard [2].

The deformed model diagram and vertical displacements at an intermediate stage of testing (at P = 20,000 kN) for various soil models are shown in Figures 3-4.

Table 2 presents the results of determining the bearing capacity of a barrette on the ground by analytical and numerical methods in comparison with the results of field tests.

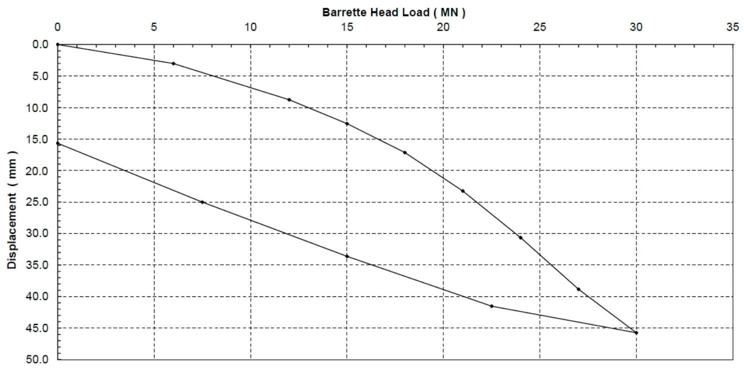


Figure 2. Results of full-scale static tests of barrette piles

a) *b)*

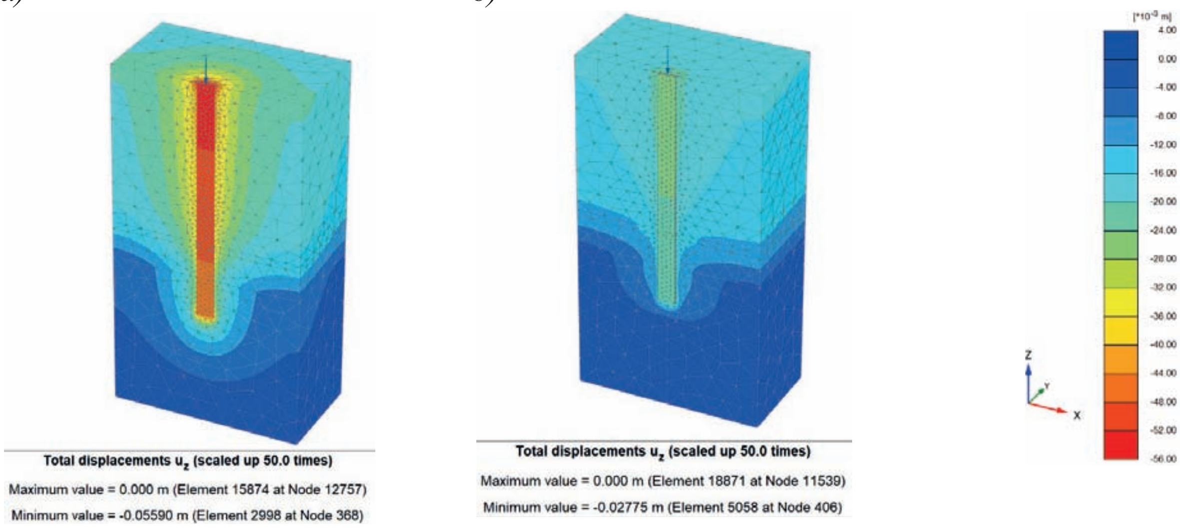
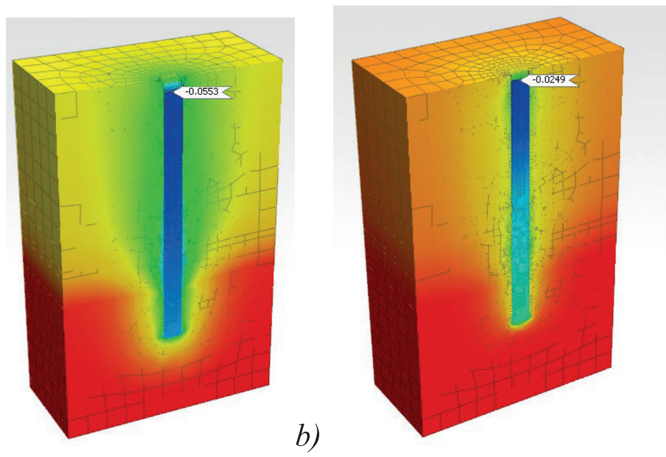


Figure 3. Deformed state and vertical displacements of the FE model in PLAXIS 3D: a) Mohr-Coulomb; b) Hardening Soil



a) b)

Figure 5. Deformed state and vertical displacements of the FE model in MIDAS GTS NX: a) Mohr-Coulomb; b) Hardening Soil

Table 2. Bearing capacity of pile-barrets by various methods

	Methodology for calculating the bearing capacity of piles on the ground	Bearing capacity of the pile on the ground, kN
	Field test results, $F_{d,site}$	27500
	Analytical classical method [1], $F_{d,calc1}$	27285 (-1%)
Considering unloading	PLAXIS 3D software for Hardening Soil, $F_{d1,HS}$	23700 (-13,8%)
	MIDAS GTS NX software for Hardening Soil, $F_{d2,HS}$	23600 (-14%)
Taking into account unloading	PLAXIS 3D software for Mohr-Coulomb, $F_{d1,\ MC}$	14500 (-47%)
	MIDAS GTS NX software for Mohr-Coulomb, $F_{d2,MC}$	16440 (-40%)

The combined load-settlement graph for the various considered methods for determining the bearing capacity of the barrette is shown in Figure 5.
Thus, the results of field tests of the bearing capacity of barrette piles with a section of 800×2800 mm and a length of 37 m in comparison with the results of numerical and analytical calculations using various programs showed the following:
• for 13.8 - 14.0%, the results of field tests turned out to be higher than the bearing capacity of the piles than in the numerical modeling in PLAXIS 3D and MIDAS GTS NX programs using the HS model;
• for 40.0 - 47.0%, the results of field tests turned out to be higher than the bearing capacity of piles in numerical modeling in PLAXIS 3D and MIDAS GTS NX programs using the MC model;
• 1.0% higher than the bearing capacity of piles, calculated from the results of analytical methods using tabular soil resistance [1].
It is clearly seen from the given example that the results of mathematical modeling of testing a barrette in a deep pit differ significantly from the graphs of barrett displacement under static load when using different soil models (MC and HS). This discrepancy can be explained by the fact that after the development of the bottom of the pit, part of the subgrade is unloaded and the subsequent loading is performed along the secondary branch "unloading-reloading", which is not taken into account in the MC model.

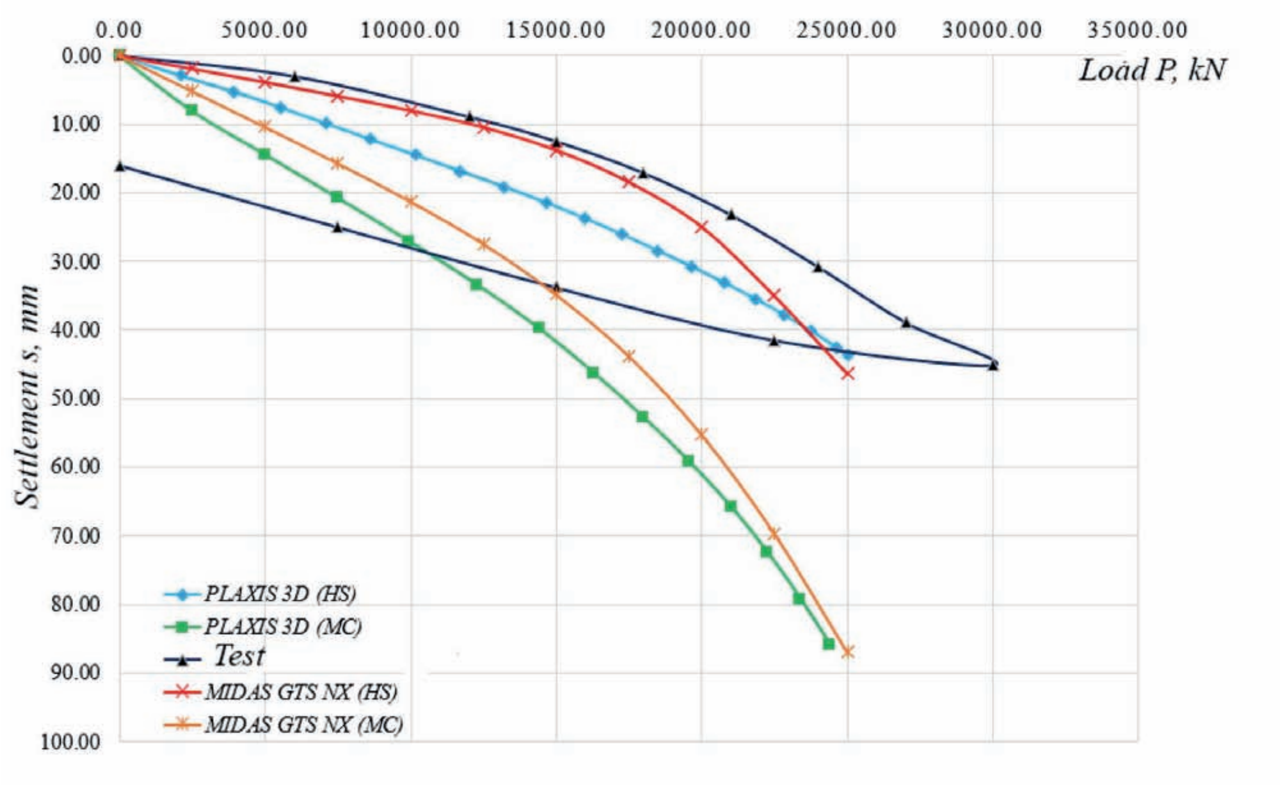


Figure 6. Combined diagram Load vs. Settlement

CALIBRATION OF GEOMECHANICAL MODEL PARAMETERS

Comparison of the calculation results using the Hardening Soil model showed good convergence in bearing capacity with field data (Table 2). At the same time, the model developed in the Midas GTS NX software package most accurately describes the behavior of the barrett under load (Fig. 5). However, the graphs begin to diverge in the range of loads of 15000-25000 kN, in which the piles are supposed to work as part of the foundation of a high-rise building. Therefore, in order to obtain reliable results in further geotechnical calculations, it is necessary to adjust the parameters of the mathematical model.

The characteristics of the soil and the characteristics of the contact elements along the barrett-soil boundary make a significant contribution to the nature of the load-settlement curve.

Russian standards [2] do not allow adjusting the strength parameters of soils for calculations based on the first limiting state. The deformation parameters of the model depend on the strength [15]; therefore, the model was calibrated by adjusting the interface elements.

Judging by the graph of the numerical test (Fig. 6), weak soil layers subjected to plastic flow during shear along the "pile-soil" boundary after reaching the load value of 15,000 kN. Part of the efforts are transferred to stronger and tougher soils, in particular, gravel-pebble soil, within which the calibration of the parameters of work on the lateral surface was carried out.

In the software package Midas GTS NX, the deformation and strength characteristics of the "interface" elements were assigned taking into account the coefficient of strength and stiffness reduction at the material boundary R = 0.6 for all types of soils, adopted in accordance with the Russian code of rules for pile foundations [1]. However, there is no value of

the coefficient of work on the lateral surface of the piles for coarse-grained soils and it is proposed to determine it empirically in the document [1].
The work on the side surface of the barrette in coarse soil is better than in sand, given its structure. After adjusting the parameters of the interface elements, taking into account $R = 0.8$ within the gravel-pebble soil (Fig. 6). It was possible to almost accurately describe the behavior of the barrette under load (Fig. 7).

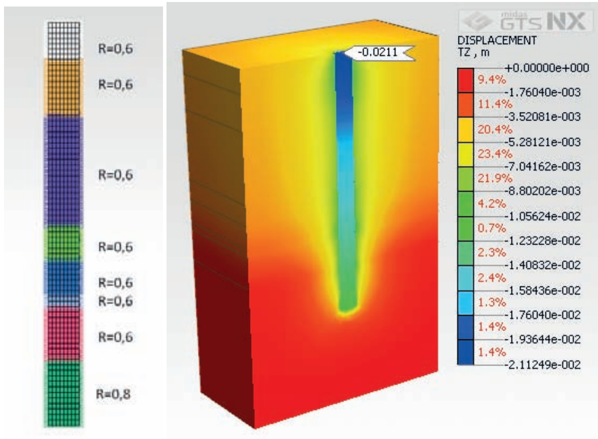


Figure 6. Assigned R-factors after calibration and calculation results

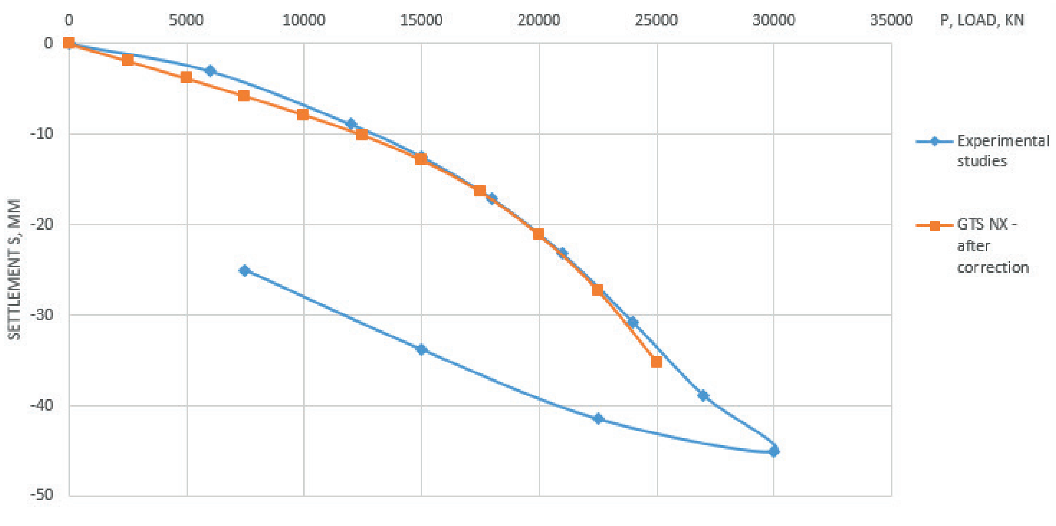


Figure 7. Load vs.settlement plots based on the results of the corrected model calculation and the results of field tests

CONCLUSIONS

As a result of the studies, it was found that modeling the bearing capacity of a pile-barrets with a section of 800x2800 mm and a length of 37 meters along the soil, performed in a software package using the HS model for soil conditions in Hanoi, Vietnam, showed values close to the results of static field tests.
The presented method of numerical calculations using the HS soil model in the PLAXIS 3D and MIDAS GTS NX programs describes the results of static field tests for construction sites with a large thickness of soft soils with sufficient accuracy for practical purposes.
To perform the final numerical calculations of the pile foundations of high-rise buildings, it is necessary to calibrate the numerical model based on the results of field tests. It is recommended to adjust the parameters of the interface elements for the "barrette-ground" contact. The value of the coefficient of reduction of strength and stiffness of contact elements for barrett in coarse soils is recommended to be used higher than in sands.

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