Research of the bearing capacity of a augered pile with expansion along the pile body

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Abstract. Augered piles are used to reinforce the soil and connect to the foundation to ensure the sustainability of the project. This is an advanced method that can support large structures on soft ground. Augered piles are one of the most widely used structural solutions for foundations used by designers for high-rise buildings, in projects with heavy loads, bridge construction and for buildings located on soft soils. Due to their ability to withstand heavy loads without affecting neighboring buildings when constructing foundations, bored pile foundations are increasingly being used in civil, industrial, and bridge and road projects in Vietnam. Geotechnical conditions in Vietnam are mainly represented by soft soils, so many engineers are working to optimize the section of the augered pile to increase their bearing capacity. However, studies of augered piles capable of expanding the body of the pile to increase the bearing capacity along the side surface and reduce the volume of concrete have not been carried out. Investigation of the type of augered pile with the above characteristics is one of the most important tasks. The load on a augered pile, with widening along the body of the pile, increased from 15.4% to 20.8% compared to a conventional augered pile with the same total volume, and the same precipitation. The load on a augered pile with widening along the body of the pile increases from 15.4% to 20.8% compared to a conventional augered pile with the same volume of concrete. For augered piles with expansion along the body of a pile with the same outer diameter (D1200mm), as compared to conventional augered piles, the load decreased by 241 (tons), equal to 7.94%, but the volume of concrete decreased by 19.8 m3, which is equivalent to 37, 4%.

1. Introduction
Augered piles are one of the foundations solutions widely used in high construction all over the world and in Vietnam. They are usually designed for heavy loads, so the quality of the pile is always of greatest concern.

In Vietnam, augered piles have been widely used in construction for more than ten years. At present, it is estimated that about 50 ÷ 70 thousand meters with a diameter of 0.8 ÷ 2.5 m are produced annually in Vietnam at a cost of about 1300 ÷ 1400 billion VND.
Many scientific studies have been carried out to determine the bearing capacity of augered pile [1] [2] [3] [4] [5] [6] [7] (Fig. 1a), augered piles with a widened heel [8] [9] [10] (Fig. 1b). However, there has been no scientific work or research examining the performance of enlarged cross-section piles along the body and base of the pile (Fig. 1c). In this article, the authors focus on the study of the bearing capacity of this type of augered pile to assess the bearing capacity as well as the concrete savings of the augered pile.

1.1 Description of the structure of the widened pile

The structure of the widened pile consists of two parts, combined into a single bored pile, the production of the pile takes place in several stages. Basically, widened augered piles are manufactured and constructed as traditional augered piles. However, there is a difference in that widening augered piles have the effect of expanding the body of the pile, expanding the pile bearing area, thereby increasing the bearing capacity of the pile as compared to a augered pile with the same volume of concrete.

After the well cleaning process, we need to add:

- Part 1: Reinforced concrete modules, which creates a new boundary for the augered piles.
- Part 2: Reinforced concrete augered piles.

The model is shown in Figure 2:
The task of the pile sheathing module is to create the edge of the pile so that the base of the pile is larger than the area of the hole and also strengthens the soil where it should expand. Details of the pile shell module:
The work proceeds in 4 stages. Augered piles are installed in the ground using special bored machines. Augered machines can usually drill up to 50 meters (this is stage 1), then install the base expansion device and continue expanding the edge (this is stage 2), then when changing the nozzle drive in the pile (this is stage 3). Another advantage in using this type of piles: during their installation, there is practically no vibration and noise, which has a good effect on the stability of the soil. The drilling method directly depends on the condition of the soil layers. If the place where the building is
being erected has unstable soil under it, such as sand, silt, groundwater, gravel, etc., then the augered piles must be reinforced with a steel frame or other structures. After the pile is made in place, cement is poured over its body (this is stage 4), which further strengthens the entire foundation.

![Diagram of concrete construction equipment from augered piles with widening](image)

**Figure 5.** Model of concrete construction equipment from augered piles with widening

After the equipment is installed, the pile shell module is reinforced and installed. They are all removed into the hole by a crane, then the hydraulic system (7) will work to supply hydraulic oil to the hydraulic equipment (6) to push the reinforced concrete shells (4) from the outside. At the same time, concrete is poured from concrete pumps through pipes (3) to lower the pile through the gate (5). Where the piles are pulled, they will be filled with concrete until the jacking device is enlarged to its design size and the concrete is also filled. Then assemble the hydraulic device into the steel pipe (2) and use the moving device 1 to pull the hydraulic device onto the next module for further expansion and pouring of concrete. Just like that until the end of 1 pile construction.

**2. Materials and methods**

**2.1. Materials**

When solving this problem, the data of pre-design tests of 3 augered piles with a static indentation load were used.

It should be noted that the parameters of the subgrade necessary for the use of elastic and elastoplastic models are determined by the corresponding tests provided for by the Vietnamese regulatory documents.

In accordance with the above, a simulation was carried out of the interaction of a single pile with the surrounding soil, which has the characteristics shown in Table 1 according to the data of a geological survey of construction conditions in Vietnam.

The calculated area of the soil massif for a pile with a length of $L = 46.8$ m, a diameter of $d = 1.2$ m, the thickness of the compressed one is $60$ m and had dimensions of $40 \times 40$ m.
Table 1. Soil model parameters (Mor-Coulomb model)

| No. | Layer description of soil | N  | $\gamma_{sat}$ (kN/m$^3$) | $\gamma_{unsat}$ (kN/m$^3$) | $C$ (kPa) | $\varphi$ (°) | $E$ (kPa) | V  | Z  |
|-----|---------------------------|----|--------------------------|-----------------------------|--------|-----------|----------|----|----|
| 1   | Strong clay               | 6  | 18,6                     | 18,6                        | 20,5   | 14°36'    | 3900     | 0,45| 2,3 |
| 2   | Alluvial soil             | 16 | 19,0                     | 19,0                        | 50,0   | 17°50'    | 6000     | 0,45| 9,2 |
| 3   | Strong clay               | 22 | 18,1                     | 18,1                        | 32,5   | 14°25'    | 15800    | 0,45| 5,5 |
| 4   | Fractionated sand with silt | 30 | 19,0                     | 15,0                        | 1      | 33°00'    | 11250    | 0,35| 14,5|
| 5   | Fractionated sand with gravel | 45 | 20,0                     | 16,0                        | 1      | 42°00'    | 61200    | 0,35| 7,3 |
| 6   | Assorted gravel with sand | 68 | 20,0                     | 16,0                        | 1      | 45000'    | 88800    | 0,35| 21,2|

(*) $\gamma_{sat}$ - Unit weight soil above phreatic line; $\gamma_{unsat}$ - Unit weight soil below phreatic line.

2.2 Methods

In fact, piles often go through many layers of soil with different physical properties. This article presents the calculation of the bearing capacity of a pile by the finite element method (FEM). Using Plaxis 3D-Foundation software, the calculations of the above 3 cases with the following data:

Table 2. Pile (Model of elasticity)

| No. | Pile                              | Length (m) | $\gamma$ (kN.m$^3$) | Diameter (m) | Max Load | E (kPa) | V  | Displacement piles (m$^3$) |
|-----|-----------------------------------|------------|---------------------|--------------|----------|---------|----|---------------------------|
| 1   | Roundpile (Option 1)              | 46,8       | 24                  | 1,2          | $\gamma_{Plaxis}$ | 3E7     | 0,2 | 52,9                      |
| 2   | Extensions along the pile body (Option 2) | 46,8     | 24                  | 1,2          | $\gamma_{Plaxis}$ | 3E7     | 0,2 | 33,1                      |
| 3   | Extensions along the pile body (Option 3) | 46,8    | 24                  | 1,51         | $\gamma_{Plaxis}$ | 3E7     | 0,2 | 52,9                      |

3. Results of research

3.1. Results

Shown in the figure fig. 6, fig. 7, fig. 8 load-settlement plots obtained as a result of calculations using the program.

PLAXIS 3D-Foundation, using an elastic and elastoplastic model of the subgrade, in a given range of changes in the vertical load, gives a similar result. This indicates the possibility of its application for solving practical and research problems related to the issues of interaction of piles with a subgrade.

Table 3. Table for calculating the maximum carrying capacity of the pile according to Plaxis 3D- Foundation

| No. | Option | Volume (m$^3$) | Max load (tons) | Draft (mm) |
|-----|--------|---------------|----------------|------------|
| 1   | Option 1 | 52.9         | 3.037          | -100       |
| 2   | Option 2 | 33.1         | 2.636          | -100       |
| 3   | Option 3 | 52.9         | 3.420          | -100       |
3.2. Analyzed results
As a result of the analysis carried out by the Plaxis software, one can come to the conclusion: when using pile models (option 3), the section of which expands along the pile body, a decrease in
conventional piles (option 1) with the same total volume of concrete. However, in the case of maintaining the diameter (option 2), the load capacity as well as the load resistance deteriorate.

### Table 3. The dependence of the settlement on the alternative load 1,2,3

| No. | Draft (mm) | Loads (Tons) | Option 1 (D1200 volume: 52.9 m³) | Option 2 (D1200 volume: 33.1 m³) | Option 3 (D1510 volume: 52.9 m³) | Load (%) |
|-----|------------|--------------|----------------------------------|----------------------------------|----------------------------------|----------|
| 1   | 0          | 0            | 0                                | 0                                | 0                                | 0        |
| 2   | 20         | 925          | 822                              | 1.090                            | 17.9                             |
| 3   | 40         | 1.765        | 1.625                            | 2.131                            | 20.8                             |
| 4   | 60         | 2.345        | 2.231                            | 2.768                            | 18.0                             |
| 5   | 80         | 2.763        | 2.608                            | 3.238                            | 17.2                             |
| 6   | 100        | 3.037        | 2.795                            | 3.503                            | 15.4                             |

**Figure 9.** Curves of the dependence of the pile settlement on the load option 1,2,3
4. Conclusion
The application of the above results in practice will reduce construction time, save raw materials for the construction of piles and reduce the cost of the project, and increase the efficiency of capital use. The above research will serve as a pre-requisite for the author's study of the bearing capacity of a group of augered piles with expansion along the body of the pile and the simultaneous development of a model of the construction of extended augered piles with expansion along the body of the pile.

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