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Research Paper

# A design method for plastic tube cast-in-place concrete pile considering cavity contraction and its validation

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ABSTRACT

Bearing capacity calculation method and field static load test (SLT) program were carried out simultaneously to study the bearing characteristics of individual *Plastic Tube Cast-in-Place Concrete Pile* (TC pile), which are increasingly being employed for support of embankments in southeast China. The bearing capacity calculation method considering pile setup (i.e., setup calculation method) was built up according to the cylindrical cavity contraction and horizontal consolidation theories. A series of SLTs on different dates were applied to study the bearing behavior of TC pile and to verify the validity of the established setup calculation method. During TC piles installation, there is about 45% contraction in cylindrical volume due to the extraction of steel casing. Both theoretical and experimental results show that the calculated outcomes considering cylindrical cavity contraction agree well with measured ones. The difference value between them is not more than 12%. On the other hand, if the cylindrical cavity contraction is ignored, the calculated bearing capacities of TC piles are overestimated by 160–300%. The setup of TC pile is mainly due to the increment of pile shaft resistance with time elapsed. Cylindrical cavity contraction accompanied by TC pile installation causes much loss of pile shaft resistance.



## 1. Introduction

Pile-supported reinforcement system has been widely employed to treat the soft ground because of its good reinforcement effect, low cost, and short construction period, etc. At present, the piles generally used for this system include the prefabricated tube pile, driven cast-in-place pile, and deep cement mixing pile, etc. [17,8]. Recent years, a new type of pile with plastic tubes fixed on the outside of pile, as shown in Fig. 1, has been developed. This type of pile with a diameter of 120–200 mm and a length of 6–20 m, called the AuGeo pile, was exploited by the Cofra company in Netherlands, and applied in the railway and expressway projects [12]. In China, the authors improved the AuGeo pile into a single-wall corrugated plastic tube cast-in-place concrete pile, referred to as TC pile [9,7,10].

Fig. 2 presents the 7 construction steps for TC pile: (a) Assembling the PVC tubes, pile tips, and tube joints into the TC casing. (b) Inserting the TC casing into the steel casing. (c) Driving the TC casing using an excavator. (d) Injecting water into TC casing to counter the earth pressure and prevent its collapse. (e) Extracting the steel casing but leaving the TC casing in the soil after the water injection is over. (f) Repeating the steps (a)–(e) until lots of TC casings have been installed, and then drawing the water out of individual TC casings. (g) Inserting the steel reinforcement cage in the top 3–5 m portion and pouring concrete into the TC casing.

At present, there is little in the literature about the TC or AuGeo piles. Cortlever [12] introduced the AuGeo piling system and its application. Chen et al. [9] studied the effect of plastic tube on the compressive strength of TC pile concrete, and proposed a simplified settlement calculation method for TC pile. Chen et al. [7,10] investigated the TC pile-supported embankment system via a field test. However, the above papers do not involve the bearing capacity calculation of TC pile. In terms of pile formation process, the TC pile is obviously different from the driven cast-in-place pile or pre-cast pile, as shown in Fig. 3. During the TC pile installation, the cylindrical cavity expansion happens first under the installing of steel casing, and next cylindrical cavity contraction comes after the extraction of steel casing, as shown in Fig. 3(a). However, there is no cylindrical cavity contraction in the constructions of driven cast-in-place or pre-cast piles, as shown in Fig. 3(b) and (c). Thus, it may be inappropriate when the bearing capacity theory for piles in Fig. 3(b) and (c) is employed to calculate the bearing capacity of TC pile in Fig. 3(a). For TC pile, the cylindrical cavity contraction

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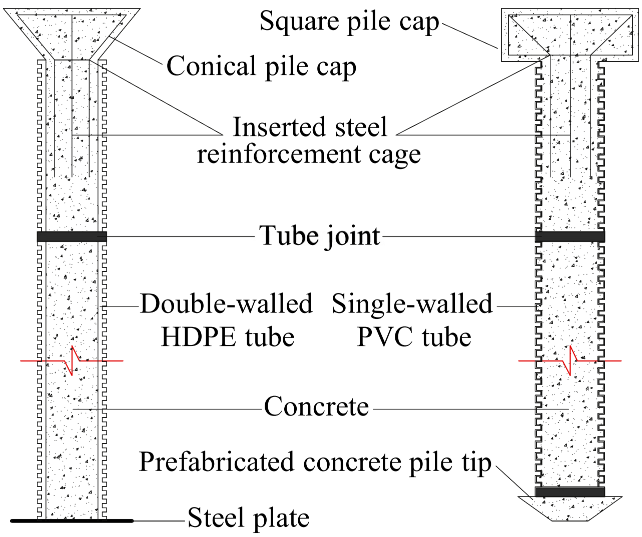


**Fig. 1.** Composition between AuGeo pile in left and TC pile in right.

should be considered to estimate the bearing capacity. In current cavity contraction theories [20,32,5,18,33], the key difference among them is the selection of soil constitutive model. Compared with the Mohr–Coulomb and Modified Cambridge models, the Tresca model contains fewer parameters, which can facilitate the application of cavity contraction theory. Therefore, the cavity contraction theory developed by Houlsby and Withers [20] was employed to estimate the bearing capacity of TC pile in this paper. In addition, due to the excess pore pressure dissipation caused by pile installation, the bearing capacity of single pile results in increasing with time elapsed, often called as "setup" [30,2,24,25,7,10,19]. That should be taken into account in the bearing capacity calculation of individual TC pile.

In this paper, based on the feature of TC pile formation, the bearing capacity calculation method considering pile setup (i.e., setup calculation method) for TC pile was established by employing the cylindrical cavity expansion theory followed by cylindrical cavity contraction and horizontal consolidation theories. The field SLTs on different dates for TC piles were conducted to verify the effectiveness of the setup theory.

## 2. Setup calculation method for individual pile

### 2.1. Setup calculation method for single TC pile (considering cylindrical cavity contraction)

The anisotropy and coupling effect of subsoil are not considered. The formation process of TC pile considering cylindrical cavity contraction can be explained as: A cavity in semi-infinite body is expanded from radius zero to radius $r_b$ of steel casing, and then contracted to radius $r_s$ of TC pile shaft, as shown in Fig. 4. Correspondingly, the internal cavity pressure increases from initial pressure $\sigma_0$ to $\sigma_{rb}$, and then decreases to $\sigma_{rs}$. For cylindrical cavity expansion, a plastic zone of expansion $r_{pb}$ is formed as the internal cavity pressure $\sigma_{rb}$ is large enough, and the initial excess pore pressure $\Delta u_1(r)$ is simultaneously caused in the plastic zone, as shown in Fig. 4(a). For cylindrical cavity contraction, a plastic zone of contraction $r_{ps}$ emerges as the internal cavity pressure $\sigma_{rs}$ is small enough, and the initial excess pore pressure $\Delta u_1(r)$ will change into $\Delta u_2(r)$, as exhibited in Fig. 4(b). Beyond the plastic zone, the soil remains the elastic characteristics and the initial pore pressure $u_i$ is unchanged.

#### 2.1.1. Excess pore pressure caused by cylindrical cavity expansion

Correspondingly, the initial excess pore pressure $\Delta u_1(r)$ is

$$\Delta u_1(r) = \begin{cases} Y \cdot \ln(r_{pb}/r); & r_b \leqslant r \leqslant r_{pb} \\ 0; & r > r_{pb} \end{cases} \tag{1}$$

where $Y = 2s_u$; $s_u$ is the undrained shear strength.

#### 2.1.2. Plastic zone caused by cylindrical cavity contraction

As the radius $r_b$ reduces to $r_s$, the plastic zone of contraction $r_{ps}$ is formed and expressed as,

$$r_{ps} = 0.7 \times \sqrt{I \cdot (r_b^2 - r_s^2)} \tag{2}$$

where $I = 2G/Y = G/s_u$; $G$ is the shear modulus of soil.

The radial stress $\sigma_r$ and hoop stress $\sigma_\theta$ in the plastic zone of contraction ($r_s \leqslant r \leqslant r_{ps}$) are calculated by the following equations.

$$\sigma_r = \sigma_{hi} - \frac{1}{2}Y + Y \cdot \ln\frac{r_{pb} \cdot r}{r_{ps}^2} \tag{3}$$

$$\sigma_\theta = \sigma_{hi} + \frac{1}{2}Y + Y \cdot \ln\frac{r_{pb} \cdot r}{r_{ps}^2} \tag{4}$$

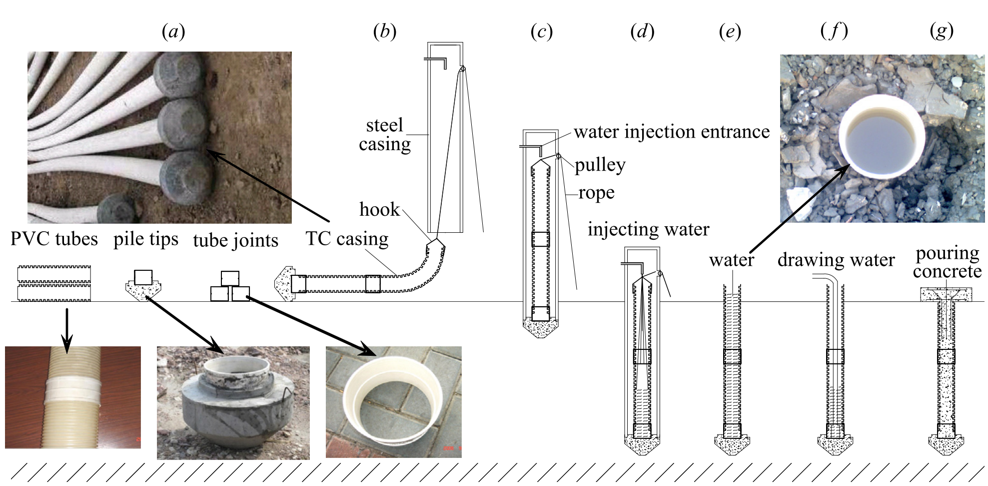


**Fig. 2.** Construction procedure of TC piles.