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Uplift tests of jet mixing anchor pile

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Abstract

The jet mixing anchor pile is a new kind of supporting technology for foundation pit engineering in soft clay. The engineering features of jet mixing anchor pile as well as the difference between it and normal anchor bolt are introduced. The uplift tests of 4 jet mixing anchor piles are presented in detail to obtain the ultimate bearing capacity and load–deformation relationship of the piles. Load-transfer analysis, which is rarely applied in the analysis of uplift piles, is carried out on the piles with a hyperbolic calculation model. The load transfer method focuses on the interface between pile and soil, with which the non-linear behavior, the bearing capacity and the engineering features of the anchor piles can be fully studied. The calculated load–displacement curves of the piles have close agreement with that of the pullout tests, indicating that the proposed analytical solution is reasonable and feasible in predicting the bearing capacity of the piles. Thus, with this study, the supporting stiffness of the anchor pile can be predicted in the design stage of the foundation pit engineering, which is very important and meaningful in practical engineering. The decay curve of shear stress of soil surrounding the pile is derived with the load-transfer method, through which the minimum transverse space of each two piles can be decided against the pile group effect. Engineers can optimize the length and spacing of group piles through this.

Keywords: Jet mixing anchor pile; Uplift test; Load-transfer analysis; Pile group effect

1. Introduction

The jet mixing anchor pile is a new kind of supporting technology for foundation pits and slopes. Besides having some similar characteristics to soil anchors (Miyata et al., 2009), it has some extra engineering features and advantages. The jet mixing anchor pile is good in deformation control and capable of maintaining the stability of the whole supporting structure. It can be applied to excavations in much the same manner as a multi-anchor wall (Richard et al., 2011) and can meet the strict demand for deformation. Compared with traditional supporting technology, it is much lower in cost and more environment-friendly. Jet mixing anchor piles and struts are both used in a long strip excavation in the city of Wuhan, China. It is reported that for each section of 26 m in length along the exaction, 7 days was requires for excavation when using anchor piles, 2 days less than that required for struts. On the other hand, though concrete struts need to be removed by explosive demolition, the strands in the anchor piles can be recoverable for recycling use, which reduces the cost by about

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20%. It has been applied to more than 120 excavation projects and brought about significant economic and social benefit (Liu, 2011), which are proof of the feasibility and maturity of this technology. The deepest foundation pit supported by jet mixing anchor pile is 27 m in depth.

A series of pullout tests on jet mixing anchor pile were conducted in Jingjiang, in the Jiangsu province of China. The soil layer properties, process and results of the tests are presented in this paper. The load-transfer method is that commonly used for calculations of compression piles (Hirayama, 1990; Cem et al., 2012) but has not yet been widely accepted in uplift piles. Even in the methods currently used (Reddy et al., 1998; Shubhra et al., 2007)), the application of the load transfer method is not simplified enough. The proposed method in this manuscript is simple with fewer parameters but a clear derivation, and the results are satisfactory. The hyperbolic load–displacement model, which is widely used in the analysis of compression piles and soil anchors, is applied to derive the implicit relationship between the tension load and the deformation of the test piles. The decay mode of the shear stress of the soil surrounding the pile is obtained based on the load-transfer analysis, through which the minimum transverse space of each two piles can be decided against the pile group effect.

2. Definition and engineering features of jet mixing anchor pile

Pile foundation engineering is widely studied all over the world (Pastaskorn et al., 2011; Kiyoshi et al., 2011). Compared with normal anchors, Jet mixing anchor piles are more like piles. They are made of steel strands and cemented soil by swing-injected agitation and are used to reinforce and support foundation soils and slopes. The difference between typical jet mixing anchor piles and normal anchors is shown in Fig. 1.

Because the diameter of the jet mixing anchor pile (400–1000 mm) is much larger than that of normal anchors (less than 100 mm), the contact area and the frictional resistance between the pile and soil is also larger. The cemented soil is infused into the hole by high pressure jet grouting whereas normal anchors are made by low-pressure grouting. Together with the fix function of the anchor plates at the bottom part of the steel strand, the bond between the cement grout and steel strand is very strong. These engineering features make it possible for anchor piles to be used in soft soil, especially in silt clay, where normal anchors are not recommended by engineering specifications.

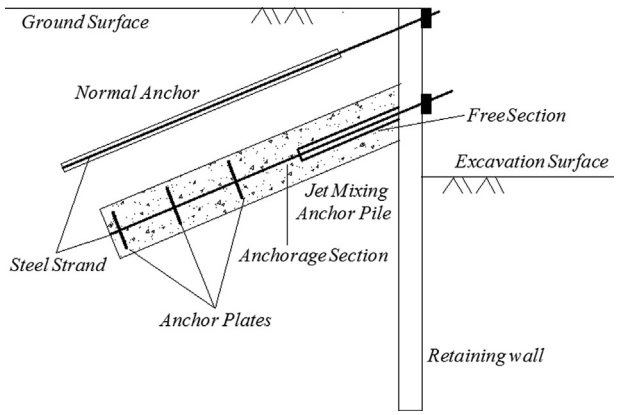

Fig. 1. Difference between jet mixing anchor pile and normal anchor.

Typical jet mixing anchor piles can be divided into two sections: the free section and anchorage section. As shown in Fig. 1, the steel strand of the free section is not bonded with the cement grout so that it can be pre-stressed in posterior construction.

3. Uplift tests

The Kaixuan project is located in the city of Jingjiang, Jiangsu province of China. Uplift tests were carried out on 4 jet mixing anchor piles in order to investigate the ultimate bearing capacity and load–deformation relationship of the piles of the project. All the 4 test piles are divided into two groups by length, see Table 1. The steel strand is composed of 3ϕ 15.2 mm steel bars. The schematic diagram and photo of the test equipment are shown in Figs. 2 and 3.

The failure criterion and termination condition of the test are as follows:

(1) The anchor pile is pulled out from the foundation soil.
(2) The displacement of the head of the anchor pile under one load level is two times than that under the nearest former level.
(3) The anchor pile is broken under the tension load.

The pile test is ended if any of the former 3 condition happens. It was found that the limitations of the tension load of the tests was about 500 kN with a series of load and unload process.

All of the uplift tests were carried out in the second layer of the foundation soil, see Fig. 4. The soil is a mucky silt clay. The parameters of the soil profile are shown in Table 2.

The load–unload curves of the 4 test piles are shown in Fig. 8(a)–(d), where (a) and (b) are from group 1. Several conclusions can be made from the figures. The final displacements of the 2 test piles from each group were in good agreement, which indicates the tests are reliable. Since there is no obvious yielding in the curves before the axial load reaches 400 kN, it can be deduced that the ultimate bearing capacity of the piles is satisfactory. Jet mixing anchor piles can be applied

Table 1
Parameters of the test piles.

Group number	Whole length (m)	Free section length (m)	Anchorage section length (m)	Diameter (mm)
1	18	6	12	600
2	24	11	13	600