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Study on Field Tests of Capsule-type Underreamed Anchor

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Capsule-type underreamed anchor is a new type of anchor that can change the spatial morphology and geometrical size of the underreamed anchor by adjusting the size of the prefabricated bag and therefore meeting the engineering requirement on bearing capacity. A destructive pull-out experiment based on the engineering demands was carried out for this type of underreamed anchor, which was then compared with the conventional anchor. The results showed that the underreamed anchor overcame the problems of low compressive strength and small size of grouting body in the anchoring segment by the function of high-pressure grouting and reaming through bag expansion. This feature is important for the construction works in soft soil which is usually difficult to achieve with the conventional anchor. The uplift bearing capacity of the underreamed anchor was increased significantly by adjusting the size of the prefabricated bag. The data from field test provided an important framework for the study of the load-carrying mechanism and damage mode of capsule-type underreamed anchor and also for the popularization of the anchor in engineering.

1. Introduction

As the rapid urbanization accelerated over the past decades in China, the shortage of construction land has currently become a major problem. Underground space development and exploitation has now oriented towards greater depth and the safety of such underground space development has become a major concern (Chekire et al (1997)) A large number of underground transport hubs, multi-layer malls, underground car parks, granaries and civil air defense facilities for reservoirs are emerging in large and medium-sized cities. All these underground infrastructures bring new challenges for rock-soil anchorage in large-scale foundation pit and anti-floating with abundant amount of groundwater. High-pressure jet grouting combined with capsule-type underreamed anchor is invented to meet the massive demand of underground space constructions (Kuihua et al (2013)).

To improve the bearing capacity of the bolt in soil and to adapt the varying engineering requirements in complex strata, underreamed anchor technique is not widely used. Three commonly used methods to maintain the geometry of the anchoring segment of conventional bolts are reaming with cutter, blasting reaming and hydraulic reaming (Liao and HSU (2003)). The representative bolts made according to these mechanisms are as follows: reamer bolt for mechanical reaming developed by Fondedile Foundations Ltd. (UK) (Madhav et al (2008)), underreamed anchor with scalable steel sheet manufactured by a Swedish company (Narasimha et al (2006)), underreamed anchor for blasting reaming process manufactured by a Czech company (Park et al (2013)), and high-pressure jet reamer anchor now popular in the UK (Ren et al (2010)).

Efforts have been made to develop the underreamed anchor technique in terms of bearing capacity by numerous companies worldwide. However, some technical bottlenecks remain unsolved. For example, cutter-based expansion performs well in compact cohesive soil, but has difficulty to drill in the sandy soil with high groundwater table (Soong et al (2011)). Blasting expansion carries a great risk, disturbing the space morphology and geometrical size of the soil deposits which usually results in a poor construction (Wang et al (2006)). High-pressure jet reaming is associated with the difficulty of removing the soil after reaming. However, the remaining soil can cause the decrease of the length and diameter of the anchoring segment, hence affecting the bearing capacity of the underreamed anchor.

Underreamed anchor with grouting in the bag at one end can solve the defects of the above-mentioned reaming techniques. This type of anchor consists of an anchoring segment which is composed of a bag with

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predetermined diameter into which grout of high compressive strength is injected. The bolt manufactured with this structure can be used for a wider range of soil types and achieves a higher construction quality; it not only maintains the geometry of the anchoring segment but also improves the bearing capacity. Destructive pull-out tests were carried out and the load-carrying and deformation characteristics of the underreamed anchor were discussed in this paper. The testing data are valuable for the application of the anchor in engineering (Zhang et al (2006)).

2. Characteristics of construction process

As mentioned above, capsule-type underreamed anchor can improve the bearing capacity of soil by adjusting the size of the bag at one end and therefore changing the geometry of the anchoring segment and the size of the expanding body. The core structure is the grouting body with high compressive strength enclosed in the bag at one end of the anchor. The grouting body is made of cement slurry with strength not less than 40 MPa, which is injected to the bag through the grouting hole at high pressure during the construction process. The anchor itself is surrounded by cement soil formed by high-pressure jet over a larger diameter. By combining high-pressure jet reaming with expansion of bag injected with grouting body, the defects of conventional underreamed anchor are overcome (Xiao and Chen (2008)).

3. Field test

A comparative field test was performed using 3 capsule-type underreamed anchors and 2 conventional anchors.

3.1 An overview of the project

The capsule-type underreamed anchors being tested were located in the foundation pit of World Profit Center in Sanlitun Embassy District of Liangmahe, Chaoyang District, Beijing. The floor space is 50371.46 m^2, and the total construction area is 98968.00m^2. There are 17 floors (from 3rd floor onward), with north building standing 77.05 m tall and the south building standing 64.90 m tall. The three buildings in the middle stand 17.40 m tall and have 4 floors of underground car parks. The foundation pit was excavated by open-excavation sequential-operation method. The depth of the foundation pit that was excavated openly is approximately 18.68 m, and the floor space is approximately 10 thousand square meters. The soil nail wall was used in the upper part of the foundation pit support structure, and the pile-anchor system in the lower part. For water drop, the long-spiral high-pressure stir-jet grouting pile was used as the waterproof curtain.

3.2 Engineering geological and hydrogeological conditions

The surface elevation of the construction field is 36.53-37.81 m with flat terrain. Topographically, the construction field is located in the middle and lower part of Yongdinghe alluvial-proluvial fan. With reference to the geotechnical investigation report, the physical and mechanical indicators of each soil layer are displayed in Table 1. The groundwater level was very high in the construction field. According to water-level observation data, three types of groundwater are identified within the investigation depth, namely, perched groundwater, phreatic water and confined water. The anti-seismic intensity is 8 degree, and the construction field belongs to class 2. Thus, the soil within 20m below the surface is considered non-liquefiable.

Table 1: Soil mechanical parameters

soli	h (m)	r (kN/m)	c (kPa)	φ (°)	K (cm/s)
clayey silt	0.4～7.3m	20.2	24	25	$1×10^{-4}$
fine sand	0.4～1.6m	20.1	0	25	$3×10^{-3}$
clayey silt	1.2～3.2m	19.5	30	15	$2×10^{-5}$
clayey silt	1.4～3.9m	20.3	36	18	$1×10^{-5}$
fine sand	0.3～3.7m	20.2	0	25	$4×10^{-3}$
clayey silt	1.7～4.9m	20.1	36	20	$2×10^{-5}$
fine sand	1.5～3.5m	20.3	0	30	$6×10^{-3}$
clayey silt	2.1～7.2m	20.5	38	20	$2×10^{-5}$

3.3 Design of the underreamed anchor and parameter selection

The design parameters and design load of the underreamed anchor are shown in Table 2.

Table 2: Design parameters of anchors

Parameter	Incident angle (°)	Diameter of underreamed anchor (mm)	Length of underreamed anchor (m)	Diameter of the no-under-reamed anchor (mm)	Length of no-underreamed anchor (m)	Length of the free segment (m)
1.	90	600	4	150	6	5.5
2	90	600	4	150	6	5.5
3	90	600	4	150	6	5.5
4	90	—	—	150	8	5.5
5	90	—	—	150	6	5.5

4. Methods and Results

4.1 Instruments

The instruments used in the tests consist of a hydraulic jack, an automatic static load tester, a high-precision pressure sensor, a high-pressure oil pump, reaction force bracket, two number of dial gauges, and steel girder. Photos of equipment installation and loading are shown in Fig. 1.

(a)

(b)

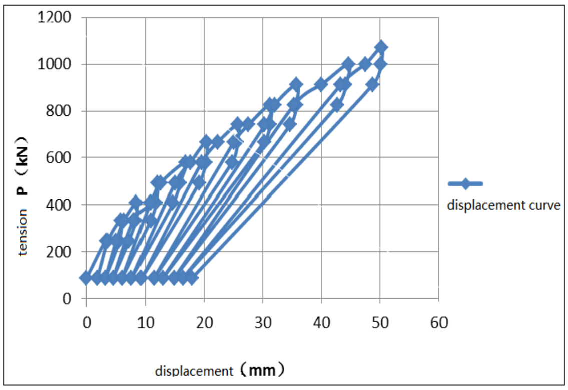
Figure 1: Equipment installation and loading

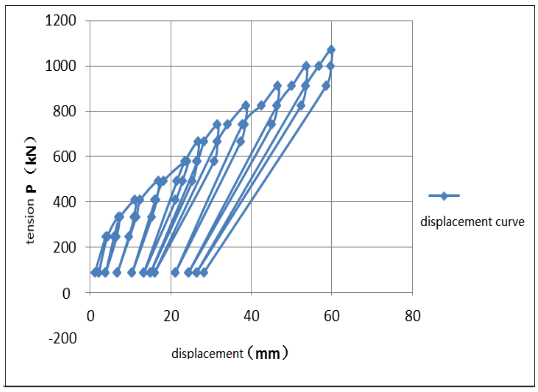
4.2 Experimental method

An uplift force was applied on the expansion bolt by stepped cycling using the hydraulic jack; stepped loading was controlled with the pressure sensor and the displacement at the head of the bolt was recorded using the dial gauge. Stepped cyclic loading was performed according to Technical Specification for Underreamed Anchor by Jet Grouting. The load levels, time interval for observing the displacement and failure criteria of bolts are all confirmed according to the specifications (Zhang et al (2006)).

In the tests, the high-pressure grouting pressure, grouting slurry and other influencing factors were controlled to be consistent. All the tests eventually terminated after reaching the failure status as determined by the following specified failure criteria (Zhu et al (2011)): ① The displacement of the anchor head caused by the load of the former grade is 1/2 of that caused by the load of the latter grade; ② the displacement of the anchor head continued to grow; ③ the body of the anchor rod failed.

4.3 Experimental findings

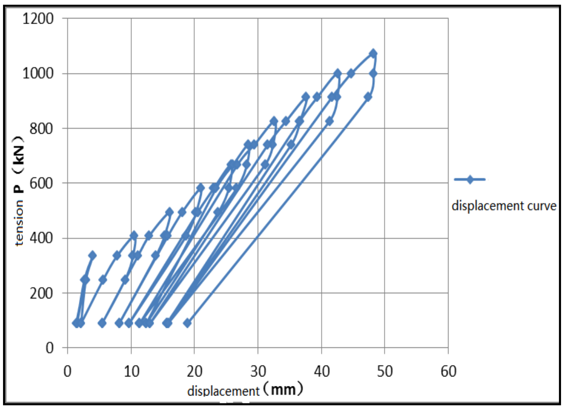


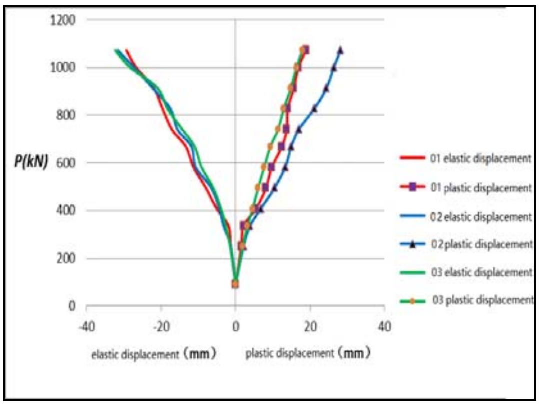


The load-displacement curves of all three anchors are shown in Fig. 2

(a) Anchor 1#

(b) Anchor 2#





(c) Anchor 3#

(d) Elastic-plastic displacement of anchors

Figure 2: Load-displacement curve of the underreamed anchor

5. Results

Anchors 1#-3# are capsule-type underreamed anchor, and anchors 4#-5# are conventional anchor. The loading process of the capsule-type underreamed anchor is described as follows:

When the load reached 1180 KN for the anchor 1#, a steel strand failed, so the experiment could not be continued. According to the specification, it was inferred that the ultimate pull-out strength of anchor 1# was not less than 1130 KN.

When the load reached 1100 KN for anchor 2#, the displacement of the head of the anchor increased rapidly, and the anchor was pulled out. Combining with the load-displacement curve and elastic-plastic displacement of anchor 2#, the ultimate pull-out strength of anchor 2# was 1072 KN.

When the load reached 1040 KN for anchor 3#, rapid increase in displacement was not observed. Moreover, there were no any obvious sign of damages. It was found that the ultimate pull-out strength of anchor 3# was not less than 1040 KN.

Therefore, the ultimate bearing capacity of anchor 1#, 2# and 3# was about 1130 KN, 1070 KN and 1040 KM, respectively; the maximum displacement was 52.86 mm, 51.79 mm and 47.43 mm, respectively. The average ultimate bearing capacity and maximum displacement, were taken for the expanding head, obtained from all the anchors was 1072 KN and 50.86 nmm, respectively.

Anchors 4# and 5# were conventional anchor, whose ultimate load was 740 KN and 780 KN and the maximum displacement was 83.45 mm and 95.57 mm, respectively.

6. Comparison with conventional anchors

Compared with conventional anchors, capsule-type underreamed anchor had a significant increase in ultimate pull-out strength. Moreover, the displacement at the head of the underreamed anchor was also smaller than that of the conventional anchor, further signifying the efficiency of underreamed anchor. According to the experimental data, the ultimate pull-out strength of three underreamed anchors was about 1000 KN larger than that of conventional anchor. The average ultimate pull-out strength of underreamed anchors was 1070 KN and that of the conventional anchor was 760 KN. In other words, the average ultimate pull-out strength of underreamed anchors is about 1.40 times the average ultimate pull-out strength of conventional anchors.
In addition to the aspects of ultimate pull-out strength and the direction of displacement of anchor end, the capsule-type underreamed anchor was also superior to conventional anchor in many other aspects. The capsule-type underreamed anchor has the significant characteristic, being corrosion resistant as it consists of an anticorrosive grease coating, PE seamless casing, bag & grouting body and metal cap. Therefore, the capsule-type underreamed anchor is greatly improved in corrosion resistance and durability and has a greater economic benefit compared with the conventional anchor (Zhu et al (2014)).

7. Conclusions

The present study provided an overview of the development and current status of underreamed anchor. The construction process and prominent features of the capsule-type underreamed anchor were described in detail as opposed to the defects of the conventional anchor. Finally, the ultimate pull-out strength and elastic-plastic displacement of the capsule-type underreamed anchor were studied by field test. The following conclusions can be drawn from this study.
(1) Capsule-type underreamed anchor overcame many defects of the traditional anchor during the construction process. Higher ultimate pull-out strength was also achieved with the less deformation.
(2) This new underreamed anchor consisted of a bag that expanded after grouting as well as a pressure-balancing device. Such design renders higher construction quality and better anticorrosion and durability performance compared with the conventional underreamed anchor.
(3) The combination of high-pressure jet reaming and reaming through bag expansion in anchor safely maintained the morphology and size of the anchoring segment. This improved the bearing capacity and reduced the displacement of the head of the anchor.

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