Bi-directional load testing of diaphragm wall

Jianmin Zhu[1], W. Gong[2], G. Dai[2], and K. Yin[3]

[1] Nanjing Dongda Bi-directional Pile Test Co., Ltd., 61#, Sipailou, Nanjing 210096, China.
[2] School of Civil Engineering, Southeast University, 2#, Sipailou, Nanjing 210018, China.
[3] Nanjing Saibao Hydraulic Equipment Co., Ltd., 13#, Xinggu Road, Nanjing 211164, China.

ABSTRACT

Diaphragm wall has been used as deep foundation to resist vertical load. Bi-directional load testing has been used to determine the bearing capacity. Typical testing projects, including a 3.4×3.4 m enclosed rectangular diaphragm wall, an L-shaped diaphragm wall panel with 3.0×1.0 m in two directions, and several rectangular diaphragm wall panels(barrette piles) were reviewed. At Nanjing Jinmao Square, the 6.0×1.2 m rectangular rock socketed diaphragm wall panel was tested. The loadcell, construction and test results were discussed. The bearing capacity was 314 MN.

Keywords: bi-directional load testing; bearing capacity; diaphragm wall; barrette pile

1 INTRODUCTION

Diaphragm wall is generally used as earth(and water) retaining wall in deep excavation. In recent years, it's also used as deep foundation to resist vertical load transferred from superstructure. Thus, it's bearing capacity shall be checked or tested as other type of foundations(Gong and Dai 2016).

Considering the size of the diaphragm wall, it is difficult to carry out the full-scale static load testing. Alternatively, one single panel could be selected and tested(Gong and Dai 2016). For this reason, the diaphragm wall panel is the same as a barrette pile.

Over the past few decades, barrette piles have been widely used in urban construction in Asia(Ng and Lei 2003). Conventional testing method includes kentledge and anchorage(piles or barrettes). Since the barrette pile or the diaphragm wall panel provides high bearing capacity, the anchorage method is more practical in use. In Bangkok, a barrette pile was loaded to 52.9 MN(Thasnanipan et al. 2002). In Taipei, the ultimate load applied was as much as 70 MN(Hsu et al. 2017).

Another testing method for high bearing capacity foundation is the O-cell testing, or bi-directional load testing. This method has been widely used in pile testing(Fellenius et al. 1999, England 2003, Ishihara 2010), and the mobilized bearing capacity can overpass 300 MN(Gong and Dai 2016, Deng et al. 2017, www.loadtest.com, www.ddzph.com).

In Chinese mainland, the bi-directional load testing is usually called self-balanced method. Since 1996, it has been used in thousands of foundation tests(piles, diaphragm walls, open cassions). Many major projects, for instance, sea-cross bridges, Yangtze River bridges, and high-rise buildings, have adopted the bi-directional load testing. Up to now, more than 20 tests' bearing capacity have overpassed 100 MN(www.ddzph.com).

In 1999, the first bi-directional load testing standard was issued in Jangsu Province. In 2009, the second edition was issued(DGJ32/TJ 77-2009). Nowadays, the test standards for bridges and buildings have been issued in 2009 and 2017, respectively(JT/T 738-2009, JGJ/T 403-2017). For the loadcell product, the standard was issued in 2013(JT/T 875-2013).

This paper gives an overview of bi-directional load testing of diaphragm walls in Chinese mainland, and focus on the 314 MN test at Nanjing Jinmao Square.

2 BI-DIRECTIONAL LOAD TESTING AND TYPICAL PROJECTS IN CHINESE MAINLAND

2.1 Bi-directional load testing

The principle of the bi-directional load testing is shown in Fig. 1.

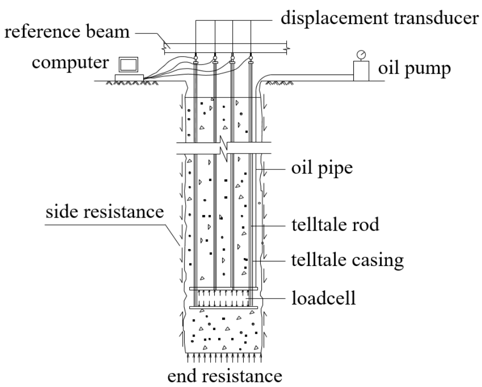


Fig. 1 Principle of bi-directional load testing

The loadcell (specially made jacks) is welded with the steel cage, and then placed at a chosen position, in which the bearing capacity of the upper portion pile and the lower portion pile are approximately the same.

The loadcell works in two directions, upward mainly against side resistance and self-weight of the upper portion, downward mainly against side resistance and end resistance of the lower portion. When the bearing capacity of the two portions are obtained, the equivalent ultimate bearing capacity of the whole pile could be calculated.

2.2 Enclosed rectangular diaphragm wall project

The enclosed rectangular diaphragm wall is used as the foundatioin of an overpass bridge, on road G209, Hejin-Linyi, at K23+385m.

The designed foundation was 7.0×7.0 m in-plane, with height of 18.0 m. The wall thickness was 0.8 m. As it was too large to carry out the test, a small scale foundation was constructed and tested, see Fig. 2(Chen et al. 2007, Gong and Dai, 2016).

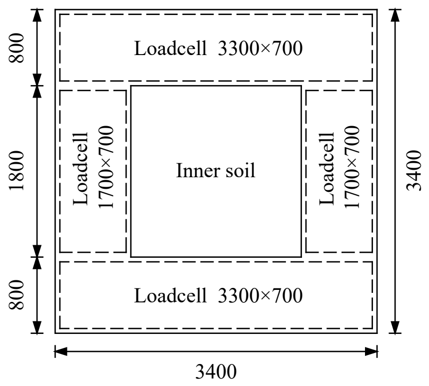


Fig. 2 Enclosed rectangular diaphragm wall (unit: mm)

The outer size was 3.4×3.4 m, with wall thickness of 0.8 m. The height was 15.6 m, with 0.6 m above the ground. The inner soil was kept still to provide bearing capacity(Chen et al. 2007).

4 pieces of rectangular loadcells, with 2 of 3.3×0.7 m and 2 of 1.7×0.7 m, were fabricated, see Fig. 3. The loadcells were placed at 2.0 m above the bottom. The equivalent ultimate bearing capacity of the diaphragm wall was approximately 35.0 MN(Chen et al. 2007).

Fig. 3 One piece of rectangular loadcell

2.3 Tianjin Station project

Tianjin Station is a transportation hub, which consists of several railways, subways, a light rail and Beijing-Tianjin intercity railway.

The diaphragm wall was used in the project. The test panel was 1.2×2.8×48.0 m. Base grouting was used to enhance the bearing capacity. The loadcell was shown in Fig. 4. The equivalent ultimate bearing capacity was approximately 50.6 MN(Gong and Dai 2016).

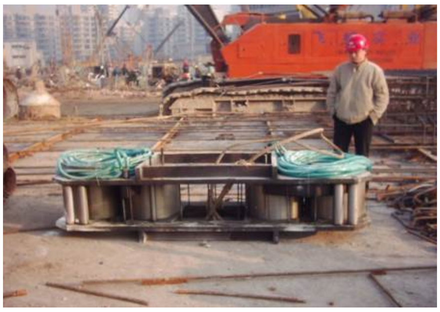


Fig. 4 The loadcell for Tianjin Station project

2.4 Nanjing Jinlun Fenghua project

Nanjing Jinlun Fenghua project is a high-rise building, and it's still under construction. 2 diaphragm wall panels of 6.0×0.8 m(in-plane) were selected for testing. The base grouting technology was adopted.

The loadcell was shown in Fig. 5.

Fig. 5 The loadcell for Nanjing Jinlun Fenghua project

3 NANJING JINMAO SQUARE PROJECT

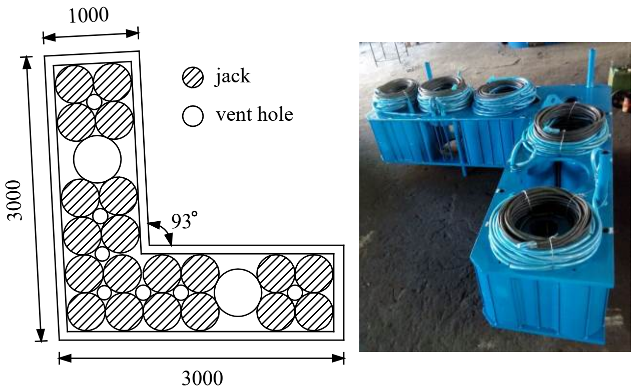
Nanjing Jinmao Square is a high-rise building. The rock socketed diaphragm wall was used.

3.1 Loadcell

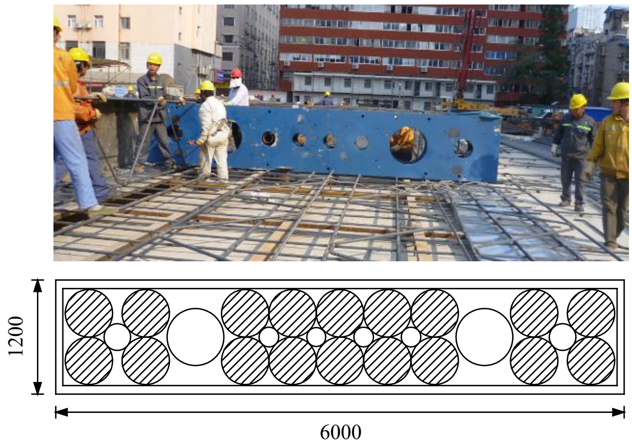
3 panels of 2 types were selected to test the bearing capacity(Fig. 6). SQ1 was an L-shaped panel in-plane. The length in two directions was 3.0 m, and the width was 1.0 m. SQ2-1 and SQ2-2 were rectangular panels, they were both 6.0×1.2 m in-plane. The loadcells were fabricated following the shape of the panels.

The designed loading capacity for loadcell SQ1 was 2×150 MN, and it was 2×198 MN for both loadcell SQ2-1 and loadcell SQ2-2.

In the following, only the SQ2-1 panel's loadcell, construction and test results were discussed.



a) L-shaped loadcell for SQ1



b) Rectangular loadcell for SQ2-1 and SQ2-2

Fig. 6 The loadcell for Nanjing Jinmao Square project (unit: mm)

3.2 Site conditions and instruments

The site conditions were shown in Fig. 7. The loadcell was placed 7.0 m above the bottom. 10 layers of strain gauges were installed. Displacement at 5 positions were measured during the test, see Fig. 7.

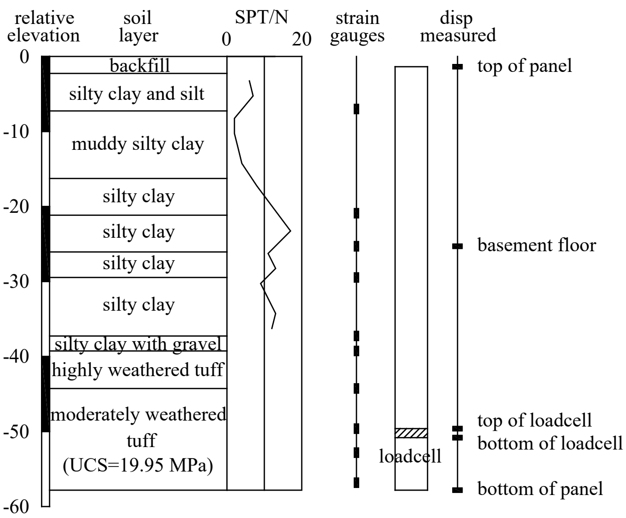


Fig. 7 Site conditions and instruments layout

3.3 Construction and testing

From Oct 20 to Oct 29, 2014, the SQ2-1 panel was excavated to the relative elevation of -57.8 m with grab machine and milling machine(Fig. 8). It meant that the rock socketed segment length was approximately 13.5 m(moderately weathered tuff). Then the bottom sediment was cleaned until the thickness < 50 mm. On Oct 30, the steel cage was lower down(Fig. 8). On Oct 31, the concrete was poured. The height of the diaphragm wall panel was approximately 56.4 m.

On Nov 7, approximately 5.7 t cement with w/c=0.5 was grouted to the base of the panel.

The test was carried out on Dec 9, 2014, following the slow maintained load test method, which was specified in DGJ32/TJ 77-2009(Fig. 9).

The expected load of 2×198 MN was divided into 15 load steps. In each load step, the increment was 2×13.2 MN, and the first increment was 2×26.4 MN.

When loaded to 2×158.4 MN, the upper portion panel moved upward increasingly, and the pressure couldn't maintain stable. Then the test was terminated.

Fig. 8 The excavation and lowering of the steel cage (loadcell)

Fig. 9 Field test

3.4 Test results

The load-displacement curve of SQ2-1 is shown in Fig. 10. It reveals that the upper portion panel's ultimate bearing capacity Q_{us} is 145.2 MN. For the lower portion, the displacement is relatively small, and the ultimate bearing capacity Q_{ux} is 158.4 MN for safety concern(Gong and Dai, 2016, Deng et al. 2017).

According to DGJ32/TJ 77-2009, the whole panel's equivalent ultimate bearing capacity Q_u can be calculated by Eq. (1).

$$Q_u = \frac{Q_{us} - W}{\gamma} + Q_{ux} \tag{1}$$

where W is the self-weight of the upper portion; γ is the correction factor, for clay and silt γ=0.8, for sand γ=0.7, for rock γ=1.0, for multi-layered soil, weighted average value could be adopted(DGJ32/TJ 77-2009).

The results are shown in Table 1.

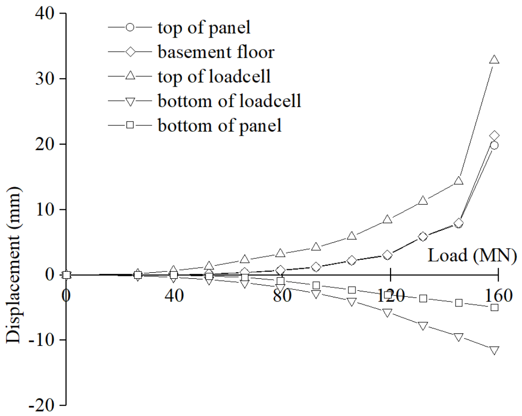


Fig. 10 Load-displacement curve

Table 1. The whole panel's equivalent ultimate bearing capacity

Q_{us} (MN)	Q_{ux} (MN)	W (MN)	γ	Q_u (MN)
145.2	158.4	5.16	0.9	314

The axial forces derived from strain gauges are shown in Fig. 11. The relationship between the skin friction and the displacement, the end resistance and the displacement, could be determined. Then an equivalent load-settlement curve corresponding to the top-down loading method could be constructed, as shown in Fig. 12(Gong and Dai, 2016, Deng et al. 2017).

The max equivalent load is 314 MN, with settlement of 49.43 mm.

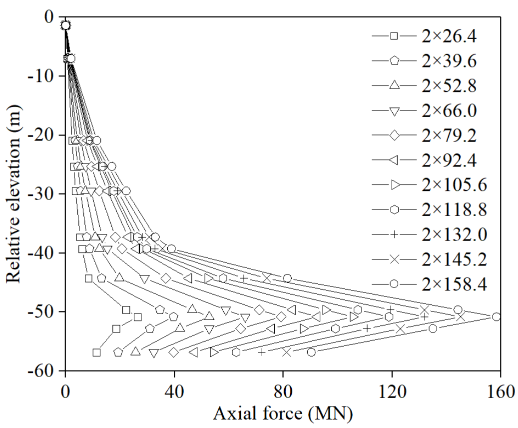


Fig. 11 Axial force distribution

4 CONCLUSION

Bi-directional load testing was used in an enclosed rectangular diaphragm wall, an L-shaped diaphragm wall panel, and several rectangular diaphragm wall panels(barrette piles). In Nanjing Jinmao Square project, the 6.0×1.2×56.4 m rock socketed diaphragm wall panel was tested, and the equivalent ultimate bearing capacity was 314 MN.

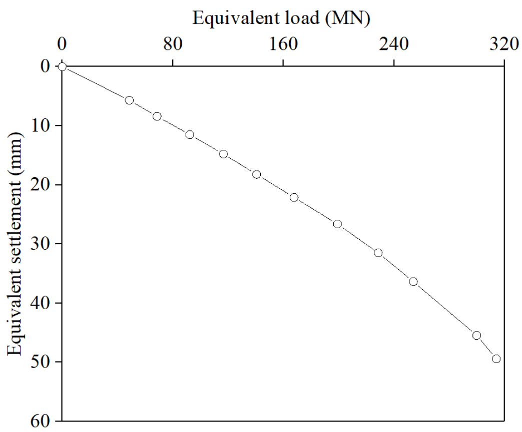


Fig. 12 Equivalent load-settlement curve

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