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Comparison between the tensile behaviors of rock-socketed barrette and drilled shaft

COMPARAISON ENTRE L'ELASTICITE DE LA BARRETTE FIXEE DANS LA CAVITE DE LA ROCHE ET CELLE DE l'ARBRE DE FORAGE

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ABSTRACT: This paper deals the tested results from tensile loading tests of two instrumented drilled shafts and two other barrettes socketed in rock at an office building project on the northwest side of Taipei, Taiwan. Due to some differences in local geological conditions of the building site, two sets of pile test were completed. The tests at one site included a 45.7m long drilled shaft with diameter 1.5m and a 34.5m long barrette with size 1.2 x 2.7m. The tests at the other site included a 49.7m long drilled shaft with diameter 1.5m and a 50.3m long barrette, which also has the size of 1.2 x 2.7m. Considering the cut-off level of these tested piles was 25m below ground surface, the main capacity of these piles was provided by the part of the pile socketed in the andesite rock layer. The tested results showed that the barrette pile has higher capacity than that of the drilled shaft. In addition, the capacity of the barrette in the north was higher than that of the south. Similar result was also observed for the drilled shafts. In addition, at both tested sites, the pile frictional resistance of the drilled shaft did not show significant variation in the rock socket layer. However, the pile friction resistance of the barrettes increased with depth in the same rock socket layer.

Résumé: Ce document traite des résultats des essais de la traction de deux arbres de forage et de deux barrettes insérées dans des cavités de roches dans un projet de construction de bureaux au nord-Ouest de Taipei à Taïwan. En raison de certaines différences dans les conditions géologiques locales du chantier, des essais de deux types de pieux de fondations ont été réalisées. Les essais effectués sur l'un des sites comprenaient un arbre de forage de 45,7 m de longueur et un diamètre de 1,5 m . Les barrettes utilisées font 34,5 m de longueur et de 1,2 x 2,7 m de largeur. Les essais sur l'autre site comprenaient un arbre de forage de 49,7 m longueur et de 1,5 m de diamètre . Les barrettes utilisées font 50,3 m de longueur et 1,2 x 2,7 m de largeur. Étant donné que le niveau de coupure de ces pieux testés était de 25 m de la surface du sol, la force principale de ces pieux provient des barrettes fixées dans les cavités des couches de roches andesites. Les résultats testés ont montré que la barrette a une capacité supérieure à celle de l'arbre de forage. En outre, la capacité de la barrette dans le nord était plus élevée que celle du sud. Un résultat similaire a également été observé pour les arbres forages. De plus, sur les deux sites testés, la résistance aux frottements de l'arbre de forage n'a pas montré de variation significative au niveau de la couche rocheuse. Cependant, la résistance aux frottements des barrettes augmentait progressivement lorsqu'elles s'enfoncent dans les cavités des mêmes couches de roches.

KEYWORDS: drilled shaft, barrette, tensile loading test, rock socket

1 INTRODUCTION

The rectangular pile or also often called as barrette pile has been of frequent use in recent years in Taiwan, particularly for installing friction piles because of higher shaft resistance that is mobilized in comparison with that of the circular pile. Better compressive performance of a barrette over a circular pile was observed by Ishihara (2016). In this paper, in-situ prototype tests are introduced in which frictional resistance of barrette type pile is compared with that of the circular drilled shaft, subjected to tensile loading.

Both drilled shaft and barrette pile are planned as foundation type of a high rise building project located at northwest part of Taipei, Taiwan. In order to gain enough design information on pile/soil interaction, the ultimate pile loading test is proposed ahead of the design stage. Two sets of loading tests are planned at the north and the south side, respectively, due to some different local geological conditions. In general, the subsurface conditions of the site consist of backfill, underlain by a clay layer, followed by andesite rock which is underlain by sandstone and shale bedrock. The strength of clay in the north is weaker than that of the south. In addition, a gravel layer is observed sandwiched between the top clay layer and the bottom bedrock. The andesite rock has different degrees of weathering and is filled with gravel and soil in the open voids (Figure 1). The tested piles in the north include a 45.7m long drilled shaft with diameter 1.5m and a 34.5m long barrette with size 1.2 x 2.7m. In the south side, although carried the same dimension of that of the north side, the length of the drilled shaft and the barrette are 49.7m and 50.3m, respectively.

Considering the cut-off level of all tested piles is 25m below ground surface, the main capacity of the piles is the frictional resistance contributed by the part of the pile socketed in the andesite rock layer. The capacity of drilled shafts socketed into rock is, in general, controlled by factors such as rock strength, socket roughness, socket geometry, rock fractures and possible slurry/shaft wall smear effects. Determining these factors on shaft capacity can be difficult to measure. Pile capacity can also be affected by the properties of gravel and in-filled soil in open voids between weathered cobble-size andesite rocks, as show in Figure1 (Lin et al. 2007). To help determining these effects, instrumented pile loading test is a common local practice to estimate the load capacity of piles.

Figure 1. The properties of gravel and in-filled soil in open voids between weathered cobble-size andesite rocks.

This paper presents the tensile loading test results of two barrettes and two drilled shafts, especially on the performance of a drilled shaft and a barrette tested at the same site. Again, considering the cut-off level at 25m below ground surface, the development of frictional resistance along the section socketed in andesite rock is the main concern of the tests. Unit frictional resistance of this socketed part based on these load test results are evaluated and compared to current practices. The t-z curve is also derived in the paper for comparison.

2 SUBSURFACE CONDITIONS

The subsurface conditions at this site can be roughly divided into the northern site and southern site. At the northern site, in addition to the top 1m of backfill material, typical underlying subsurface conditions at the site consists of nearly 21m of soft clay underlain by 3m of silty sand, and nearly 20m of weathered andesite rock consisting of cobbles and boulders. The andesite cobbles and boulders are mixed with weathering gravel and soil. Beneath the andesite rock, sandstone/shale bedrock is encountered. Some typical soil properties at the northern site are listed in Table 1.

At the southern side of the testing site, a nearly 39m thick of soft to hard clay is sandwiched between the top 3m thick backfill layer and the bottom 1m thick silty sand layer. Less weathered andesite rock cobbles and boulders (compared to the northern side), mixed with gravel and soil, underlies the silty sand layer. Again, typical soil properties at southern site are listed in Table 2.

The unconfined compressive strength of intact andesite cobbles and boulders is approximately 130MPa. Based on the local engineer's experience, the compressive strength of the rock mass is approximately between 15MPa and 40MPa. In addition, the porosity and the unit weight of the andesite cobbles and boulders range from 10.0% to 15.0% and 21.48 kN/m^3 to 22.66 kN/m^3, respectively.

Table 1. Subsurface condition at northern site

Depth (m)	Description	Classification	SPT N	Water content (%)	Void ratio	Unit weight (kN/m^3)	C (kN/m^2)
0.0~2.8	Backfill	SF	1.5~2	-	-	-	-
2.8~3.5	Very soft silty clay	CL	1.5	36.23	1.04	17.84	2.06
3.5~15.45	Very soft silty clay	CL	1~1.5	43.21	1.21	17.37	2.45
15.45~18.5	Soft silty clay	CL	2.5~3	41.46	1.17	17.47	3.63
18.5~22.0	Soft silty clay and some sand	CL	3~4.5	42.0	1.15	17.69	3.92
22.0~23.85	Silty sand	SM	9	-	-	-	-
23.85~38.6	Andesite rock and gravel and silty sand mixture	-	20~50/8cm	-	-	-	-
38.6~39.3	Sandstone	-	50/5cm	-	-	-	-
39.3~44.0	Sandstone/Shale	-	50/3cm	-	-	-	-

3 PILE CONSTRUCTION

The tested shaft DN on the northern side of the testing site were installed via reverse circulation method by using a Hitachi model S-600 machine. The DN shaft, with a diameter of 1.5m, is 45.7m long. In general, excavation is conducted via tri-blade auger. When hard rock cobbles and boulders is encountered, the hammer grab method is used to remove the rock out. Drilling is also done with a polymer slurry pumped into a shaft borehole. The slurry-soil mixture is discharged from the centrally placed pump pipe to allow settlement in the tank. The tremie method is used for shaft concreting, using a slump between 18 and 22cm. The design 28-day unconfined compressive strength of the concrete is 27,468 kN/m^2.

On the southern side of the testing site, the DS shaft was installed using the casing method. The diameter and the length of the shaft are 1.5m and 49.7m, respectively. The Hitachi RT-200A II heavy duty casing rotator is used for casing installation. The hammer grab method is also used for rock excavation.

In addition, 1.2m x 2.7m barrette piles of lengths 34.5m (BN) and 50.3m (BS) were also installed at both the northern and southern ends of the site, respectively. The Masago hydraulic long bucket is used for barrette installation.

Table 2. Subsurface condition of southern site

Depth (m)	Description	Classification	SPT-N	Water content (%)	Void ratio	Unit weight (kN/m^3)	C (kN/m^2)
0.0~2.5	Backfill	SF	11	-	-	-	-
2.5~4.5	Firm silty clay	CL	4~5	-	-	-	-
4.5~13.0	Very soft silty clay	CL	1~1.5	40.71	1.15	17.63	4.51
13.0~25.5	Soft silty clay	CL	2~4	39.94	1.16	17.38	3.34
25.5~37.5	Firm silty clay	CL	5~8	37.36	1.10	17.53	4.32
37.5~41.7	Stiff silty clay	ML	10~14	26.89	0.77	19.04	7.65
41.7~43.0	Silty sand	-	14	-	-	-	-
43.0~70.5	Andesite rock and some silty sand	-	50/13cm~50/6cm	-	-	-	-

To evaluate the total load carried at different depths along the shafts, both rebar gages and telltales are installed at several selected depths of each shaft and barrette. These gauges are attached to the rebar cage in sets of four at each depth and are protected. In addition, four PVC pipes are attached to the rebar gage of each shaft for sonic logging integrity testing. The pile loading test setup is given in Figure 2.

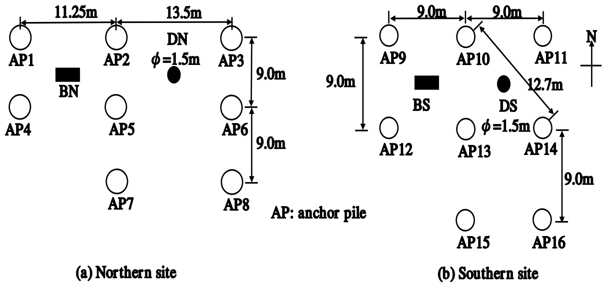

Figure 2. Arrangement of pile loading tests.

4 TEST RESULTS AND DISCUSSION

The testing procedures suggested by ASTM D3689-90 (1995) are used for shaft tension load test. The concrete elastic modulus obtained from the tested results and used for interpretation of axial load along shaft is shown in Figure 3. The load versus displacement relations at the pile head of the two circular drilled shafts and two other barrette piles are shown in Figure 4 for comparison. Under the same displacement, whether in north or in south site, the barrette pile shows higher capacity than that of the drilled shaft. In addition, the capacity of the barrette in the north is higher than that of the south. Similar result is also observed for the drilled shafts. The axial load along shaft of each pile under the maximum applied loading is presented in Figure 5. Comparison on the axial load along depth between pile head down to 30m deep, both drilled shaft show similart transfer trend. Both barrette piles also show similar trend. However, when deeper than 30m, the drilled shaft and the barrette in the north site show similar transfre trend, so do the drilled shaft and the barrette in the south site.

The relationship of load vs displacement and the relationship of pile frictional resistance vs. displacement at selected level of the piles socketed in the north and in the south are given in Figure 6 and 7, respectively. The ultimate capacity determined by the methods of Butler and Hoy (1977), Chin (1970), Davisson (1972) and Fuller and Hoy (1970) were also given in the figures for comparison.

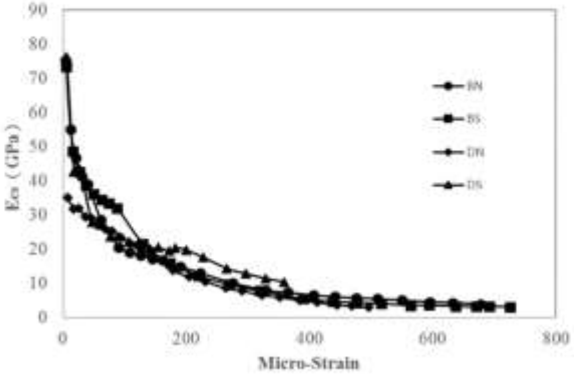

Figure 3 The relationship between elastic modulus of concrete and micro-strain.

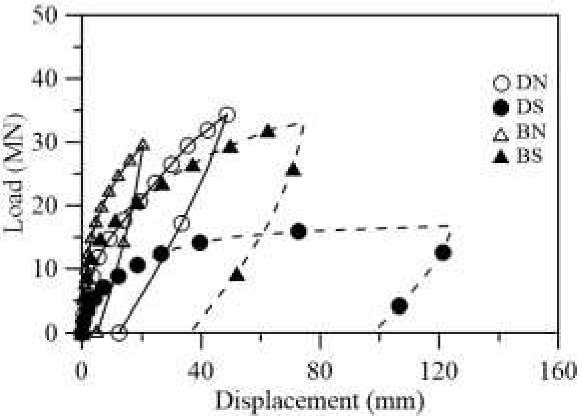

Figure 4. Load versus displacement of the pile head.

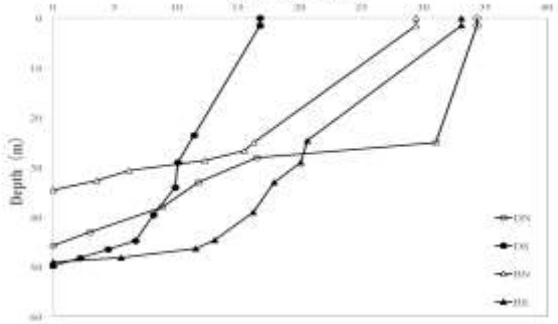

Figure 5. Axial load along depth at the maximum applied load.

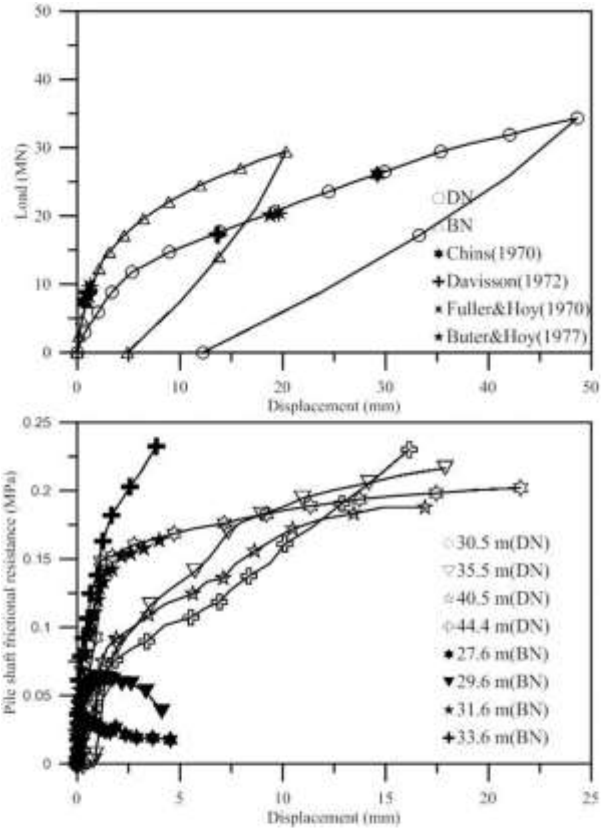

Figure 6 The load vs displacement at pile head and shaft unit frictional resistance versus displacement relationships of barrette and drilled shaft in the north side.

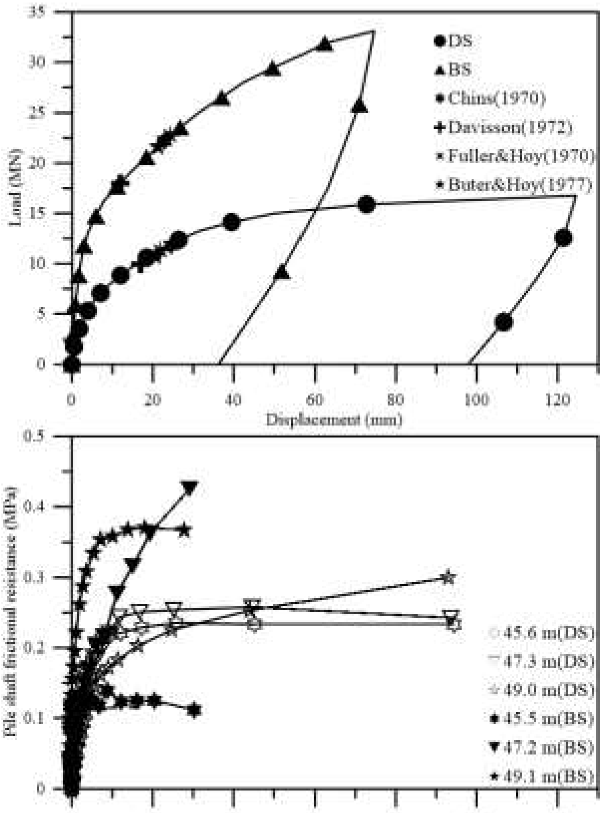

Figure 7. The load vs displacement at pile head and shaft unit frictional resistance versus displacement relationships of barrette and drilled shaft in the south side.

As shown in Fig. 6, the pile frictional resistance of the drilled shaft do not have significant variation in the rock socket layer. Hardening behavior is also observed for the drilled shaft. However, the results of the pile friction resistance of the barrettes increases with depth in the same rock socket layer. Also, softening behavior is observed for the barrette at depth 27m to 29m below ground surface. In general, the stiffness of the pile frictional resistance vs displacement relationship of the barrette is higer than that of the drilled shaft.

The frictional resistance vs displacement relationship of the piles in the south is similar to the performance of the piles in the north. However, the frictional resistance of the drilled shaft reaches it's ultimate value at displacement around 10mm as shown in Fig. 7.

5 SUMMARY AND CONCLUSIONS

The behavior of drilled shafts and barrette piles socketed in andesite rock, subjected to tensile loading, was investigated by full scale load tests. From the study in this paper, the following observations can be summarized:

1. Among the ultimate capacity interpretation methods by Chin (1970), Davisson (1972), Fuller and Hoy (1970) and Butler and Hoy (1977), the Chin and the Davisson's methods gave the highest and the lowest ultimate capacity, respectively.
2. Under the same displacement, whether in north or in south site, the barrette pile showed higher capacity than that of the drilled shaft. In addition, the capacity of the barrette in the north was higher than that of the south. Similar result was also observed for the drilled shafts.
3. At both tested sites, the pile frictional resistance of the drilled shaft did not show significant variation in the rock socket layer. However, the pile friction resistance of the barrettes increased with depth in the same rock socket layer.
4. In general, at both north and south sites, the stiffness of the pile frictional resistance vs displacement relationship of the barrette was higher than that of the drilled shaft.

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