sciendo
DOI: 10.2478/ace-2018-0057
ARCHIVES OF CIVIL ENGINEERING
Vol. LXIV ISSUE 4 2018

ANALYSIS OF THE BARRETTE LOAD INVESTIGATION OF THE TALLEST BUILDING IN EUROPEAN UNION

G. KACPRZAK[1], S. BODUS[2]

The paper presents a static load test of a pile with the largest vertical load in Poland to-date up to the force of 23000 kN. The test was performed in the centre of Warsaw on the construction site of a future high-rise building to be the tallest building in European Union. The designed building height measured from the ground level is 310 meters including an 80-metre mast. The foundation of the building was designed as a Combined Piled Raft Foundation (CPRF) utilising the barrettes and diaphragm walls technology. The test was carried out on barrettes with lengths of approx. 28 and 34 m and was aimed to estimate the stiffness (load-settlement relation) of the designed 17.5 metre-long barrette situated below the foundation level. In addition to that a series of extensometric sensors was placed inside the barrette to determine the distribution of the axial force.

Keywords: Piled-raft foundation, barette, base injection, extensometer

1. INTRODUCTION

The article presents the process and results of a static barette test performed in Poland on the construction site of a high-rise building to become the tallest building in European Union. [4] The skyscraper will consist of two parts: usable floors (with a roof at the height of 230 m) and a mast (80 m). The building will reach the height of 310 m. This means that its height will exceed the European Union's tallest building at present – London's The Shard (309.6 m), not to mention the neighbouring

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[1] PhD., Eng., Warsaw University of Technology, Faculty of Civil Engineering, Al. Lecha Kaczyńskiego 16, 00-637 Warsaw, Poland, e-mail: g.kacprzak@il.pw.edu.pl
Warbud S.A. Ul Domaniewska 32, 02-672 Warsaw, Poland
[2] MSc., Eng., Warbud S.A. Ul. Domaniewska 32,
02-672 Warsaw, Poland, e-mail: seweryn.bodus@warbud.pl

Palace of Culture and Science which has been is the tallest building in Poland for over half a century. A view of the designed building is shown in Figure 1.

Fig. 1. View of the designed building and its 80-metre mast – a "bird's eye view”

2. STRUCTURAL DESCRIPTION

The building has a reinforced concrete structure in a slab and column construction with perimeter edge beams. The stability of that part of the building will be ensured by a centrally located reinforced concrete core. Stability of the level above will be ensured by wall systems in the form of communication cores displaces in relation to the main core. The underground part of the building will be built within a excavation whose shoring will be made of 80 and 100 cm thick diaphragm walls and soldier piling.

The foundation was designed as a piled raft system in the technology utilising barettes and diaphragm walls with a foundation slab in accordance with a design conception, with a thickness from 3.0 m to 3.6 m under the high-rise part and 1.5 m to 2.5 m outside the footprint of the high-rise part. Additionally, in order to reduce structure settlements the barette bases with a cross-section of 0.8 x 2.8 m, length of 17.5m and 20.0m in the high-rise part, they were injected with the use of jet grouting injection technology.

In order to determine a correct cooperation of structural elements with the ground substrate, it is necessary to correctly estimate the stiffness of the soil and the elements reducing settlement (barettes). The best definition of barette stiffness is obtained on the basis of a barette loading test. Knowing the nature of the operation of such an element in the form of a load-settlement dependence, the designer may accept for further calculations a correct stiffness of the designed foundation, pile/barette.

3. PROCESS AND DESCRIPTION OF THE IN SITU BARETTE LOAD TEST

Stiffness of the 17.5 m long barettes was estimated for the foundation design with the largest vertical test load for barettes in Poland so far, reaching a force value of 23000 kN. Tested barettes with a cross-section of 280x80 cm had a length of about 28 m and 34 m. Along the first 10 meters the ground was disturbed in order to weaken the resistance of the barette skin - assuming a partial lack of cooperation with the medium after the excavation. In addition to that a row of extensometric sensors was placed inside the barette to determine the distribution of the axial force (force in the target barette head, i.e. at a depth of approx. 16 m below the level of the test barette head). Based on the conducted research, the designer was able to assume the actual stiffness of the designed barettes in the calculation spatial model of the entire building. [5]

Due to the fact that construction work on the site was in progress, barette loading test was performed outside the area of the designed structure, in similar soil conditions. For the load test barette types B81 and B82 were chosen with dimensions of 0.8 x 2.8 m and respective lengths of approximately 34 and 28 m. The barette test was carried out using the traditional method including anchoring, and two arrangements of anchoring barettes were assumed - in the first test the barettes were arranged in the shape of the letter "H", in the second test they were in a "cross" arrangement. Each of the loading structures consisted of a main beam, anchored to the four neighbouring barettes. The lengths of the anchoring barettes were chosen by assuming the transfer of 1/4 of the load value by one barette.

Figure 2 presents a view of loading structure of barette B82 where you can see transverse profiles based on mounting supports and the main beam on which there are upper beams fastened to the anchor barettes with SAS 950/1080 rods at 40 mm diameter. [4]

The “cross” arrangement of anchor barettes concerned barette B81. The difference in construction also assumed a connection of the main beam with anchor barettes to which a steel structure/plate girder was attached connecting the reinforcing cage bars the steel box and the anchor bars to clip the entire structure above (Fig. 3).

Measurement of the loads exerted on the barette by means of hydraulic cylinder was carried out on the basis of the oil pressure in the cylinders. The load was exerted by means of sixteen hydraulic cylinders connected to one hydraulic pump. Displacement of the loaded barette was measured by three dial gauges. Sensors were attached to the test barette head and their feet rested on a rigid beam. Irrespective of measurement performed with displacement sensors, the settlement of the test barette was checked with the use of the levelling method. Displacements of the anchor barettes were measured with single dial gauges.

Fig. 2. View of loading structure of the barette B82 (author's photo)

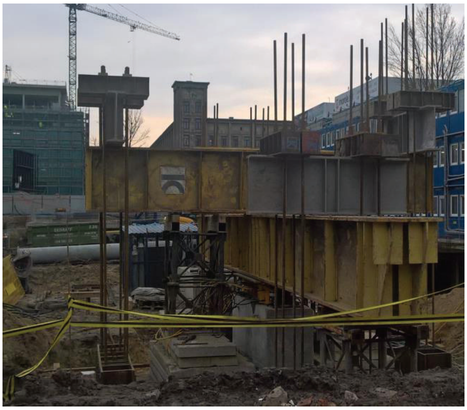

Fig. 3. View of loading structure of the barette B81 (author's photo)

One of the assumptions regarding the foundation of the designed building was the injection of the barette base in the location of the core and the high part of the building (17.5 and 20 metre barettes). Tested barettes were also subjected to injection after cover with concrete. Jet grouting was injected under the base of a barette ended with a flexible membrane through injection tubes in two stages and was carried out in accordance with the patent of the Road and Bridge Research Institute. Each stage assumed stressing the barette base with the pressure of 2.5 MPa. [4]

The ground conditions occurring near the load tests were assumed on the basis of the barette specification boreholes and the available geological engineering report. An example geological cross-section is presented in Figure 4.

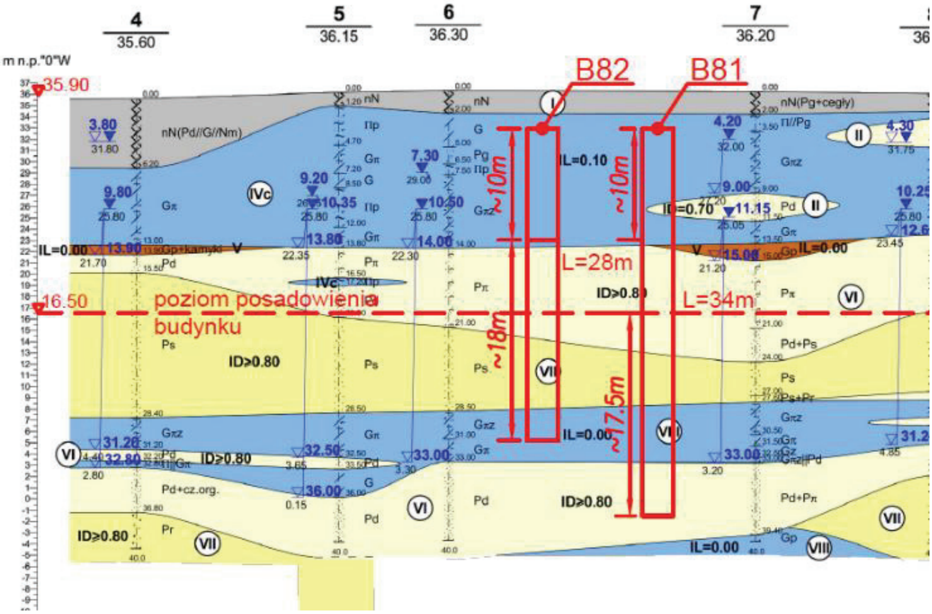

Fig. 4. An example geological cross-section with marked outlines dimension of the tested barettes [4]

Barette lengths were chosen assuming that the first test would be performed on a barette with a base ended in layer VIII clays – barette B82 with length of approx. 28.0 m - and the second test on a barette ended in layer VI sands – barette B81 with length of approx. 34.0 m (Fig. 4.).

4. RESULTS

During the consecutive stages of loading, displacements of the B82 barette head were recorded. The results are presented in Table 1. Table 2 presents the values of axial force distribution from extensometric measurements for the final load value. Figure 5 shows the load-settlement curve for the head of the tested barette.

Table 1. Loads and settlement of B82 barette head at the level of approx. 3m bgl

LOAD [kN]	SETTLEMENT [mm]
2542	0.36
5088	0.83
7236	1.38
9409	2.03
11619	2.88
13802	3.68

Table 2. Results of extensometric measurements - distribution of force and strains in B82 barette sections

Depth [m]	Force in barette core [kN]	Skin friction along barette section [kN]	Strain along barette section [mm]
0	13802	627	0.72
7	13175	699	0.37
10.05	12476	1630	0.32
13.10	10846	2320	0.25
16.15	8526	2138	0.19
19.20	6388	2562	0.11
22.25	3826	1351	0.05
24.30	2475		
26.35	2475 – barette base force		

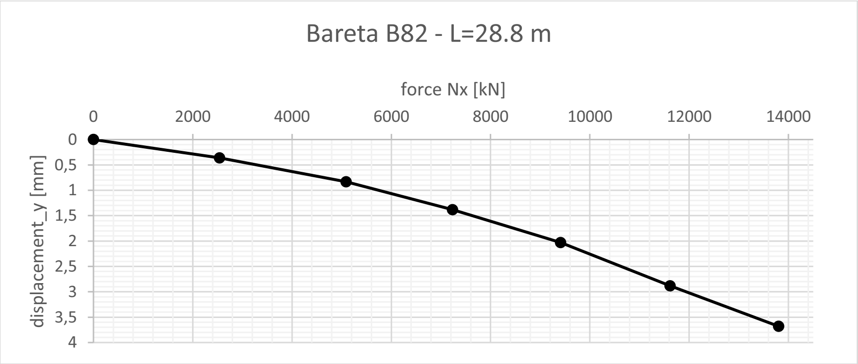

Fig. 5. The load-settlement curve of the tested B82 barette

During the consecutive stages of loading, displacements of barette B81 head were recorded. The results are presented in Table 3. Table 4 presents the values of axial force distribution from extensometric measurements for the final value of applied load. Fig. 6 shows the load-settlement curve of the tested barette. Force distribution in the form of a force-depth diagram for subsequent values of the applied load is shown in Figure 7.

Table 3. Loads and settlement of B81 barette head at the level of approx. 3m bgl

LOAD [kN]	SETTLEMENT [mm]
2418	0.48
4827	1.12
6861	1.73
8923	2.42
11025	3.30
13092	4.03
15104	4.89
17131	5.80
18771	6.41
20001	7.08
22855	8.73

Table 4. Results of extensometric measurements - distribution of force and strains in B81 barette sections

Depth [m]	Force in barette core [kN]	Skin friction along barette section [kN]	Strain along barette section [mm]
0	22855	1061	2.32
10.55	21794	1499	0.69
13.50	20295	588	0.67
16.55	19707	1176	0.63
19.60	18531	1765	0.57
22.65	16766	2648	0.48
25.70	14118	1470	0.43
28.75	12648	3530	0.31
31.80	9118	2353	0.15
33.85	6765		
34.85	6765 – barette head force		

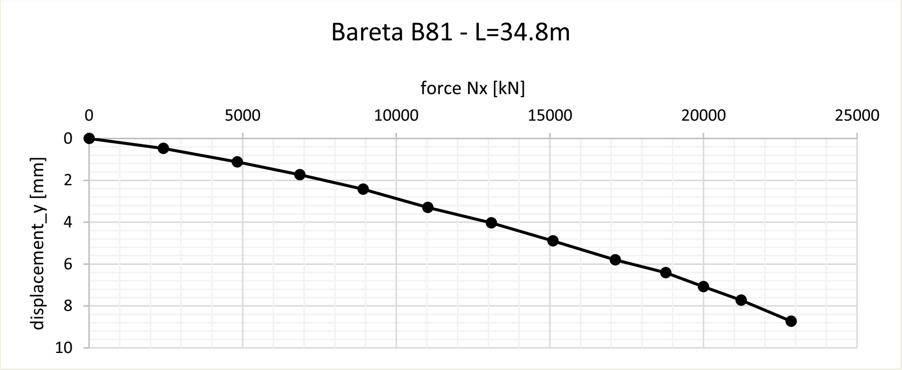

Fig. 6. The load-settlement curve for the head of tested B81 barette

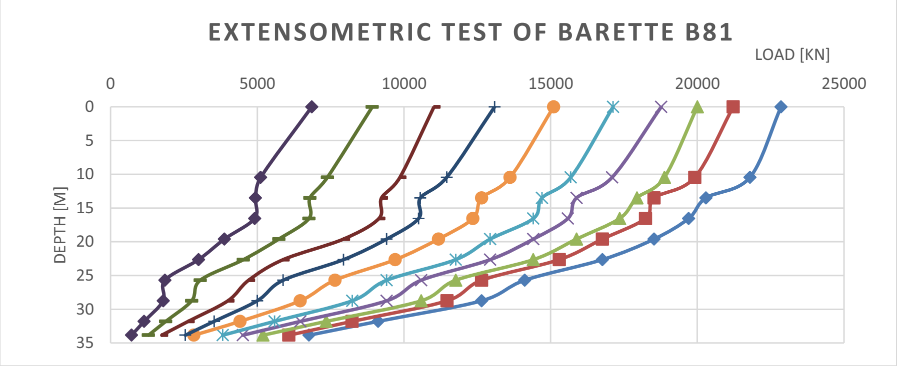

Fig. 7. Distribution of force in barette B81 from extensometric test for subsequent applied load values

5. STIFFNESS ESTIMATION OF THE BARETTE

5.1. BARETTE B81

The section in Figure 4 shows the work diagram of the tested barettes. In order to determine the stiffness of barette B84 results of extensometer measurements of axial force distribution in the individual sections were used (Table 4). Assuming the target barette head at a depth of 19.5 m bgl (16.5 m below barette head including 3.0 m pre-excavation) the value of the force in its core is 19707kN. Together with the determination of stiffness of the examined barette, its elastic shortening over barette length of 16.5 meters was also taken into account. Then we obtain the final stiffness

$$\frac{F}{s} = \frac{19.7}{8.72 - (2.32 + 0.69 + 0.67)} = \frac{19.7}{0.00504} = 3910\ [MN/m] \tag{5.1}$$

5.2.BARETTE B82

Figure 4 shows an operation diagram of the tested barettes. In order to estimate the stiffness of the 18 m barette based on clays under the designed building in the test area, barette B82 was made as a 28 m barette with soil mixing within the depth of the first 10 meters. Such a procedure was performed in order not to take into account the ground after the excavation. The final stiffness of the tested barette was determined as the ratio of the obtained load value at the depth of 10m below barette head to settlement taking into account the elastic shortening of the barette over the depth of 10 metres. The calculations are presented below.

$$\frac{F}{s} = \frac{12.48}{3.68 - (0.72 + 0.37)} = \frac{12.48}{0.00259} = 4818\ [MN/m] \tag{5.2}$$

6. CONCLUSION

Static barette loading tests are the best estimate of the actual course of the force-settlement relationship in the head of the tested barette. In addition to that, based on the obtained results of extensometric tests, the authors were able to estimate the stiffness of a single barette at the foundation level of the designed building. The stiffness of the barettes working in a piled raft system can be estimated using the coefficients of interaction of a barette group, of the raft – on the basis of R. Katzenbach, Sleppla (2015), A. Mandolini et al. (2005).

Based on the implementation of the model of soil taking into account all interactions (soil-raft-barettes) with barettes working as part of CPRF, the designer is able to properly design the structure of the whole building. [5, 6]

Another method of determining the stiffness of a piled-raft foundation may be to create a numerical 3D model in which the modelled ground and the underground structure will take into account all the interaction factors of the structural elements with the ground [5]. In that case the results of barette load tests constitute a basis for the calibration of parameters of the ground model in the numerical analysis. This approach will be used in the next work of the authors of this article.

REFERENCES

1. G. Kacprzak, P. Kravchenko, W. Smolak, "Load distribution between elements of piled raft foundation in weak ground", Civil and Environmental Engineering, no 4(2013), Bialystok University of Technology Publishing
2. G. Kacprzak, "Comparison analysis of raft-pile system – theory and practice", Technical transactions, 3-Ś/2011 Book 21 Year 108, 59-72, Cracow University of Technology Publishing
3. B.Kutera, G.Kacprzak, "The pile stiffness in a piled-raft foundation", Technical transactions, Civil Engineering 2-B/2013, 59-69
4. G. Kacprzak, S. Bodus, B. Kłosiński, P. Rychlewski, "Raport dotyczący sztywności baret dla inwestycji Varso Tower w Warszawie, przy ulicy Chmielnej 71", (Report on barette stiffness for Varso Tower Project in Warsa wat 71 Chmielna St.) WARBUD/IBDiM, Poland, Warsaw 2018
5. G. Kacprzak, S. Bodus, "*Numerical analysis of the load distribution under the piled raft foundation of the high-rise building"*, Ann Warsaw Univ. Life Sci. – SGGW, Land Reclam. 50 (2):129-13
6. R.Katzenbach, S.Leppla, "Realistic Modelling of Soil-Structure Interaction for High-Rise Builgings", Technische Uniwersitat Darmstadt, Institute and Laboratory of Geotechnics, Germany 2015
7. A.Mandolini, G.Russo, C.Viggiani, "Pile foundations: Experimental investigations, analysis and design", Italy 2005

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Tab. 4. Wyniki z pomiarów ekstensometrycznych - rozkład siły oraz odkształcenia na odcinkach barety B81

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SUMMARY:

The paper presents a static load test of a pile with the largest vertical load in Poland to-date up to the force of 23000 kN. The test was performed in the centre of Warsaw on the construction site of a future high-rise building to be the tallest building in European Union. The designed building height measured from the ground level is 310 meters including an 80-metre mast. The foundation of the building was designed as a Combined Piled Raft Foundation (CPRF) utilising the barrettes and diaphragm walls technology. A 3.6 m thick slab was designed under the high-rise part, 1.5 and 2.5 metre thick outside of the high-rise part. The designed barrettes with cross-sections of 0.8 x 2.8m and length of 17.5 m and 20.0 m in the high-rise part have been injected. The test was carried out on barrettes with lengths of approx. 28 and 34 m and was aimed to estimate the stiffness (load-settlement relation) of the designed 17.5 metre-long barrette situated below the foundation level. In the first 10 meters the ground was disturbed in order to weaken the pile skin reaction. In addition to that a series of extensometric sensors was placed inside the barrette to determine the distribution of the axial force. The results served as a basis for the adoption of correct soil parameters in the numerical 3D model used for barrette testing and then for the calibration of an entire underground model of the designed building. The final aim of the designer was to determine the stiffness of the subsoil under the foundation slab and the stiffness of barrettes in the piled-raft system of the designed building.

ANALIZA BADANIA OBCIĄŻANIA BARET NAJWYŻSZEGO BUDYNKU W UNII EUROPEJSKIEJ

Słowa kluczowe: Fundament płytowo-palowy, bareta, iniekcja podstawy, ekstensometr

STRESZCZENIE:

Artykuł przedstawia próbne badanie statyczne pala przy jak do tej pory największym obciążeniu pionowym w Polsce do siły rzędu 23000kN. Badanie zostało wykonane w centrum Warszawy, na terenie przyszłego budynku wysokościowego mającego być najwyższym budynkiem w Europie. Zakładana wysokość budynku licząc od poziomu terenu to 310 metrów z uwzględnieniem 80-cio metrowego masztu. Fundament budynku został zaprojektowany jako posadowienie płytowo-palowe w technologii baret i ścian szczelinowych. Zaprojektowano płytę o grubości 3.6m pod częścią wysokościową oraz poza obrysem części wysokościowej o grubości 1.5m i 2.5m. Projektowane barety o przekroju 0.8x2.8m i długości 17.5m i 20.0m w części wysokościowej zostały zainiektowane. Badanie wykonane było na baretach o długości około 28m i 34m, i miało na celu oszacowanie sztywności (relacja obciążenie-osiadanie) docelowo projektowanej barety o długości 17.5m poniżej poziomu posadowienia fundamentu. Na pierwszych 10-ciu metrach grunt został naruszony w celu osłabienia pracy pobocznicy. Dodatkowo wewnątrz barety został umieszczony ciąg czujników ekstensometrycznych do wyznaczenia przebiegu siły osiowej. Wyniki stanowiły bazę do przyjęcia poprawnych parametrów gruntowych w numerycznym modelu 3D służącym do testowania baret, a następnie do kalibracji pełnego modelu podziemia projektowanego budynku. Celem końcowym projektanta było wyznaczenie sztywności podłoża pod płytą fundamentową oraz baret pracujących w układzie płytowo-palowym projektowanego budynku