APPLICATION OF STATIC LOADING TESTS TO STEEL PIPE PILES WITH LARGE DIAMETERS IN CHINA OFFSHORE WIND FARMS

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In China, wind energy is regarded to be an important source of clear energy in recent years, which will generate 17 % of renewable sources by 2030 with the existing capacity of 10.2 GW by 2015 and predicted to be 150 GW by 2030[1]. numbers of Offshore wind farms are under construction or to be built in coastal areas. steel pipe pile with large diameters (more than 1.5 m) are frequently observed in these projects. In this paper, field static loading tests results will be introduced in three offshore wind farms in China. These loading test methods include axial compression load test (test A) and uplift loading test (test B) [2]. The main information of test piles in these projects is introduced in table 1.

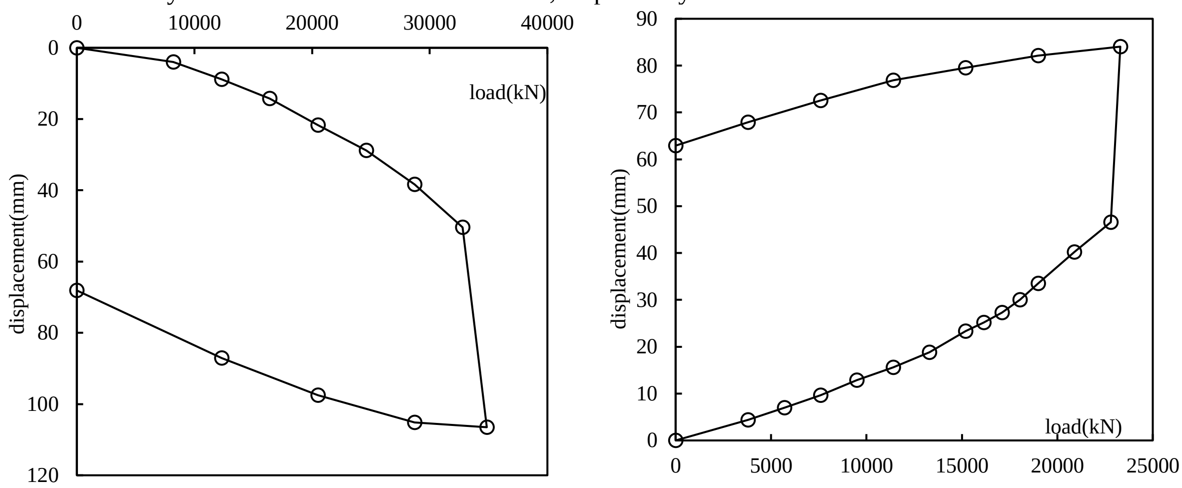
Table 1 parameters information of test piles in three projects field tests

Project name	Pile name	Pile length(m)	Pile diameters (m)	L/D	Test method
Project 1	ZK01	71.5	2.0	35.8	A and B
	ZK28	77.5	2.0	38.8	A and B
Project 2	1-9	46.6	1.8	25.9	A and B
	2-9	39.4	1.8	21.9	A and B
Project 3	S1	93.7	2.8	33.5	A and B
	S2	93.7	2.8	33.5	A and B

In the above three projects, both axial compression load test (A) and uplift loading test (B) were conducted at the same piles. These 6 steel pipe piles are with diameters of 1.7m to 2.8m and length of 39.4m to 93.7m, the measurements were taken to record the behaviour of these piles throughout loading test. Fibre optic sensors were used along these pile body to measure the strain change with loading steps, then the compressing and uplift ultimate shaft resistance of piles at each soil layer can be given. Vertical capacities from two kinds of loading test of each pile were compared, and soil resistance at each layer were calculated. The positive shaft resistance from top loading tests and negative ones from uplifting loading tests were given to find out the conversion factor γ (the ratio of positive shaft resistance to the negative shaft resistance) of different soil layers of each piles.

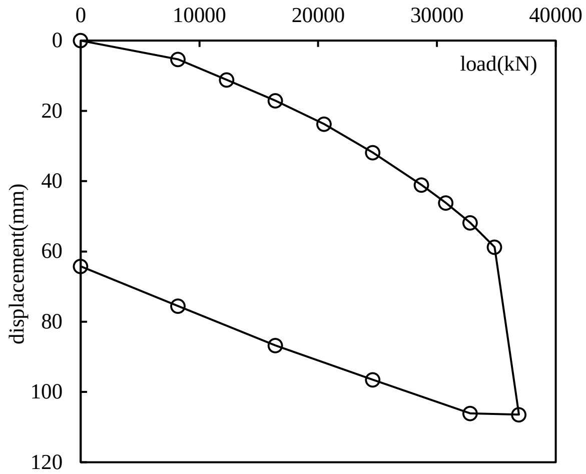
Project 1

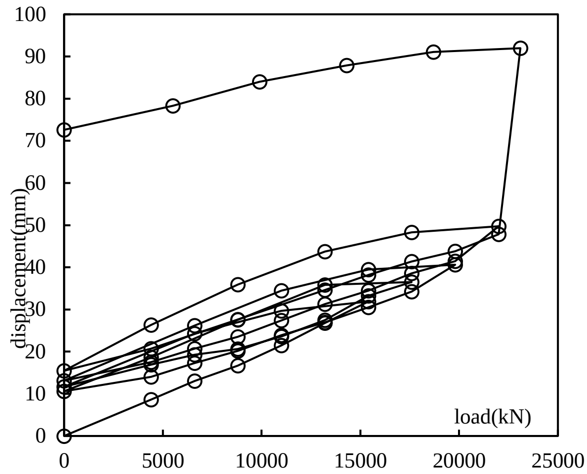
this wind farm project is located in the coast area of Jiangsu province, the soil profile consists of marine clay and sand. the relative parameters are shown in table 1, the vertical capacity results are shown in fig.1**[3]** and fig.2, the shaft resistance of each layer is shown and table 2 and table 3, respectively.



(a) **(b)**

Fig.1 ZK01 (a) the downward load-displacement of pile top from test A and (b) the uplift load-displacement of pile top from test B





(a) **(b)**

Fig.2 ZK28 (a) the downward load-displacement of pile top from test A and (b) the uplift load-displacement of pile top from test B

From fig.1, the vertical compressing capacity of ZK01is 32800kN, the total shaft resistance is 31076kN, the uplifting capacity of ZK01 is 22800kN; the vertical compressing capacity of ZK28 is 34850kN, the total shaft resistance is 33260kN, and the uplifting capacity of ZK28 is 22000kN.the ration of total positive shaft resistance and negative one is 0.73 and 0.66.

Table 2 the shaft resistance of ZK01 from compress load test and uplifting load test

Elevation of layer top (m)	**Elevation of layer bottom (m)**	**Thickness of layer (m)**	**Soil type**	**Compressing shaft resistance (kPa) A**	**Uplift shaft resistance (kPa) B**	**B/A**
-10.1	-12.72	2.62	mud	23	11	0.48
-12.72	-20.62	7.90	Silt clay with mud	54	20	0.37
-20.62	-23.62	3.00	Silt sand	67	36	0.54
-23.62	-31.82	8.20	Silt sand	107	69	0.64
-31.82	-41.62	9.80	Silt clay with mud	105	81	0.77
-41.62	-57.92	16.30	Silt clay	94	77	0.82
-57.92	-59.62	1.70	Silt clay	95	79	0.83
-59.62	-63.70	4.08	Silt sand	128	101	0.79

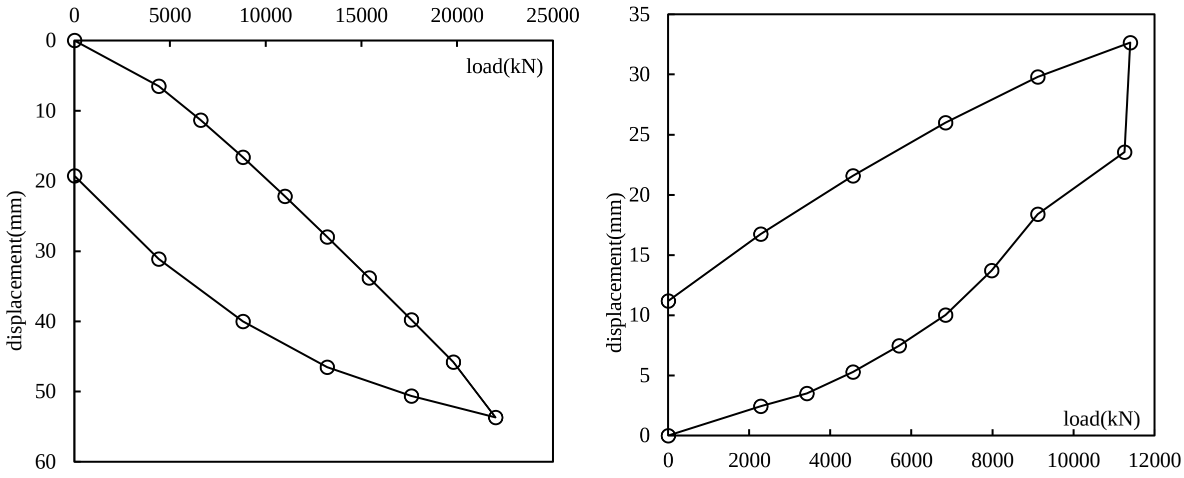
Table 3 the shaft resistance of ZK28 from compress load test and uplifting load test

Elevation of layer top (m)	**Elevation of layer bottom (m)**	**Thickness of layer (m)**	**Soil type**	**Compressing shaft resistance (kPa) A**	**Uplift shaft resistance (kPa) B**	**B/A**
-10.5	-11.87	1.37	Silt sand	32	9	0.28
-11.87	-19.77	7.90	Silt clay with mud	40	12	0.30
-19.77	-23.07	3.30	Silt sand	63	31	0.49
-23.07	-30.07	7.00	Silt sand	77	44	0.57
-30.07	-40.17	10.10	Silt clay with mud	80	53	0.66
-40.17	-52.17	12.00	Silt sand	103	66	0.64
-52.17	-56.77	4.60	Silt clay	111	81	0.73
-56.77	-64.17	7.40	Silt sand	135	93	0.69
-64.17	-66.07	1.90	Silt clay	97	64	0.66
-66.07	-69.60	3.53	Silt	114	77	0.68

From table 2 and table 3, it is obvious to see that the ultimate resistance from uplift loading tests are lower than that from compressing loading test. The ration of their shaft resistance is range from 0.28 to 0.83.

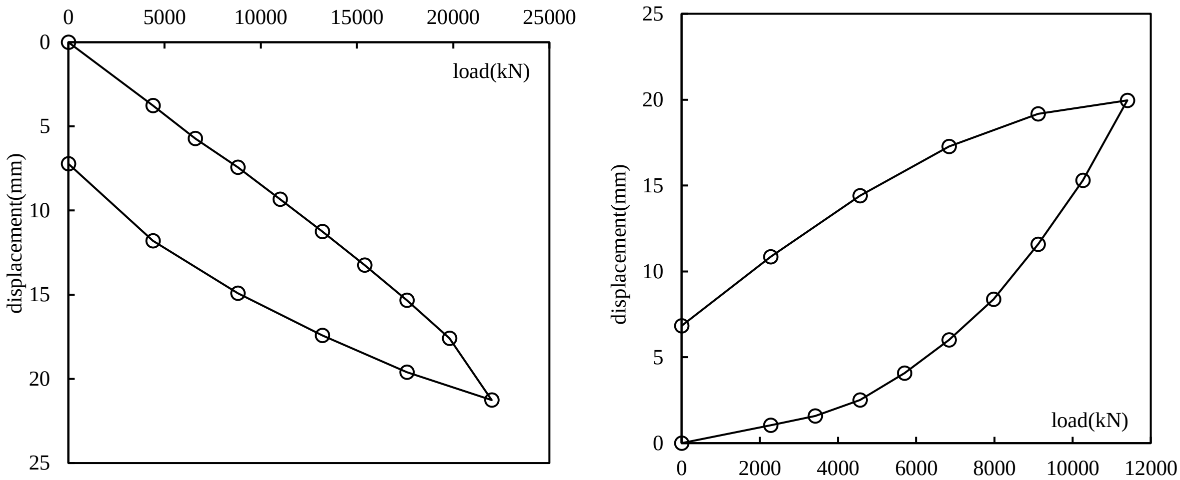
Project 2

The offshore wind farm is located in the sea are of Fujian province, two piles (1-9 and 2-9 in table 1) conducted with test A and test B at each pile. The vertical capacity is shown in Fig.3 and Fig.4, and the shaft resistance from two loading methods are shown in table 4 and table 5.



(a) (b)

Fig.3 1-9 (a) the downward load-displacement of pile top from test A and (b) the uplift load-displacement of pile top from test B



(a) (b)

Fig.4 2-9 (a) the downward load-displacement of pile top from test A and (b) the uplift load-displacement of pile top from test B

From Fig.3, the vertical compressing capacity of 1-9 is more than 22000kN, the total shaft resistance is 17902kN, the uplifting capacity of 1-9 is 11400 kN; the vertical compressing capacity of 2-9 is more than 22000 kN, the total shaft resistance is 6941 kN, and the uplifting capacity of ZK28 is 11400kN.

Table 4 the shaft resistance of 1-9 from compress load test and uplifting load test

Elevation of layer top (m)	**Elevation of layer bottom (m)**	**Thickness of layer (m)**	**Soil type**	**Compressing shaft resistance (kPa) A**	**Uplift shaft resistance (kPa) B**	**B/A**
-4.8	-12.6	7.8	Fine sand	71.2	48.1	0.68
-12.6	-16.2	3.6	Medium sand	77.5	53.4	0.69
-16.2	-21.6	5.4	clay	63.1	44.8	0.71
-21.6	-22.6	1.0	medium coarse sand	92.9	62.1	0.67
-22.6	-27.0	4.2	Fully weathered granite	122.5	72.3	0.59
-27.0	-43.3	16.3	strongly weathered granite	145	77.4	0.53

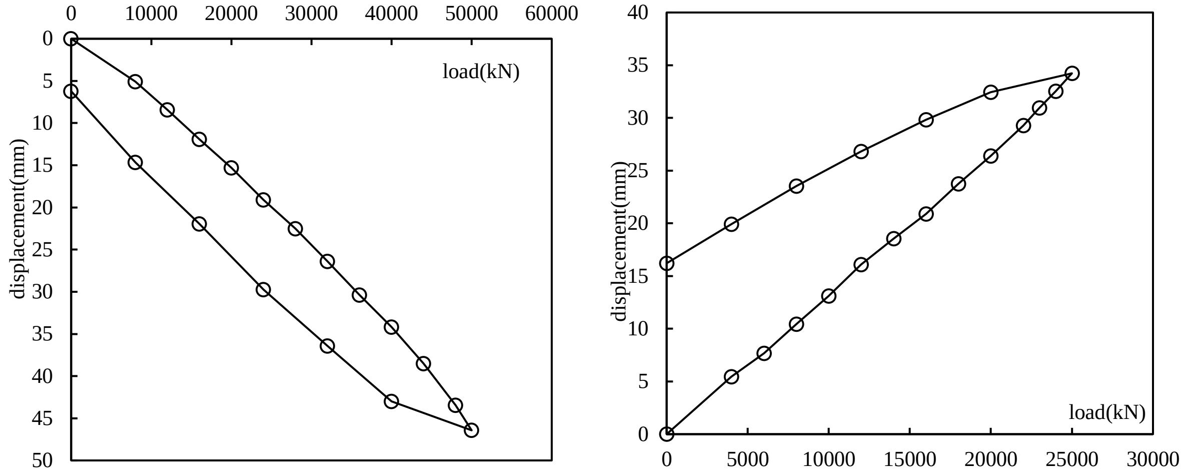
Table 5 the shaft resistance of 2-9 from compress load test and uplifting load test

Elevation of layer top (m)	**Elevation of layer bottom (m)**	**Thickness of layer (m)**	**Soil type**	**Compressing shaft resistance (kPa) A**	**Uplift shaft resistance (kPa) B**	**B/A**
-6.1	-14.5	8.4	medium coarse sand	70.7	59	0.83
-14.5	-18.5	4.1	Fully weathered granite	116.9	86.9	0.74
-18.5	--31.00	12.5	strongly weathered granite	145	107.8	0.74

From table 4 and table 5, it is obvious to see that the ultimate resistance from uplift loading tests are lower than that from compressing loading test. The ration of their shaft resistance is range from 0.53to 0.83.

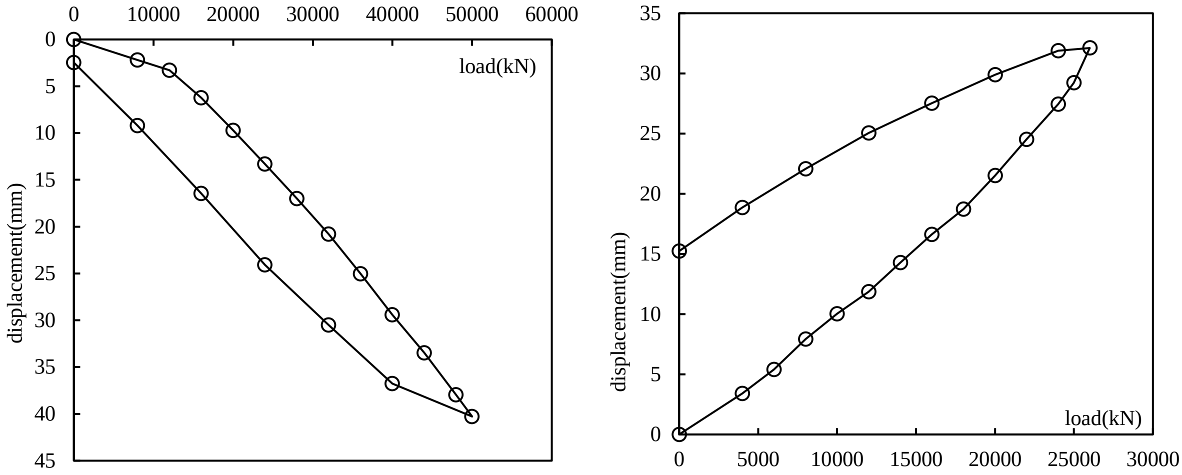
Project 3

The offshore wind project is also located in the coast area of Jiangsu province, the soil profile in this area is also sand and clay. Two test piles (S1 and S2, shown in table 1) were conducted with compression load test and uplift load test at each of same piles. The vertical capacity curves are shown in Fig.5 and Fig.6, and the shaft resistance from two loading methods are shown in table 6 and table 7.



(a) **(b)**

Fig.5 S1 (a) the downward load-displacement of pile top from test A and (b) the uplift load-displacement of pile top from test B



(c) **(d)**

Fig.6 S2 (a) the downward load-displacement of pile top from test A and (b) the uplift load-displacement of pile top

Table 6 the shaft resistance of S1 from compress load test and uplifting load test

Elevation of layer top (m)	**Elevation of layer bottom (m)**	**Thickness of layer (m)**	**Soil type**	**Compressing shaft resistance (kPa) A**	**Uplift shaft resistance (kPa) B**	**B/A**
-13.5	-27.7	14.2	Silt clay with mud	22	11	0.50
-27.7	-31.2	3.5	Silt clay	56	28	0.50
-31.2	-60.5	29.3	Silt sand	72	36	0.50
-60.5	-73.5	13.0	Fine sand	101	50	0.49
-73.5	-85.5	12.0	Fine sand	119	60	0.50

Table 7 the shaft resistance of S2 from compress load test and uplifting load test

Elevation of layer top (m)	**Elevation of layer bottom (m)**	**Thickness of layer (m)**	**Soil type**	**Compressing shaft resistance (kPa) A**	**Uplift shaft resistance (kPa) B**	**B/A**
-13.50	-27.70	14.20	Silt clay with mud	22	11	0.50
-27.70	-31.20	3.50	Silt clay	56	28	0.50
-31.20	-60.50	29.30	Silt sand	72	36	0.50
-60.50	-73.50	13.00	Fine sand	101	51	0.50

-73.50	-85.50	12.00	Fine sand	121	61	0.50

From table 6 and table 7, it is obvious to see that the ration of their shaft resistance is range from 0.49 to 0.50.

In conclusion, the ratio of positive shaft resistance to the negative shaft resistance of different soil layers of each piles ranged from 0.45 to 0.83, which are lower than these suggested by the Code or in onshore projects [4-7]. The values of conversion factor and plugging effect coefficient in this paper can be used in offshore wind farm projects and provide reference to engineering practice.

Keywords: *Static Loading Tests; Steel Pipe Piles; Large Diameters; Offshore Wind Farms*

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