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Study on the generalized model of the lateral frictional resistance distribution under the ultimate state of the bored piles based on stratum structure

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ABSTRACT

Based on the results of the ultimate load distribution of the part of the bored piles in the vertical static load field test of single pile, combined with the analysis of the relevant piles and soil data, found that the lateral friction resistance distribution of the bored pile in the ultimate load state was mainly related to structure of the soil layer on the pile side. Based on this, the side resistance distribution mode of the pile under the ultimate load conditions is generalized into a trapezoid, wing-shaped, micro-arc, and "R" shaped. The lateral friction resistance of the pile is positively correlated with the hardness of the soil, and the depth, thickness can influence the pattern of distribution of lateral friction resistance.

Keywords: Stratigraphic structure; Bored pile; Ultimate load; Lateral friction resistance; Distribution mode; Generalization

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1. Introduction

As a foundation form with a long history, a good bearing capacity and a wide range of applications, the pile foundation is playing an increasingly important role in life with the continuous development of the construction industry. Among them, cast-in-situ piles are widely used in various engineering constructions due to the advantages of convenient construction, flexible size selection, and large bearing capacity of single piles.

The lateral resistance distribution of a pile is of great significance for the analysis and research of its bearing capacity and settlement. Liu Jinli [1] made a relevant analysis of the lateral resistance distribution pattern of the working load state and believed that the nature of the soil layer was the main influencing factor.

Generally speaking, we usually divide the bearing state of piles into two states: working state and limit state. The working state refers to the state when the pile can work normally, and the corresponding load at this time is the working load; and the limit state refers to the state when the pile can withstand the limit equilibrium, the corresponding load is called the limit load at this time. Most of the related scholars' researches on pile-side resistance have started from the working load state and rarely used the limit load state. However, the limit state, as the critical point of large settlement and stable load, is of great significance for the application of piles in practical engineering.

Jiang Jianping [2] et al. believed that the stratigraphic structure refers to the overlapping, stacking form or spatial combination of strata in the stratigraphic sequence. For pile foundations, the stratigraphic sequence around the pile varies, and the influence on the lateral resistance distribution pattern is also extremely complicated.

The author has collected a large number of field test data for cast-in-place piles, including axial force, lateral resistance, load settlement curve, the pile's own parameters and related geological and soil layer data, etc. the test pile locations cover the coastal inland of China, the northern and southern regions of China, including various pile lengths and various geological conditions of the soil layer.

Based on previous research, this paper collects the data of side resistance under the limit load state, combines it with the concept of stratum structure, and makes a generalized classification model of side resistance that is different from previous people. It is hoped to summarize the influence of formation structure on the lateral resistance distribution in the limit state and provides a basis for determining the distribution of lateral resistance for the actual project, and further determines the bearing capacity of the cast-in-place pile.

2. Generalized classification of lateral resistance distribution patterns

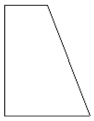
2.1 Generalization method

Generalization follows the principle of "simplification of complexity and simplicity", and simplifies the complicated lateral resistance curve into a curve or line chart that is similar to the shape of the measured image.

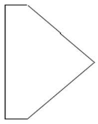
Because the effect of stratigraphic structure on the distribution of lateral resistance is mainly studied, the soil layer is first divided into six categories according to hardness refer to Liu Jinli's classification results: ultra-soft soil, soft soil, softer soil, harder soil, hard soil, and hard soil.

2.2 Side Resistance Generalization Mode

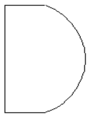
According to the methods and principles above, the distribution of lateral resistance is divided into four categories along the pile body under the limit load state of the cast-in-place pile. A simplified diagram of the generalization mode is shown in Figure 1.



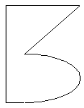
(a) Positive trapezoidal distribution



(b) Wing-shaped distribution



(c) Micro-arc distribution



(d) "R" shaped distribution

Fig.1 A brief map of the pattern of generalization of lateral friction resistance along the pile body

3. Generalization model of pile-side resistance based on stratum structure

Considering the complexity of the stratum structure, the generalization model study combines the following aspects: stratum structure factors in terms of hardness combination, stratum structure factors in terms of a certain soil layer thickness, stratum structure factors in terms of the depth of a certain soil layer, and soil layer collocation Stratigraphic factors in combination. The detailed analysis of these four generalized classifications combined with specific cases will be described below. Since there are many pictures and cannot be listed one by one, only some of them are taken as examples.

3.1 Positive trapezoidal distribution

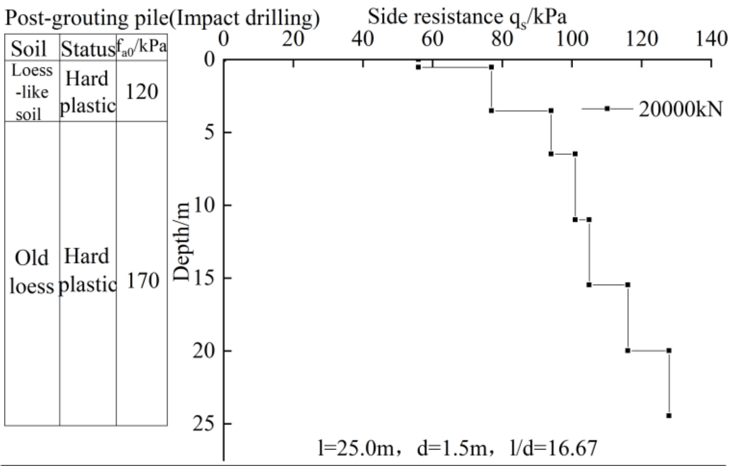
The side resistance distribution diagram is as follows: from the top of the pile to the end of the pile, the curve gradually increases at an angle.

3.1.1 Formation structure factors in terms of hardness combination

Figure 2-4: The hardness distribution of the soil layer is as follows: soft-softer-harder-hard. The soil on the side of the top pile is the softest and the bottom is the hardest.

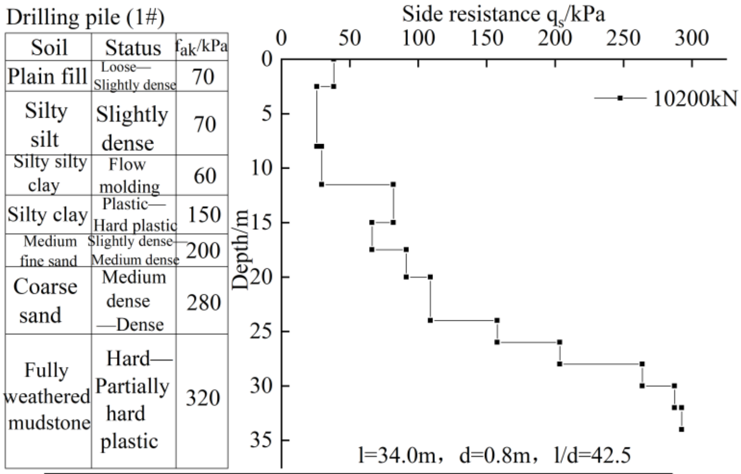
3.1.2 Stratigraphic factors in the thickness of a certain soil layer

Take old loess for example. When the thickness of the soil layer accounts for more than four-fifths of the pile length, the overall distribution of side resistance changes little, and the curve is excessively soft. See Figure 2.



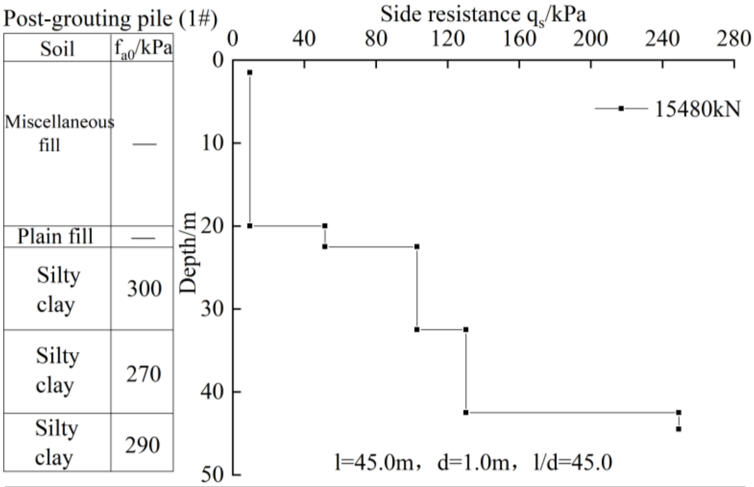
Q_0/kN	2000	3000	4000	5000	6000	7000	8000	9000	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000	21000
α	0.64	0.65	0.59	0.56	0.56	0.55	0.54	0.54	0.53	0.50	0.48	0.46	0.46	0.45	0.44	0.42	0.41	0.41	0.40	—
s/mm	0.55	0.95	0.95	1.23	1.77	2.45	2.45	2.18	2.32	3.00	3.55	4.36	5.32	7.09	7.77	9.27	10.50	12.41	17.45	65.73

Fig.2 Distribution curves of shaft resistance, tip resistance ratio and pile top settlement under the extreme load conditions using static load tests on piles in Yulin[3]（α is the tip resistance ratio, α = total tip resistancepile Q_p / top load Q_0)



Q_0/kN	2040	3060	4080	5100	6120	7140	8160	9180	10200
α	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.05
s/mm	1.02	1.94	2.96	4.51	6.55	9.14	12.24	16.66	22.67

Fig.3 Distribution curves of shaft resistance, tip resistance ratio and pile top settlement under the extreme load conditions using static load tests on piles in Qingdao[4]



Q_0/kN	1720	2580	3440	4300	5160	6020	6880	7740	8600	9460	10320	11180	12040	12900	13760	14620	15480	16340
α	0.00	0.10	0.07	0.08	0.11	0.14	0.14	0.14	0.16	0.17	0.18	0.19	0.22	0.25	0.28	0.31	0.36	—
s/mm	0.74	1.61	2.48	3.22	3.84	4.59	5.58	6.32	7.07	8.06	8.93	10.79	12.02	14.38	17.73	21.45	28.39	41.28

Fig.4 Distribution curves of shaft resistance, tip resistance ratio and pile top settlement under the extreme load conditions using static load tests on piles in Xingyang[5]

3.2 Wing-shaped distribution

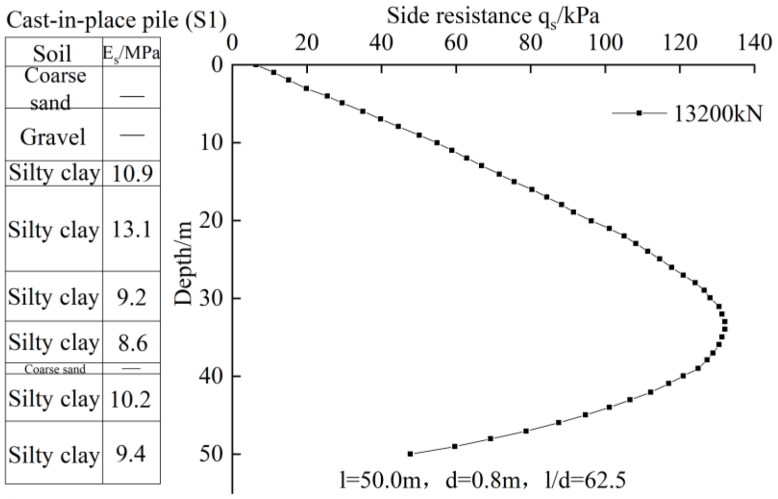
The distribution diagram of side resistance is as follows: the curve of the middle part of the pile is obviously sharp, and the side resistance at the end of the pile is smaller.

3.2.1 Formation structure factors in terms of hardness combination

The hardness distribution of the soil layer is as follows from Figure 5 to Figure 8: softer—harder (hard) or the entire soil layer is distributed in softer (harder) layers. The whole is dominated by a large range of silty clay or clay.

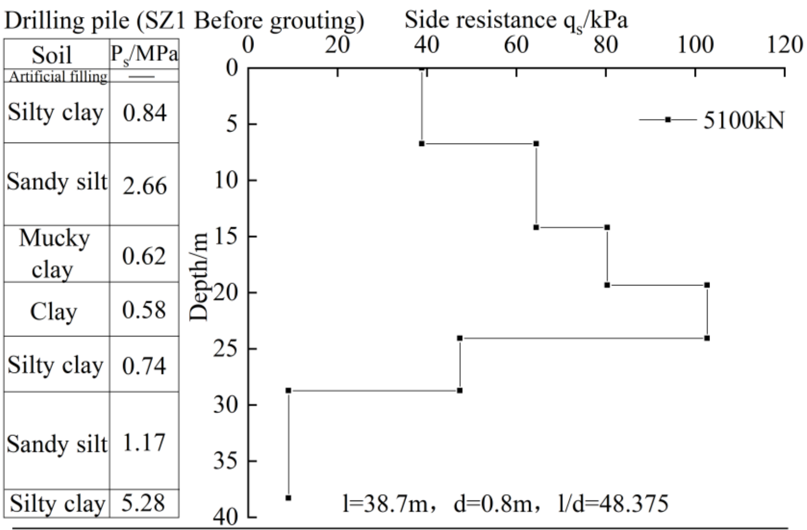
3.2.2 Stratigraphic factors in the thickness of a certain soil layer

Take silty clay, subclay, clay and sand, and silt as examples. Under the influence of no muddy soil and rock layer or pebbles layer around the pile, if there is silty clay and clay in a very thick range along the pile body, and the extremely thin sand and silt are mixed, then the sand, There is no unevenness on the side resistance curve of silt. As shown in Figure 5, Figure 7, Figure 8. Conversely, if all the sand along the pile is thick sand and silt, and mixed with very thin silty clay, clay, or the thickness of the two are staggered, the curve will appear bump change corresponding to the different soil layers as shown in Figure 6.



Q_0/kN	2400	3600	4800	6000	7200	8400	9600	10800	12000	13200	14400	15600
α	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.08	0.10	0.14
s/mm	1.61	2.81	4.41	6.42	8.03	10.03	12.04	14.85	18.06	21.67	36.52	56.19

Fig.5 Distribution curves of shaft resistance, tip resistance ratio and pile top settlement under the extreme load conditions using static load tests on piles in Xi'an[6]



Q_0/kN	600	900	1500	1800	2400	3000	3600	4200	4800	5100	5400
α	0.00	0.00	0.01	0.01	0.02	0.03	0.03	0.03	0.03	0.04	0.08
s/mm	1.37	2.06	3.43	4.34	6.40	8.23	10.97	13.94	17.60	19.66	48.69

Fig.6 Distribution curves of shaft resistance, tip resistance ratio and pile top settlement under the extreme load conditions using static load tests on piles in Shanghai[7]

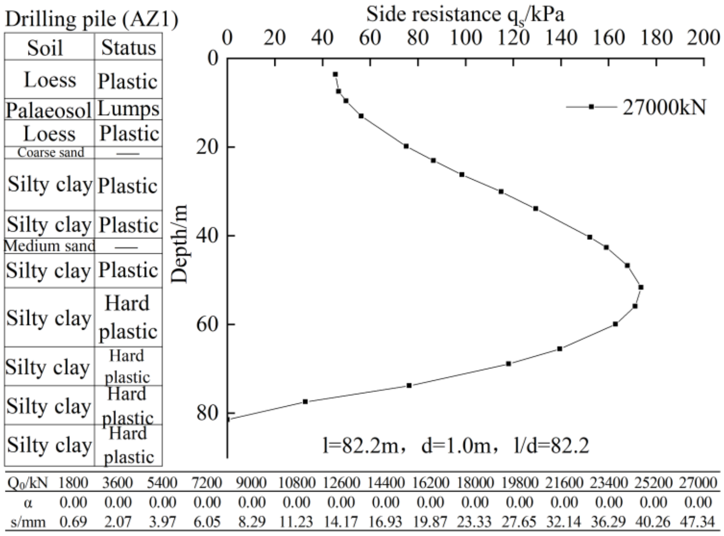


Fig.7 Distribution curves of shaft resistance, tip resistance ratio and pile top settlement under the extreme load conditions using static load tests on piles in Xi'an[8]

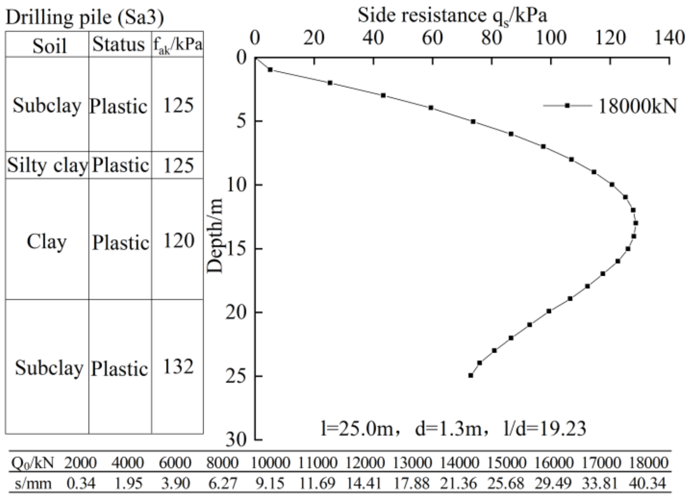


Fig.8 Distribution curves of shaft resistance, tip resistance ratio and pile top settlement under the extreme load conditions using static load tests on piles in Xi'an[9]

3.3 Micro-arc distribution

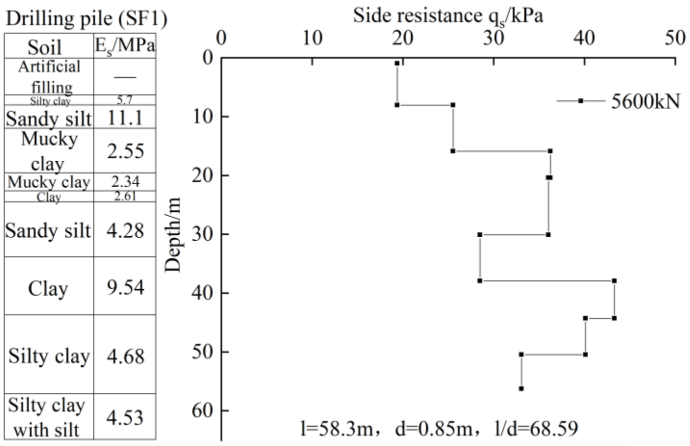
The side resistance distribution chart is as follows: the overall side resistance distribution is more uniform, the middle part is slightly protruding or the whole is roughly on a vertical line.

3.3.1 Formation structure factors in terms of hardness combination

The soil layer hardness distribution from Figure 9 to Figure 13: softer-harder (softer), with softer layers as the mainstay; or harder-harder, with harder layers as the mainstays. The soil layer has no sudden change in hardness, and the transition section is not obvious. Generally, it is an interactive transition layer formed by a soil layer close to the hardness. The soil layer is almost all silty clay, no rock layer.

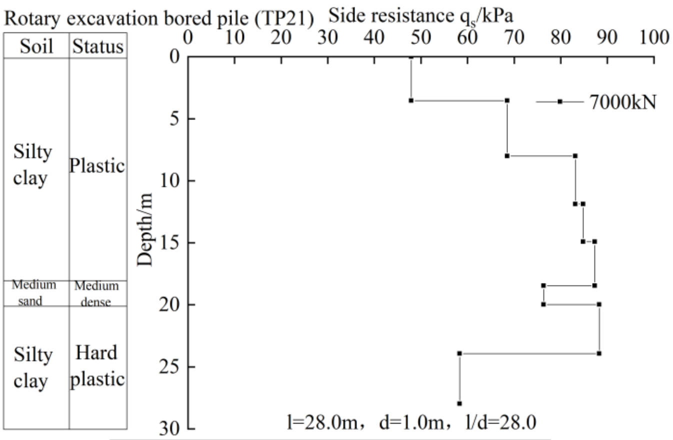
3.3.2 Stratigraphic factors in the thickness of a certain soil layer

Take silty clay, subclay, clay and sand, and silt as examples. The law is the same as the section of 3.2.2. As shown in Figure 10, Figure 13. Conversely, as shown in Figure 9, Figure 11, Figure 12.



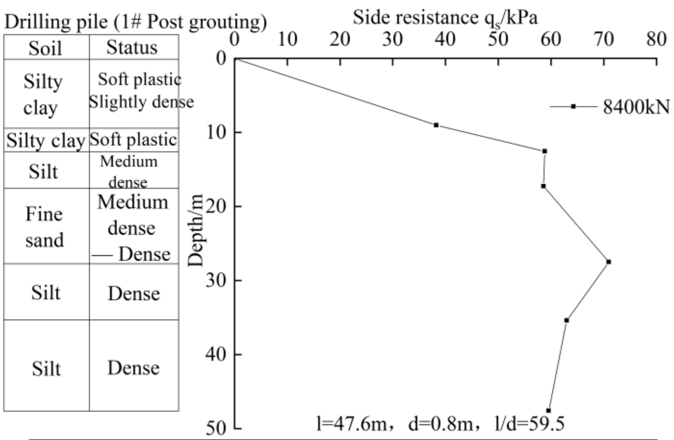
Q_0/kN	1600	2400	3200	4000	4800	5600	6400	6800
α	0.00	0.01	0.01	0.02	0.02	0.02	0.05	0.07
s/mm	1.74	3.04	4.35	6.09	10.43	17.83	69.57	105.22

Fig.9 Distribution curves of shaft resistance, tip resistance ratio and pile top settlement under the extreme load conditions using static load tests on piles in Shanghai[10]



Q_0/kN	2000	3000	4000	5000	6000	7000	8000
α	0.03	0.03	0.04	0.05	0.05	0.07	—
s/mm	0.98	2.16	3.73	6.67	15.69	25.69	62.94

Fig.10 Distribution curves of shaft resistance, tip resistance ratio and pile top settlement under the extreme load conditions using static load tests on piles in Xi'an[11]



Q_0/kN	1400	2100	2800	3500	4200	4900	5600	6300	7000	7700	8400
α	0.12	0.11	0.10	0.09	0.08	0.08	0.08	0.09	0.12	0.13	0.16
s/mm	1.60	2.84	3.90	5.14	6.56	8.33	11.17	13.83	17.55	20.92	25.53

Fig.11 Distribution curves of shaft resistance, tip resistance ratio and pile top settlement under the extreme load conditions using static load tests on piles in Zhengzhou[12]

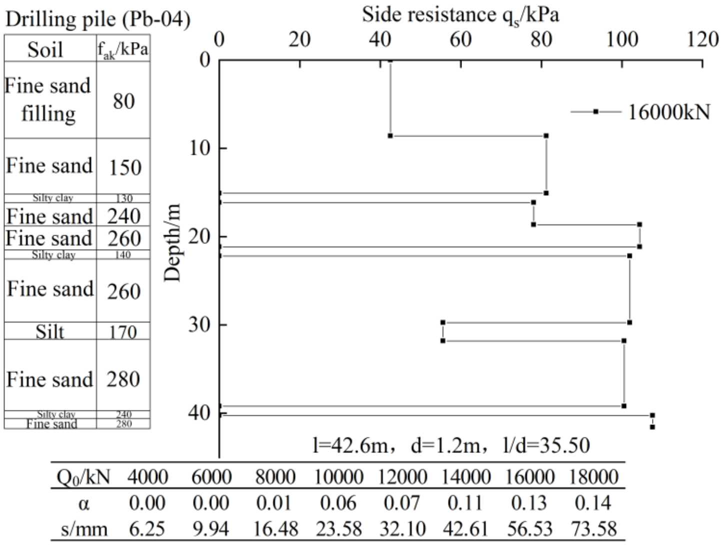


Fig.12 Distribution curves of shaft resistance, tip resistance ratio and pile top settlement under the extreme load conditions using static load tests on piles in Tangshan[13]

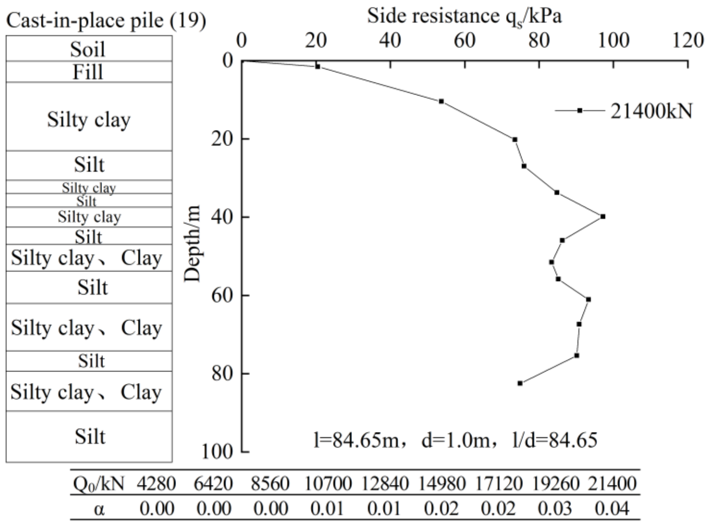


Fig.13 Distribution curves of shaft resistance, tip resistance ratio and pile top settlement under the extreme load conditions using static load tests on piles in Tianjin[14]

3.4 "R" shaped distribution

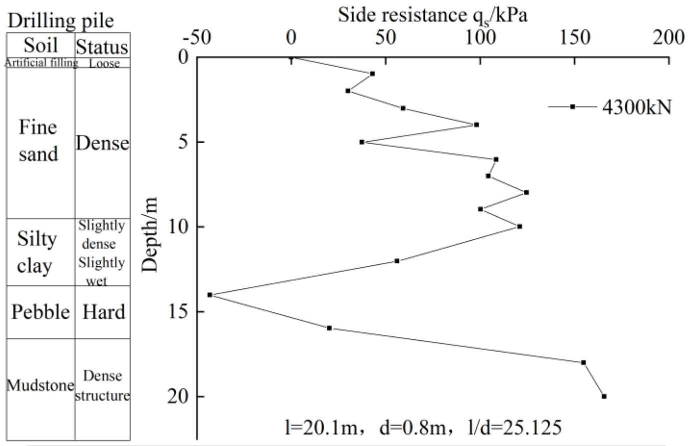
The side resistance distribution diagram shows that the curve has a significant depression in the middle of the pile body, the side resistance at the end of the pile is large, and the side resistance at the top of most piles is small, almost close to zero.

3.4.1 Formation structure factors in terms of hardness combination

The hardness distribution of the soil layer in Figure 14 and 15: soft—harder—softer—hard (hard), the middle part is soft, and the bottom is the hardest, and the hardness of the bottom soil layer is significantly different from the hardness of the upper connecting layer, that is, the bottom The hardness of the soil layer increased sharply. Most piles that meet this type have more than a quarter of the entire hard soil layer or hard soil layer at the bottom.

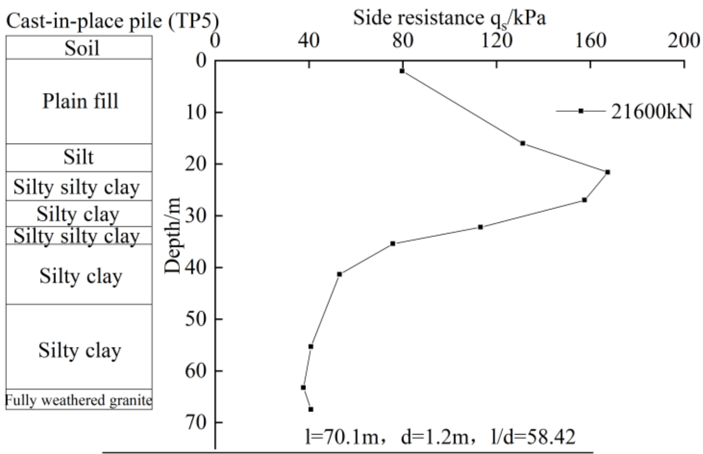
3.4.2 Stratigraphic factors in the thickness of a certain soil layer

Take rock formations as an example. Rock layers are generally distributed at the end of piles as a bearing layer. The thinner the thickness of the rock layer, the less obvious the abrupt change in the lateral resistance curve at the position of the pile end as shown in Figure 14 and 15.



Q_0/kN	860	1290	1720	2150	2580	3010	3440	3870	4300	4730
α	0.11	0.08	0.10	0.10	0.10	0.10	0.11	0.11	0.10	0.13
s/mm	0.30	0.59	1.79	3.50	4.98	6.62	8.50	11.61	15.76	29.55

Fig.14 Distribution curves of shaft resistance, tip resistance ratio and pile top settlement under the extreme load conditions using static load tests on piles in Lanzhou[15]



Q_0/kN	4800	7200	9600	12000	14400	16800	19200	21600
α	0.06	0.05	0.06	0.06	0.12	0.06	0.08	0.35
s/mm	4.27	5.76	8.54	13.02	25.61	30.95	45.46	61.46

Fig.15 Distribution curves of shaft resistance, tip resistance ratio and pile top settlement under the extreme load conditions using static load tests on piles in Guangdong[16]

4. Traits of Lateral Resistance

(1) The numerical values of most lateral resistance distribution curves are positively related to the hardness of the soil layer around the

pile, that is, the lateral resistance value increases as the soil layer hardness increases and decreases as the soil layer hardness decreases.

(2) There is a small number of lateral resistance values at the pile body that do not match the formation hardness. For example, the lateral resistance of a pile side is smaller than that at a hard soil layer.

(3) Due to the above two reasons, a variety of lateral resistance characteristics have been formed under the influence of the stratum structure and other factors. Therefore, in addition to the stratigraphic structure as the main influencing factor, the lateral resistance generalization model should also consider other influencing factors.

5. Conclusion

Combining with the general analysis of the lateral resistance distribution curve model of the cast-in-situ field test, the following conclusions are drawn.

(1) After simplifying and generalizing the lateral resistance distribution curve, it is found that the most important influencing factor of the lateral resistance distribution mode under the limit load state of the cast-in-place pile is the stratum structure, and the lateral resistance distribution map is generalized into four modes.

(2) The main factors in the stratum structure are the stratum structure factors in terms of hardness combination, and the rest include the stratum structure factors in the thickness of a certain soil layer and the stratum structure factors in the depth of a certain soil layer.

(3) The generalized results of the side resistance distribution pattern under the limit load state can be used for the analysis and reference of the side resistance test results. For projects that are difficult to perform field tests, according to the field geological data and the relevant conclusions in the article, the limit load state is performed Judgment of side resistance distribution.

(4) The field test data of the limit load state currently used is limited. In addition, due to the complexity of the stratum structure, the analysis of the correlation between it and the side-resistance distribution model is also limited, and it needs to be continuously supplemented and improved in the future.

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