Bearing mechanism of a single socketed pile in soft rock

Mou roche incruster roche poteau les échos

C. Mei, X.D. Fu□, B. Huang, B.J. Zhang, Z.J. Yang
School of Civil Engineering, Wuhan University, Wuhan, Hubei, China

ABSTRACT: A series of model pile load tests using the self-design test apparatus have been carried out to investigate the effects of pile diameter, socketed depth and overburden pressure on the bearing behaviour of drilled shaft in simulated soft rock. Because of the large variation of pile stiffness, Chin-Kondner criterion was recommended to determine the bearing capacity of model piles from Q-s curve. Additionally, the suitability of base capacity prediction by using spherical cavity theory has been explored. The results showed that the capacity of drilled pile increases obviously with increasing socketed depth, pile diameter and overburden pressure. Further, the experimental results have been compared with calculation value of spherical cavity used to predict ultimate end-bearing capacity, and their relative error has been analysed. The research has revealed that the end-bearing capacity of drilled pile in soft rock can be reasonably predicted by spherical cavity expansion theory.

RÉSUMÉ : À des fins de recherche pieu souples roche incruster roche burden of performance, ont mené des modèles. Étant donné que les denous dureté, Chin-Kondner pour déterminer dans pieu modèles limitation des tunnels. Défoncer la doctrine à l'extrémité pieu souples roche incruster roche l'applicabilité des tunnels d'analyse a également été débattue. Les résultats de l'étude ont montré qum, Au fur et à mesure que la profondeur denous sentier, roche, la pression accrue, notamment en pieu beaucoup plus de tunnels. Les résultats des essais à partir des calculs avec ballon orifice d'expansion, ainsi que ceux qui les erreurs, Ballon orifice que l'expansion de conserver à l'extrémité pieu roche souples roche enchâsser dans l'analyse des tunnels.

KEYWORDS: simulated soft rock; model test; bearing capacity; spherical cavity theory

1 INTRODUCTION

Rock-socketed drilled piles have received much adoption in huge construction projects, such as high-rise buildings, long-span bridges and offshore drilling platforms, due to its properties, which offer high bearing capacity, stiffness and good seismic performance. So many drilled piles are docketed in soft rock because of the soft rock's widely distribution in the world, for instance, about 60% of drilled piles was embedded in soft rock in Najing, China (Liu 1998) and over 90% in Korea (Lee 2013).

In this paper, the synthetic materials as cement, plaster, medium sand, water and concrete hardening accelerator, have been applied to obtain soft rock sample in model tests. And then an experimental study was conducted on the bearing capacity of socketed pile in soft rock, which put into these factors as socketed depth, pile diameter and overburden pressure into consideration. In addition, ultimate load criteria and application of spherical cavity expansion to calculate end-bearing capacity of socketed pile in soft rock were discussed.

2 EXPERIMENT PROGRAM

2.1 *Synthetic material of soft rock*

Drawing on the experience of predecessors (Johnston 1986; Indraratna 1990), the mixtures of Portland cement, gypsum powder, river sand, concrete hardening accelerator and water were used to form synthetic soft rock. With the proportion of cement: plaster: sand: water: concrete hardening accelerator = 4.5%:5.0%:84.71%:4.75%:1.04%, the specimens were prepared for 1.8g/cm^3 density with curing time of 7 days. After uniaxial and triaxial compression tests, the average value of uniaxial compressive strength was 1.44MPa and deformation modulus =157.88MPa (confining pressure=0kPa), and the parameters of Mohr-Coulomb were attained as follow, cohesion intercept c=0.34MPa, friction angle φ =43.40°.

2.2 *Design of model pile*

The model piles were made from aluminum alloy with diameters of 24mm and 40mm. The surfaces of model piles were knurled to simulate a roughened pile surface, and it could make sure of good interaction between the model pile and soft rock.

2.3 *Equipment*

The model pile tests were performed on the self-developed apparatus, which could capture the deformation shape of rock or soil during pile loading with CT scanning technique (Fu 2015), as detailed in Fig.1. These parameters as pile diameter, pile length and overburden pressure affecting the performance of pile bearing could also be investigated by this apparatus.

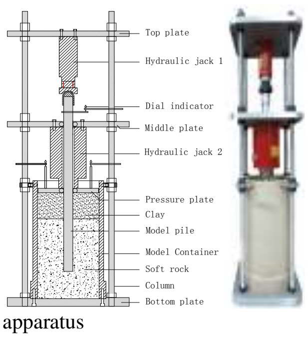


Figure 1 Model test apparatus

2.4 *Testing program*

Consideration was given to these factors as pile diameter, socketed depth and overburden pressure, and the details of testing program were listed in Table 1.

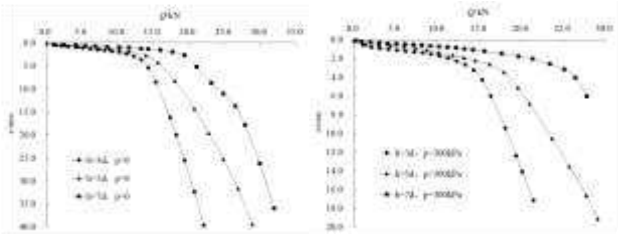
Table 1 Model test programs of socketed pile in soft rock

No.	Pile diameter (d/mm)	Socketed depth (h)	Overburden pressure (p/kPa)
A1	24	3d	0
A2	24	5d	0
A3	24	7d	0
A4	24	5d	100
A5	24	5d	300
A6	24	5d	500
A7	24	3d	300
A8	24	7d	300
B1	40	5d	0
B2	40	5d	300
B3	40	7d	0

3 RESULTS OF MODEL TESTS

3.1 *Influence of socketed depth*

The test results of model piles with diameter d=24mm were shown in Fig. 2. It is observed that bearing capacity of the model pile increases significantly with the increase of socketed depth.

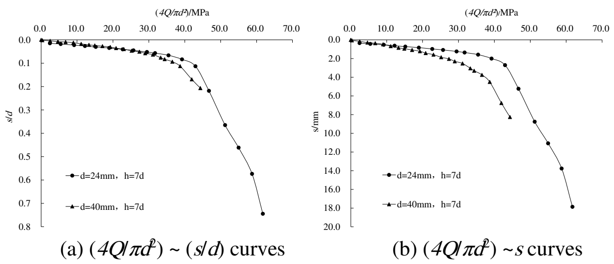


(a)Overburden pressure=0 (b) Overburden pressure=300kPa

Figure 2 Influence of socketed depth on load-settlement curve

3.2 *Influence of pile diameter*

The results were given in Fig.3 (a), which showed the normalized load ($4Q/\pi d^2$) against the normalized displacement (s/d). The curves of different pile diameters display the same shape, which indicates that they had the same failure pattern. For the same socketed depth, the bearing capacity increases markedly with the growth of pile diameter. But when pile diameter increases, the side shaft resistance and base resistance decreases slightly, as illustrated by Fig.3 (b). It is widely accepted that the size effect caused the decrease of side shaft resistance and base resistance.

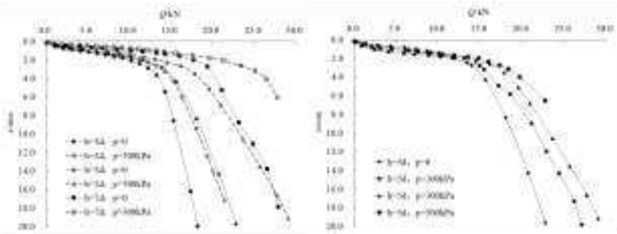


(a) ($4Q/\pi d^2$) ~ (s/d) curves (b) ($4Q/\pi d^2$) ~s curves

Figure 3 Different diameters on bearing curves

3.3 *Influence of overburden pressure*

The behavior of soft rock is highly dependent on stress level and stress state. The results with different overburden pressure were presented in Figs.4 (a) and (b). As evident form the figures, the overburden pressure had little effect on the initial line of Q-s curve, which indicated that overburden pressure may count for little of bearing capacity increase at the beginning of loading program.



(a) (b)

Figure 4 Different overburden pressure on bearing curves

4 DISCUSSION OF BEARING MECHANISM OF SINGLE PILE IN SOFT ROCK

4.1 *Failure criteria*

There are many "interpreted" failure criteria proposed in the literature to determine the bearing capacity of piles using pile test results for different pile types. Because of the variability in axial stiffness over the length of model pile (due to diameter variability), the Chin-Kondner (1970) method was recommended to determinate bearing capacity of model rock-socketed pile, as given by:

$$Q = \frac{s}{C_1 s + C_2} \quad (1)$$

$$Q_u = \frac{1}{C_1} \quad (2)$$

where Q = load at the pile head, s = pile-head displacement, C_1 and C_2 are curve fitting parameters. Q_u is the ultimate load of the pile.

For the Chin-Kondner criterion, few point may be scatted due to the elastic displacement of the pile or the displacements within the loading apparatus at the beginning of loading. The ultimate capacities of model piles were listed in Table.2.

Table 2 Bearing capacity using Chin-Kondner method

Diameter (d/mm)	Socketed depth	Overburden pressure	Ultimate bearing capacity (kN)
24	3d	0	22.73
24	5d	0	30.1
24	7d	0	32.26
40	5d	0	49.63
40	7d	0	72.96

4.2 *Method for predicting base resistance*

The application of cavity expansion theory to calculate the base pile resistance was first presented by Gibson (1950). Many scholars concentrated on this problem later, but their research was mostly on the pile capacities in clay or sand (Yeung 1989; Randolph 1994; Yasufuku 1995). And cavity expansion theory did not work on the capacity of pile socketed in hard rock. But there is something needed to be clarified that whether well and reasonable or not its application as for soft rock.

Vesic (1972) presented approximate solutions for limiting pressures for a spherical cavity solutions in a cohesive frictional material and applied these solution to the determination of bearing capacity for deep foundations. Fig.5 indicates the assumed failure mechanism for frictional soils. Base on the Mohr-Coulomb criteria, the Vesic cavity expansion pressure p_u in Eq. (3) was given by

$$p_u = (q' + c'\cot\varphi')\frac{3(1+\sin\varphi')}{3-\sin\varphi'}(I_{rr})^{\frac{4\sin\varphi'}{3(1+\sin\varphi')}} - c'\cot\varphi' \quad (3)$$

where reduced rigidity index $I_{rr} = \frac{\eta I_r(1+\Delta)}{1+\eta I_r \Delta}$, rigidity index $I_r = \frac{G}{c' + q'\tan\varphi'}$, $\eta = \frac{3-\sin\varphi'}{3\cos\varphi'}$, $q' = \frac{1+2K_0}{3}\gamma h$; G= shear stiffness and Δ is the average volumetric strain in the plastic zone. In this paper, the average volumetric strain calculated by the empirical suggestion relation of Yasufuku et al. (2001) $\Delta = 50(I_r)^{-1.8}$.

Yansufuku and Hyde (1995) suggested this simple equation relating p_u to q_b showed as follow,

$$q_b = \frac{1}{1-\sin\varphi'} p_u$$

(4)

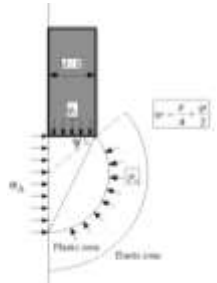


Figure 5 Failure mechanism assumed for pile in soft rock

4.3 *Comparison of bearing capacities-load tests versus calculation*

The bearing capacity of the socketed part in rock for rock-socketed pile, contains the side resistance and end resistance. It is generally believed that separating side and base resistance to be calculated also works well in practice.

For model pile with diameter d=40 mm, the measured average value of ultimate side shaft resistance was about 760kPa. In the following calculation, the shear resistance was selected with this value approximately. The calculation and model test results were listed in Table 3.

Table 3 Comparison of ultimate bearing capacity of cavity expansion and model tests

d/mm	*h*	Q_u by calculation(kN)			Q_u by model test (kN)
		Q_b	Q_s	Q_u	
24	3d	14.11	4.11	18.22	22.73
24	5d	14.12	6.85	20.97	30.12
24	7d	14.12	9.59	23.70	32.26
40	5d	39.23	19.01	58.24	52.58
40	7d	39.26	26.62	65.88	72.96

As indicated in Table 6, the error between the calculated ultimate bearing capacities and model testing ultimate bearing capacities was 19.8%, 30.4%, 26.5%, -10.8%, 9.7%, respectively. In calculation of side capacity of model pile with diameter 24mm, the real shear resistance would be a bit larger than the measured shear resistance of pile with diameter 40mm, so the real error given preciously would be smaller. Additionally, it appears that these factors caused the error as follow: the method calculating average volumetric strain was according to the empirical suggestion of Yasufuku et al (2001); the calculation method ignores influence between side and base resistance; the unfavorable effect on the model pile settlement was caused by the small deformations in the loading frame.

Based on the analysis mentioned above, there is a strong possibility and reasonability that spherical cavity expansion theory could be used to analyze the bearing mechanics of socketed pile in soft rock.

5 CONCLUSION

(1) It is a convenient and effective way to use these materials as sand, plaster, cement, concrete hardening accelerator to simulate soft rock, especially for the purpose of the model tests.

(2) The ultimate bearing capacity of the model pile in soft rock tends to increase markedly with the growing of overburden pressure.

(3) For model test of socketed pile in soft rock, it is a good recommendation to utilize Chin-Kondner (1970) hyperbolic method to determine the bearing capacity. However, some consideration should be given on ignored influence of slight deformation of testing equipment.

(4) The base resistance of socketed pile in soft rock was reasonably predicted using spherical cavity expansion theory.

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