

Influencing Factors and Evaluation Criteria of Pile Foundation Settlement in Karst Area

Anbing HU

Highway Administration of Huizhou Municipality
Huizhou, China
E-mail: l88618092@qq.com

Shanglin QIN

Institute of Rock and Soil Mechanics
Chinese Academy of Sciences
Wuhan, China
E-mail: slqin@whrsm.ac.cn

Hongming LUO

Institute of Rock and Soil Mechanics
Chinese Academy of Sciences
Wuhan, China

Abstract—In karst area, lots of piles through several caves and then supporting in a cave roof, thus forming more complex pile-soil-cave interaction. Research on the pile foundation settlement in beaded karst region, has strong theoretical and engineering significance to further improve the design theory of the pile foundation and guide the foundation design and construction. In this paper, it is found that in the stage of the construction of pile foundation, cave has little effect on the settlement. Under the upper load, the impact of the cave quantity and spacing is not significant, and the impact of the cave width is significant. In the effect of consolidation of the cave fillings, the cave has the greatest influence on the settlement. Overall speaking, the cave size has the greatest impact on the total settlement of the pile foundation, the cave quantity is the second, and the cave spacing has the minimal impact.

Keywords—karst; pile foundation; settlement; influence

I. INTRODUCTION

With the development of the infrastructure in China, more and more projects are located in the karst area[1-2]. Although there are many researches about the effect of karst cave on the pile bearing characteristics and the cave stability, but many of the existing researches is focus on pile supported on a single cave roof, very few consider the situation of the pile through several caves (i.e. string-beaded caves)[3-5]. In fact, in karst area, lots of piles through several caves and then supporting in a cave roof, thus forming more complex pile-soil-cave interaction, the current pile foundation design codes in this regard are failed to provide effective design calculation method[6-9]. Therefore, research on the pile foundation settlement in beaded karst region, has strong theoretical and engineering significance to further improve the design theory of the pile foundation and guide the foundation design and construction.

II. ANALYSIS METHOD

Use finite element numerical calculation method, considering the pile foundation construction load, the pile

upper load and the influence factors of the karst, the calculation is divided into 4 stages.

The first stage: the simulation of gravity, calculate the initial stress of the axisymmetric numerical model.

The second stage: the simulation of pile foundation construction, calculate the deformation and stress, the main load is pile weight.

The third stage: apply the upper load 158.7 T, calculate the stress and deformation under the action of external load.

The fourth stage: reduce the elastic modulus of the filling material (reduced by 70%), calculate the influence of the soft filler consolidation settlement on the stress and deformation of the pile.

III. ANALYSIS SCHEME

The analysis can be divided into the following conditions:

Combination conditions 1: The number of karst cave is respectively 1, 2, 3, the diameter is 3.6m, the spacing is 1.8m;

Combination condition 2: The number of karst cave is 3, the height is 3.6m, the width is respectively 2.4m, 3.6m, 4.8m, the spacing is 1.8m;

Combination condition 3: The number of karst cave is 3, the diameter is 3.6m, the spacing is respectively 0.6m, 1.2m, 1.8m.

IV. ANALYSIS OF THE INFLUENCING FACTORS OF THE PILE FOUNDATION SETTLEMENT

The settlement deformation of pile influenced by the cave quantity under the different load stages of pile construction, upper load and cave effect is shown in Fig. 1.

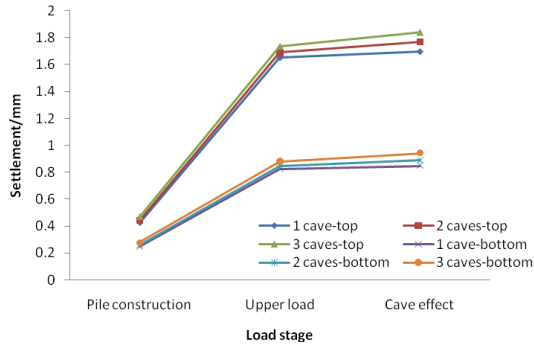


Figure 1. The settlement of pile influenced by the cave quantity under different load stages

In the stage of the construction of pile foundation, cave quantity has little effect on the settlement caused by the load of pile weight, the settlement at the top of the pile is 0.43~0.47mm, and it is 0.25~0.28mm at the bottom, the settlement of 3 caves is respectively 0.02mm and 0.04mm larger than that of 2 caves and 1 cave. Under the upper load, the total settlement the differential settlement of the top and the bottom of the pile increase significantly, but the impact of the cave quantity is still not significant, the top settlement increases to 1.65~1.73mm, the bottom settlement increases to 0.82~0.88mm, the settlement of 3 caves is respectively 0.03mm and 0.08mm larger than that of 2 caves and 1 cave. In the effect of consolidation of the cave fillings, the increment the total settlement the differential settlement of the top and the bottom of the pile are very small, the top settlement is 1.70~1.84mm, the bottom settlement is 0.85~0.94mm, at this time, the cave quantity has the largest influence on the settlement, the settlement of 3 caves is respectively 0.07mm and 0.14mm larger than that of 2 caves and 1 cave.

The settlement deformation of pile influenced by the cave width under the different load stages of pile construction, upper load and cave effect is shown in Fig. 2.

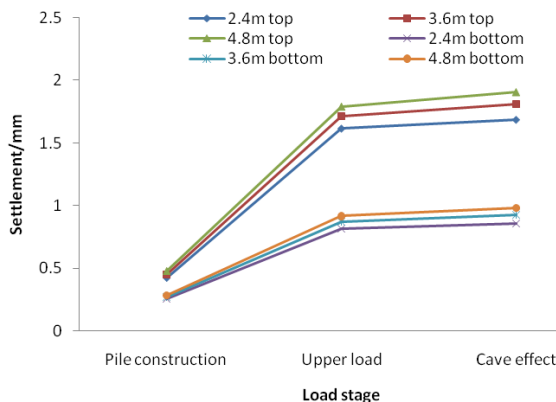


Figure 2. The settlement of pile influenced by the cave width under different load stages

In the stage of the construction of pile foundation, cave width has little effect on the settlement caused by the load of pile weight, the settlement at the top of the pile is

0.42~0.48mm, and it is 0.26~0.29mm at the bottom, the settlement of 4.8m width is respectively 0.03mm and 0.06mm larger than that of 3.6m width and 2.4m width. Under the upper load, the total settlement the differential settlement of the top and the bottom of the pile increase significantly, and the impact of the cave width is significant, the top settlement increases to 1.62~1.79mm, the bottom settlement increases to 0.82~0.92mm, the settlement of 4.8m width is respectively 0.08mm and 0.17mm larger than that of 3.6m width and 2.4m width. In the effect of consolidation of the cave fillings, the increment the total settlement the differential settlement of the top and the bottom of the pile are very small, the top settlement is 1.69~1.91mm, the bottom settlement is 0.86~0.98mm, at this time, the cave quantity has the largest influence on the settlement, the settlement of 4.8m width is respectively 0.10mm and 0.22mm larger than that of 3.6m width and 2.4m width.

The settlement deformation of pile influenced by the cave spacing under the different load stages of pile construction, upper load and cave effect is shown in Fig. 3.

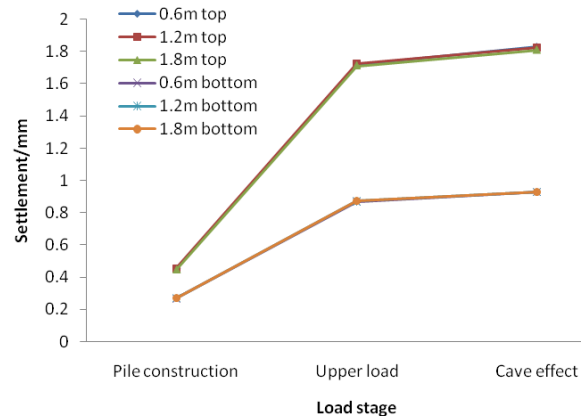
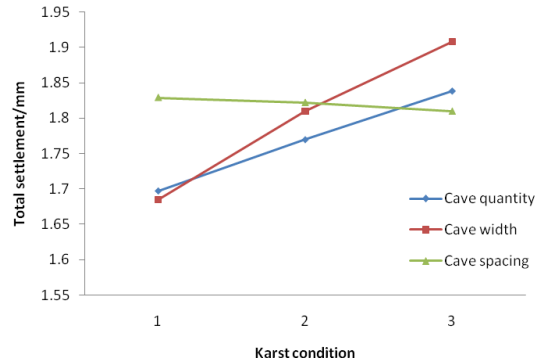


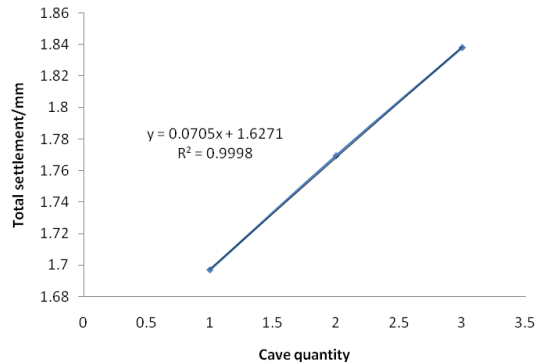
Figure 3. The settlement of pile influenced by the cave spacing under different load stages

In the stage of the construction of pile foundation, cave spacing has little effect on the settlement caused by the load of pile weight, the settlement at the top of the pile is 0.45~0.46mm, and it is 0.27mm at the bottom, the settlement of 0.6m spacing is not more than 0.01mm larger than that of 1.2m spacing and 1.8m spacing. Under the upper load, the total settlement the differential settlement of the top and the bottom of the pile increase significantly, but the impact of the cave spacing is still not significant, the top settlement increases to 1.71~1.72mm, the bottom settlement increases to 0.87mm, the settlement of 0.6m spacing is not more than 0.01mm larger than that of 1.2m spacing and 1.8m spacing. In the effect of consolidation of the cave fillings, the increment the total settlement the differential settlement of the top and the bottom of the pile are very small, the top settlement is 1.81~1.83mm, the bottom settlement is 0.93mm, the settlement of 0.6m spacing is respectively 0.01mm and 0.02mm larger than that of 1.2m spacing and 1.8m spacing.

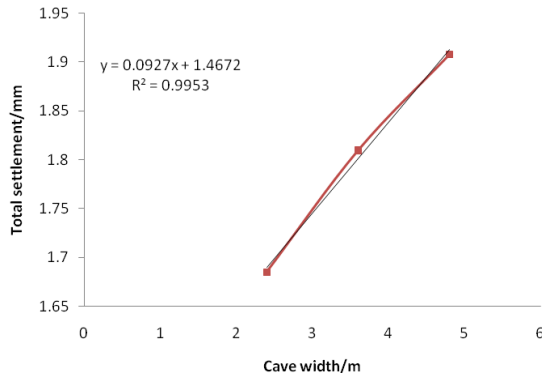
Fig. 4 shows the variation law of the total settlement of the pile foundation in different load stages under different karst conditions.



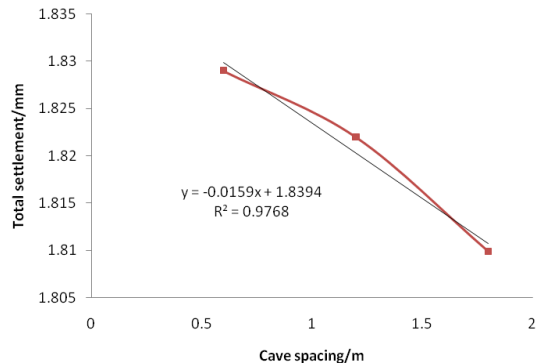
(a) Karst condition



(b) Cave quantity



(c) Cave size



(d) Cave spacing

Figure 4. The total settlement of pile under the influence of karst cave (Karst condition 1,2,3 respectively represents the cave number 1,2,3; the cave width 2.4,3.6,4.8m; the cave spacing 1.8,1.2,0.6m)

It can be seen from Fig. 4(a), with the increase of the number of karst cave, the size of the cave and the decrease of the distance between the karst cave, the total settlement of pile caused by the impact of the karst cave is gradually increasing.

The cave size has the greatest influence on the total settlement of pile, under the same conditions of 3 caves, the cave width increases from 2.4m to 4.8m, the total settlement of pile increases from 1.685mm to 1.908mm, in the case of a 100% increase in the size of karst cave, the total settlement of pile increases 13.23%.

The cave quantity has great influence on the total settlement of pile, which increases from 1.697mm of one cave to 1.838mm of three caves, in the case of a 200% increase in the number of karst cave, the total settlement of pile increases 8.31%.

The cave spacing has minimum influence on the total settlement of pile, under the same conditions of 3 caves, the cave spacing reduces from 1.8m to 0.6m, the total settlement of pile increases from 1.810mm to 1.829mm, karst spacing decreases by 66.7%, the total settlement of pile only increases 1.05%.

It can be seen from Fig. 4 (b), with the increase of the number of karst cave, the total settlement of pile increases, use the linear function to fit the empirical formula, the correlation coefficient reaches 0.999, the fitting formula is

$$s = 0.0705m + 1.6271 \quad (1)$$

where, m is the cave quantity.

It can be seen from Fig. 4 (c), with the increase of the width of karst cave, the total settlement of pile increases, use the linear function to fit the empirical formula, the correlation coefficient reaches 0.998, the fitting formula is

$$s = 0.0927b + 1.4672 \quad (2)$$

where, b is the cave width (m).

It can be seen from Fig. 4 (d), with the decrease of the spacing of karst cave, the total settlement of pile increases, use the linear function to fit the empirical formula, the correlation coefficient reaches 0.988, the fitting formula is

$$s = -0.0159d + 1.8394 \quad (3)$$

where, d is the cave spacing (m).

It can be known from the comparison of the slopes of three empirical formulas, the slope of the cave size formula is maximum, indicating that the cave size has the greatest impact on the total settlement of the pile foundation, the cave quantity is the second, and the cave spacing has the minimal impact.

V. EFFECT EVALUATION OF THE BEADED CAVE ON THE TOTAL SETTLEMENT OF THE PILE FOUNDATION

Using the total settlement of the pile to evaluate the effect of karst on the pile foundation, the control indexes can be seen in Tab. 1.

TABLE I. THE PILE TOTAL SETTLEMENT EVALUATION INDEX

Total settlement (mm)	Cave quantity	Cave width (m)	Cave spacing (m)
1.6~1.7	1	0.5~2.5	>8.5
1.7~1.8	1~3	2.5~3.5	2.5~8.5
1.8~1.9	3~4	3.5~4.7	0.5~2.5
1.9~2.0	4~5	4.7~5.7	/
2.0~2.1	5~7	5.7~6.8	
2.1~2.2	7~8	6.8~7.9	
2.2~2.3	8~10	7.9~9.0	
2.4	11	10.0	

VI. CONCLUSION

Use finite element numerical calculation method, calculation is taken considering the pile foundation construction load, the pile upper load and the influence factors of the karst. It is found that the cave size has the greatest impact on the total settlement of the pile foundation, the cave quantity is the second, and the cave spacing has the minimal impact. In the case of a 100% increase in the size of karst cave, the total settlement of pile increases 13.23%, while karst spacing decreases by 66.7%, the total settlement of pile only increases 1.05%. And the control indexes are given when using the total settlement of the pile to evaluate the effect of karst on the pile foundation.

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