Study on the change state of stress ratio of pile and soil during service period

Hong-Ying Jiang¹, Jia-Ming Lu²

¹School of civil engineering, xijing College, Xi’an 710123, China
²Qin and han dynasties new town development and construction group co., LTD, Xi’an 710000, China
E-mail: 1312984559@qq.com

Abstract. Based on the simulation experiment of the soil consolidation settlement and used the stochastic theory, the regulation of load sharing ratio between pile and soil in composite foundation during construction and consolidation settlement of soil is studied. A simplified probabilistic model is proposed to estimate the load sharing ratio. It provides a reference basis for better study of the predictability of composite foundation and other structural prediction studies based on a variety of materials.

1. Introduction
The composite foundation is neither an ideal elastic material nor an ideal plastic material. It is a system structure composed of different materials. It has interaction and synergy in the internal evolution. The structural elements that constitute the common characteristics of the composite foundation are not isolated, but a complex and singular combination. In recent years, people have explored a lot about the structure of granular materials from the perspective of micromechanics, but their research and engineering applications have not yet been well integrated. The basic problem of particulate matter is still a puzzling puzzle [1]. Therefore, the mechanical properties of a system composed of different materials still need a great deal of research. Based on the experiment, the change of pile-soil stress ratio in the process of consolidation and settlement of soil is studied in this paper, so as to provide a reference for the predictability of life prediction of rigid pile composite foundation and the prediction of different material system structure.

2. Experiment introduction
The experiment was simulated at a reduced rate of 1:10, as shown in Figure 1. The test box is 250mm with a height of 150mm, a thickness of 6mm, and a hole at the bottom, which is used to artificially cause soil settlement. The pile body is made of cement mortar bar, 50 mm in diameter, painted with scale, vertical to the bottom. A well graded breccia (particle size greater than 2mm, 50% of the total weight) is used as a cushion. The thickness is 30mm. A wooden hammer is used to knock it until it is dense enough. The pressure sensor is attached to the bottom of the pile to monitor the change of the pile’s stress. Four micro pressure cells are fixed in the soil to monitor the change of soil pressure. The uniform load is applied to the upper part, slowly and gently until the given value is reached. The first level load is set at 0.48kpa. Prior to the application of the next stage load, the computer must record the previous pressure value. The data to be calculated must be the average of the ten measured data, and the standard error must be kept under control.
3. Analysis of the experiment results

3.1. Change laws of macroscopic load sharing ratio
In the early stage of the experiment, the soil was subjected to a large load. With the increase of load, pile insert cushion, pile play a role, the pile-soil stress ratio increases, the synchronous deformation of pile soil, pile top of the cushion into basic stability. Then, due to the consolidation and settlement of soil, the stress transfer process is produced in the soil between piles, and the peak stress is transferred to the pile body once again. Then the pile is once again thrust into the cushion, and again the stress redistribution occurs.

3.2. Evolution law of micro cushion material
The cushion is a typical granular structure, internal stress distribution is anisotropic \[5\]. There are the focus chain in the cushion, the chain generate granular arch \[5\]. The formation of these stress chains leads to uneven stresses, which tend to be concentrated in some local regions and exhibit nonlinear characteristics. A transfer process of stress: when the soil consolidation settlement, the cushion bottom surface appeared uneven phenomenon (Figure 2). There is stress distribution within the cushion, and so is the stress chain. The original bulk arch structure collapse, cushion material appears in the bottom of the loose and dense convex phenomenon appeared in the base, then reorganize arch \[6\]. Completing another process of stress transfer.

In the cushion, there exist an effect of granular arch and the phenomenon of jam, and the critical value of internal shear resistance is as follows: \(\tau_f = \mu \bar{\sigma}\), where \(\bar{\sigma}\) is mean value of normal stress, \(\bar{\sigma} = q + \gamma\) (\(q\) is the load value of the upper part, \(\gamma\) is unit volume weight of the cushion material ), \(\mu = \tan \phi\); \(\phi\) is the limit value of friction angle inside material particles. When the cushion thickness, with a constant pressure and other conditions, the greater the stiffness and the greater friction angles \(\phi\) of cushion material, the degree of anisotropy is bigger, more easy to take the bulk of the arch, block effect, lateral stress is easy to transfer, easy to pile body stress chain, most stress transfer to the pile. Therefore, the pile-soil stress ratio will be higher.

4. Theoretical model
The test results show that the stress ratio evolution rule: when a building in the construction process, the adjustment process, including the compression of soil between piles of cushion material compression and pile body piercing. These are all completed during the whole loading process, and the stress ratio is adjusted under the incremental load increment. So the load of the pile and soil can be superimposed. When soil is consolidated, the unloading of soil between piles and the adjustment of stress ratio are also completed under the negative increment of gradual load unloading. Here we assume \(R_{cr}\) is used to
represent the critical bearing capacity of the soil. Assuming that there is a change in the load shared by the \( n \) times, the \( R_{cr} \) can be expressed as follows:

\[
R_{cr}(f) = \sum_{i=1}^{n} R_{cr}(f_i - f_{i-1})
\]

(1)

Where, \( R_{cr}(f_i - f_{i-1}) \) is the \( i \)th increment of load on the soil when the increment of loading is \( f_i \). When \( f < f_i \), there is \( R_{cr}(f_i - f_{i-1}) \rightarrow 0 \), that is, the increment of load on the soil is zero when there is no increment of loading.

During the adjustment of loading increments, there exist both complexity and randomness. If the probability of \( p(n, f) \) is used to characterize the pile-soil load sharing statistics. When the loading amount is \( f \), the load sharing condition of pile-soil has changed \( n \) times, and each time is independent of each other.

When the load force changes from \( f \) to \( f + \Delta f \), change takes place in the load-bearing status of the piles and the soil, which has no bearing on \( f \) but only on \( \Delta f \). Then, when there is a load increment \( \Delta f \), the probability of the soil load sharing with \( n \) times is increased by:

\[
P_{s} = \lambda_{2} \Delta f + o(\Delta f)
\]

(2)

Where, \( o(\Delta f) \) is a higher order infinitesimal, \( \lambda_{2} \) is the strength of the load transferred to the soil during the adjustment, \( \lambda_{2} \) is related to the distance between the pile and the pile, and is related to compactness of cushion material, and is closely related to the cushion material occlusal friction. For the purpose of simplicity, \( \lambda_{2} \) is adopted as a constant. At the outset, the cushion is pressed as compact, with the load borne mainly by the soil. As the load increases, the pile head begins to stick into the cushion and the probability that the soil continues to bear the load increment will become random variables subject to negative exponential distribution. Therefore, the probability of transferring load increment for the pile to share is as follows:

\[
P_{p} = \int \Delta f \lambda_{2} e^{-\lambda_{2} \Delta f} = \lambda_{2} \Delta f + o(\Delta f)
\]

(3)

Where, \( \lambda_{2} \) is the strength of load transferred to the piles during the process of loading, in physical sense, is the same as \( \lambda_{2} \). During the whole process, there is a probability relationship \( P_{s} + P_{p} = 1 \) whether \( f \) is any value. Therefore, Kolmogorov equations [7] can be established as follows:

\[
P'_{s}(f) = -\lambda_{2} P_{p}(f) + \lambda_{2} P_{s}(f)
\]

(4)

\[
P'_{p}(f) = -\lambda_{2} P_{p}(f) + \lambda_{2} P_{s}(f)
\]

(5)

When the initial conditions \( P_{s}(0) = 1 \), \( P_{p}(0) = 0 \) are met, i.e. without loading, the probability of the soil bearing the load is 1, and the probability of loading on the pile is 0. The linear differential equation can be solved as follows:

\[
P_{s}(f) = \frac{\lambda_{2}}{\lambda_{1} + \lambda_{2}} \left[ 1 - e^{-\lambda_{1} + \lambda_{2}} f \right]
\]

(6)

\[
P_{p}(f) = \frac{\lambda_{1}}{\lambda_{1} + \lambda_{2}} \left[ 1 - e^{-\lambda_{1} + \lambda_{2}} f \right]
\]

(7)
Thus, Formulas (6) and (7) reflect the curve of relation between $P_s(f)$, $P_p(f)$ and load $f$, as shown in Figure 3.

This relationship curve reflects the constant adjustment process of the ratio of pile and soil sharing in the consolidation process of soil. When the soil consolidation settlement is relatively stable, when the system reaches a relatively stable state, the relative bearing capacity of the soil is as follows:

$$ P_{sa}(f) = \frac{\lambda_2}{\lambda_1 + \lambda_2} $$  \hspace{0.5cm} (8)

Therefore, when the state of the transition reaches a relatively steady state, the absolute carrying capacity of the soil is:

$$ P_{sa} = \lambda_1 P_{sr} $$  \hspace{0.5cm} (9)

And the bearing capacity of the pile is:

$$ P_{pa} = 1 - P_{sr} $$  \hspace{0.5cm} (10)

Therefore, when the state is stabilized, the ratio of the ultimate load sharing between the soil to the pile is mainly related to $\lambda_2$ (strength of the load shared by the pile). Therefore, the change state of the stress ratio of the pile and soil during the service period is the first stage, that is, the repetition of the construction stage.

**5 Conclusion**

Through the microscopic analysis of the evolution law of the load sharing ratio of the pile and soil in two stages, the main characteristics are obtained:

1) In the two adjustment process, the stress ratio has an evolution law, and the statistic of the bearing capacity can be described by the Poisson process;

2) When the pile penetration, the cushion has response process: continuous self-organization to arch and stress transfer.

There are many complicated factors and random factors in the system structure of multi material combinations with granular materials, which brings many difficulties to the theoretical research. We will try to expand the experimental and theoretical research, and further in-depth study.

**References**
[1] Ebrahim Alizadeh, François Bertrand, Jamal Chaouki. Development of a granular normal contact force model based on a non-Newtonian liquid filled dashpot [J]. Powder Technology 2013 (237):202–212.

[2] Jiang Yan. Research the cushion of rigid pile composite foundation [D]. Zhengzhou: College of civil engineering, Zhengzhou University, 2010.

[3] Yang Guanghua, Li Deje, Guan Dashu. Optimization design of rigid pile composite Foundation [J]. Chinese Journal of Rock Mechanics and Engineering. 2011(04):818-825.

[4] I. Albert, J. G. Sample, A. J. Morss, S. Rajagopal, A.-L. Baraba'si, and P. Schiffer. Granular drag on a discrete object: Shape effects on jamming [J]. Physical Review E, 2001(64): 061303-1-061303-3.

[5] Ning Guo, Jidong Zhao. The signature of shear-induced anisotropy in granular media [J]. Computers and Geotechnics 2013 (47):1–15.

[6] Jacco H, Snoeijer, Martin van Hecke, et al. Force and weight distributions in granular media: Effects of contact geometry [J]. Physical Review E. 2013(64): 030302-1-030302-5.

[7] Liu Jiakun. Application of stochastic process [M]. Beijing: Science press. 2000:47-52.