

Study on friction coefficient of soft soil based on particle flow code

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Abstract. There has no uniform method for determining the micro parameters in particle flow code, and the corresponding formulas obtained by each scholar can only be applied to similar situations. In this paper, the relationship between the micro parameters friction coefficient and macro parameters friction angle is established by using the two axis servo compression as the calibration experiment, and the corresponding formula is fitted to solve the difficulties of determining the PFC micro parameters which provide a reference for determination of the micro parameters of soft soil.

1. Research status of PFC micro parameters

PFC is a kind of numerical simulation tool based on discrete element, which is often used to simulate the granular particles. When a geotechnical problem is hard to explain from macro perspective, particle flow code provides micro way for analysis. Micro parameters for input are the following: the contact stiffness between particles as k_n , k_s ; parallel contact stiffness between particles as pb_k_n , pb_k_s ; particle friction coefficient as $fric$; particle density as ρ . For the problem of how the micro parameters corresponds to the properties of the actual simulated specimen, Zhao has studied the influence of micro parameters on the macro characteristics in parallel bond model^[1]. Zhou Guoqing has studied the applicability of damping coefficient by simulating Curved cantilever beam and ball falling collision^[2]. Zengyuan has carried out biaxial simulation experiments and discussed the effects of particle shape, friction coefficient and porosity on macroscopic properties^[3]. The micro parameters in the simulation are obtained by trial and error method. The trial-and-error method is based on the simulation of the biaxial servo compression as the calibration test and achieved by constantly modifying the micro parameters that may affect the stress-strain curve to make stress-strain curve of the simulated compression test the same as the stress-strain curve of the actual experiment^[4,5]. The adjustment of micro parameters has relevant rules. Zhang zhongwei has studied the effect of different micro parameter^[6]. In recent years, the researchers have tried to obtain the empirical formula for the relationship between microscopic parameters and macroscopic parameters. Zhi jiewang has established empirical formula for 3D porosity and 2D porosity in practice in a new suggestion for determining porosities in DEM study^[7].

How to select the micro parameters to make the simulation sample close to the real sample is always a hot issue in the study of particle flow parameters. The method of trial and error is the only way to identify micro parameters, by constantly adjusting the micro parameters to make stress-strain curves in calibration test as close as reality. The existing formulas obtained by each scholar can only be applied to similar situations. In this paper, the relationship between the friction coefficient and friction angle is analyzed, which provide a reference for determination of the micro parameters of soft soil.



2. Study on the relationship between friction coefficient and soil friction angle

The micro parameters in the PFC are summarized in Table 1. The micro parameters which affects the friction angle are as follows: contact stiffness between the particles as kn , ks ; friction coefficient as $fric$; parallel bond strength as pb_sn , pb_ss . From qualitative point of view, larger soil friction angle corresponds to larger contact stiffness, Stiffness is mainly used to calculate the displacement and force of particles in PFC and is not the main factor that influences the friction angle. To study the relationship between the friction coefficient and the friction angle, it is necessary to control the parameters other than friction coefficient.

Table 1.Micro parameters.

Micro para	kn	ks	pb_kn	pb_ks	$fric$	pb_sn	pb_ss	ρ
unit	pa	pa	Pa	pa	1	pa	pa	Kg/m^3

The number of necessary simulation can be reduced by Orthogonal analysis, which can also facilitates parameter control. Let: $fric^a L^b R^c kn^d ks^e \rho^f T^g$ be dimensionless, where L , R are the length and width of the specimen, and T is the time step of the loading, We get:

$$1^a L^b L^c (MT^{-2} L^{-1})^d (MT^{-2} L^{-1})^e (ML^{-3})^f T^g = 1 \quad (1)$$

M , L , T corresponding index should be equal, so there are:

$$\begin{cases} d + e + f = 0 \\ b + c - d - e - 3f = 0 \\ -2d - 2e + g = 0 \end{cases} \quad (2)$$

Three independent solutions are: $(1, -1, 0, 0, 0, 0)$, $(0, 0, -1, 1, 0, 0)$, $(0, 2, -1, 0, 1, 2)$. The three dimensionless quantities are: LR^{-1} , $kn^{-1}ks$, $R^2 kn^{-1} \rho T^{-2}$.

Obtained by Buckingham theorem:

$$\phi = F(fric, LR^{-1}, kn^{-1}ks, R^2 kn^{-1} \rho T^{-2}) \quad (3)$$

For the PFC calibration test, LR^{-1} , $kn^{-1}ks$, $R^2 kn^{-1} \rho T^{-2}$ are set value, then we can vary value of $fric$ from 1 to 20 and do 20 set of biaxial servo simulation, each confining pressure is taken 1Mpa, 3Mpa, 5Mpa. Draw Mohr stress circle, calculate common tangent, then we can get corresponding tangent friction angle. Drawing of Mohr stress circle is shown in Figure 1.

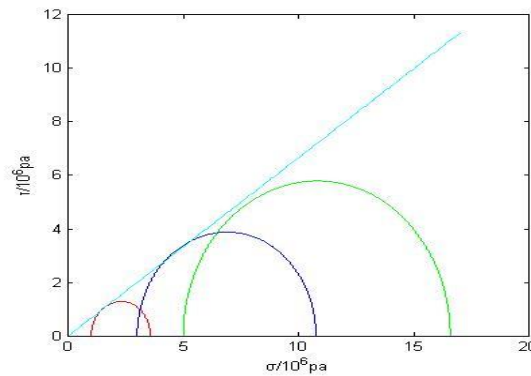


Figure 1.Moore stress circle.

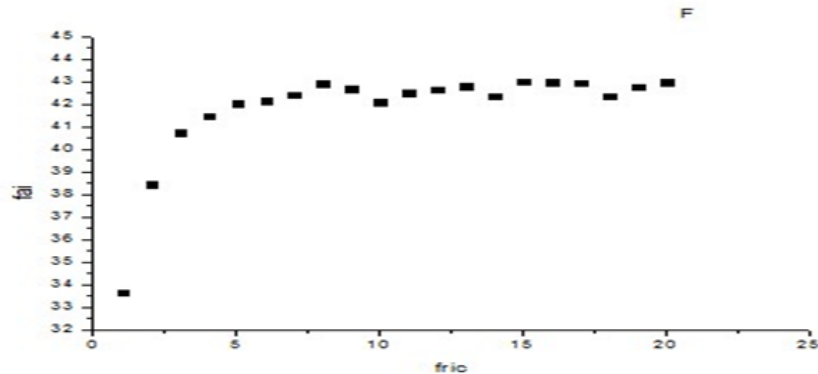
In Figure 1 we can see that common tangent pass through the origin, which represent that the simulated soil sample has no cohesive force. The parallel bond in PFC is used to prevent the relative rotation between particles, we set micro parameter relate to parallel bond 0 at beginning for that the soil sample we simulate is silt or sand.

The biaxial servo pressure simulation test is carried out, and the friction angle corresponding to the microscopic parameter $fric$ is obtained as shown in Table 2.

Table 2. Fric and corresponding friction angle.

fric	1	2	3	4	5	6	7	8	9	10
fai	33.66	38.448	40.74	41.49	42.06	42.15	42.43	42.92	42.68	42.108
fric	11	12	13	14	15	16	17	18	19	20
fai	42.503	42.66	42.81	42.37	43.01	42.97	42.95	42.38	42.78	43

The data points in Table 2 are plotted in the form of scatter plots, as shown in Figure 2.

**Figure 2.** Fric and corresponding friction angle scatter diagram.

It can be seen from the scatter diagram that while fric increase from 1 to 20, corresponding friction angle increase, which is consistent with the actual law. When the fric value in the range of [1,8], fric and the friction angle is approximately linear relationship, this trend is in accord with conclusion get by Oda M[9] , In the range of [8,20], relationship is no longer linear so it is not wise to fit all data point with single linear equation. In addition, when the fric is increased to 10, the friction angle is stable at about 42 degrees, and the friction angle of the sand in the actual project is generally in the range of 20 degrees to 40 degrees, most of which is about 30 degrees. It is proved that the selection for the parameters of silty soil is correct. The difference table is used to determine the characteristics of the data distribution. Form analysis of difference table we draw the conclusion that the data can be fitted by the cubic function, In order to make the fitting function smooth at the data points, the three order spline function is used to fit the data. When the value of fric is 0, it is considered that there is no bearing capacity of soil, and a total of 20 data points are fitted to the 19 three order spline function. As shown in formula (4), x represents the microscopic parameter fric, the calculated function value is the corresponding friction angle. The data point calculated by formula and the experimental data points are drawn together in Figure 3, from which we can see that the fitting of the three order spline function is in good agreement.

$$\left\{ \begin{array}{ll}
 28.872 + 3.54x + 1.872x^2 - 0.624x^3 & (1 \leq x < 2) \\
 18.888 + 18.516x - 5.616x^2 + 0.624x^3 & (2 \leq x < 3) \\
 39.57 - 0.42x + 0.405x^2 - 0.045x^3 & (3 \leq x < 4) \\
 33.81 + 3.9x - 0.675x^2 + 0.045x^3 & (4 \leq x < 5) \\
 35.91 + 3.6050x - 0.7125x^2 + 0.0475x^3 & (5 \leq x < 6) \\
 56.43 - 6.655x + 0.9975x^2 - 0.0475x^3 & (6 \leq x < 7) \\
 100.32 - 26.155x + 3.832x^2 - 0.1825x^3 & (7 \leq x < 8) \\
 -86.56 + 43.92x - 4.927x^2 + 0.1825x^3 & (8 \leq x < 9) \\
 -126.232 + 57.931x - 6.527x^2 + 0.2418x^3 & (9 \leq x < 10) \\
 97.063 - 17.3955x + 1.785x^2 - 0.0595x^3 & (10 \leq x < 11) \\
 -61.326 + 25.8015x - 2.142x^2 + 0.0595x^3 & (11 \leq x < 12) \\
 37.038 + 1.035x - 0.068x^2 + 0.0017x^3 & (12 \leq x < 13) \\
 -541.15 + 136.18x - 10.53x^2 + 0.27x^3 & (13 \leq x < 14) \\
 940.61 - 181.34x + 12.15x^2 - 0.27x^3 & (14 \leq x < 15) \\
 26.81 + 3.33x - 0.225x^2 + 0.005x^3 & (15 \leq x < 16) \\
 67.77 - 4.35x + 0.255x^2 - 0.005x^3 & (16 \leq x < 17) \\
 -746.785 + 132.9425x - 7.425x^2 + 0.1375x^3 & (17 \leq x < 18) \\
 296.81 - 43.295x + 2.43x^2 - 0.045x^3 & (18 \leq x < 19) \\
 -320.50 + 54.175x - 2.7x^2 + 0.045x^3 & (19 \leq x \leq 20)
 \end{array} \right. \quad (4)$$

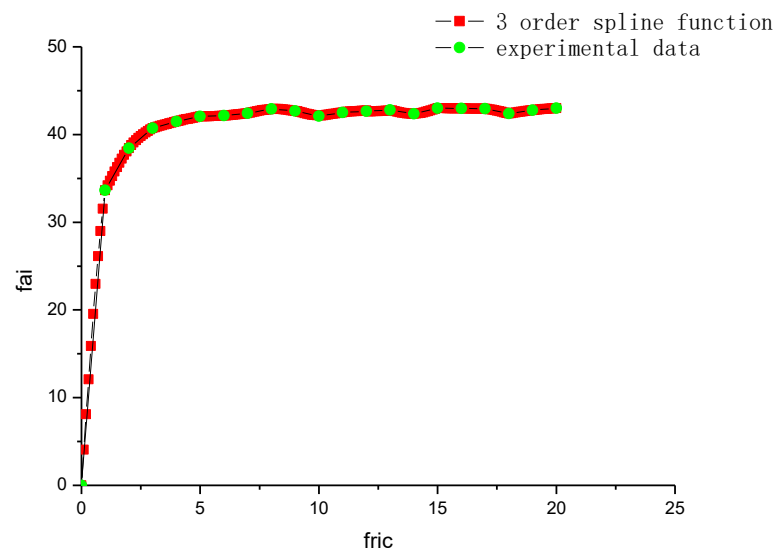


Figure 3.Comparison of fitting results.

3. Conclusion

In this paper, the method to determine micro parameters is established, and put into use of large area load problem of the foundation. The load limit criterion for simulation of PFC foundation is also provided. The main conclusions are as follow: (1) the relationship between the friction angle and the friction coefficient is not linear relationship.(2)the empirical formula for determining micro parameters is proposed.

References

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