

Influence of moisture content on main mechanical properties of expansive soil and deformation of non-equal-length double-row piles: A case study

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Abstract. The mechanical properties of expansive soil are very unstable, highly sensitive to water, and thus easy to cause major engineering accidents. In this paper, the expansive soil foundation pit project of the East Huada Square in the eastern suburb of Chengdu was studied, the moisture content of the expansive soil was considered as an important factor that affecting the mechanics properties of expansive soil and the stability of the non-equal-length double-row piles in the foundation pit support. Three groups of direct shear tests were carried out and the quantitative relationships between the moisture content and shear strength τ , cohesion c , internal friction angle ϕ were obtained. The effect of cohesion and internal friction angle on the maximum displacement and the maximum bending moment of piles were analyzed by the finite element software MIDAS/GTS (Geotechnical and Tunnel Analysis System). Results show that the higher the moisture content, the smaller the matrix suction, and the smaller the shear strength; the cohesion and the internal friction angle are exponentially related to the moisture content, and both are negatively correlated. The maximum displacement and the maximum bending moment of the non-equal length double-row piles decrease with the increase of the cohesion and the internal friction angle. When the cohesion is greater than 33 kPa or the internal friction angle is greater than 25.5° , the maximum displacement and maximum bending moment of the piles are relatively small, however, once crossing the points (the corresponding moisture content value is 24.4%), the maximum displacement and the maximum bending moment will increase significantly. Therefore, in order to ensure the stability and safety of the foundation pit support structure of the East Huada Square, the moisture content of the expansive soil should not exceed 24.4%.

Keywords: case study; expansive soil; moisture content; non-equal length double-row piles; shear strength

1. Introduction

Expansive soil is a kind of high plasticity clay that is mainly composed of montmorillonite, illite, and other strong hydrophilic minerals (Dai and Safarpour 2021, Forsat *et al.* 2021, Ghamkhar *et al.* 2021, Khadimallah *et al.* 2021a, Khadimallah *et al.* 2021b, Kumar *et al.* 2021, Madenci 2021, Tlidji *et al.* 2021). There are three significant features, shrinkage, expansion, and fracture development, which lead to the extremely unstable mechanical properties of expansive soil (Ma *et al.* 2021, Zhao *et al.* 2021, Ting *et al.* 2018, Hou *et al.* 2021, Huang *et al.* 2021c, Huang *et al.* 2021d, Jiao *et al.* 2021, Liu *et al.* 2021d, Moradi *et al.* 2021, Xu *et al.* 2021d, Dong *et al.* 2022, Luo *et al.* 2022, Yang *et al.* 2022, Yu *et al.* 2022).

These features cause foundation uplift or collapse, and they can easily cause building cracks and other disasters (Liu *et al.* 2011). Non-equal-length double-row piles are a kind of space gantry support structure composed of two rows of parallel and reinforced concrete piles with different lengths and crown beams on piles (Liu *et al.* 2021c). This

system has the advantages of good stiffness performance and small horizontal displacement of the pile body (ZHENG *et al.* 2010). It can overcome the problem of the anchor cable, bolt, and other supporting forms not providing enough anchoring force (LIN *et al.* 2010, Huang *et al.* 2020, Chen *et al.* 2021a, Chen *et al.* 2021b, Feng *et al.* 2021, Lu *et al.* 2021). This is why the system is very popular among researchers and widely used in foundation pit engineering (Hashemi *et al.* 2019, Al-Furjan *et al.* 2020c, Al-Furjan *et al.* 2020d, Al-Furjan *et al.* 2020e, Al-Furjan *et al.* 2020f, Bai *et al.* 2020, Cheshmeh *et al.* 2020, Li *et al.* 2020a, Lori *et al.* 2020, Najaafi *et al.* 2020, Shariati *et al.* 2020c, Xiong *et al.* 2020, Guo *et al.* 2021b, Liu *et al.* 2021a).

In relation to the engineering characteristics of expansive soil such as easy softening and the wide range of shear strength, many scholars have produced relevant discussions (Allam *et al.* 2020, Bekkaye *et al.* 2020, Menasria *et al.* 2020, Bakoura *et al.* 2021, Guellil *et al.* 2021, Hachemi *et al.* 2021, Hadji and Avcar 2021, Merazka *et al.* 2021, Tahir *et al.* 2021a, Tahir *et al.* 2021b, Zerrouki *et al.* 2021). Liu and Yin (2010) stated that the increase of cracks in expansive soils was the main factor affecting the strength attenuation, especially the cohesion. Liu *et al.* (2011) used the standard wet sand method and the dripping

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method to test expansive soils, and they discussed the relationship between the moisture content and cohesion and the internal friction angle of expansive soils. Xie *et al.* (2005) examined the influence of temperature on the shear strength of expansive soil through a triaxial drainage shear test. Yang *et al.* (2022), Alias *et al.* (2014) examined the influence of the expansive soil size effect on the experiment with an indoor direct shear test and a large-scale field shear test. Shen *et al.* (2008) used a finite element method to discuss the influence of pile spacing on the force of double-row piles. Tang *et al.* (2010) discussed the influence of pile row spacing on the stress of double-row piles with the finite element method. Liu *et al.* (2010) discussed the influence of different layout modes on pile stress using a nonlinear finite element method. Recently, many researchers showed that stability analysis of the structure can have essential role on the mechanical properties of various systems (El-Hassar *et al.* 2016, Fahsi *et al.* 2017, Nejad *et al.* 2017, Setoodeh and Rezaei 2017, Sobhy 2017, Issad *et al.* 2018, Sadoun *et al.* 2018, Younsi *et al.* 2018, Ahmed *et al.* 2019, Asgari *et al.* 2019, Boulefrakh *et al.* 2019, Ebrahimi *et al.* 2019c, Ebrahimi *et al.* 2019e, Karami *et al.* 2019c, Mohammadi and Rastgoo 2019, Chikr *et al.* 2020, Ebrahimi *et al.* 2020b, Farokhian and Kolahchi 2020, Rabhi *et al.* 2020).

However, little research has been done on the effect of the moisture content of expansive soil on the mechanical properties of the soil and the deformation of the unequal-length double-row piles. Therefore, this discussion is mainly focused on three aspects. First, expansive soil is the highly plastic clay of unsaturated soil that can easily absorb water and swell, reducing the shear strength, so the moisture content is the main influencing factor discussed. Second, through a direct indoor shear test, the effects of the moisture content change on the shear strength, mocha angle, and cohesion of the expansive soil in eastern Chengdu are discussed. Third, the finite element software MIDAS-GTS is used to analyze the influence of the cohesion and the internal friction angle of the expansive soil on the supporting structure of non-equal length double-row piles, and the proposed moisture content is given.

2. Geological background of the study area

The site of the study area- the East Huada Square was located in the eastern suburb of Chengdu Plain. The expansive soil in this area is mainly clay and silty clay, which is in a rigid plastic state with abundant cracks. On the excavation face of the foundation pit, it was found that red clay was the main part of the soil. Some gray-green and white minerals with hard textures were also found, as shown in Fig. 1. Expansive soil expands after absorbing water; then the shear strength decreases and the soil softens, as shown in Fig. 2. The free expansion rate of the soil in the study area ranged from 39.03% to 43.89%, and the average expansion rate was 41.46%. According to the specification JGJ 120-2012 (Tan and Wang 2013) and GB 50112-2013 (Gao *et al.* 2018), the expansive soil here belonged to the category of weak expansive soil.



Fig. 1 The natural expansive soil in the foundation pit of the East Huada Square

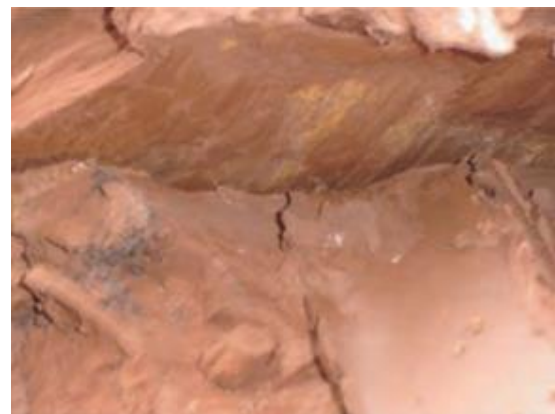


Fig. 2 The expansive soil under water softening condition in the foundation pit

3. Experimental methods

3.1 Experimental instruments

The expansive soil direct shear test instruments mainly include (1) the strain-controlled shear apparatus: the shear box, vertical pressure equipment, shear transmission device, dynamometer, and displacement measurement system; (2) the ring knife: inner diameter 61.8 mm, height 20 mm; and (3) the displacement measurement equipment: a percentile meter with a measuring range of 10 mm and a minimum indexing value of 0.01 mm.

The expansive soil moisture content detection experimental instrument consisted of (1) an electric oven: the oven was able to control the temperature within the range of 105–110°C; and (2) a balance: with a mass of 200 g and a minimum graduation value of 0.01 g.

3.2 Direct shear test

The direct shear test was used to test the shear strength. The expansive soil samples were divided into three groups (Adamian *et al.* 2020, Al-Furjan *et al.* 2020a, Al-Furjan *et al.* 2020b, Li *et al.* 2020b, Liu *et al.* 2020b, Zare *et al.* 2020, Dai *et al.* 2021b, Habibi *et al.* 2021, He *et al.* 2021, Huang *et al.* 2021b, Liu *et al.* 2021b, Zhang *et al.* 2021).

Table 1 Experiment results of the expansive soil

Group	Part	Compressive stress σ (kPa)	Shear strength τ (kPa)	Moisture content ω (%)	Cohesion c (kPa)	Internal friction angle ϕ (°)
1st: water loss	Water loss for 10 d	100	220.52	9.7	108.50	50.38
		200	369.74			
		300	457.74			
		400	593.69			
	Water loss for 5 d	100	169.33	16.8	66.84	41.67
		200	240.32			
		300	302.42			
		400	445.31			
	Water loss for 2 h	100	115.33	22.2	38.33	35.48
		200	177.30			
		300	242.11			
		400	331.31			
2nd: natural with water addition	Natural soil	100	88.97	24.4	33.47	26.43
		200	127.44			
		300	157.43			
		400	244.67			
	Water addition A	100	74.94	25.8	30.34	20.91
		200	111.93			
		300	128.12			
		400	196.88			
	Water addition B	100	58.75	27.5	28.21	19.95
		200	89.32			
		300	117.43			
		400	170.41			
3rd: softened with water addition	Softened soil	100	34.42	29.5	15.20	11.21
		200	50.89			
		300	78.22			
		400	91.34			
	Water addition C	100	27.32	31.3	14.11	5.86
		200	34.21			
		300	43.43			
		400	58.43			
	Water addition D	100	13.01	34.2	12.72	3.12
		200	19.90			
		300	23.87			
		400	32.48			

Each group was divided into three parts according to the different moisture content. The expansive soil obtained from the same location in the newly excavated foundation pit was divided into two groups. In the first group, three parts of expansive soils were kept at room temperature for 2 h, 5 days, and 10 days, respectively. In the second group, one was the natural soils, while the other two were made by adding water. The increment of the moisture content was controlled between 1.5% and 2%. In the third group, the expansive soils that had been softened by water in the foundation pit were split into three parts to make “softened soil samples.” In which, one part of the softened soil was retained, while water was added to the other two parts, and the increment of the moisture content was controlled

between 1.5% and 2%.

After preparing the soil samples, 100 kPa, 200 kPa, 300 kPa, and 400 kPa of vertical pressure were applied on the soil samples in each part. The fixed pin was pulled out and immediately shear behavior with a shear rate of 0.8 mm/min was carried out.

3.3 Moisture content test

First, a 50 g soil sample was selected and put into a weighing box to measure the mass of the humidified soil m_0 , which was accurate to within 0.01 g. Next, the weighing box and the sample were put into the oven and dried to a constant weight at 105–110°C. Then the weighing

box was cooled to room temperature in the dryer, and the box was added to the dry soil mass and the mass m_d was measured, with an accuracy of 0.01 g.

The moisture content of the sample was calculated by Eq. (1), the results are shown in Table 1.

$$\omega = \left(\frac{m_0}{m_d} - 1 \right) * 100 \quad (1)$$

4. Experimental analysis

4.1 Influence of the moisture content on the shear strength of the expansive soil

Based on the results of shear tests (Huang *et al.* 2021a, Luo *et al.* 2021, Xu *et al.* 2021a; Li *et al.* 2022, Shi *et al.* 2022, Wang *et al.* 2022), the shear compressive stress -shear strength envelopes of expansive soils with different moisture content were plotted, as shown in Fig. 3. The cohesion and the internal friction angle for various moisture content conditions were also obtained and recorded in Table 1. The functional relationship between the shear strength and the moisture content under the conditions of 100 kPa, 200 kPa, 300 kPa, and 400 kPa compressive stress were drawn as well, as shown in Figs. 4-7.

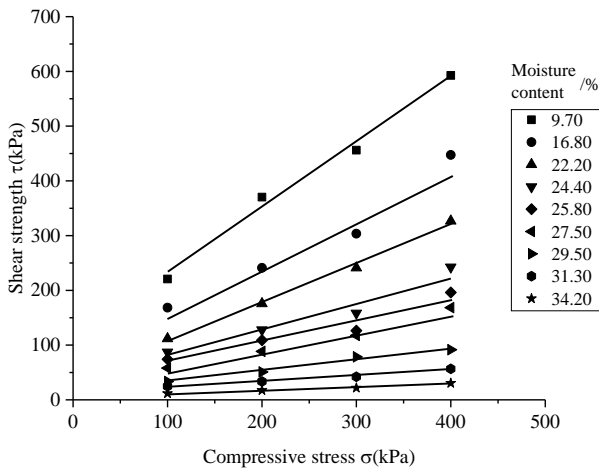


Fig. 3 The shear strength of the expansive soil under different compressive stress

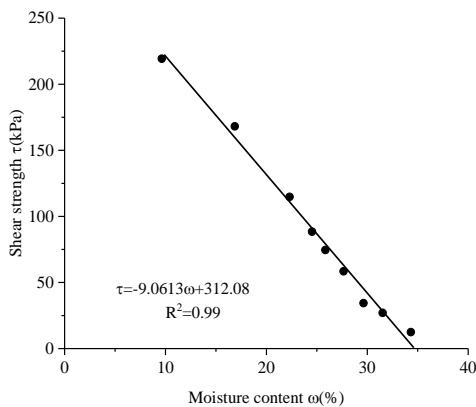


Fig. 4 Relationship between the shear strength and the moisture content under 100 kPa compressive stress

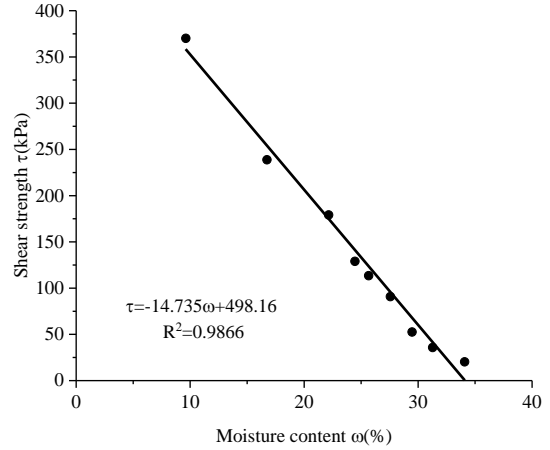


Fig. 5 Relationship between the shear strength and the moisture content under 200 kPa compressive stress

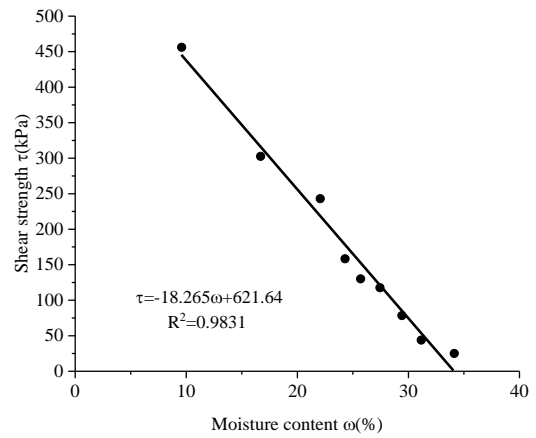


Fig. 6 Relationship between the shear strength and the moisture content under 300 kPa compressive stress

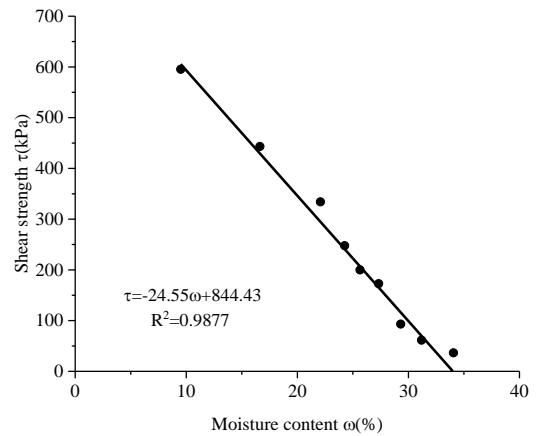


Fig. 7 Relationship between the shear strength and the moisture content under 400 kPa compressive stress

From Fig. 3, it can be seen that the shear strength of the expansive soils increased with the increase of the shear stress, and the maximum shear strength reached 593 kPa. However, the shear strength hardly changed with the change of the shear stress, and the minimum shear strength was 13 kPa in the softened expansive soils. The maximum moisture content was less than 22.5% in the 1st group, while the minimum moisture content was more than 29% in the 3rd

group. It is clear that an increase of the moisture content will lead to a sharp decrease in the shear strength of expansive soils. Expansive soil is a kind of unsaturated soil that has the characteristics of matrix suction, unlike saturated soil, and the matrix suction of expansive soil will be smaller with the increase of moisture content, which will cause a decrease of the apparent cohesion, reducing the shear strength.

From Figs. 4-7, it can be seen that under the same shear compressive stress, the shear strength decreased with the increase of the moisture content. Compared with the four regression equations, the initial shear strength of the expansive soils increased from 312.08 kPa to 844.43 kPa, and the absolute value of the linear slope increased from 9.0613 kPa to 24.55 kPa with the increase of the shear compressive stress. These changes indicate that the influence of the moisture content on the shear strength was more significant with the increase of the shear compression stress. The shear compressive stress was mainly influenced by the pore water pressure of the expansive soils, which can be explained by the effective stress principle: The total stress σ acting on the shear plane of the specimen is the sum of the effective stress σ' and the pore water pressure μ . The pore water pressure acts on the free water in the soil and does not produce internal friction between the soil particles. However, effective stress can produce internal friction strength. Therefore, with the increase of the shear compressive stress, the pore water pressure between the soil particles decreases and the effective stress increases, so the shear strength increases with the increase of the shear compressive stress.

4.2 Influence of the moisture content on the cohesion

According to the data for the cohesion and moisture content in Table 1, the logarithmic relationship was obtained and shown in Fig. 8.

It can be seen that the cohesion of the expansive soils decreased with the increase of moisture content. For soil with water loss, when the moisture content increased from 9.7% to 22.2%, the cohesion decreased from 108.55 kPa to 38.33 kPa, with an average decrease of 5.618 kPa. For softened soils, the moisture content increased from 29.5% to 34.2%, and the cohesion decreased from 11.21 kPa to 3.57 kPa, with an average decrease of 1.63 kPa. Therefore, the effect of the moisture content on the soil with water loss was much greater than the effect on softened soil. The reason for this is that there is an electrostatic force on the surface of expansive soil particles. This force can polarize and absorb some water molecules on the surface of the soil particles, thus forming a layer of hydration film. With the increase of the moisture content, the hydration film becomes thicker and the electrostatic force weakens, but the hydration film cannot transmit the hydrostatic pressure. This leads to the expansion of the soil on one hand and the weakening of the Van der Waals force between soil particles on the other hand, which in turn leads to the decrease of the cohesion of expansive soil. However, when the moisture content increases to make the Van der Waals force between soil particles very small, the influence of the moisture content on the cohesion becomes weak.

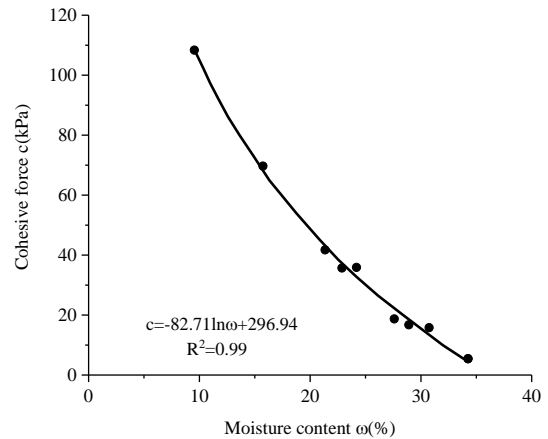


Fig. 8 The fitting curve of the cohesion and the moisture content

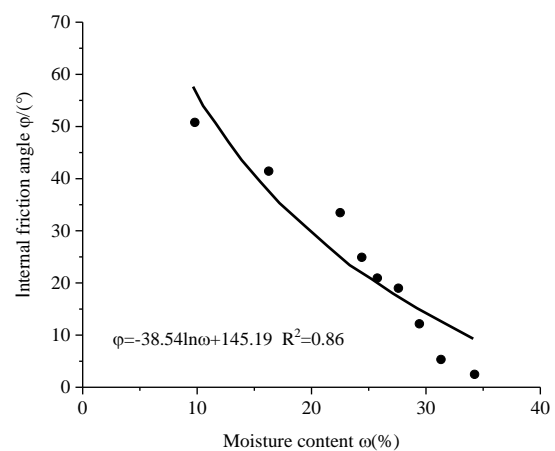


Fig. 9 The fitting curve of the internal friction angle and the moisture content

4.3 Influence of the moisture content on the internal friction angle

The relationship between the internal friction angle and the moisture content was shown in Fig. 9.

According to equation shown in Fig. 9, with the increase of the moisture content, the angle of the internal friction decreases, and the degree of influence becomes smaller and smaller. The reason for this can also be analyzed from the point of view of the hydration of expansive soil particles: When the moisture content is small, the hydration film between soil particles is thin or even absent. Because of the irregularity of soil particles, the particles can use their edges and corners to occlude each other and to limit the occurrence of relative displacement, and the degree of occlusion between soil particles can be expressed by the internal friction angle. However, when the moisture content increases, the hydration film between the soil particles becomes thicker and the distance between each soil particles increases. Then the water molecules fill the gap between the edges and corners, and this action weakens or even dissipates the occlusion relationship, leading to the decrease of the internal friction angle and the decrease of the shear strength of the expansive soil.

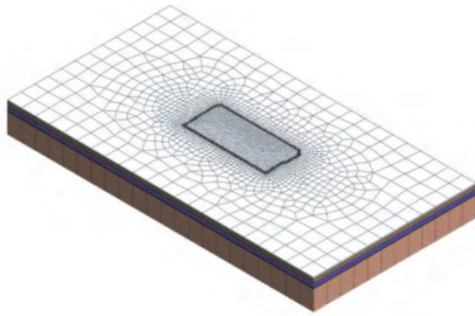


Fig. 10 The finite element model of the foundation pit

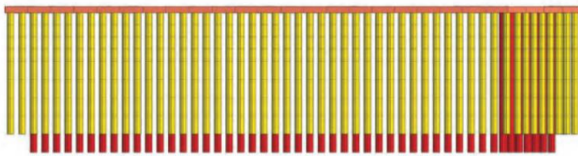


Fig. 11 The model of the non-equal length double-row piles

5. Numerical simulation on the influence of the moisture content on the non-equal-length double-row piles

In expansive soil foundation pit engineering, the main factor affecting the soil properties is moisture content (Karami *et al.* 2019a, Karami *et al.* 2019b, Al-Furjan *et al.* 2021, Soleimani-Javid *et al.* 2021). Moisture content also affects the shear strength of the soil by influencing the internal friction angle and the cohesion of the soil, thus affecting the support structure of non-equal-length piles (Habibi *et al.* 2016, Habibi *et al.* 2018a, Habibi *et al.* 2018b, Ebrahimi *et al.* 2019a, Esmailpoor Hajilak *et al.* 2019, Habibi *et al.* 2019b, Habibi *et al.* 2019d, Habibi *et al.* 2019e, Pourjabari *et al.* 2019, Safarpour *et al.* 2019a). Therefore, the internal friction angle and the cohesion of the soil were taken as variables directly in the simulation (Habibi *et al.* 2017, Safarpour *et al.* 2018, Habibi *et al.* 2019a, Habibi *et al.* 2019c, Safarpour *et al.* 2019b, Alipour *et al.* 2020, Ebrahimi *et al.* 2020a, Ghazanfari *et al.* 2020, Safarpour *et al.* 2020, Chen *et al.* 2022).

The numerical model was established with the finite element software MIDAS/GTS (Lan *et al.* 2021, Wei *et al.* 2021, Xu *et al.* 2021b, Xu *et al.* 2021c, Ali *et al.* 2022). The entire model was divided into two parts: The crown beam and the pile body. The two parts were regarded as isotropic linear elastic materials (Ebrahimi *et al.* 2019b, Ebrahimi *et al.* 2019d, Hashemi *et al.* 2019, Moayedi *et al.* 2019, Mohammadgholiha *et al.* 2019, Mohammadi *et al.* 2019, Ebrahimi *et al.* 2020c, Habibi *et al.* 2020, Moayedi *et al.* 2020a, Moayedi *et al.* 2020b, Oyarhossein *et al.* 2020, Shariati *et al.* 2020a, Shariati *et al.* 2020b, Shokrgozar *et al.* 2020). The expansive soil was regarded as a Mohr-Coulomb elastic-plastic material, (Liu *et al.* 2020a, Wang *et al.* 2020, Zhou *et al.* 2020, Dai *et al.* 2021a, Guo *et al.* 2021a, Shao *et al.* 2021, Wu and Habibi 2021) and the material parameters are shown in Tables 2 and 3. Since the

Table 2 Physical parameters of the non-equal length double-row piles

Name	Concrete type	Elastic Modulus E(MPa)	Poisson's ratio μ	Weight γ (kN·m ⁻³)
Top beam	C30	30 000	0.33	25
Pile	C30	30 000	0.33	25

Table 3 Physical parameters of the expansive soil

Plasticity index Ip	Liquid limit(%)	Plastic limit(%)	Free expansion rate δ_{ef} (%)	Compression modulus Es(MPa)
19.6	44.15	24.55	41.46	12.1

pile body was a non-equal-length pile, the pile body was divided into the A and B pile types. The design of the source model was as follows: The foundation pit was 204 m long, 88 m wide, and 15 m high. The top of the A-type and B-type piles was 0.5 m lower than the natural ground, and the diameter of the pile core was 1.2 m. There were 301 A-type piles, with an embedded depth of 8.5 m, a cantilever length of 14.5 m, a pile design total length of 23 m, and a pile core spacing of 2.0 m. Additionally, there were 316 B-type piles, with an embedded depth of 4.5 m, a cantilever length of 14.5 m, a pile design total length of 19.0 m, and a pile core spacing 2.0 m. The model was established as shown in Figs. 10 and 11.

5.1 Influence of the cohesion on the non-equal-length double-row piles

Based on the source model, and keeping the friction angle unchanged, seven groups of finite element models were established by using cohesion of 5.5 kPa, 11 kPa, 22 kPa, 33 kPa, 44 kPa, 55 kPa, and 99 kPa successively. After the model calculation was completed, the maximum displacement and the maximum bending moment of the non-equal-length piles were extracted from the calculation results of each group, and the maximum displacement and cohesion of the piles and the maximum bending moment of the piles were plotted with Excel, as shown in Figs. 12 and 13.

It can be seen from Figs. 12 and 13 that when the cohesion c of the expansive soil was greater than 33 kPa, the maximum displacement of the pile and the maximum bending moment of piles A and B were generally stable with little change. When the cohesion c was less than 33 kPa, the maximum displacement of the pile body changed significantly, and the range value was 29 mm, accounting for 87.88% of the maximum difference of displacement. The maximum moment difference of the type A pile was 420 kN·m, accounting for 77.78% of the maximum moment difference of the type A pile. The maximum moment difference of the type B pile was 580 kN·m, accounting for 88.55% of the maximum moment difference of the type B pile. Therefore, based on the fixed pile structure, the cohesion of the expansive soil in the eastern suburb of Chengdu should be above 33 kPa. Compared with Table 1, the moisture content of expansive soil should be less than 24.4%.

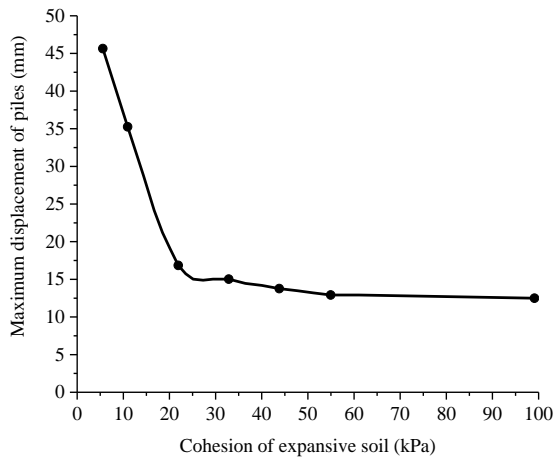


Fig. 12 Relationship between the cohesion and the maximum displacement

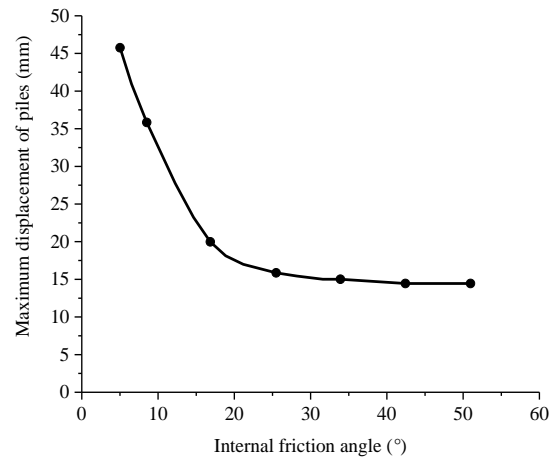


Fig. 14 Relationship between the internal friction angle and the maximum displacement

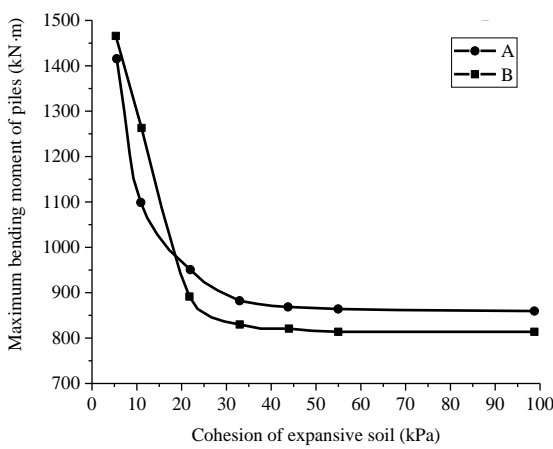


Fig. 13 Relationship between the cohesion and the maximum bending moment of the A- and B-type piles

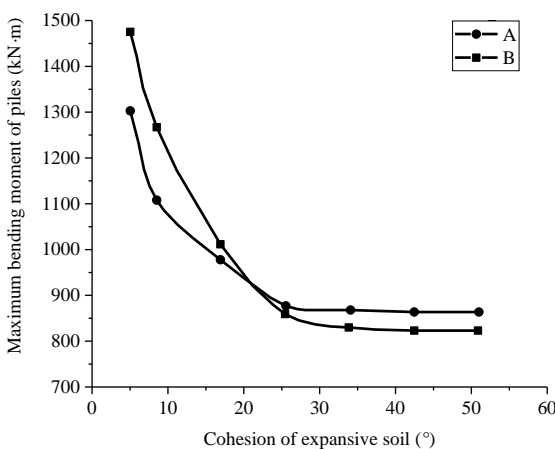


Fig. 15 Relationship between the internal friction angle and the maximum bending moments of the A- and B-type piles

5.2 Influence of the internal friction angle on the non-equal-length double-row piles

Based on the source model and keeping cohesion unchanged, seven groups of finite element models were established successively with internal friction angles φ of 5°, 8.5°, 17°, 25.5°, 34°, 42.5°, and 51°. After the calculation of the model, the maximum displacement of the non-equal long pile and the maximum bending moments of piles A and B were extracted from the settlement results of the model, and the maximum displacement diagram and the maximum bending moment diagram of the piles were drawn, as shown in Figs. 14 and 15.

From Figs. 14 and 15, it can be seen that the maximum displacement and the maximum bending moment of the type A and B piles decreased with the increase of the internal friction angle. However, when the internal friction angle was greater than 25.5°, the maximum displacement and the maximum bending moment were generally stable, and the change was minimal. When the internal friction angle was less than 25.5°, the maximum displacement range of the pile body was 30 mm, accounting for 95.23% of the maximum difference. The maximum bending moment range of the A-type pile was 430 kN·m, accounting for 96.63% of the maximum difference of the A-type pile bending moment.

The maximum bending moment range of the B-type pile was 620 kN·m, accounting for 94.66% of the maximum difference of the A-type pile bending moment. It can be seen that the internal friction angle of the expansive soil in the eastern suburbs of Chengdu should be greater than 25.5°. According to Table 1, the moisture content of expansive soil should be less than 24.4%.

In conclusion, an increase of moisture content will lead to the increase of the maximum displacement of a pile and the maximum bending moment of pile types A and B, so the moisture content must be controlled. According to the results of the finite element numerical simulation, the maximum moisture content should not exceed 24.4%.

6. Conclusions

(1) The expansive soil samples in the eastern suburb of Chengdu were tested with the direct shear test, and the moisture content was measured. A linear regression of the experimental data was performed using Excel. Then it was determined that the shear strength and cohesion of expansive soil were inversely proportional, and the analysis

showed that the expansive soil was unsaturated soil. The greater the moisture content, the smaller the matrix suction, and the smaller the shear strength. The cohesion c and the internal friction angle ϕ of expansive soil had an exponential relationship with the moisture content, and both the cohesion and the internal friction angle decreased with the increase of the moisture content. The decrease of cohesion occurred because the thickness of the hydration film between the soil particles thickened with the increase of the moisture content, resulting in the weakening of the molecular force between the soil particles. The reason why the angle of the internal friction decreased was that the increase of that moisture content caused the occlusal relationship between the soil particles to weaken or even disappear, thus reducing the friction between the soil particles.

(2) By using finite element software MIDAS/GTS, the influences of the cohesion and the internal friction angle of the expansive soil on the deformation of the non-equal-length piles in the eastern suburbs of Chengdu were analyzed. The calculation results were counted, and the maximum displacement diagrams of the piles varying with c and ϕ as well as the max bending moment diagrams of the type A and B piles were drawn with Excel. The results show that the maximum displacement of the non-equal-length piles decreased with the increase of the cohesion and the internal friction angle, and the maximum bending moment of the A and B non-equal-length piles decreased with the increase of the cohesion and the internal friction angle. Consequently, for the expansive soil in the eastern suburb of Chengdu, it is suggested that its moisture content should not exceed 24.4%.

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