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Analysis on the affecting factors of interface friction coefficient between expansive soil and geogrid by pullout tests

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ABSTRACT: The interface friction coefficient (IFC) between soil and geosynthetic is an important parameter in design as well as in researches of reinforcement structure. Pullout tests and direct shear tests have been widely used to study the IFC (sand/geosynthetic) with consideration of the size of tests apparatus，function of reinforcement, and even the evaluation of pullout resistance in critical conditions. However, we know little about the IFC (expansive soil/geogrid) in both limit condition and working stress with consideration its main affecting factors. Thus four affecting factors were selected as affecting factors of IFC according to the orthogonal principle, and nine pullout tests designed by orthogonal table L9 (4^3) have been carried out to further investigate the relationship between IFC and four affecting factors. The main affecting factors of IFC and their influencing orders were obtained, and a corresponding analysis method with consideration of both the critical state and working stress conditions is suggested

1 INTRODUCTION

The interface friction coefficient (IFC) between soil and geosynthetic is an important parameter in design as well as in researches of reinforcement structure. Pullout tests and direct shear tests have been widely used to study the IFC (sand/geosynthetic) with various geosynthetic materials taking into account, and based on the previous researches, in our opinion, the progress of investigation on the IFC may be roughly divided into three stages.

1. The 1st stage, from 1960s to mid-1980s. The pull out and direct shear tests were originally used for making clear the mechanism of reinforcement, and a lot of researches on the IFC between geosynthetic and sand have been conducted. These studies are carried out by Ingold,(1982,1983), McGown and Andrawes, (1982), Myles, B. (1982), A.Sridharan et al (1988), Jewell,R.A.et al (1984), Koerner et al (1986).
2. The 2nd stage, from the mid-1980s to the beginning of the 21st century. The pullout and direct shear tests were used for not only making clear the mechanism of reinforcement but also evaluate the design and analysis parameters of reinforced soil structure，thus researches on the IFC between geosynthetic and sand as well as cohesive soil have been carried out by A.Bouazza et al, (1994), Ashoke K.Karmokar (1998), H Ochiai,(1996,1998), Linrong Xu, (2001),M.L.Lopes et al (1996), Wislon-Fahmy, et al, (1994) and so on.
3. The 3rd stage, from the beginning of this new century (Linrong Xu, 2001). Although a number of pullout and direct shear tests with consideration of the size effect of tests apparatus，function of reinforcement, and evaluation of pullout resistance have been conducted for different purposes. The interpretation of those testing-data, however, remains a complicated problem, because there are many affecting factors influencing on IFC, such as the soil type and its condition, the type of geosynthetic and their physical and mechanical properties, pullout speed and tests conditions, and so on. On the other hand, previous researches emphasized particularly on the interface parameters (including IFC) between reinforcement and soils only in critical state (limit state), and in order to meet the requirement of practical engineering development in design and researches, both the parameters in critical state and working stress are needed. Thus it is necessary that the researches begin to further investigate the IFC with taking the affecting factors into consideration and a corresponding analysis method (Process analysis method) with consideration of. both the critical state and working stress conditions is suggested

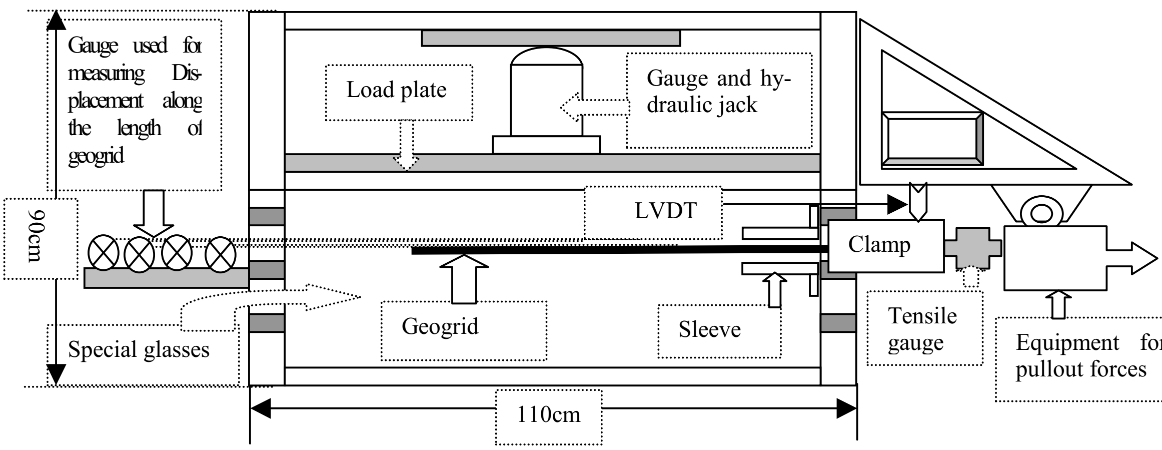

Figure.1. Schematic geogrid/expansive soil interface pullout tests configuration

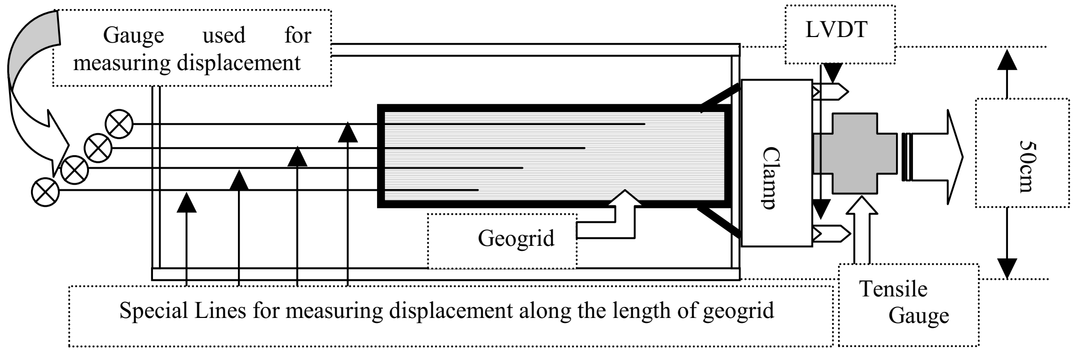

Figure.2. Cross section of pullout tests

2 EQUIPMENT AND MATERIALS

2.1 *Equipment of model tests:*

The pullout box, which was used to study interface parameters between geogrids and expansive soil, has its dimensions of 1.10m lengths, 0.5m width, and 0.8m height (Figure 1 and 2). The reduction of the influence of the top boundary on the pullout resistance of the reinforcement and the uniform distribution of the applied vertical stresses are achieved by placing over the top of the soil a smooth neoprene slab having a thickness of 0.0025m. To reduction the influence of the front wall on that resistance, a steel sleeve is used which extended 0.2m inside the box (Figure 1). The pull out force, obtained by a combination of electrical and hydraulic system, is transmitted to spacemen by a clamp (Figure 1 and 2). The confinement stress is applied by placing four hydraulic jacks on the top of the box (Figure 1). The pullout force and the confinement stress are measured with load cells (Figure 1 and 2). The frontal displacement and displacement along the length of the geogrid are measured by two LVDT and four linear potentiometers (Figure 2).

2.2 *Materials used in pullout tests*

The soil used in pullout tests is expansive soil as illustrated by the particle size distribution cures shown in Figure 4, its main minerals are illite and kaolin, and its geotechnacal parameters are listed in Table 1. Its free expansive rate $\delta_{ef} = 64\%$, and it is a weak expansive soil according to China criteria (Hongqi Fang & Minzhong Yang, 1999;) ; The expansive rate with load δ_{ep} is decrease with increase of load, but variable with the increase of water content. and $\delta_{ep} = -2.25\%$, when ω=10.9%, load pressure= $50KPa$; $\delta_{ep} = -0.28\%$, when ω=10.9%, load pressure = $30KPa$。The expansive rate without load pressure is almost constant after 24 hours. The geogrid used in pullout tests is TGDG25/SDL-25, which is made in Chongqing Qinglai Plastic Company of P.R.China, with tensile strength ≧25kN/m, extension rate≦10%,and its physical properties of listed in Table 2.

2.3 *Arrangement of pullout tests*

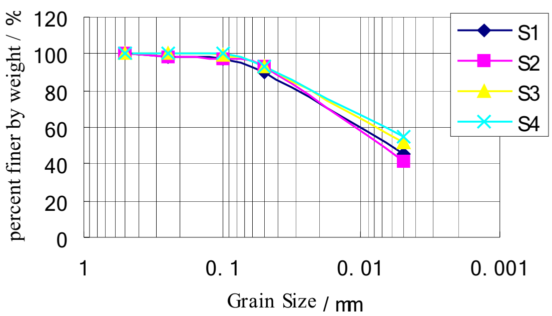

Figure 4 Distributions of grain size

With considerations of four affecting factors (load pressure, water contents of expansive soil and its $\omega_{opt} = 22.8\%$, the size of geogrids and pullout speed), and each factor has three levels (Table 3). Nine pullout tests are designed by using orthogonal table L9 (4^3), and parameters (IFC) between expansive soil and geogrid are carried out by pullout tests in strain control manner.

Table 1 Summary of geotechnacal parameters of expansive soil

Unit weight G_s	Liquid limit ω_L	Plastic Limit ω_P	Shrinkage Limit ω_s	Water Content of Expansive soil ω_e	Plasticity Index I_P	Shrinkage Index I_s	Shrinkage Coefficient λ_s
2.73	44.5%	26.7%	12.5%	37.5%	17.8	32.0	0.40

Table 2 Summary of geogrids of physical properties

Tests Sample	product name	Polymer	Open. area (%)	Apertures (*mm*), Machine Direction	Apertures (*mm*), Cross Machine Direction	Thickness (*mm*) Rib	Thickness (*mm*) Junction	Ultimate wide-width tensile Strength (*kN/m*)[a]
G1	G25	pet	62	10.5	2	0.60	2.30	28.1

Table 3　The Levels of affecting factors

Factors / Levels	Load Pressure (KPa)	Water Content of Expansive Soil (%)	Size of Geogrid (Length×Width) (mm)	Pullout Speed mm/min
1	50	18.00	32×24	0.247
2	100	23.27	40×24	0.943
3	200	28.00	40×32	3.137

3　PROCESS ANALYSIS OF PULLOUT RESULTS

In order to carry out process analysis of pullout results, the concept of Equivalent Pullout Displacement is suggested as following:

$$\chi = \chi_j / \chi_{max}$$

χ —Equivalent Pullout Displacement (EPD);

χ_j —Pullout displacement measured at frontal end;

χ_{max} —Frontal displacement when the pullout force arrive at its maximum;

Based on displacement measured along the whole length of geogrid in nine pullout tests, the process of pullout tests were divided into ten stages in the term of EPD by time serial order, and

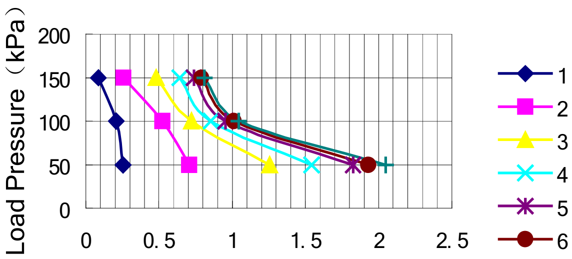

Fig. 5. Value of affecting degree

they are 0.15, 0.30, 0.45, 0.60, 0.75,0.90,1.0,1.25, 1.5 and 1.75, respectively. The frontal displacements and displacements along the length of reinforcement (geogrids used in pullout tests) measured in nine pullout tests were sorted into ten classes according to their EPD respectively, and the affecting degreess of four factors on the IFC in every stage of pullout tests process were obtained through the analysis of range method. Thus the relationship between each affecting factor (Load pressure, Water content of expansive soil, the size of geogrids and Pullout speed) and the affecting degree on the IFC are drawn into Figure 5,6,7 and 8, respectively.

3.1　*Load pressure*

From Figure 5:the spaces between curves 1and 2 is bigger than that among curves 3,4,5,6 and 7, and the spaces among curves 2,3,4,5,6 and 7decreases in turn. This means that the increment of IFC decreases as EPD grows for a certain load pressure, and the more the EPD, the less the increment of IFC influenced by Load pressure.

The affecting degree of load pressure on the IFC varies with the variable of load pressure as the EPD increases. The affecting degree decreases as the increase of load pressure, and when the load pressure reaches to a value, the IFC keeps almost constant despite of the increment of load pressure.

3.2　*Water content of expansive soil:*

At the beginning of pullout tests, the variable of water content

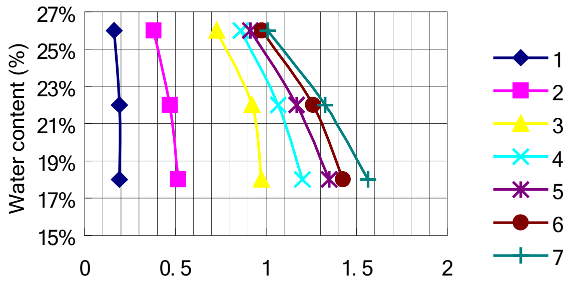

Fig. 6 value of affecting degree

almost have no effect on the IFC (curves 1,2 of Fig. 6), and we can deduced other conclusions (From curves2, 3,4,5,6 and 7of Fig.6) as following:

First: the variable of water content has influence on the affecting degree of IFC, the difference of affecting degree is decrease as the of the increase of water content, and ①the difference of affecting degree is more when the water content ≧ ω_{opt} than that ≦ ω_{opt}, ②the difference of affecting degree on the IFC becomes more efficient when the EPD grows, ③when the IFC is maximum, its corresponding water content is not equal to ω_{opt}, this means that except for maximum density of fill, the ω_{opt} could not control the maximum IFC.

Second: the spaces among curves 1,2,3,4,5,6 and 7 are gradually decreased in turn; this means the increment of IFC is decrease as EPD increase for certain water content. The increment varies with variable of water contents, the increment is less when the water content ≧ ω_{opt} than that ≦ ω_{opt}. And when the water content reaches a certain value, the increment of water content will lead the decrease of IFC.

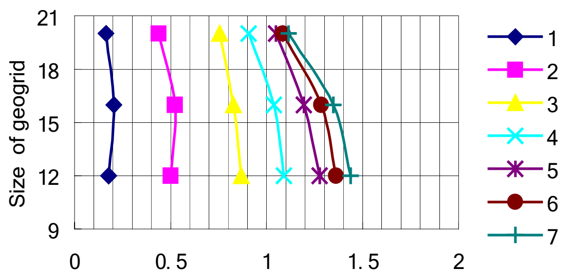

Fig. 7. Value of affecting degree

3.3　*The size effect of geogrids*

From Fig.7: That the variable of geogrids size has almost no influence on the IFC at the beginning of pullout tests (curve 1), and the size effect of geogrids on the IFC is gradually grow as EPD increases (Curves 2,3,4,5,6and7)

The spaces among curves 1,2,3,4,5,6 and 7 decrease gradually in turn, this means that the size effect of geogrids on IFC decreases gradually with EPD increases for a certain size of geogrid, and this will be more obviously when the size of geogrids is bigger.

3.4 *Pullout Speed*

From Fig.8：the space among curves 1、2、3 are bigger than that among curves4、5、6、7. This means that the affecting degree on IFC (between geogrids and expansive soils) gradually decreases as the EPD increases for a certain value of pullout speed. In the beginning of pullout tests, there is little difference of affecting degree on the IFC when the variable of pullout speed (curve 1). However, the difference of affecting degree gradually increases with the EPD increases (from Curves 2，3，4，5，6 and 7), the affecting degree on IFC is maximum when pullout

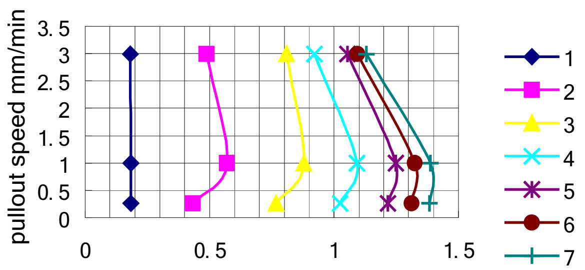

Fig. 8. Values of affecting degree

speed 1.0mm/min, and the 2nd and 3rd orders of pullout speed are 0.2mm/min and 2.94mm/min respectively.

4 CONCLUSIONS:

This paper has quantitatively illustrated the influence of four affecting factors on the interaction parameter (IFC) between geogrid and expansive soil. the results show that the first-order effect on the IFC between expansive soil and geogrid is Load Pressure (LP), the Water Content of Expansive Soil (WCES) is the 2nd order, and the Size Effect of Geogrid (SEG) and the Pullout Speed (PS) are the 3rd and the 4th respectively. Based on the data and interpretation presented above, following conclusions are obtained:

1. With the EPD increase, the affecting degree on the IFC decreases for a certain load pressure, while the difference of affecting degree gradually increases as the variable of load pressure.
2. At the beginning of pullout tests, all four affecting factors almost have no effect on IFC of interface between geogrids and expansive soil, gradually the affecting degree and their difference increase as the EPD increases.
3. The difference of affecting degree on the IFC is more when water content $\geqq \omega_{opt}$ than beyond the $\leqq \omega_{opt}$, and with EPD increase, the affecting degree on IFC decreases for a certain water content as well as the increment of water content.
4. The maximum density of expansive soil (as fill) is controlled only by its optical water content, however, the interface-strength between expansive soil and geogrid depend on not only the water content of expansive soil but also the physical and mechanical properties of geogrids.
5. The size effect of geogrid has a little influence on the IFC between expansive soil and geogrid, and the affecting degree is gradually increases as the EPD increase.
6. Among four affecting factors, the pullout speed has the least influences on the IFC, the variable of pullout speed has some effect on IFC, and when the pullout speed is 1.0mm/min, its affecting degree is most powerful according to the data from pullout tests

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