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Research on process separation of pullout tests based on orthogonal design theory

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ABSTRACT: The interface friction coefficient (IFC) between reinforcements and soil is an important parameter in design and researches of reinforced soil structure. For obtaining the reasonable value of IFC, it is very significant to research on the process separation of pullout tests. Thus, twenty-seven pullout tests between geogrid and expansive soil designed by orthogonal table L_9 (3^4) were performed. The variable rules of IFC defined by different criteria had been given, as well as the affecting degree of factors influencing on IFC. And in accordance with the concept of 'equivalent pullout displacement' (EPD) presented and the performance of IFC, the process of pullout tests were divided into two parts and three stages, with which the IFC could be reasonably gained in various displacement states. Thus it's possible to obtain the IFC both in limit and working stress states.

1 INTRODUCTION

The interface friction coefficient (IFC) between reinforcements and soil gained in pullout tests is usually used in the limiting equilibrium analysis of reinforcement structures. But the theoretical results do not agreee well with the measured one, sometimes the agreeable tendency doesn't meet the practical requirement or even in opposite (Rowe 1996). The authors think the reason is that the IFC is measured in limit state, but the reinforced structure is usually under working stress conditions (Xu 2001, Xu et al. 2002). Therefore, for obtaining the reasonable value of IFC, it is very important to research on the process separation of pullout tests.

With many researches on IFC and lots of IFC test data, the authors summarized the selection principle of the test method of gaining reasonable IFC (Xu 2001, Xu 2003) and four affecting factors were selected as affecting factors of IFC (Xu 2001, Xu et al. 2002) according to the orthogonal principle. Through investigating the relationship between IFC and four affecting factors, main affecting factors of IFC and their influencing sequences were obtained. The analysis results showed that the reasonable IFC could only be gained through analyzing the test process (Xu 2001, Xu et al. 2002). Thus, the research on the process analysis of pullout tests based on the conventional test method has the important academic significance in gaining the reasonable value of IFC.

In this paper, pullout tests between geogrid and expansive soil designed by orthogonal table L_9 (3^4) (Ren 2001) were performed. Simultaneously, the changing rules of IFC under different codes and the influence of affecting factors on IFC were analyzed through the principle of process analysis. Based on the rules and in accordance with the presented concept of 'equivalent pull-out displacement' (EPD) (Xu 2001), the whole process of pullout tests were divided into two parts and three stages, thus it had laid the foundation to gain the reasonable IFC in the design and the analysis of reinforcement structures.

2 TEST ARRANGEMENT

According to the orthogonal table L_9 (3^4) (Ren 2001), four affecting factors (load pressure (LP), water contents of expansive soil (WCES), the size of geogrids (SG) and pullout speed (PS)) were selected, and each factor had three levels (Table 1), and 9 tests were arranged. With consideration of the experimental error, each test was carried on 3 effective repetitions, thus altogether 27 effective pullout tests were performed. Parameters (IFC) between expansive soil and geogrids were carried out by pullout tests in strain control manner.

Table 1. The levels of affecting factors.

Factors / levels	LP (kPa)	WCES (%)	SG (mm) (Length × width)	PS (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

The test equipment, materials, the set up and the way of the tests as well other conditions can be detailedly seen in the authors' previous papers (Xu 2001, Xu et al. 2002).

3 PULLOUT DISPLACEMENT PROCESS ANALYSIS

The so-called pullout displacement process analysis (Xu 2001) means: based on the value of IFC measured in the whole test process, according to the different displacement condition between geogrid and soil, test process is divided into stages. A series of analyses are carried out in each stage, and the analysis results are compared during the whole process.

In order to carry out process analysis, the concept of Equivalent Pullout Displacement (EPD) is presented and defined as follows:

$$\chi = \chi_j / \chi_{max} \quad (1)$$

where:

- χ = Equivalent Pullout Displacement (EPD);
- χ = Pullout displacement measured at frontal end;
- χ = Frontal displacement when the pullout force arrive at its maximum.

When analyzing the test results, firstly, the average values of the 3 effective repetition experiments were obtained. With the concept of 'equivalent pullout displacement (force)' put forward by the author (Xu 2001), the process of the pullout tests arranged by the orthogonal design principle L_9 (3^4) was divided into 10 sections (levels). The corresponding equivalent pullout displacement was 0.16, 0.32, 0.45, 0.64, 0.75, 0.90, 1.0, 1.32, 1.5 and 1.75 respectively. Among them, the first 7 levels were called the primary process (χ = < 1.0), and the latter 3 levels were called the secondary process ($\chi > 1.0$). When the value of χ is 1, the corresponding IFC or the pullout force reached the maximum value. In order to discuss the affecting rules of the affecting factors to the IFC, the value of friction parameter and the pullout force corresponding to each testing section (level) were calculated out, and extreme difference analysis was carried out to gain the quantification value of the level of the affecting factors. The relationship between EPD and the level of the affecting factors was curved (Figure 1, Figure 2).

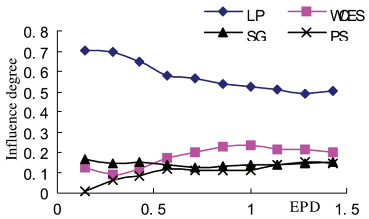

Figure 1. Influence of affecting factors on IFC defined by Chinese Criteria during the procedure of pullout tests.

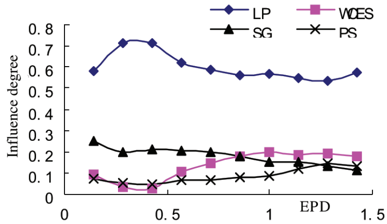

Figure 2. Influence of affecting factors on IFC defined by FHWA (GRI-GG5) during the procedure of pullout tests.

4 PROCESS ANALYSES ON INFLUENCE OF AFFECTING FACTORS ON IFC

4.1 *The process analysis of friction parameter between Geogrid and expansive soil*

In Figure 1 and Figure 2, x-coordinate is EPD; y-coordinate is the quantification coefficient of affecting factor to IFC. IFC in Figure 1 is defined by Chinese codes (*Highway Geosynthetic Experiment Code* 1998, *Geosynthetic Test Code* 1999) and in Figure 2 is defined by the FHWA code GRI-GG5 (Rowe 1996, Zhang et al. 2000).

From Figure 1 and Figure 2, the sequence of influence degree of each affecting factor on IFC (from high to low) is LP, WCES, PS, and SG. Among them, LP is the primary affecting factor, whose influence degree gradually reduces as the EPD increases; the SG has almost no effect on influence degree; the influence degrees of WCES and PS increase slowly.

Therefore, according to Figure 1 and Figure 2, the whole pullout test process may be divided into three stages as follows:

First stage: The EPD is smaller than or equal to C(C is a constant less than 0.5). In this stage, the influence degree of affecting factors changes unsteadily. The influence degree of LP drops rapidly or drops disorderly. The influence degrees of WCES and PS increase slowly.

Second stage: The EPD rises to 1.0. In this process, the influence degree of affecting factors changes regularly and steadily. The influence degree of LP is a slowly drop stage. The influence degree of WCES rises continually. Both of the influence degree of SG and PS are basically unchanged.

Third stage: The EPD is bigger than or equal to 1.0. At this stage, all the affecting factors change steadily. The influence degree of PS rises a little; others have the tendency of extremely slow drop.

4.2 *Change rule of friction coefficient*

4.2.1 *Comparative analysis of IFC by different criteria*

Figure 3 to Fig. 6 are the comparative curves of IFC defined by FHWA and Chinese Code when the EPD is 0.16, 0.64, 1.0 and 1.32 respectively. Through comparative analysis: (1) the value of IFC defined by the FHWA and that defined by the Chinese Code differed greatly from each other; (2) the values of IFC defined by FHWA and Chinese Code varied obviously with different tests, and the degree of variation is related to the combination of affecting factors; (3) during the pullout tests (from Figure 3 to Figure 6), when the EPD is not bigger than or equal to 1.0, both of the IFC defined by FHWA and Chinese Code respectively rise, the increasing scope of IFC defined by FHWA are relatively bigger and the maximum is 2.5; while the IFC defined by Chinese Code are all less than 1.0. When the EPD is bigger than or equal to 1.0, both IFC defined by two criteria drop slowly.

Although the IFC defined by FHWA and Chinese Code differs greatly in the value, the changing rules and the influence degrees of affecting factors on IFC are quite consistent in the whole pullout test process as shown in Figure 1 and Figure 2.

4.2.2 *Process analysis on variation rules of IFC*

As was shown in Figure 3 Figure 6, in the process that the EPD increased from 0.16 to 1.0 (i.e. the primary process), the IFC of all pullout tests increased continuously. But in the process that the EPD increased from1.0 to1.32 (i.e. the secondary process), the IFC

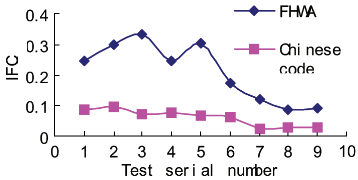

Figure 3. Compare with IFC defined by different criteria when the equivalent pullout displacement is 0.16.

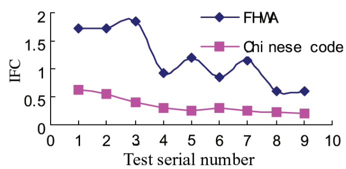

Figure 4. Compare with IFC defined by different criteria when the equivalent pullout displacement is 0.64.

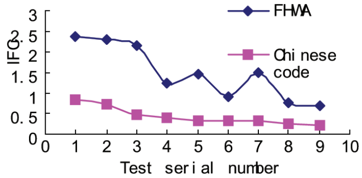

Figure 5. Compare with IFC defined by different criteria when the equivalent pullout displacement is 1.0

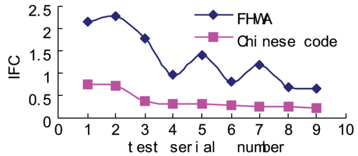

Figure 6. Compare with IFC defined by different criteria when the equivalent pullout displacement is 1.32.

decreased a little. We can learn from this that the IFC increased in the primary process of pullout tests (χ = < 1.0), and decreased in the secondary process (χ > 1.0). So, this kind of rule should be considered when the IFC is used to analyze reinforced soil structures.

5 PROCESS ANALYSES ON INFLUENCE OF AFFECTING FACTORS ON PULLOUT FORCES

5.1 *Results of pullout force tests*

The influence degrees of affecting factors on pullout forces in pullout tests between geogrid and expansive soil were reflected in Figure 7.

5.2 *Analyses on results of pullout force tests*

As was shown in Figure 7, the sequence of influence degrees (from high to low) of affecting factors on pullout forces was: WCES, SG, LP, PS. When the EPD exceeded 1.0, the influence of WCES on pullout forces was weakened to some extent, that of SG almost unaltered and that of LP and PS strengthened to some degree.

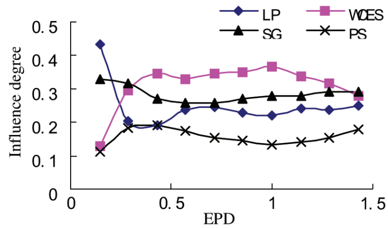

Figure 7. Influence of affecting factors on pullout forces between reinforcement and expansive soil defined by Chinese Criteria during the procedure of pullout tests.

6 ANALYSES AND SUMMARY

From the discussion above, we can learn that:

(1) The process analysis on the pullout tests data between geogrids and expansive soil showed the values of IFC defined by FHWA and Chinese Code differed distinctly.

(2) The influence degrees and sequences of affecting factors on interface parameters: (1) the sequence (from high to low) of influence degrees of affecting factors on IFC was: LP, WCES, SG and PS. This rule did not change with the difference of the definition of IFC; (2) the sequence (from high to low) of influence degrees of affecting factors on pullout forces was: WCES, SG, LP, PS.

(3) Process separation of pullout tests. The process analysis on interface parameters (IFC and pullout forces) in pullout tests showed that the influence degrees of affecting factors on interface parameters changed regularly. With regard to this rule and the concept of EPD, the whole process of pullout tests could be divided into two parts and three stages. First part is the primary process ($\chi = < 1.0$) and the other one is the secondary process ($\chi > 1.0$). The IFC increased in the primary process and decreased in the secondary process. The three stages were: (1) $\chi = < C$ (generally, $C = < 0.5$). The influence degrees of affecting factors changed unstably; (2) $C < \chi = < 1.0$ (generally, $C = < 0.5$). The influence degrees changed regularly; (3) $\chi > 1.0$. The influence degrees changed more stably.

7 CONCLUSIONS

The analyses on data from twenty-seven pullout tests designed by orthogonal table L_9 (3^4) showed that:

(1) The values of IFC defined by different criteria were distinctly different, but their variation rules in the pullout tests were accordant.

(2) The affecting factors of interface parameters between geogrid and expansive soil and the sequences of these factors were gained. They are valuable for reasonable adjustment of interface parameters in engineering design.

(3) The idea of process analysis and the concept of EPD were put forward. In consideration of affecting factors' influence on IFC and variation rules of IFC, the whole process of pullout tests were divided into two parts and three stages, with which the IFC could be reasonably gained in various displacement states.

(4) The design parameters between reinforcement and soil varied regularly with different displacement states. It is possible to gain parameters between reinforcement and soil if the concept of EPD is used and practical conditions of displacement observations and requirements of engineering technology are taken into account.

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