EFFECT OF SPACING OF TRANSVERSE MEMBER ON PULLOUT RESISTANCE OF BEARING REINFORCEMENT

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ABSTRACT

The bearing reinforcement was developed as a cost-effective earth reinforcement. It is composed of a longitudinal member and transverse members. The longitudinal member is made of a deformed bar, which exhibits a high pullout friction resistance. The transverse members are a set of equal angles, which provide high pullout bearing resistance. The present article studies the influence of the spacing of the transverse members on the pullout mechanism of the bearing reinforcement. The tested soils are coarse-grained soils: well-graded gravel (GW), well-graded sand (SW), crushed rock (GP) and poorly-graded sand (SP), which have different grain size distribution and friction angles. The transverse member interference is classified into three zones. Zone 1 $(S/B \le 3.75)$ is block failure where all transverse members act like a rough block. Zone 2 $(3.75 < S/B < 25)$ is member interference failure. Zone 3 $(S/B > 25)$ is individual failure.

Keywords: Bearing reinforcement, coarse-grained soils, pullout resistance, transverse member interference

INTRODUCTION

Soil reinforcing materials such as strips and grids, etc. have been developed in the past two decades so as to increase their functional abilities for reinforced structures. In Thailand, a widely use strip reinforcement is the ribbed steel reinforcing strip (It is 50 mm in width and 4.2 mm in thickness with yield strength of 520 MPa). This reinforcement is conveniently transported to a factory for galvanization and to a construction site as well as simple and fast to install due to its strip shape. Because it is not produced in Thailand and is imported from Africa, the construction cost is relatively high due to the high import charges. The steel grid reinforcement can be locally manufactured. This reinforcement has been extensively studied at the Asian Institute of Technology by Prof. D.T. Bergado and his co-workers (Bergado et al., 1988, 1996; Shivashankar, 1991; Chai, 1992; Tin et al., 2011). The advantage of the grid reinforcement is that the pullout bearing resistance in the resistant zone is high. However, the total volume (weight) of steel grid reguired is still high because of wasted transverse (bearing) bars in the active (unstable) zone. The transportation and installation of the grid reinforcement are less convenient than those of the strip reinforcement.

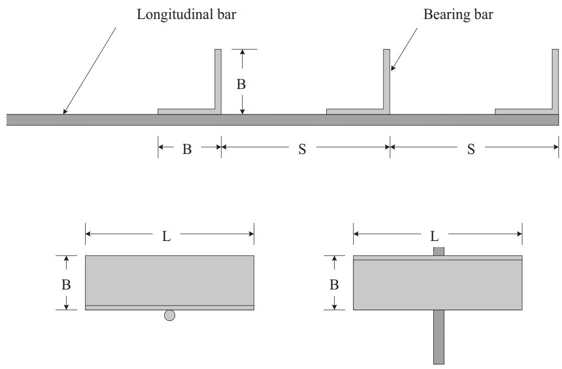

Fig. 1 Configuration of the bearing reinforcement (Horpibulsuk and Niramitkornburee, 2010).

Horpibulsuk and Niramitkornburee (2010) have introduced a new cost-effective earth reinforcement designated as “Bearing reinforcement”. It is simply installed, conveniently transported and possesses high pullout and rupture resistances with less steel volume. Figure 1 shows the typical configuration of the bearing reinforcement, which is composed of a longitudinal member and transverse (bearing) members. The longitudinal member is a steel deformed bar and the transverse members are a set of steel equal angles. This reinforcement has been introduced into practice in Thailand since 2008 by the Geoform Co., Ltd. Several earth walls stabilized with the bearing reinforcements have been constructed at various parts of Thailand. This mechanically stabilized earth (MSE) wall is designated as “Bearing Reinforcement Earth (BRE) wall” (Horpibulsuk et al., 2011).

Performance of the test BRE wall on a hard ground was investigated in the campus of Suranaree University of Technology (SUT) (Horpibulsuk et al., 2010 and 2011). The PLAXIS program was successfully used to simulate the performance of the BRE wall (Suksiripattanapong et al., 2012). In addition to the numerical analysis, the limit equilibrium design is generally considered for the BRE wall design due to its simplicity and conservation. The internal stability of the BRE wall deals with the rupture and pullout mechanisms. The pullout resistance is the sum of the pullout friction and bearing resistance. Based on the available researches on the pullout bearing mechanisms of different reinforcement types (Alforo et al., 1995; Hayashi et al., 1999; Alforo and Pathak, 2005; AASHTO, 2002; Bergado et al., 1988, 1996; Shivashankar, 1991; Chai, 1992).

Horpibulsuk and Niramitkornburee (2010) depicted that the maximum pullout bearing resistance of transverse member for the bearing reinforcement embedded in a poorly graded sand is dependent upon the spacing of transverse member. The proposed equation of interference factor was applicable to a particular compacted sand. This paper aims to study effect of spacing of transverse member on pullout resistance of the bearing reinforcement embedded in different coarse-grained soils. The tested soils were well-graded gravel, well-graded sand, poorly graded sand and crushed rock. Both the well-graded sand and the well-graded gravel are consistent with the specification of the Department of Highways, Thailand. The tested soils contain fine particles less than 12% and cover all coarse grained types, classified by the Unified Soil Classification System (USCS).

LABORATORY INVESTIGATION

The tested soils consisted of 4 soil types with different grain size distributions and friction angles. They were well-graded gravel (GW), well-graded sand (SW), crushed rock (GP) and poorly graded sand (SP) according to the Unified Soil Classification System (USCS). The average grain sizes, D_{50} were 5.7, 1.0, 7.0 and 0.31 mm for GW, SW, GP and SP, respectively. Strength parameters of all compacted soils obtained from a large direct shear apparatus with the diameter of 35 cm. The friction angles were 45, 42, 40 and 40 degrees, for GW, SW, GP and SP, respectively. The high friction angles (greater than 36 degrees) are acceptable for MSE wall construction in Thailand. The crushed rock (GP) and the poorly graded sand have the same friction angle but different grain size distribution and average grain size, D_{50}. These two soils were presented to study the effect of D_{50} on the pullout bearing mechanism. The pullout test results in these soils bring out a clear picture on the effect of gradation, average grain size and friction angle on the pullout mechanism and the failure pullout resistance. The grain size distribution curves of the studied soils compared with the specification of the Department of Highways, Thailand are presented in Fig. 2. The applied normal stress was 30, 50 and 90 kPa. These different applied normal stresses were considered to simulate total vertical stress (due to dead and live loads) on the bearing reinforcement at different depths. The pullout rate of 1 mm/min was adopted throughout the tests. The leg length, *B*, and the length, *L*, of the tested transverse members (steel equal angles) were 40 mm and 150 mm, respectively. The spacing between transverse members, *S*, varies from 150 to 1500 mm, depending upon the numbers of transverse member. In this study, number of transverse members, *n*, are 1 to 4, which is generally the case in practice. The testing details can be referred to Horpibulsuk and Niramitkornburee (2010).

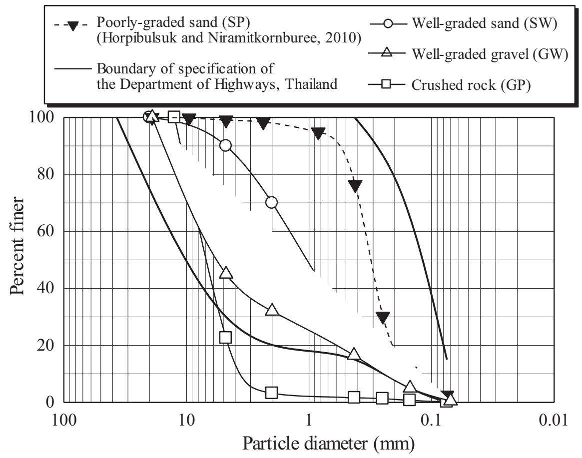

Fig. 2 Grain size distribution of the studied soils (Suksiripattanapong, et al., 2012b).

TEST RESULTS

The bearing reinforcement consists of several transverse members placed at regular intervals. The pullout resistance of the bearing reinforcement can be increased by increasing either the length of longitudinal member or the number of transverse member. The former is more expensive because the contribution of pullout bearing resistance is relatively higher than that of the pullout friction resistance. It was revealed that for steel grid, the transverse member interference, which controls the development in the pullout resistance, is dependent upon the spacing of transverse member and the diameter of transverse members (Bergado and Chai, 1994 and Bergado et al., 1996). Similarly, Horpibulsuk and Niramitkornburee (2010) demonstrated that the transverse member interference for the bearing reinforcement is controlled by the spacing of transverse member and leg length of transverse member, *B*, regardless of length of transverse member, *L*. During the pullout of the bearing reinforcement, the transverse members interfere with each other. A dimensionless parameter, transverse member spacing ratio, S/B was introduced to investigate the influence of spacing, *S*, and dimension (*B* and *L*) of transverse members on the pullout bearing characteristics. Generally, the larger the S/B, the higher the pullout bearing resistance up to a certain maximum value, due to less interference among transverse members.

Figure 3 shows the typical relationship between maximum pullout bearing force, P_{bn} and transverse member spacing ratio, S/B for 40x150 mm transverse members (n = 2 to 4) under different applied normal stresses compared with maximum pullout bearing force of a single isolated transverse member (n = 1), P_{b1} for all tested soils. The result is in agreement with that reported by Horpibulsuk and Niramitkornburee (2010), indicating that the failure mechanism of the bearing reinforcement is classified into three zones, depending upon the S/B value. Zone 1 is referred to as block failure when the $S/B \leq 3.75$. Zone 2 is regarded as member interference failure when $3.75 < S/B < 25$. Zone 3 ($S/B > 25$) is individual failure where soil in front of each transverse member fails individually. The interference factor, *F* was proposed as follows (Horpibulsuk and Niramitkornburee, 2010):

$$F = \frac{P_{bn}}{nP_{b1}} = a + b\ln\left(\frac{S}{B}\right) \quad (1)$$

where *a* and *b* are constant, depending upon *n*. These two constants can be obtained with the two physical conditions: 1) when S/B equals 3.75, the interference factor equals $1/n$ since P_{bn} and P_{b1} are the same, and 2) when S/B equals 25, the interference factor equals unity. These two conditions establish the lower and upper values of *F* at corresponding values of S/B = 3.75 and 25, respectively. From these two conditions, the constants *a* and *b* can be determined by the following equations:

$$b = 0.527\left[1 - \frac{1}{n}\right] \quad (2)$$

$$a = 1 - 3.219b \quad (3)$$

It is found that the interference factor, *F* predicted by Eqs. (2) and (3) can fit the experimental data. Based on the previous (Horpibulsuk and Niramitkornburee, 2010) and present studies, it is concluded that the member interference is dependent on only the S/B, irrespective of grain size distribution and friction angle for the soils investigated. These two factors play a great role on the P_{b1} (Suksiripattanapong and Horpibulsuk, 2012). As such, even with the same S/B (same *F*), P_{bn} values would be different for different grain size distribution and friction angle.

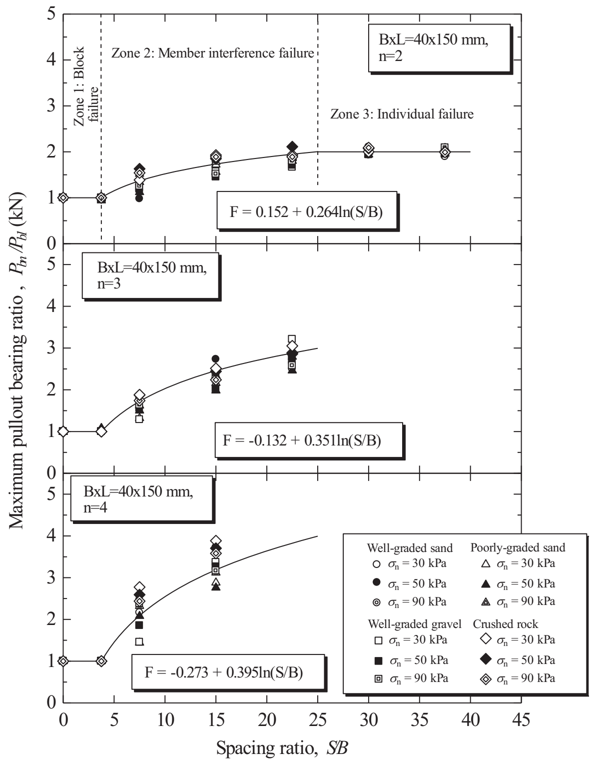

Fig. 3 Measured and predicted P_{bn}/P_{b1} and S/B relationship for 40x150 mm transverse members (Suksiripattanapong et al., 2012b).

CONCLUSIONS

This article presents effects of spacing of transverse member on pullout resistance of the bearing reinforcement embedded in different coarse-grained soils. The member interference is essentially dependent on the S/B, irrespective of grain size distribution and friction. The transverse member interference zones are classified into three zones. Zone 1 $(S/B \leq 3.75)$ is block failure where all transverse members act like a rough block. Zone 2 $(3.75 < S/B < 25)$ is member interference failure. Zone 3 $(S/B > 25)$ is individual failure.

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