A NOVEL MECHANICALLY STABILIZED EARTH WALL IN THAILAND - BEARING REINFORCEMENT EARTH (BRE) WALL

S. Horpibulsuk[1] , and C. Suksiripattanapong[2]
[1]Professor and Chair of School of Civil Engineering, Suranaree University of Technology, Thailand;
Email: suksun@g.sut.ac.th
[2]Ph.D. Scholar, School of Civil Engineering, Suranaree University of Technology, Thailand

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 bearing reinforcement earth (BRE) walls have been applied as a bridge abutment and a retaining structure along mountainous areas in several projects of the Department of Highways, Thailand since 2008. Based on the laboratory and field studies and design experience, the design method of the BRE is presented. The examination of external stability is performed using the conventional method (limit equilibrium analysis) assuming that the composite backfill-reinforcement mass behaves as a rigid body. The internal stability deals with rupture and pullout resistances of the reinforcement. The pullout resistance of the bearing reinforcement is approximated using the modified punching shear mechanism. The maximum tension plane is the bilinear failure mechanism (coherent gravity structure hypothesis).

Keywords: Bearing reinforcement earth wall, coarse-grained soils, pullout resistance

INTRODUCTION

Mechanically stabilized earth (MSE), an engineered composite material has been used extensively for construction of earth retaining wall and embankment slope in highway engineering works. A MSE wall is inexpensive, requires a simple construction operation in a shorter period of time, and has been known as an effective preservation of environmental conditions through erosion protection and control. Moreover, the MSE wall can exhibit tolerance to large deformation.

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. The bearing reinforcement was connected to the facing panel at the tie point (2 U shape steel) by a locking bar (a deformed bar) (*vide* Fig. 2). This mechanically stabilized earth (MSE) wall is designated as “Bearing Reinforcement Earth (BRE) wall” (Horpibulsuk et al., 2011). 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. Figure 3 shows an example of a successful BRE wall as a highway structure in Saraburee Interchange project, Thailand.

For a BRE wall design, an examination of external and internal stability is a routine design procedure. The examination of external stability is generally performed using the conventional method (limit equilibrium analysis) assuming that the composite backfill-reinforcement mass behaves as a rigid body. The internal stability of the BRE wall deals with the rupture and pullout resistances of the reinforcement. The practical equations for estimating pullout resistance of the bearing reinforcement with different transverse members were proposed by Horpibulsuk and Niramitkornburee (2010) and Suksiripattanapong et al. (2012b). The equations were successfully used to design the BRE wall in Thailand.

A full-scale test BRE wall was designed by the limit equilibrium analysis and constructed in the campus of Suranaree University of Technology (Horpibulsuk et al., 2010 and 2011). The performance of the BRE wall was measured and reported. The small lateral movement and settlement were observed. The PLAXIS program was successfully used to simulate the performance of the BRE wall (Suksiripattanapong et al., 2012a). Based on the laboratory and field investigations and the numerical analysis, the limit equilibrium design, which is generally considered for the BRE wall design due to its simplicity and conservation is introduced in this paper. This method has been adopted to design several BRE walls under the Department of Highways, Thailand.

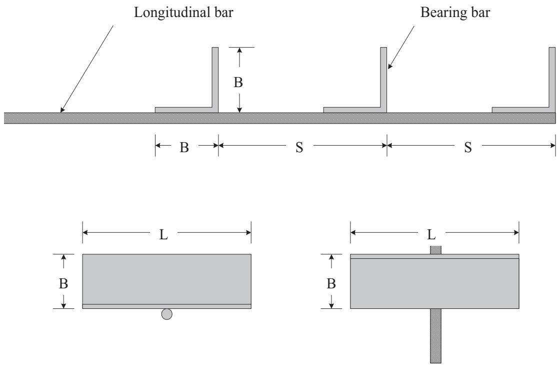

Fig. 1 Configuration of the bearing reinforcement (Horpibulsuk and Niramitkornburee, 2010).

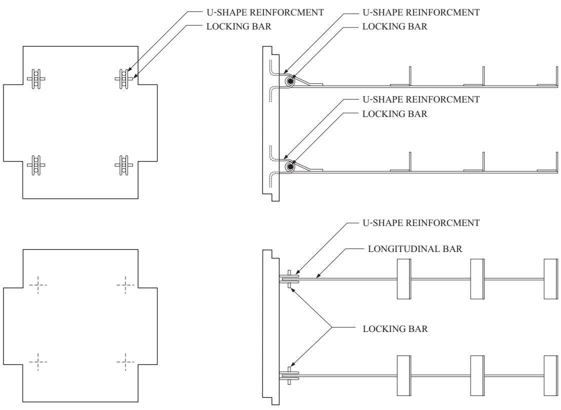

Fig. 2 Connection of the bearing reinforcement to wall facing

Fig. 3 Application of BRE wall for highway structure in Suraburee Interchange project.

REINFORCED BACKFILL SOIL

Backfill is an important material affecting the pullout resistance of bearing reinforcement. The coarse-grained soils, which are not sensitive to change in moisture content, are recommended. Material to be used as a backfill soil must be tested and certified from a laboratory and must have the following properties.

- Liquid limit must not be greater than 30%.
- Plasticity index must not exceed 6%.
- Coefficient of uniformity must be greater than 4.
- pH as determined by AASHTO T-289 “Determination of soil for use in corrosion testing” must be between 5 and 10.
- Organic content as determined by AASHTO T-267 “Determination of organic content in soils by loss on ignition” must not exceed 1%.
- Friction angles as determined by AASHTO T-236 “Direct shear test of soils under consolidated drained conditions” should be greater than 32.
- Gradation of backfill for the bearing reinforcement is presented in Table 1.

Table 1 Gradation of backfill for bearing reinforcement

Particle size (mm)	Percent passing (%)
37	100
4.75	30-100
0.425	15-100
0.150	5-65
0.075	0-15

- Electrochemical properties should be
    - Soil resistivity as determined by AASHTO T-288 “Standard method for determining minimum laboratory soil resistivity” must not be less than 3000 Ωcm.
    - Sulfates as determined by ASSHTO T-290 “Standard method for determining water-soluble sulfate ion content in soil” must not exceed 200 ppm.
    - Chloride ion content in soil as determined by ASSHTO T-291 “Standard method for determining water-soluble chloride ion content in soil” exceeds 100 ppm.

If the resistivity is greater than or equal to 5,000 Ωcm, the chloride and sulfate requirements may be waived.

BEARING REINFORCEMENT EARTH WALL DESIGN

The pullout mechanism of bearing reinforcement in laboratory (Horpibulsuk and Niramitkornburee, 2010 and Suksiripattanapong et al., 2012a) and the performance of bearing reinforcement earth wall (Horpibulsuk et al., 2010 and 2011; and Suksiripattanapong et al, 2012b) were investigated in order to determine the design method of BRE wall. For a BRE wall design, an examination of external and internal stability is a routine design procedure (Lee et al., 1973; Anderson et al., 1985; and McGown et al., 1998). The examination of external stability is generally performed using the conventional method (limit equilibrium analysis) assuming that the composite backfill-reinforcement mass behaves as a simi-rigid structure. The examination of external stability (*vide* Fig. 4) consists of the overturning, sliding, bearing capacity and slope stability. Internal mechanism deals with the rupture resistance and pullout resistance. (*vide* Fig. 5)

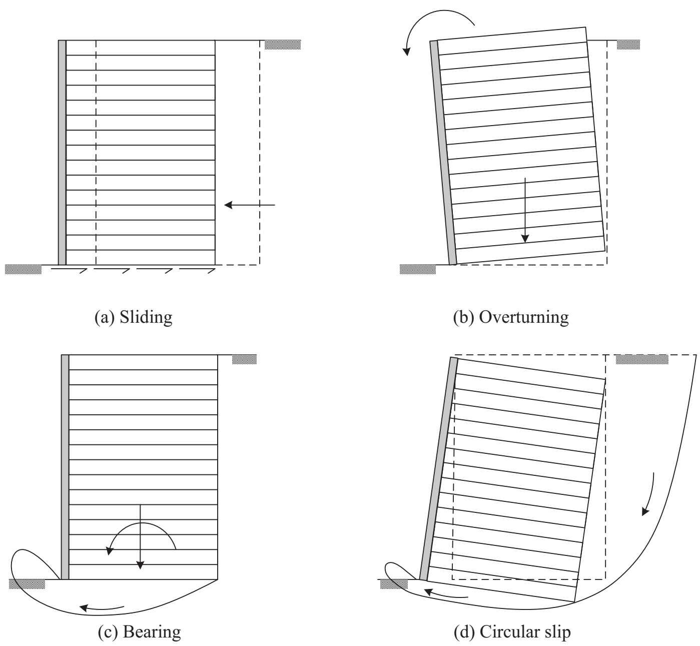

Fig. 4 External stability of reinforced earth wall

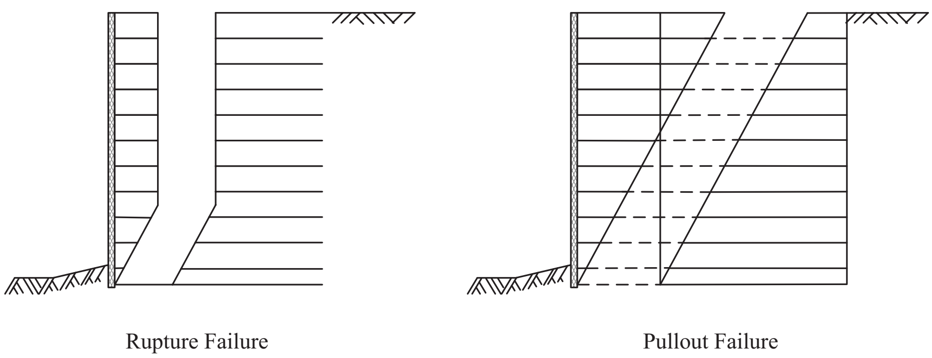

Fig. 5 Internal stability of reinforced earth wall

EXTERNAL STABILIITY

The BRE wall can be assumed as a rigid body when the vertical spacing of the reinforcements is less than 800 mm for the examination of the external stability. The embedded length of the bearing reinforcement of higher than 0.7 times the wall height is recommended (ASSHTO, 1996 and 2002).

The BRE wall has the external stability when no movement in three directions: horizontal, overturning, and vertical (bearing capacity). The horizontal and overturning stability were examined by law of statics. The vertical movement was examined by bearing capacity theory. For an examination of external stability, two cases of the live load are considered: 1) live load on both reinforced and unreinforced zones and 2) live load on unreinforced zone. The live load on reinforced zone increases stability against sliding and overturning but decreases stability against bearing failure. Case 2 is used to determine the factors of safety against sliding and overturning while the case 1 is used to determine the factor of safety against bearing failure. The conventional (limit equilibrium) method can be employed for this examination with the live load of about 20 kPa. This surcharge load is commonly taken for the MSE wall design in Thailand. AASHTO's Standard Specifications Highway Bridge Section 5.8 recommends that the factors of safety against sliding, overturning, and bearing failure should be greater than 1.5, 2.0, and 2.5, respectively.

INTERNAL STABILIITY

The internal stability analysis deals with rupture and pullout mechanisms. The pullout resistance against rupture failure is the product of the yield stress cross sectional area of the longitudinal member. The reinforcement corrosion is approximated from AASHTO (2002):

Galvanized loss

- 15 micron (0.015 mm) per year at first 2 years
- 4 micron (0.004 mm) per year in subsequent years

Steel loss

- 12 micron (0.012 mm) per year after zinc depletion for the remaining years until design life

The failure plane and approximate *K* for the BRE wall (Horpibulsuk et al., 2010 and 2011 and Suksiripattanapong et al., 2012) are shown in Fig. 6. The possible failure plane (maximum tension plane) and the maximum tension forces in the reinforcement can be approximated from the coherent gravity structure hypothesis. The lateral earth pressure, σ_h, at each reinforcement level is calculated using $K = K_0$ at the top of the wall and decreases linearly to $K = K_a$ at 6 m depth. Below a 6 m depth, $K = K_a$ is used.

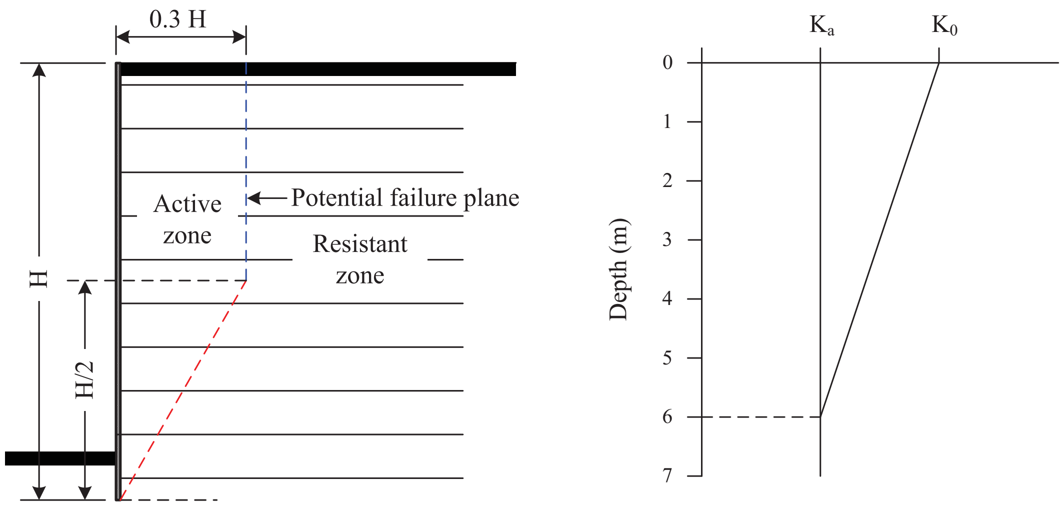

Fig. 6 Failure plane and approximate *K* for bearing reinforcement earth wall (Horpibulsuk et al., 2010 and 2011 and Suksiripattanapong et al., 2012)

Pullout Bearing Resistance of a Single Isolated Transverse Member (n = 1)

The pullout resistance, P_t of the bearing reinforcement is the sum of the pullout friction, P_f and bearing resistance, P_b.

$$P_t = P_f + P_b \tag{1}$$

Maximum pullout friction resistance, P_f, of the longitudinal member can be calculated from

$$P_f = \left(c_a + \sigma_v \tan\delta\right) D L_e \tag{2}$$

where c_a is the adhesion, δ is the skin friction angle, D is the diameter of the longitudinal member, L_e is the length of the longitudinal member in resistance zone and σ_n is the normal stress. Horpibulsuk and Niramitkornburee (2010) and Suksiripattanapong et al. (2012b) have studied pullout of a deformed bar embedded in different coarse-grained soils. It is found that the δ/ϕ ratio about 1.47. The high δ/ϕ ratio is because of the contribution of the skin roughness of the deformed bar. The δ/ϕ ratio of 1.0 was recommended for design.

Laboratory test results showed that the maximum bearing stress of a single isolated transverse member, $\sigma_{b\max}$, in coarse grained soil can be approximated by the modified punching shear mechanism (Fig. 7). It is assumed that (a) there are only two failure zones: active (ABD) and rotationalzone (ABC); (b) the stress state beyond the rupture line AC can be expressed by normal stress, σ_n, and horizontal stress, $K\sigma_n$, which are all the principle stresses and K is the horizontal earth pressure coefficient; and (c) the strength on AC is fully mobilized. The pullout bearing resistance can be approximated from:

$$P_b = N_q \sigma_n B L \tag{3}$$

$$N_q = \exp\left[\left(\frac{\pi}{2} + \phi\right)\tan\phi\right]\tan\left(\frac{\pi}{4} + \frac{\phi}{2}\right) \tag{4}$$

where N_q is bearing capacity factor, depending upon the mode of failure, σ_n is normal stress, B is leg length of transverse member and L length of transverse member.

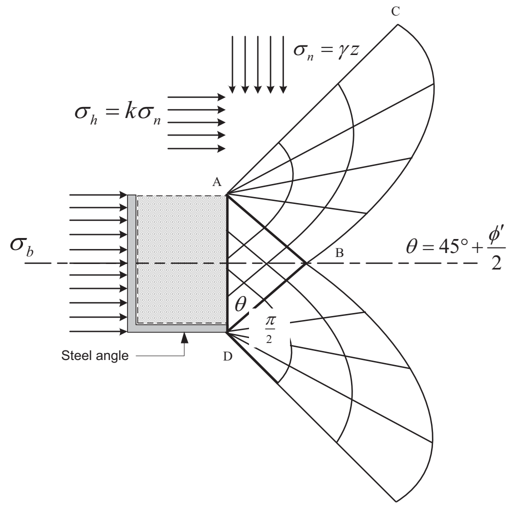

Fig. 7 Possible failure mechanism of a single isolated transverse member (Horpibulsuk and Niramitkornburee, 2010)

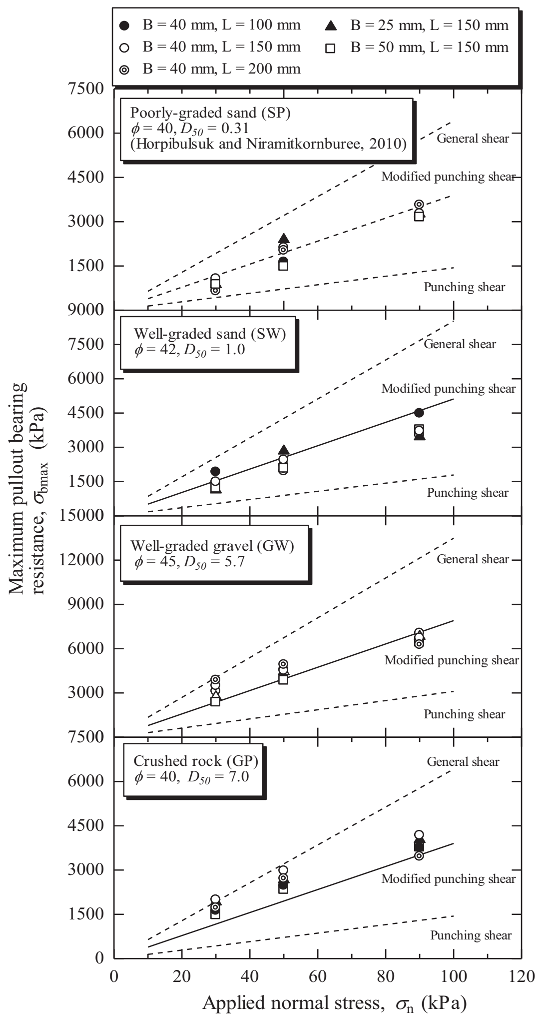

Fig. 8 Maximum pullout bearing resistance of a single isolated transverse member for all tested soils (Suksiripattanapong et al. 2012b).

The maximum pullout bearing resistance can be determined from the plasticity solutions. Using the proposed equations (Eqs. 3 and 4), the comparison between the measured and predicted maximum bearing stresses are shown in Fig. 8.

Pullout Resistance of the Bearing Reinforcement ($n > 1$)

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 9 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):

$$F = \frac{P_{bn}}{nP_{b1}} = a + b\ln\left(\frac{S}{B}\right) \quad (5)$$

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:

$$b = 0.527\left[1 - \frac{1}{n}\right] \quad (6)$$

$$a = 1 - 3.219b \quad (7)$$

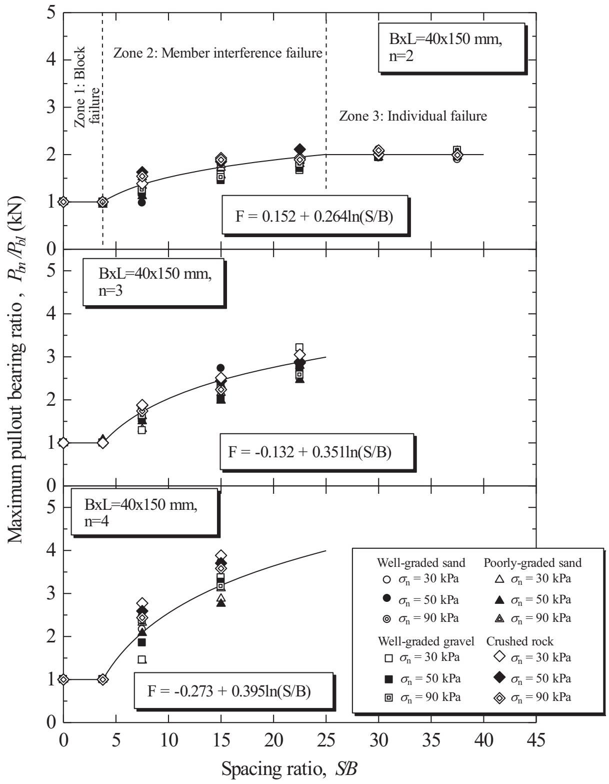

Fig. 9 Measured and predicted P_{bn}/P_{b1} and S/B relationship for 40x150 mm transverse members (Suksiripattanapong et al., 2012b).

It is found that the interference factor, F predicted by Eqs. (5) to (7) can fit the experimental data. Based on the previous (Horpibulsuk and Niramitkornburee, 2010 and Suksiripattanapong et al., 2012b), 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.

CONCLUSIONS

This paper presents the feature of the bearing reinforcement earth (BRE) wall, which was developed by the School of Civil Engineering, Suranaree University of Technology and the Geoform Co., Ltd. The advantage of the bearing reinforcement is simple and fast installation, convenient transportation, and high pullout and rupture resistances with less steel volume. The bearing reinforcement earth (BRE) walls have been applied as a bridge abutment and a retaining structure along mountainous areas in several projects of the Department of Highways, Thailand since 2008. The design method of the BRE wall, which is based on the laboratory and field studies and the design experience, is introduced. The design consists of an examination of external and internal stability. The examination of external stability consists of the overturning, sliding, bearing capacity and slope stability. The examination of internal stability deals with rupture and pullout mechanisms.

ACKNOWLEDGEMENTS

The authors are grateful to the Thailand Research Fund (TRF), the Office of Small and Medium Enterprises Promotion (OSMEP), the Geoform Co., Ltd, the Science and Technology Research Grant by the Thailand Toray Science Foundation (TTSF) and the Suranaree University of Technology for financial support, facilities and equipment. Financial support provided from the Higher Education Research Promotion and National Research University Project of Thailand, Office of Higher Education Commission is also appreciated.

REFERENCES

AASHTO (2002). Standard Specifications for Highway and Bridge, 7th Ed. American Association of State Highway and Transportation Officials, Washington D.C.

Alfaro, M.C., Pathak, Y. P. (2005). Dilatant stresses at the interface of granular fills and geogrid strip reinforcement. Geosynthetics International 12 (5): 239-252.

Alfaro, M.C., Hayashi, S., Miura, N., Watanabe, K. (1995). Pullout interaction mechanism of geogrid strip reinforcement. Geosynthetics International 2 (4): 679-698.

Bergado, D.T., Chai, J.C. (1994). Prediction of pullout load-displacement relationship for extensible reinforcement. Geotextiles and Geomembranes 30 (5):295-316.

Bergado, D.T., Sampaco, C.L., Alfaro, M.C., Balasubramaniam, A. (1988). Welded-Wire Reinforced Earth (Mechanically Stabilized Embankments) With Cohesive Backfill On Soft Clay. 2nd Progress Report Submitted to USAID Bangkok Agency.

Bergado, D.T., Chai, J.C., Miura, N. (1996). Prediction of pullout resistance and pullout force-displacement relationship for inextensible grid reinforcements. Soils and Foundations 36 (4): 11-22.

Chai, J.C. (1992). Interaction between Grid Reinforcement and Cohesive-Frictional Soil and Performance of Reinforced Wall/Embankment on Soft Ground, D.Eng.Dissertation, Asian Institute of Technology, Bangkok, Thailand.

Hayashi, S., Shaha, J. T., Watanabe, K. (1999).Change in interface stress during pullout test on grid strip reinforcement. Geotechnical Testing Journal, ASTM, 22: 32-38.

Horpibulsuk, S., Niramitkornburee, A. (2010). Pullout resistance of bearing reinforcement embedded in sand. Soils and Foundations 50 (2):215-226.

Horpibulsuk, S., Suksiripattanapong, C., Niramitkornburee, A. (2010). A method of examining internal stability of the bearing reinforcement earth (BRE) wall. Suranaree Journal of Science and Technology 17 (1):1-11.

Horpibulsuk, S., Suksiripattanapong, C., Niramitkornburee, A., Chinkulkijniwat, A., Tangsuttinon, T. (2011). Performance of earth wall stabilized with bearing reinforcements. Geotextiles and Geomembranes 29 (5): 514-524.

Shivashankar, R. (1991). Behaviour of Mechanically Stabilized Earth (MSE) Embankment with Poor Quality Backfills on Soft Clay Deposits, including a Study of the Pullout Resistance, D.Eng. Dissertation, Asian Institute of Technology, Bangkok, Thailand.

Suksiripattanapong, C., Horpibulsuk, S. (2012). Effect of particle size on the pullout mechanism of bearing reinforcement. Proc. International Conference on Ground Improvement and Ground Control, 30 Oct. – 2 Nov. 2012, University of Wollongong, Australia

Suksiripattanapong, C., Chinkulkijniwat, A., Horpibulsuk, S., Rujikiatkamjorn, C., Tangsuttinon, T. (2012a). Numerical analysis of bearing reinforcement earth (BRE) wall. Geotextiles and Geomembranes 32:28-37.

Suksiripattanapong, C., Horpibulsuk, S., Chinkulkijniwat, A., Chai, J.C. (2012b). Pullout resistance of bearing reinforcement embedded in coarse-grained soils. Geotextiles and Geomembranes (in press).

Tin, N., Bergado, D.T., Anderson, L.R., Voottipruex, P. (2011). Factors affecting kinked steel grid reinforcement in MSE structures. Geotextiles and Geomembranes 29: 172-180.