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Field investigation of bearing reinforcement earth wall in Mae Moh mine, Thailand

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ABSTRACT: In this research, a bearing reinforcement earth (BRE) wall with a residual clay stone backfill was successfully implemented as an alternative truck ramp support for an on-site crusher plant in the Mae Moh mine, Thailand. The performance of the BRE wall during and after the end of construction as well as during the service state was evaluated in terms of settlement, bearing stress, lateral movement, lateral earth pressure and tension force in the reinforcements. The bearing stress which was uniformly distributed was found to increase rapidly with construction time, which was in agreement with the relatively uniform settlements. The lateral wall movement at the end of construction was very small with the maximum movement (at the top of the wall) found to be less than 10 mm. As such, the ratio of lateral movement to height (δ/H) was found to be approximately 0.12%. The maximum tension plane of the BRE wall could be represented by the coherent gravity hypothesis.

1 INTRODUCTION

Mae Moh mine is located in the Mae Moh district, Lampang province, Thailand. This mine is operated by the Electricity Generating Authority of Thailand (EGAT) and is reputably the largest open-pit lignite mine in Southeast Asia. The current Mae Moh pit covers an area of 4 km by 7.5 km and is up to 490 m deep at certain locations. The excavated lignite is crushed into small, suitably-sized particles for electricity generation, with the use of an onsite crusher plant. The onsite crusher plant is composed of a crusher plant, truck ramp and natural slope. The excavated lignite is hauled by a truck to be crushed in the crusher plant through the truck ramp supported on a stable slope. Ideally, a crusher plant must be located close to the excavated lignite open pit to minimize haulage costs. The haulage cost rate increases by approximately 4.3 million US dollars) per year, for each 1 km distance the crusher plant is away from the pit.

Instead of relying on the natural slope as the truck ramp support, which is often a large distance away for the open pit, a bearing reinforcement earth (BRE) wall alternative was proposed as a vertical temporary structure close to the open pit. The bearing reinforcement system was initially developed as an inextensible reinforcement in Thailand by Horpibulsuk and Niramitkornburee (2010). It is a relatively cost-effective reinforcement system whose advantages include: availability of raw materials, simple and fast installation, convenient transportation, and high pullout and rupture resistances with a less required steel volume. The configuration of the bearing reinforcement is shown in Figure 1. It is composed of a combination of a longitudinal member and several transverse (bearing) members. The longitudinal member comprises a deformed steel bar while the transverse members are a set of equal steel angles, which produce high pullout bearing resistance. The bearing reinforcement is connected to the wall facing panel at the tie point (2 U shape steel) by a locking bar (a deformed bar) (Fig. 2). The BRE wall design method has been developed based on laboratory and full-scale tests (Horpibulsuk et al. 2011, Suksiripattanapong et al. 2012, 2013 & 2016, and Sukmak et al. 2015 & 2016).

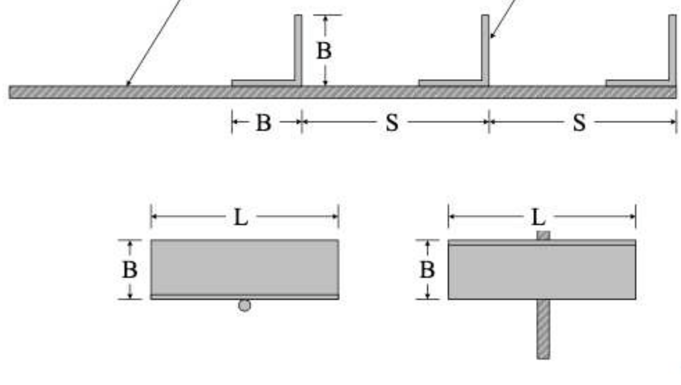

Figure 1. Configuration of the bearing reinforcement

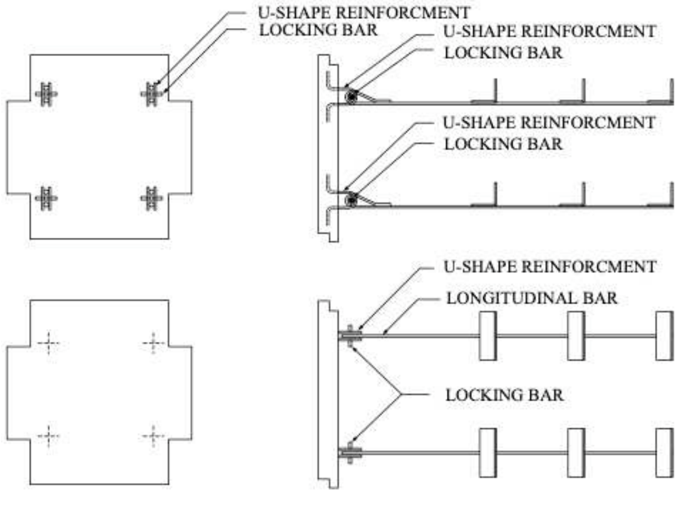

Figure 2. Connection of the bearing reinforcement to wall face

In this research, a full-scale instrumented BRE wall was constructed using claystone backfill in the Mae Moh mine as a truck ramp support for an on-site crusher plant. The measured performance of the BRE wall after the completion of construction and during the service period included settlement, bearing stress, lateral movement, lateral earth pressure and tension force in the reinforcements.

2 FULL-SCALE TEST WALL

2.1 *Backfill*

The backfill soil used for constructing the BRE wall was claystone, which was abundantly available at the Mae Moh mine. The claystone can be classified as a high plasticity silt (MH), according to the Unified Soil Classification System (USCS). Its specific gravity was 2.67. The liquid limit and plastic limit were 54 % and 36 %, respectively. The laboratory compaction characteristics under standard Proctor energy (ASTM D 698-91, 1995) was an optimum water content of 29.6 % and a maximum dry unit weight of 13.6 kN/m^3. Direct shear tests were conducted to determine the total shear strength parameters, used for practical design in the unsaturated conditions. Total strength parameters of claystone were c = 57 kPa, and ϕ'= 12 degrees. This high clay content and poor shear strength parameters are however unacceptable for the MSE wall construction according to AASHTO (2002) and the Department of Highways, Thailand specifications. Even though high quality well-graded materials are preferred for use as backfill materials, they were not used for this BRE wall due to the high economic and environmental costs.

2.2 *Construction of the BRE wall*

The instrumented BRE wall was 9 m high as illustrated in Figure 3. The ground was first excavated to 0.5 m depth below the original ground where the wall base was located. The wall facing panels were placed on a lean concrete leveling pad (0.50 m width and 0.15 m thickness) after 2 days of curing. The leveling pad was founded at 0.15 m depth below the excavated ground. In the wall construction, seven vertically facing panels and ten horizontally facing panels (15 m width) were installed in fourteen reinforcement levels.

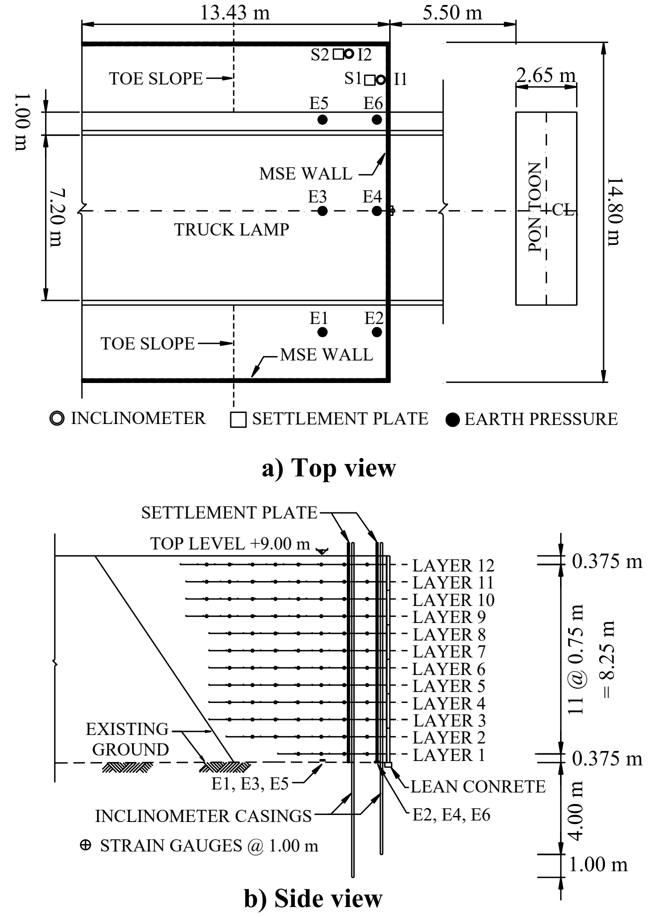

Figure 3. Schematic of the test BRE wall with instrumentation

During the field compaction, laboratory standard Proctor test (ASTM D698). The claystone was brittle and was broken down with compaction rollers. The broken backfill was compacted in layers approximately 0.15 m thick to a density greater than that of 90 % of the relative density. The total time for construction was 20 days.

2.3 *Instrumentation program*

Due to space limitation of the BRE wall, where the truck ramp was at the middle of the BRE wall for work safety requirements, only the most significant instruments were installed, which were the settlement plates, earth pressure gauges, inclinometers and strain gauges. The instrumentation of the BRE wall is shown in Figure 3. The surface settlement plates, inclinometers, and earth pressure gauges were installed in the excavated ground prior to the construction of the wall. Two settlement plates were placed beneath the wall (at 0.5 m depth below the ground surface) at 0.5 and 1.5 m from the wall face (S_1 and S_2 in Fig. 3).

S_1 measured the settlement at the front side close to the truck ramp while S_2 measured the settlement at the lateral side close to the crusher plant.

Lateral soil movements of the BRE wall both in front and at the lateral sides were recorded after the completion of construction and operation state for over 270 days. Lateral movements of the subsoil and the wall at various times were measured using two digital inclinometers (I1 and I2) located close to S1 and S2. The inclinometer casings were installed from the top of the wall down to the subsoil level of approximately 4 m (I1) and 5 m (I2) below the wall base.

Vertical earth pressures beneath the wall in truck ramp and no truck ramp zones were measured by earth pressure gauges E3 and E4 and E1, E2, E5 and E6, respectively, during construction and after the completion of construction. The earth pressure gauges were installed at 0.5 m depth below the original ground level (following the foundation excavation). The strains and tensile forces along the longitudinal members were measured with outdoor waterproof type strain gauges. The rib on the deformed steel longitudinal member was initially sharpened, following which the strain gauges were attached using a special glue.

3 FIELD TEST RESULTS

3.1 *Settlement*

Figure 4 shows the relationship between settlement and time at the front and lateral sides of the BRE wall. The measured result shows that the settlement of BRE wall at the front and lateral sides is similar. The settlement of BRE wall was recorded during three intervals: during construction, during installation of the truck ramp and during operation. The settlement of the wall during construction increases with construction time due to the increased weight of the backfill as the wall was constructed. The maximum settlement at the end of construction (20 days) is about 5 mm. The installation of the truck ramp (10 days after end of construction) results in an immediate settlement of approximately 2 mm. During operation (34 days after installation of truck ramp), the settlement of the BRE wall increases immediately because of the increase in loading from the truck weight. For the safety of the surveyor, settlement was measured while no truck was on the wall. The final settlements at the front and lateral sides of the BRE wall were measured to be between 25 to 27 mm.

3.2 *Bearing stress*

Figure 5 presents the relationship between the bearing stress and construction time at the center (E_3 and E_4) and right lateral side (E_1 and E_2). During construction the bearing stress increases rapidly with construction time (20 days) due to the increase in construction load (backfill). The bearing stress then remains constant until the truck ramp was installed. In operation, the bearing stress increases slightly because the bearing stress was measured while no truck was on the truck ramp. The slight difference in bearing stress of the BRE wall at the center (E_3 and E_4) and lateral (E_1 and E_2) sides at the end of construction is noted. It is of interest to mention that the bearing stresses measured at E_1 to E_6 are more or less similar and are close to the calculated backfill load (unit weight x backfill height) of about 150 kPa. In other words, the backfill load distribution is uniform which is in agreement with uniform measured settlement.

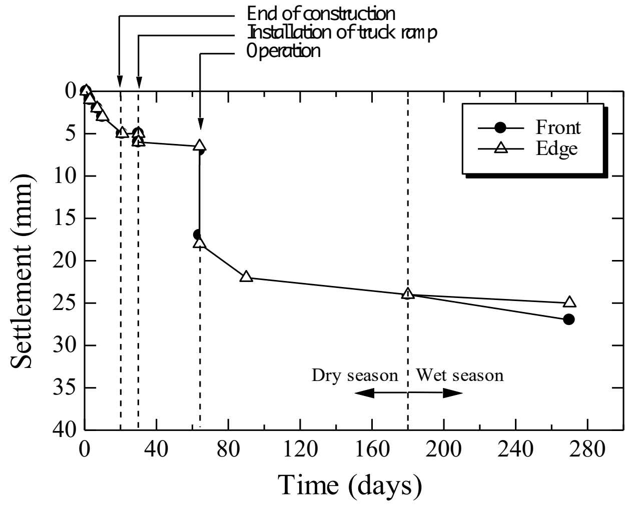

Figure 4. Settlement versus time

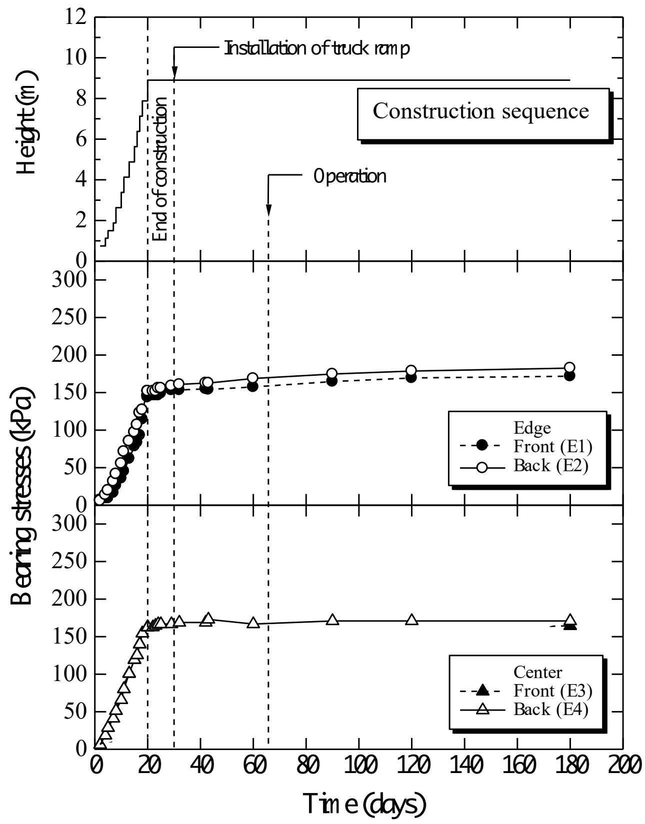

Figure 5. Bearing stress versus time

3.3 *Lateral wall movement*

The measured lateral movement of the wall face at front side after the end of construction until 270 days is shown in Figure 6. The lateral movement increases uniformly with wall height. Within 30 days after the end of construction (day 50), the lateral movement is very small with the maximum (at the top of the wall) of only less than 10 mm. As such, the ratio of lateral movement to height (δ/H) at the end of construction is approximately 0.12 %, which is lower than the allowable value of 0.4 % for inextensible reinforcement suggested by Brag et al. (2009). Immediately after the operation, the lateral wall movement increases with wall height up to a wall height of 2 m, which is in agreement with remarkable increase in settlement. Then the lateral movement increases clearly at wall height between 2.0 to 5.0 m. The lateral movement becomes constant for wall heights greater than 6.0 m. Although the lateral movement increases with construction time, the magnitude of lateral movement is insignificant. The maximum lateral movement occurring at the middle to top of the wall. The maximum measured lateral movements at the top of the wall (6.0 - 9.0 m wall height) were small, being 58 mm at 270 days. With insignificant change in the settlement and lateral movement during the service stage, this BRE wall is considered to have a very high stability.

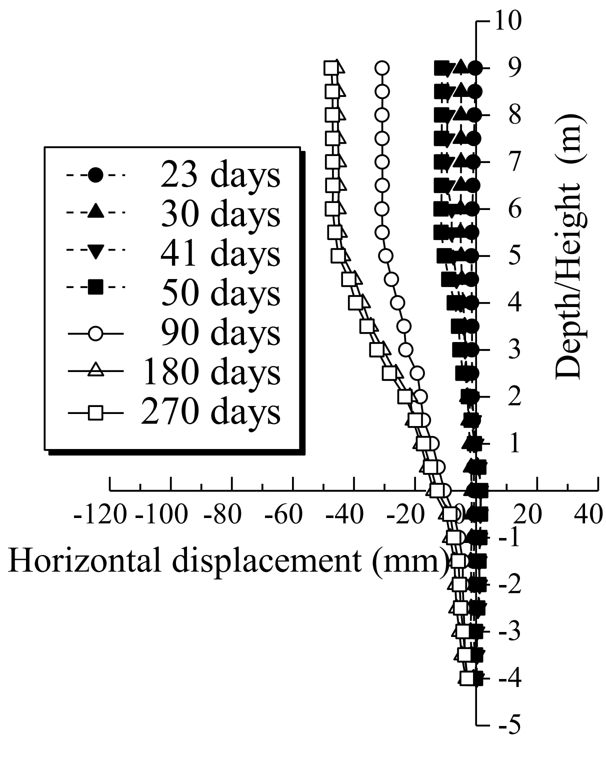

Figure 6. Lateral wall movement at front side

3.4 *Possible failure plane*

Figure 7 illustrates the reinforcement tension measured from strain gauges after the completion of construction at different wall heights and distances from wall facing. The measured reinforcement tensions (solid line) show high tension at the point near the wall face when location of reinforcement is below H/2 while high tension is at the middle and top layers of wall occurring at the points about 3 m distance from the wall face. The dash line in Figure 6 shows the bilinear type of maximum tension line (coherent gravity structure hypothesis) for coarse-grained backfill, which is close to the measured maximum tension line (solid line). In other words, the coherent gravity structure hypothesis can be applied to estimate the location of the maximum tension of reinforcement embedded in fine-gained soil.

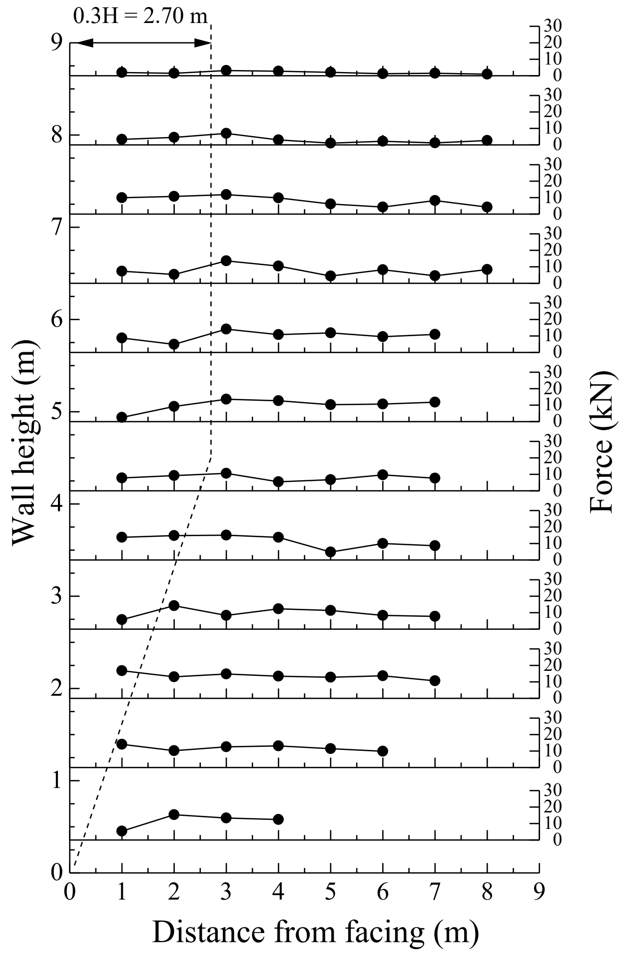

Figure 7. Possible failure plane

4 CONCLUSIONS

This paper presents the performance of the bearing reinforcement earth (BRE) wall constructed as a truck ramp support for an on-site crusher plant in Mae Moh mine. During construction, the settlement and bearing stress increased rapidly with construction time due to an increase in the backfill load. The settlement and bearing stress were uniform for the case history presented. The settlement due to the backfill was only 5 mm while the cyclic load from the truck travel caused settlement of 20 mm.

The lateral movement pattern at the front side was found to be similar with approximately the same magnitude at the end of construction but with different magnitudes at the service stage. The maximum lateral movement at the end of construction was small, of less than 10 mm. As such, the lateral movement to height ratio is only 0.12 %, which was lower than the allowable value of 0.4 % and indicated the high stability of the BRE wall. The maximum tension line for BRE wall with claystone backfill can be represented by the coherent gravity structure hypothesis.

5 ACKNOWLEDGMENTS

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