BEHAVIOUR OF AN EXCAVATION STABILISED BY AN EMBEDDED IMPROVED SOIL BERM

Thanadol Kongsomboon
Lecturer, Civil Engineering Department, Srinakarin University

Tan Thiam Soon
Associate Professor, Civil Engineering Department, National University of Singapore

Warakorn Mai-raing
Associate Professor, Civil Engineering Department, Kasetsart University

ABSTRACT: In a supported excavation in poor ground condition, the maximum wall deflection usually occur below the final excavation level, where it is impossible to install struts. One solution is to improve the soil at th level prior to excavation to provide effective lateral restraint against wall deflection. In case of large excavated area only a peripheral improved berm is necessary. Hence the term embedded improved soil berm is used in this pape This paper reports the results of a series of in-flight excavation tests conducted in the centrifuge. The results show that for an embedded berm, the berm resistance to the wall is provided by the interfacial resistance and lateral bearir capacity. Hence, foran embedded berm, the controlling parameters are the area of contact rather than the stiffness of the improved layer. Test using a very high stiffness improved layer in one of the tests shows only a marginal improvement.

KEYWORDS: EXCAVATION, SOFT SOIL, IMPROVED SOIL, BERM, SHEAR RESISTANCE

1. Introduction

In most highly developed city, a majority of the deep excavations need to be carried out near to important structures such as skyscrapers, mass rapid transit tunnels, underground utilities and poorly supported old monuments. The main design problem in such constructions is the need to avoid potentially damaging effects caused to these nearby structures as a result of excessive ground movement

However, when a thick layer of soft soil exists well below the final excavation level, such provisions may not be adequate as the maximum deflection usually occurs below the final excavation level, where it is impossible to install conventional strutting system (Cheng and Tsui, [1]). In such situations, to prevent excessive movement, one approach is to improve the soil where the maximum deflection is expected. Jet grouting and deep cement mixing have proven to be effective in such situations to control the deflection of retaining wall and hence the ground movement (Tanaka, [5], Liao and Tsai, [3], Yong and Lee., [7], Sugawara et al., [4])

In many practical situations, the area to be excavated is simply too big for complete improvement of the entire soil layer inside the excavation. Instead, a berm is provided with the expectation that if it is long enough, this is the same as improving the entire layer. The term embedded improved soil berm is used to describe this form of soil improvement. When such techniques are employed, the main focus is on the control of movement and not the stability of the excavation. But, while the effectiveness of this technique has been shown in many excavations, a comprehensive study of this stabilisation technique, in particular, how it controls the movement has yet to be carried.

In view of the shortcomings of using field data for detailed mechanistic investigation, correctly scaled physical modeling, though challenging, is still preferred. In geotechnical engineering, it is now recognised that for processes where geostatic stresses play an important role, centrifuge provides the only coherent way to carry out such physical model tests (Taylor, [6]). A centrifuge is used to create a high acceleration field to ensure correct scaling in a small model. However, for realistic simulation, it is important to ensure that key construction activities are simulated in-flight. This necessitates the development of relevant robotics, available to only a handful of centrifuge research centres.

As an improved soil berm is not constrained at one end, it is essential to establish whether it functions like a strut as is intended, or other mechanisms come into play. Thus the objective of this study is to develop an understanding of the mechanics at play when an embedded improved soil berm is provided below final excavation level in an excavation. A series of excavation tests in 100g environment, with different configurations of improved soil, had been carried out on the National University of Singapore's centrifuge (Lee et al., [2]). The results of these tests, presented in model scale(1mm model scale = 100mm prototype scale), will form the basis for the study into the mechanics of the behaviour of an improved soil berm in an excavation, in particular, the interaction of various resisting forces mobilised during an excavation, namely interfacial shear, end-bearing of berm and passive soil resistance.

2. General behaviour of an excavation stabilised by embedded improved soil

2.1 Lateral wall deflection and surface settlement

The general behaviour of an excavation stabilised with improved soil berm, will be first addressed using results from three tests. The first test, TW/O, was for an excavation test where no soil improvement had been provided. In Test TST, an entire layer of soil in the passive side was improved, so that the improved soil layer behaved like a strut when restraining the inward movement of the retaining wall. In the third test, TB-L100, a 100mm long berm with the same thickness as in Test TST is improved. The location of this berm is the same as in Test TST as shown in Fig. 1.

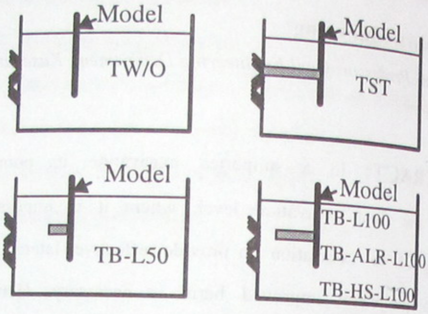


Figure 1 Typical models of excavation

Thus in Test TB-L100, there is a length of 50mm of untreated soft clay between the improved soil berm and the side of the container. This means that one end of the berm is not restrained.

The performance of the various configurations of soil improvement will be discussed in terms of the displacement of retaining wall and the settlement of the surface behind the wall. Fig. 2 shows the lateral displacement of the wall measured at a point 30mm above the ground level and the surface settlement of the ground at a distance 50mm behind the wall.

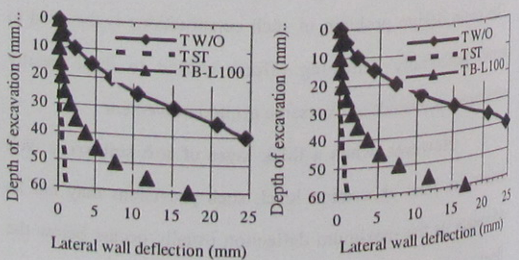


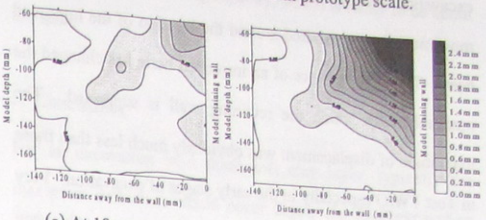
Figure 2 Lateral wall deflection and surface settlement of excavation model TW/O, TST and TB-L100

This figure shows the movement is for the entire excavation to a depth of 60mm in model scale. The figure show that in Test TW/O, where no soil improvement is provided, the wall deflection and ground settlement become excessive very shortly after excavation has reached a depth of about 10mm. In contrast, in Test TST where an embedded improved soil strut is provided, the wall displacement at this point is very well controlled and is about 1mm when the excavation reaches 60mm, while the surface settlement is slightly less than 1mm. This simple comparison clearly shows that an embedded improved soil strut is effective in controlling the movement associated with an excavation.

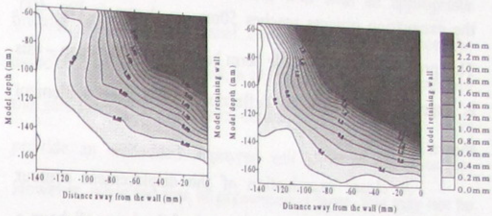
In comparison with Tests TW/O and TST, Test TB-L100 indicates that the provision of an embedded improved soil berm is also effective in restraining the wall deflection and surface settlement, especially during the early stages of excavation. During these early stages, the behaviour of an excavation stabilised by an improved soil berm is almost the same as that when stabilised by an improved soil strut. However, after about 35mm of excavation, any restrain provided by the berm is almost non-existent and the behaviour changes totally, and looks similar to that of an excavation without any soil improvement, Test TW/O.

2.2 Displacement field

Using the displacement obtained from image processing, contours of soil displacement in passive side induced by the excavation can be obtained and are shown in Fig. 3 and Fig. 4 for test TW/O and Test TB-L100 respectively. The displacement colour code starts with white color at 0.00 mm and progresses to black, which is for a displacement greater than 2.40 mm Fig. 3 clearly shows that in Test TW/O, the magnitudes of displacements in the soil near the excavation surface and beside the wall were obviously larger than those in other places. More importantly, a region with large displacement indicates a block movement, and it is interesting to note that the shape of this region increases with increasing depth, but with virtually similar shape. This pattern of behaviour is consistent with the idea of slip planes. The data indicate that the slip plane is formed when the excavation reaches just 20 mm, equivalent to 2m in prototype scale.

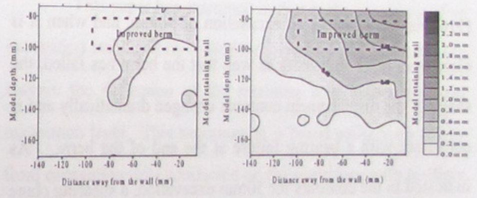


(a) At 10mm excavation (b) At 20mm excavation

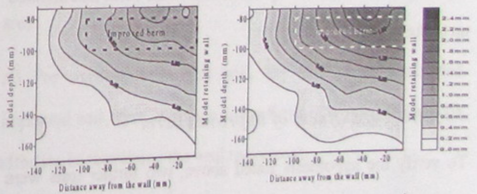


(c) At 30mm excavation (d) At 40mm excavation

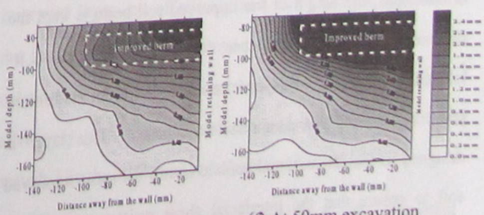
Figure 3 Displacement contours in excavation side for Test TW/O



(a) At 20mm excavation (b) At 30mm excavation



(c) At 35mm excavation (d) At 40mm excavation



(e) At 45mm excavation (f) At 50mm excavation

Figure 4 Displacement contours in excavation side for Test TB-L100

For Test TB-L100, Fig. 4 shows that the pattern is distinctly different from that in Fig. 3 for Test TW/O. The pattern indicates a sudden increase in magnitude only when the excavation reaches 45mm (Fig. 4(e)). Further, significant movement is concentrated around the location of the improved berm. Thus the presence of an improved berm has changed the mechanism by which the retaining wall is supported. The magnitude of displacement was obviously much less than those in Test TW/O especially in the early stages of excavation. Very significant movement indicative of shearing appears only when the excavation process reaches 50mm as shown in Fig. 4(f). This probably means that the berm has failed at this stage – this is supported by the wall deflection and surface settlement shown in Fig. 2.

A closer examination of the displacement contour indicates that the contours at the end of the berm all have a concave curvature for excavation less than 50mm. This means that bearing failure at the end of the berm has not occurred. However, on reaching an excavation of 50mm, and when it is clear from other indicators as well that the berm has failed, the shape of the displacement contours changed dramatically and is consistent with a bearing failure at the end of the berm. As indicated in the contours for 50mm excavation, a shearing plane is formed from the lower tip of the end of the berm and inclined up to the surface.

2.3 Effect of stiffness of improved berm

To verify the hypothesis stated above, two further tests were conducted, namely Test TB-ALR-L100 and Test TB-HS-L100. In both tests, the length of the improved soil berm is kept the same as in Test TB-L100, that is, 100 mm. In Test TB-ALR-L100, the improved soil layer is reinforced with an aluminium plate to increase its compressive stiffness. This layer is designed so that the external surface is still the same improved soil to ensure that the interfacial shear resistance mobilised would be the same as in Test TB-L100. In Test TB-HS-L100, the improved soil is cured for 6 months to increase its stiffness before being used in the test. In these two cases, the elastic moduli are as follows:

Test TB-ALR-L100

$$E_{\text{reinforced-berm}} \big/ E_{berm} = 22 - 25 \tag{1}$$

Test TB-HS-L100

$$E_{\text{high-stiffness-improved-berm}} \big/ E_{berm} = 1.2 - 1.5 \tag{2}$$

The lateral wall deflection at one point and the surface settlement at a distance of 50mm behind the wall for these two tests are shown in Fig. 5 together with results from Tests TB-L100 and TST. The results show that the wall movement and surface settlement for the different tests with improved berm of widely varying modulus are pretty much the same, especially in the early stages of the excavation. This series of results lends support to the hypothesis that the stiffness of the improved soil does not play a dominant role in an excavation where an embedded improved soil berm is used. This is unlike the case where an embedded improved soil strut is used, thus confirming that using an improved soil berm is not the same as using improved soil strut.

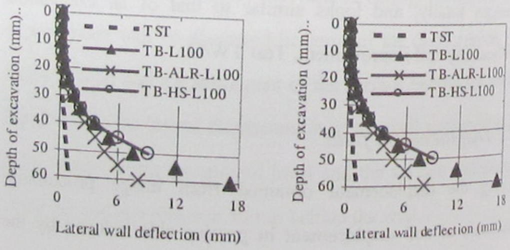


Figure 5 Lateral wall deflection and surface settlement of excavation model TST, TB-L100, TB-ALR-L100 and TB-HS-L100

This proportion provides a good indicator of the relative influence of the two different mechanisms available to restrain the wall in the case where an embedded improved soil berm has been provided. But when the increase in stiffness is nominal, such as between Test TB-L100 and TB-HS-L100 where the increase in Young's Modulus is about 35%, there is practically no difference in the behaviour between the two cases. Thus, due to the fact that the end of an embedded improved soil berm is not restrained, unlike the case in an improved soil strut, the berm can move relative to the soil. In view of this, it is the combined resistance from end bearing and interfacial shear resistance that plays an important role. In using such an embedded berm, it is therefore important to realise that when the length is changed, the end bearing that can be mobilised will be nearly the same whereas the mobilised interfacial resistance is dependent on this length.

2.4 Effect of surface area of improved berm

In the last test to be reported, Test TB-L50, the length of the improved berm is shortened to 50 mm, while the thickness is kept the same, so as to ascertain the effect of length. Effectively, in this case, the contact area for the mobilisation of interfacial shear resistance is halved, compared to that for Test TB-L100 reported earlier. The behaviour observed is shown in Fig 6 for the wall deflection and up to an excavation of 10mm, the behaviour is almost indistinguishable from Test TB-L100. Thus during the initial stage, though the contact area is now reduced by half, the combined resistance provided is nearly the same.

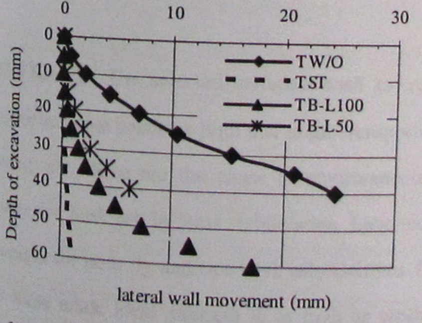


Figure 6 Lateral wall deflection and surface settlement of excavation model TW/O, TST, TB-L100 and TB-L50

This just means that the end bearing is likely to be playing a more important role for a shortened berm. For excavation beyond 10mm, deviation from Test TB-L100 occurs, and by the time the excavation reaches 20mm, this deviation has becomes significant. Though the area provided is halved, the mobilised lateral resistance against the wall is more than half. The reduction in length of the berm by half would immediately reduce the interfacial shear resistance by about the same margin, but not the bearing capacity, which is likely to be about the same

3. *Conclusion*

For an excavation in a thick soft clay layer, typically the maximum deflection would occur below the final excavation level, even when a stiff retaining wall with an appropriate bracing is used. To control this deflection and hence the associated ground movement, a typical approach is to improve the soil where the maximum deflection is expected so as to provide an embedded improved soil strut at this location. However, when the area of excavation is large, this may not be cost-effectively feasible, and the alternative is to provide an improved soil berm of sufficient length.

This paper has examined in details the behaviour of an excavation stabilized by embedded improved soil berm used to restrain the deflection of the retaining wall below the final excavation level. This examination is based entirely on results from excavation tests conducted on the centrifuge with in-flight excavating capability. The amin conclusions that can be drawn are:

A) For excavation in soft soil, the use of an embedded improved soil layer, whether in the form of a strut or berm, is effective in restraining the wall movement.

B) In the case where an entire soil layer is improved, the improved layer acts effectively as a strut, and the stiffness of the improved layer is the important parameter. However, if only a part of the soil is improved, then the improved layer effectively acts a berm, and the resistance to the wall is provided by the interfacial resistance and bearing capacity.

(C) In an embedded improved soil berm, the important parameter is the area of contact and not the stiffness of the improved layer. As shown in this paper, the use of a layer with very high stiffness will only produce a marginal improvement in resistance to the movement of the wall.

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Thanadol Kongsomboon
Civil Engineering Department, Srinakarin University
Tel. 662-6641000 ext 2030, thanadolk@yahoo.com

Tan Thiam Soon
Civil Engineering Department, National University of Singapore.
Tel. 65-6874-2160, cvetants@nus.edu.sg

Warakorn Mai-raing
Civil Engineering Department, Kasetsart University
Tel. 662-579-2265, fengwkm@ku.ac.th