

Anchorage Behaviors of Frictional Tieback Anchors in Silty Sand

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Abstract. Soil anchors are extensively used in geotechnical applications, most commonly serve as tieback walls in deep excavations. To investigate the anchorage mechanisms of this tieback anchor, a constitutive model that considers both strain hardening and softening and volume dilatancy entitled SHASOVOD model, and FLAC^{3D} software are used to perform 3-D numerical analyses. The results from field anchor tests are compared with those calculated by numerical analyses to enhance the applicability of the numerical method. After the calibration, this research carried out the parameter studies by numerical analyses. The numerical results reveal that whether the yield of soil around an anchor develops to ground surface and/or touches the diaphragm wall depending on the overburden depth H and the embedded depth Z of an anchor, this study suggests the minimum overburden and embedded depths to avoid the yield of soils develop to ground surface and/or touch the diaphragm wall. When the embedded depth, overburden depth or fixed length of an anchor increases, the anchorage capacity also increases. Increasing fixed length should be the optimum method to increase the anchorage capacity for fixed length less than 20m. However, when the fixed length of an anchor exceeds 30 m, the increasing rate of anchorage capacity per fixed length decreases, and progressive yield occurs obviously between the fixed length and surrounding soil.

1. Background

Currently, deep excavations are supported by diaphragm walls with tieback systems or internal braces. A complicated internal brace system in an excavation with an irregular area or an asymmetrical cross-section usually causes difficulty in operating within the space and increases construction expenditures. By contrast, a tieback system is more cost-effective and provides a larger excavation working space. Virtually all of the fixed anchors constructed around the Taipei Basin are typically installed in silty sand layers. Several in-situ tests have revealed that the increment of ultimate load per fixed length decreases as the fixed length increases over a threshold value [1], which shown that soils around a fixed anchor exhibit progressive yielding.

Figure 1(a) illustrates the regulation of installing tieback systems by BSI [2]. With regard to design of a tieback anchor, the fixed anchor must be installed deep enough to avoid the localized passive failure of the soil associated with the failure condition for shallow anchors, and placed far enough away from the wall to ensure against a slip failure beneath the toe of the wall and beyond the fixed anchor zone. As illustrated in Figure 2(a), an inaccurate tieback system in the deep excavation in Zhubei City,



Taiwan which constructed by Feng-Yi Construction Company had induced site disaster. Figure 2(b) exhibits that because all fixed anchors almost placed in the hatch area displayed in Figure 1(a), the tieback systems fail. Therefore, it is important to install tieback anchors in appropriate location, and the behavior of tieback anchors demand to investigate.

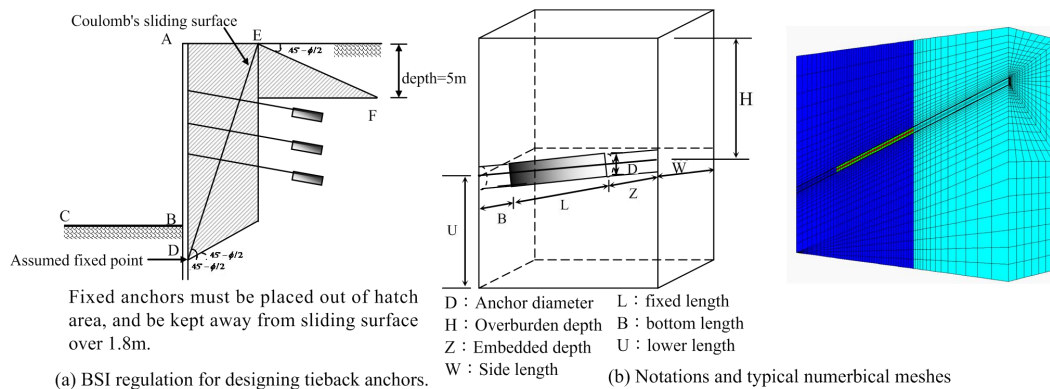


Figure 1. BSI regulation and numerical study for a tieback anchor

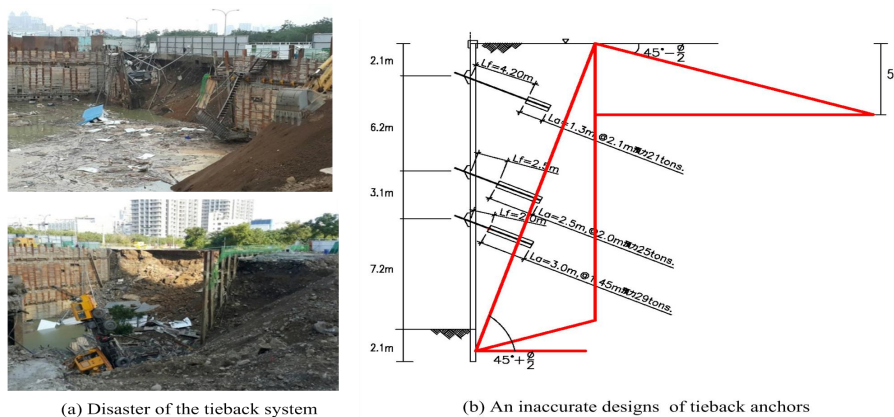


Figure 2. An inaccurate design of tieback system in a deep excavation in the Zhubei City, Taiwan

For numerical analyses, most studies have adopted techniques of 2-dimensional analyses to study the anchor behavior [3, 4]; however, the tieback anchor is an inclined anchor, the 3-D model must be established to obtain an elaborated result.

To manage these issues, this study has applied a constitutive model of sandy soils entitled SHASOVOD model and the FLAC^{3D} software to examine the anchorage behavior of tieback anchors in silty sand. To demonstrate the suitability of the numerical model in evaluating the load-displacement behavior of anchors in silty sand, the calculated results are compared with the results of in-situ anchor tests. Based on both the numerical and test results, a recommendation was presented for the design of tieback anchors in silty sand. Parametric studies on factors that affect the anchorage behavior of tieback anchors were conducted to address the anchorage capacity of the anchors.

2. Constitutive Model and Numerical Analysis

Hsu [5] suggested a constitutive model with non-associated flow rules that considers the strain hardening and softening and volume dilatancy (SHASOVOD model). Previous results demonstrate that the numerical results are in agreement with the field test results. This study used the SHASOVOD model and the FLAC^{3D} software to study the anchorage behavior of tieback anchors in silty sand.

The soil specimen used in the triaxial CD (Consolidated Drained) test was sampled from Taipei Basin. The soil is classified as silty sand, SM. The specific gravity of the sandy soil is 2.68; its maximum dry density is 16.1 kN/m³, and its minimum dry density is 12.0 kN/m³.

As mentioned above, this study adopted the constitutive model proposed by Hsu [5] to represent the stress-strain behavior of silty sand. This model is based on plasticity theory and the non-associated flow rule. The yield function f in this study is similar to Mohr-Coulomb criterion, and can be written as followings

$$f = \sigma_1 - \sigma_3 \frac{1 + \sin \phi^*}{1 - \sin \phi^*} \quad (1)$$

where σ_1 represents the major principal stress; σ_3 is the minor principal stress, and ϕ^* is the mobilized friction angle, which is a function of the accumulative plastic strain ε^p .

The plastic potential function g was required to describe the relationship between the plastic strain increment $d\varepsilon_{ij}^p$ and the stress tensor σ_{ij} . The plastic potential function can be expressed as

$$g = \sigma_1 - \sigma_3 \frac{1 + \sin \psi^*}{1 - \sin \psi^*} \quad (2)$$

where ψ^* is the mobilized dilatancy angle, which is also a function of accumulative plastic strain ε^p . To exhibit the reliability of this constitutive model, the stress-strain behaviors of sand with a relative density of 30%, determined from the triaxial test, were compared with those calculated using the proposed model. As illustrated in Figure 3, the calculated results were perfectly consistent with the triaxial test results not only for the strain hardening stage but also for strain softening stage. Hsu [5] provided a detailed elucidation of this model.

Figure 1(b) plots the typical numerical meshes and notations used to define the tieback anchor. To reduce calculation time, one-half symmetric meshes were used for the tieback anchor.

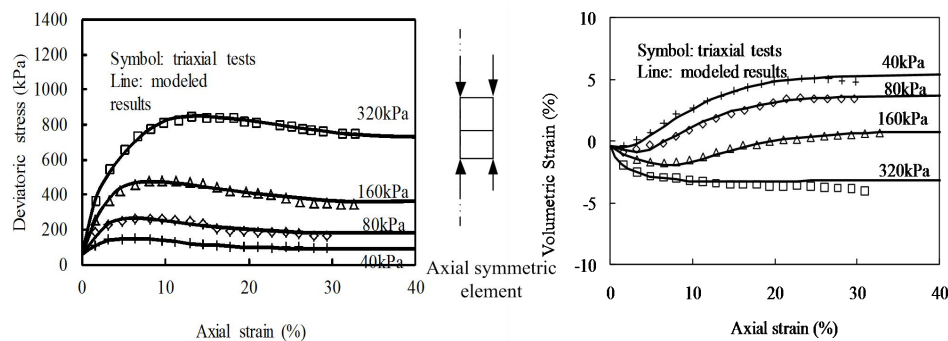


Figure 3. Comparison of measured and modeled stress-strain behavior of silty sand with a D_r of 30%

3. Verification of Numerical Results

As illustrated in Figure 4(a), two frictional anchors were placed and tested at same site to verify the suitability of the proposed numerical method. Figure 4(a) also presents information on the tested anchors and subsoil conditions.

The test anchors were pulled out following the proving test procedure, as recommended by Deutsche Industrie Norm, DIN [6]. First, an initial load was applied to the two anchors, which were subsequently stressed in five loading-unloading cycles. The test anchors were pulled out to failure after completing the five loading-unloading cycles.

The test anchors were almost anchored in silty soils, the relative density of in-situ sandy soil can be determined from the relationship between the relative density D_r and $SPT-N$ value of sandy soil of the Taipei Basin. The $SPT-N$ of 10 approximates to D_r of 30%.

As displayed in Figure 4(b), the calculated load-displacement curves of the test anchors were nearly consistent with those measured in the field tests. After the proposed model was calibrated using the

results of the pullout test on the field anchor, the numerical method was applied to elucidate the anchorage behavior of tieback anchors in silty sand.

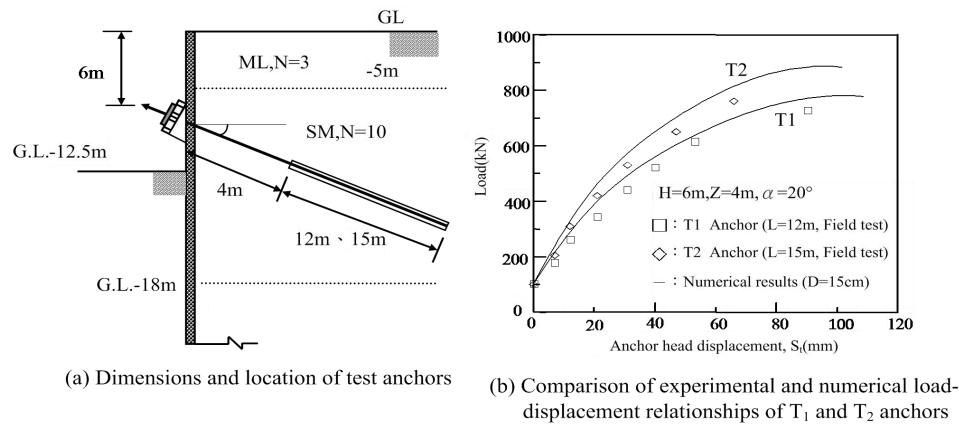


Figure 4. Field anchor information and experimental/numerical results

4. Analysis and Discussion of results

4.1. The minimum overburden and embedded depths.

As mentioned before, for designing tieback anchors, the fixed anchor must be placed a considerable distance away from ground surface, Coulomb's sliding surface [2] and diaphragm wall to avoid the yield zones develop to these regions. As illustrated in Figure 5(a), when the overburden depth $H=4\text{m}$ and embedded depth $Z=2\text{m}$, the yield zones develop to both the ground surface and diaphragm wall. Figure 5(b) displays that when the H is 6m and Z is 2m of an anchor, the yield zones merely develop to the diaphragm wall. This study uses same procedures for various overburdens and embedded depths to figure out the minimum requirements of both the overburden and embedded depths for a tieback anchor design. As demonstrated in Figure 6, the fixed anchor must be installed away from the hatch area. Figure 6 illustrates that, when the overburden $H \geq 3\text{m}$, embedded depth $Z \geq 3\text{m}$ and $H+Z \geq 8\text{m}$, then the yielding soils cannot develop to both the ground surface and diaphragm wall.

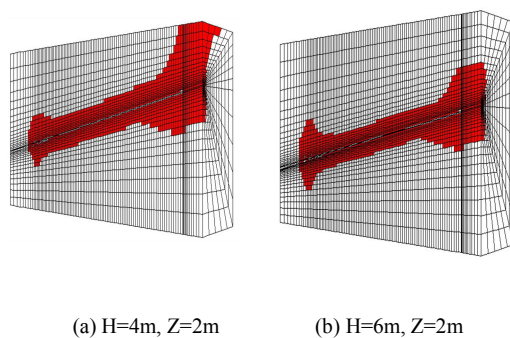


Figure 5. Yielding soil around an tieback anchor

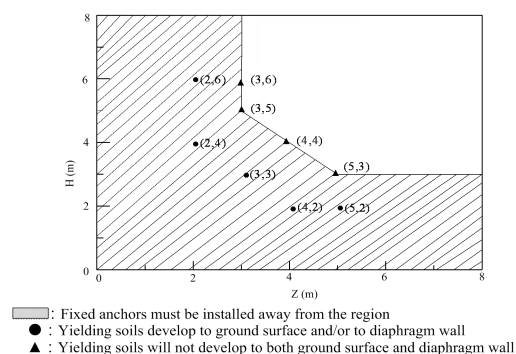


Figure 6. The minimum requirements of overburden and embedded depths of a tieback anchor

4.2. Parametric effects on the ultimate load.

Theoretically, when the embedded depth Z increases, then the shear strength of silty sand increases, the ultimate load of an anchor also increases. Figure 7(a) depicts the increment of ultimate load per embedded depth is approximately 15kN/m .

Because increasing the overburden H could raise the shear strength of sandy soil, increasing the overburden could raise the ultimate load of an anchor. Figure 7(b) indicates the increasing rate of ultimate load per overburden is around 45kN/m.

Figure 7(c) plots the relationship of ultimate load and fixed lengths. The ultimate load increases in an increasing rate with the fixed length when $L \leq 20\text{m}$, the increasing rate of ultimate load per fixed length exceeds 60 kN/m, because no progressive yield occurs between the fixed length and sandy soil; when $20\text{m} \leq L \leq 30\text{m}$, the ultimate load increased in a decreasing rate because progressive yield occurs. However, when L exceeds 30m, the progressive yield occurs obviously, thus the increasing rate of ultimate load per fixed length decreases clearly.

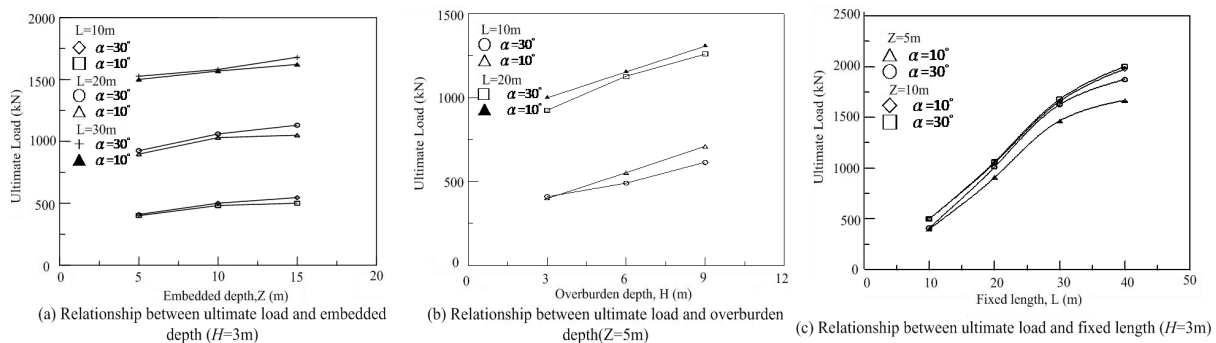


Figure 7. Parametric effects on the ultimate load for tieback anchors

5. Conclusions

The results of the numerical analyses and in-situ tests lead to the following conclusions.

- (1) Numerical results shown that the load-displacement behaviors calculated by the numerical model were consistent with those measured by experimental anchor tests.
- (2) As the overburden $H \geq 3\text{m}$, embedded depth $Z \geq 3\text{m}$, and $H+Z \geq 8\text{m}$, then the yielding soils could not develop to both the ground surface and diaphragm wall.
- (3) When the embedded depth, overburden depth or fixed length of an anchor increased, the anchorage capacity also increased. Increasing fixed length should be the optimum method to increase the anchorage capacity for fixed length less than 20m.
- (4) For an anchor with long fixed length (says, $L=40\text{m}$), a progressive yield occurred obviously between the interface of the fixed length and sandy soil, the increasing rate of the ultimate load per fixed length decreased clearly.

6. Acknowledgments

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