A simple parametric study on the distribution of geosynthetic strains in geosynthetic-reinforced piled embankment

Taehee Lee
Kyung Hee University, Korea

Su-Hyung Lee & Il-Wha Lee
Korea Railraod Research Institute, Korea

Young-Hoon Jung
Kyung Hee University, Korea

ABSTRACT: In geosynthetic reinforced piled embankments, predicting the geosynthetic strains is a very important design procedure. In this paper, to understand the geosynthetic behavior in the piled embankment, a full scale model test was conducted with a biaxial geogrid layer. The measured strains were compared with calculated values obtained by existing theories which are proposed by Zaeske (2001) and Van Eekelen et al. (2013). Comparison results show that the predicted values overestimate the measured strains in most stages of filling. To figure out the reason of differences between theoretical and experimental strains, a simple parametric study was performed. As a result of parametric study on changes of the soft soil stiffness, it is shown that the geosynthetic strains predicted by the theoretical models can be changed very sensitively ranging from 0.02 to 0.46 under low soft soil stiffness (E_s < 400 kPa) conditions. Therefore, unexpected small variables can affect a large change on the strain of geogrid under the low soft soil stiffness.

Keywords: geosynthetics, piled embankment, strains, geogrid

1 INTRODUCTION

The geosynthetic reinforced piled embankment (GRPE) is a method to construct the embankment on the soft ground. Since it is assumed that the embankment loads are transferred to the firm layer through the supporting structure composed by piles and geosynthetics, there is generally no additional treatment on the soft ground. Therefore, it is important to predict the stresses acting on each material, and all current design standards focus on predicting it. To design the GRPE, a shape of soil arch is assumed to distinguish the loads acting on the pile and soft ground. After determining the redistributed loads, the distribution of geosynthetic strains are calculated by using a kind of the catenary equation. In this paper, a full-scale test was conducted to compare the geosynthetic strains obtained by existing theories and installed strain gauges. And a simple parametric study was performed to understand the geosynthetic behaviors according to the variation of the construction condition.

2 THEORETICAL BACKGROUND

2.1 *Zaeske (2001) model*

Figure 1 shows the schematic illustration of the soil arch shape proposed by Zeaske (2001). The shape of inner soil arches is changed according to the interesting chord theorem. To obtain the redistributed loads on the piles and soft soil surface, the vertical stress on the soft ground is calculated at the soil arch crown. And it is assumed that the calculated vertical stress is uniformly distributed in all area of the soft ground. After determining the magnitude of loads toward to the soft ground, the distribution of vertical stresses on the geosynthetic surface is redefined with the triangular shape (as shown figure 2) to calculate geosynthetics strains, settlements and tensions. And the effect of soft soil support is dealt with subgrade reaction modulus (k_s).

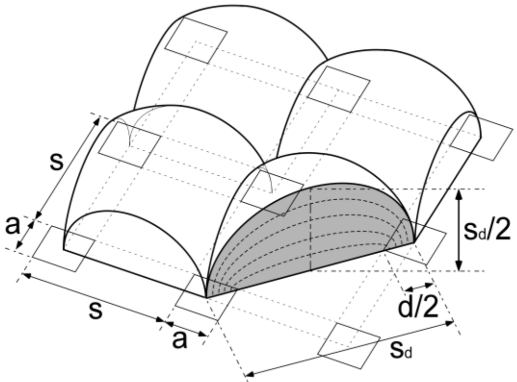


Figure 1. Schematic illustration of the soil arch model proposed by Zaeske (2001).

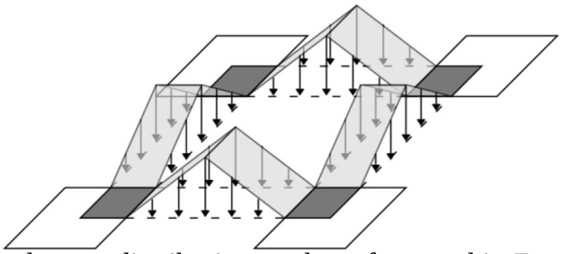


Figure 2. Vertical stress distribution on the soft ground in Zeaske's model.

2.2 *Van Eekelen et al. (2013) model*

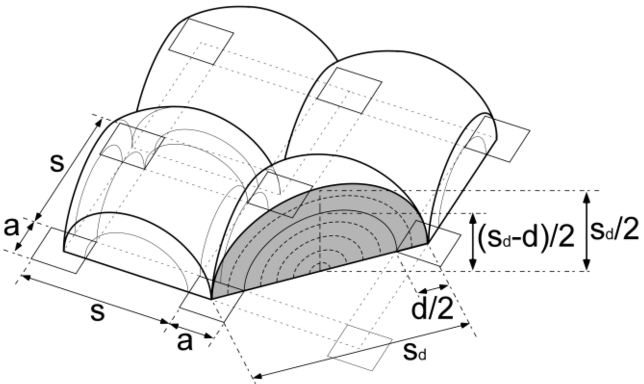
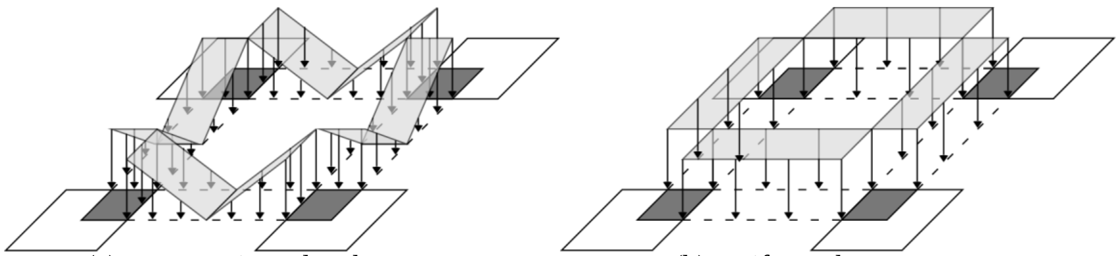


Figure 3. Schematic illustration of the soil arch model proposed by Van Eekelen et al. (2013).



(a) Inverse triangular shape (b) Uniform shape

Figure 4. Vertical stress distribution on the soft ground in concentric arches model.

Figure 3 demonstrates the concentric arches model developed by Van Eekelen et al. (2013). It is assumed that the hemispheres are continuously formed with depth to make the soil arch. To distinguish the loads on the piles and the soft ground, the distribution of vertical stresses on the soft soil surfaces is directly calculated by the concentric soil arch model. To predict the geosynthetic behaviors, the redistributed load on the soft ground is recomposed by concentrating vertical stress within rectangular areas likely Zaeske model. However, shapes of the vertical stress distribution can be changed as shown Figure 4 (a) and (b). In this model, after calculating the maximum strains within the geosynthetic by using different two shapes of the stress distribution, a distribution which occurs larger maximum strain is selected. And the modified subgrade reaction modulus ($k_{s,modified}$) is used instead of k_s to consider the all of subsoil supporting area.

3 FULL SCALE TEST

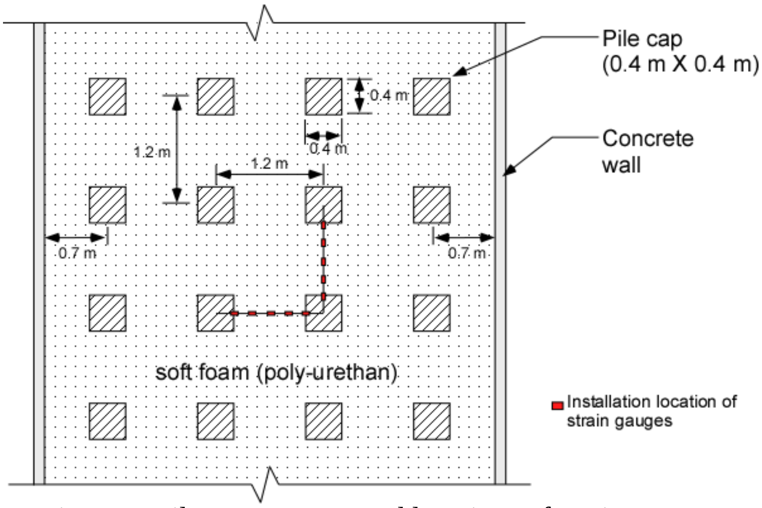


Figure 5. Pile arrangement and locations of strain gauges.

Figure 5 illustrates the pile arrangement of the test place and locations of installed strain gauges. The experiment was conducted in the concrete pit which is 5 m wide and 3 m deep. Steel cubic piles with a width of 0.4 m were placed on the bottom of the pit and the spacing between piles was 1.2 m. Soft soil was represented by the poly-urethane foam with 100 kPa of the compressive modulus. The foam was filled with 0.4 m of thickness which is the equivalent height of steel piles. The embankment on the piles and soft ground was constructed by the granular material classified SW by the Unified Soil Classification System (USCS). Fill materials has 33° of the internal friction angle obtained by drained triaxial tests. The embankment was filled and compacted with approximately 20 cm of one-layer thickness until the final height of the compacted embankments reached at the 2.6 m. The geosynthetic was laid after the compaction of 20 cm first fill material was completed. One biaxial geogrid with 40 kN/m of identical tensile stiffness for both machine and cross-machine directions was installed. The strain gauges were attached on the geogrid surface in directions consistent with the tensile resistance of the geogrid as shown Fig. 5. The geosynthetic strains were measured at the end of each filling stage.

4 COMPARISON BETWEEN THEORETICAL AND EXPETIMENTAL RESULTS

Figure 6 shows the representative strain distributions of the geogrid predicted by experimental and theoretical approaches in case that the fill height is 2.6 m. As shown Fig. 6, all results present that the maximum tensile strain occurs at the edge of pile caps. According to the theories, however, the shapes of strain distribution are quite different to each other. In case the results obtained by Zaeske’s model, since the vertical stress on the geosynthetic are assumed as a triangular shape, the strains are rapidly changed near the center of an x-axis in the graph, while the strains near the pile cap are very insensitivity. In the other hand, the results predicted by the model proposed by Van Eekelen et al. (2013) show that the vertical strains are sharply decreased near the pile caps, and strains are evenly distributed as the distance from the pile cap edge is increased. The distribution pattern of measured strains represented by square points in the Fig. 6 is similar to the results predicted by Van Eekelen et al. (2013).

The magnitudes of strains obtained by experimental measurements and theoretical predictions are at quite different levels as shown Fig. 6. The comparison results between theoretical and experimental geosynthetic maximum strains according to the filling stages are illustrated in Figure 7. In most filling stages, the geosynthetic strains are quite overestimated by theoretical predictions. The strains predicted by the theories have significant differences, and it is judged that this gap is due to the difference in the method of calculating the subgrade reaction modulus.

To figure out the reason of the gap between theoretical and experimental strains, a parametric study was conducted as shown Figure 8. If the soft soil stiffness is under 400 kPa, the theoretical geosynthetic strains can be extremely changed as shown Fig. 8. Therefore, unexpected small variables can affect a large change on the strain of geogrid under the low soft soil stiffness.

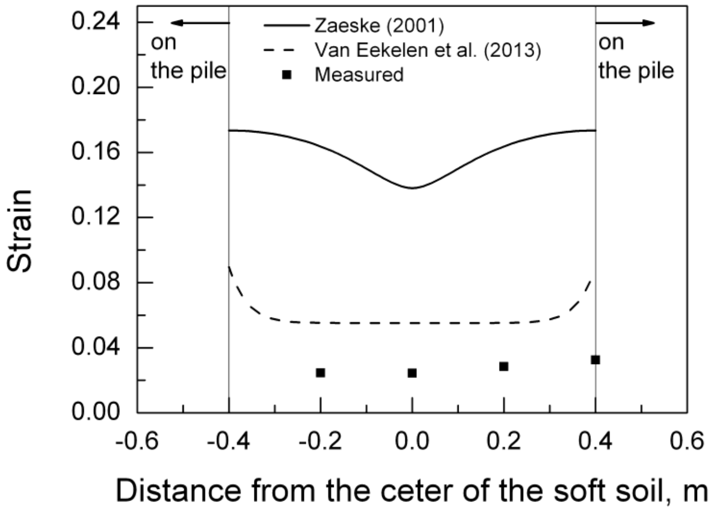


Figure 6. Comparison of strain distributions obtained by the experiment and theoretical predictions (H_{emb} = 2.6 m).

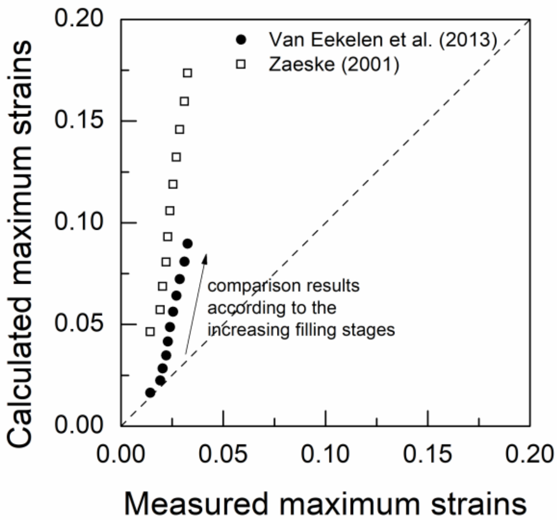


Figure 7. Comparison between calculated and measured maximum strains according to the filling stages.

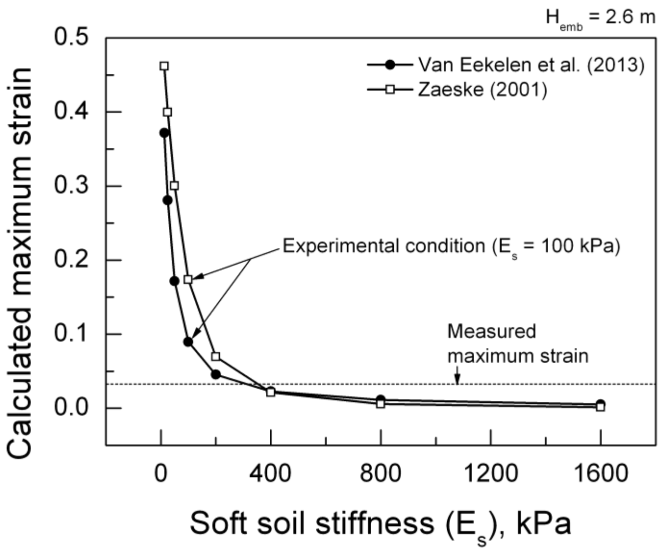


Figure 8. Variation of theoretical maximum strains according to the soft soil stiffness.

5 CONCLUSIONS

In this paper, the geosynthetic strains obtained by a full scale model test and theoretical calculations by using different two models are compared with each other. Comparison results show that the theoretical strains are tends to overestimate the measured strains. In addition, geosynthetic strains predicted by both two different model has significant gaps due to difference of calculating method for subgrade reaction modulus. As a result of parametric study on changes of the soft soil stiffness, it is shown that the geosynthetic strains predicted by the theoretical models can be changed very sensitively ranging from 0.02 to 0.46 under low soft soil stiffness (E_s < 400 kPa) conditions. Therefore, unexpected small variables can affect a large change on the strain of geogrid under the low soft soil stiffness

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