DRISI
Caltrans Division of Research, Innovation and System Information

Research Results

Assessment of Soil Arching Factor for Retaining Wall Pile Foundations

Analytical modeling used to investigate if foundation design conservative for temporary retaining walls used during construction.

Structures

MAY 2019

Project Title:
Assessment of Soil Arching Factor for Retaining Wall Pile Foundations

Task Number: 2532

Start Date: December 1, 2014

Completion Date: April 30, 2017

Task Manager:
Charles Sikorsky
charles.sikorsky@dot.ca.gov

WHAT IS THE NEED?

Retaining wall soldier pile foundations consist of two basic components, soldier piles and lagging. The soldier piles carry the full earth pressure load while the lagging, which spans the distance between the soldier piles, resists relatively small earth pressure loads. Soldier piles are either installed with pile driving equipment or are set in pre-excavated holes and then concreted in place. The most common soldier piles are rolled steel sections, normally wide flange. Lagging can be treated timber, reinforced shotcrete, reinforced cast in place concrete, precast concrete panels, or steel plates. This type of wall depends on the passive resistance of the foundation material and on the moment resisting capacity of the vertical structural members for stability.

When these retaining wall pile foundations are temporary in nature, most often the lagging consists of treated timber boards. Despite the prevalent usage of soldier pile walls to resist the anticipated loads and deformations, upon close inspection of the "Trenching and Shoring Manual" (Caltrans 2000, 2011) "AASHTO LRFD Bridge Design Specifications" (AASHTO, 2012), and based on experience gathered by CALTRANS engineers, it was concluded that the current methods may be overly conservative and a better approach could be adopted, specifically in what concerns the use of arching capability factor used in the design of soldier retaining wall systems.

WHAT WAS OUR GOAL?

The main objective of this research project is to assess the current design procedures for soldier pile walls and make recommendations for improvement, specifically with regard to 3-D effects of soil arching, sloping ground and bench width, based on an advanced nonlinear finite element parametric study.

WHAT DID WE DO?

A literature review was first performed to summarize previous studies on soldier pile retaining walls. The discussion focused on the arching effects and influence of the proximity to slopes in the estimation of earth pressures in soldier pile walls. Following a critical review of relevant technical literature, the main findings were used to define the numerical research program developed herein to evaluate the effect of the soil arching on performance of soldier piles.
Based on the literature review, a methodology was developed for assessment of the arching capability factor. A three-dimensional finite element modeling approach was proposed for the soldier piles retaining systems, in order to capture complexities of soil arching, soil movement between piles, settlement of back-fill, and anisotropy of lagging. OpenSees (Mazzoni, et al., 2009) was used to model the soldier piles and wall lagging. Linear and non-linear static (displacement-based) pushover analyses were performed. In these analyses, both stiffness and strength of the main components are explicitly modeled.

The results of the finite element parametric study are presented in the following section. However, all analytical studies considered a soldier pile with a foundation consisting of HP14x89 piles set in 24-inch diameter drilled holes with the annulus filled with concrete. Emphasis was placed on the effect of modeling options on the response of the soldier piles and main parameters changed include soil type, embedment depth, distance between piles, slope angle in front of the soldier piles retaining wall, and presence of a bench and its width.

WHAT WAS THE OUTCOME?

In this work, an assessment of the current design procedures for soldier pile wall systems was performed to gain a fundamental understanding of the effects of several parameters on the arching capability factor used in Caltrans (2011). The 3-D effects for soil arching were extensively studied as well as the influence of a sloping ground in front of the soldier pile walls through nonlinear static analyses where incremental loads were applied to the soldier pile in order to develop the passive resistance of the system.

The nonlinear finite element modeling approach and modeling assumptions were validated using experimental results available from a testing program recently performed at Oregon State University. The correlation between experimental results and results obtained using the OpenSees models developed was very good.

The first modeling assumption that plays an important contribution to the response is the load distribution. Signficantly different capacities were obtained when loads are applied on the pile head only, or when loads are distributed along the height of the wall. It was found that depending on how the load is applied the total passive resistance might not be mobilized. Thus, in the interest of the main objective of this study, the earth pressure distribution considered in design was applied to the soldier pile retaining system analyses. Nonetheless, it was shown that the modeling performed could capture the differences in the results and mobilized passive resistance.

The second modeling assumption was related to the way the soil was connected with the pile in the numerical model. For clays, it was found that compression only gaps needed to be placed connecting the pile and the soil elements, leading to a model that could capture the effect of the pile detaching from the wall. While this is clearly not an active state of stress in clay soils, the passive resistance was modeled more realistically this way. This modeling option was not needed when modeling cohesionless soils.

Based on the parametric analyses performed, the analysis results indicated that:

1. For granular soils:
    - The presence of slope in front of the pile affects the system capacity for granular soils. If a slope is present, in contrast to a flat dredge line, a decay in passive resistance is observed.
    - When results for slopes with different angles (3:2 and 2:1 slopes) are compared small differences in capacity can be observed. However, the n factor values obtained were higher for steeper slopes. This difference in capacity cannot be well explained by the Caquot and Kerisel graphs, which does not account for pile spacing, and the arching capability factor does not seem to also capture those effects.
    - The bench width plays a significant role in the passive resistance of the system for granular soils. This effect is typically not considered explicitly in design when using classical soil theories, such as logspiral and rankine. Gathering all results for the granular soils, an exponential relationship was proposed to take into account the bench width effects in the determination of the passive resistance of granular soils. This exponential relationship is a first step to address the issue, but results are very preliminary and these need to be confirmed with further numerical and experimental studies.
    - When slope is present, the arching capability factor seems conservative being related with the aforementioned considerations in design.

(2) For medium-stiff clays:

- The existence of slope in front of a soldier pile wall did not significantly affect the capacity of the system.
- Results indicate that the arching capability factors defined in CALTRANS (2011) are adequate when the slope in front of the pile is not present. The n factor obtained tended to 1.0 for large displacements (nearing 5 inches).

In terms of geometry of the soldier pile system, some conclusions can also be drawn:

1. In general, the values of the arching capability factor seemed to better estimate capacity when considering larger wall heights (15 foot versus 10 foot); (2) the n factor increases with increasing space between piles, indicating that the arching capability factor is more conservative for larger pile spacing.
2. Comparing results from 3-D and 2-D analyses, the 2-D analysis capture adequately the initial stiffness of the system for all soil types, and results between the 3-D and 2-D analyses match well for pile head displacements up to approximately 1 inch. For larger pile head displacements, the capacity of the 2-D numerical models typically is considerably greater than that of the corresponding 3-D numerical model. Thus, after a pile head displacement greater than 1 inch, 2-D analyses might be unconservative for all types of soil. These results indicate that another factor may be warrented when designing soldier pile retaining systems, where 3-D effects are very important.

WHAT IS THE BENEFIT?

While the numerical study confirmed there was conservatism in the design procedure for temporary walls used during construction, the results did not indicate whether there was sufficient conservatism to warrant an experimental program to confirm the results. Any cost savings resulting from a weakening in increased risk of failure of these temporary structure during construction.

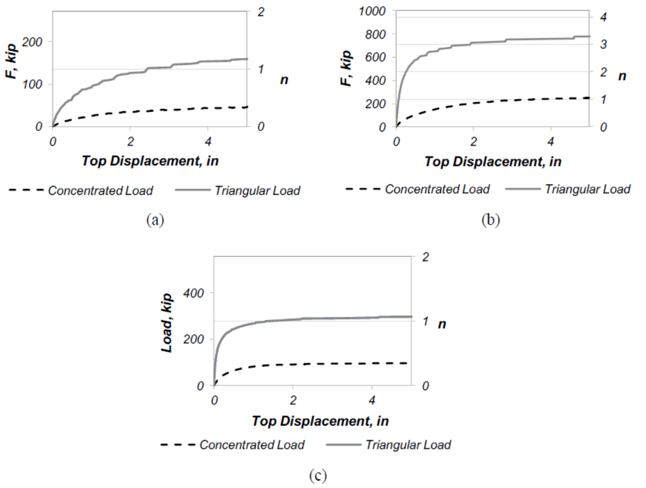

Figure 1: Comparison between capacity obtained with different load distribution: (a) medium-dense sand; (b) medium stiff clay; (c) granular cohesive soil