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Influence of wire mesh characteristics on reinforced soil model wall failure mechanisms-physical and numerical modelling

Adis Skejic*, Senad Medic, Samir Dolarevic

University of Sarajevo, Faculty of Civil Engineering, Bosnia and Herzegovina

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ABSTRACT

This paper presents the details of experimental and numerical analysis performed on three 0.8 m-high reinforced earth model walls with strip footing surcharge near the wall facing. The study investigates how wire mesh strength and geometry affect the failure mechanism. All three walls were nominally identical, except for reinforcement strength and geometry. The displacement field of the entire cross section was captured by high-resolution digital camera through transparent sidewall. The resulting images were analyzed using digital image correlation software. The results indicate that both reinforcement strength and aperture size influence the type of failure mechanism. Numerical modelling was also applied to assess the influence of sidewall friction (3D model) and reinforcement stiffness and strength (2D model) on the failure mechanism of the walls. The parameters for the numerical models were derived from independent tests and results, which were compared with the experimental observations. A good level of agreement with measurements was confirmed, even for the 2D model that excluded sidewall friction.

1. Introduction

Numerical modelling is widely used in research on reinforced earth walls to generate synthetic data on how the components interact. As such modelling relies on assumptions in setting parameters, physical modelling is often used to provide a benchmark for verification. This paper describes experimental investigation of reinforced earth walls with strip load surcharge near the facing and compares the results of numerical modelling with those obtained from physical model walls reinforced by wire mesh of different aperture sizes and strengths. Special attention was paid to how reinforcement geometry and mechanical properties affect the failure mechanism, as observed through a series of digital photographs.

1.1. Physical modelling

The understanding of soil-reinforcement interaction mechanisms can be significantly improved by observing the displacement field of reinforced earth walls surcharged at the top. Examples of physical analyses of reduced scale walls may be found in Schlosser and Long (1974), Simonini and Gottardi (2003), Xiao et al. (2016), Jacobs et al. (2016). Table 1 gives an overview of the geometrical and mechanical properties of the reinforcement used in these studies.

Xiao et al. (2016) and Simonini and Gottardi (2003) scaled down the reinforcement strength in direct proportion to the reduction in wall height. Different failure mechanisms were observed, because of discrepancies in the reference tensile strengths of the punched-drawn geogrids used for scaling.

To illustrate this difference, a strength/mobilized tension load ratio (FS_t) was introduced, viz.:

$$FS_t = \frac{F_{ult}}{F_{\max,i}} \tag{1}$$

where

FS_t -the tension failure safety factor,
F_{ult}-the ultimate reinforcement strength,
$F_{max,i}$ -the axial load for the most tensioned reinforcement layer, induced by the ultimate footing pressure measured during REW testing.

$$F_{\max,i} = \sigma_v' K_r S_v \tag{2}$$

where

$\sigma_v' = \gamma\, z + \Delta q$ -the effective vertical stress at the level of reinforcement,
K_r -the empirical lateral earth coefficient according to Berg et al. (2009),
S_v -the vertical spacing of the reinforcement layers,

* Corresponding author.
E-mail addresses: askeja@live.com (A. Skejic), senad.medic@gf.unsa.ba (S. Medic), samir.dolarevic@gf.unsa.ba (S. Dolarevic).

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Table 1
Characteristics of the reinforcement used for physical modelling of REW.

Investigation	Reinf. type	Reinf. strength [kN/m]	Ribs diameter (long/transv.) [mm]	Aperture size (long/transv.) [mm]	S/t [-]	FS_t
Simonini and Gottardi (2003)	PP	5.5	0.6/0.6	12/14	23.0	1.0
Xiao et al. (2016)	HDPE	19.0	0.76/0.76	25/99	130	3.5
Jacobs et al. (2016)	PP	30.0	N/A	30/30	N/A	> 5.0

γ -the backfill unit weight,
z -the depth of reinforcement layer measured from the top of the wall, and
Δq -the overburden stress due to surcharge load at the level of reinforcement defined by the empirical "2:1" method (vertical:horizontal distribution of the vertical pressure through sand).

The values for the FS_t ratio listed in Table 1 indicate the importance of the reinforcement scaling principle for the wall failure mechanism. Namely, $FS_t = 1.0$ resulted in wall failure due to breakage of the reinforcement in tension, while $FS_t > 1.0$ prevented such failure.

The additional parameter used for scaling reinforcement is related to geometry and the values for it were determined by the spacing to diameter ratio (S/t) for the transverse ribs, as listed in Table 1. Different authors have used a range of approaches to define the reinforcement aperture size in relation to a full-scale wall. Simonini and Gottardi (2003) scaled down the aperture size by a factor of 3 (unrelated to wall height), while Xiao et al. (2016) used a factor of 5 consistent with the wall height reduction, albeit noting that in their view reinforcement aperture size was not particularly important, as the pull-out failure mechanism is not generally an issue for walls with a reinforcement length-to-height ratio of 0.7. For the purposes of this paper, physical modelling of the soil-reinforcement interface strength and stiffness was carried out by varying the reinforcement aperture size, allowing conclusions to be derived from a comparison of the failure mechanisms for walls reinforced by typical forms of reinforcement.

Some of these experimental studies were performed with a transparent sidewall to allow the displacement pattern to be identified by observing thin colored layers of sand placed inside the backfill sand. It is, however, possible to apply more advanced measuring techniques in observing displacement during the application of footing pressure. One example of such an advanced observation technique is digital image correlation (DIC). There are only a few available studies of soil and reinforcement behaviour in which displacements have been monitored by DIC. Zhou et al. (2012) applied this technique to observe the pull-out test, while Liu et al. (2011) employed it to investigate sand deformation around the uplift plate anchor. These cases were limited to local aspects of interaction, while Jacobs et al. (2016) monitored a complete wall cross section to examine the kinematic behaviour of a wall under surface surcharge by collecting digital images through transparent glass. Since the glass had to remain transparent during testing, silicon grease could not be applied to the glass surface. As a result, direct contact of sand on the glass surface can result in shear stress generation on the surface (Jarrett, 1988; Bathurst et al. 1988; Wu et al. 2016). Tatsuoka and Haibara (1985) reported glass sand friction angles of between 6° and 9°. It is possible that this influence may increase the bearing capacity of a wall under footing pressure. A similar problem was reported by Jacobs et al. (2016), who also built model walls without applying grease to sidewall glass surfaces. Other examples of DIC technique application are to be found in works of Hu et al. (2010) and Sommers and Viswanadham (2009), but these studies relate primarily to reinforced soil slope behaviour.

1.2. Numerical modelling

Numerical modelling of reinforced earth walls was first introduced in the late seventies (Jones, 1978; Hermann and Al-Yasin, 1978; Naylor and Richards, 1978). The beginning of the current century saw significant additional progress in analysis techniques using primarily finite elements. Developed numerical models for full-scale walls may be found in works by Rowe and Skinner (2001), Hatami and Bathurst (2006), Skejic et al. (2013), Rahmouni et al. (2016), and Mirmoradi and Ehrlich (2017), among others. Most of these models were formulated in 2D by modelling the grid as a slender membrane element and assuming a perfect bond between soil and reinforcement. Hatami and Bathurst (2006) pointed out certain uncertainties, noting that the perfect bond assumption may not be appropriate for reinforcement with large apertures. It is therefore desirable to secure both measured and numerically predicted displacement results to make clear the importance of soil-reinforcement contact in physical and numerical modelling. The comparison of measured and predicted displacement results and failure mechanisms can be of use in defining the range of reinforcement aperture sizes to be simulated by planar reinforcement and a relatively simple, zero thickness contact element. In this paper, we also investigate numerically the influence of mesh aperture size on the failure mechanism by varying the soil-reinforcement interface, strength and stiffness characteristics.

An additional factor to consider in modelling reduced-scale walls is sidewall-sand friction, but this can be only examined using 3D analysis. In this study, the influence of sidewall friction on the results is investigated to demonstrate that the box dimensions for the model wall were appropriate.

2. Physical wall models

2.1. Test apparatus

Fig. 1 shows the details of a well-instrumented small-scale wall. The wall was built inside a box, with interior dimensions of 1.3 m (length) by 0.5 m (width) by 0.8 m (height). There was also a transparent sidewall made of 5.1 cm thick glass, with thinner 3.0 mm glass glued to

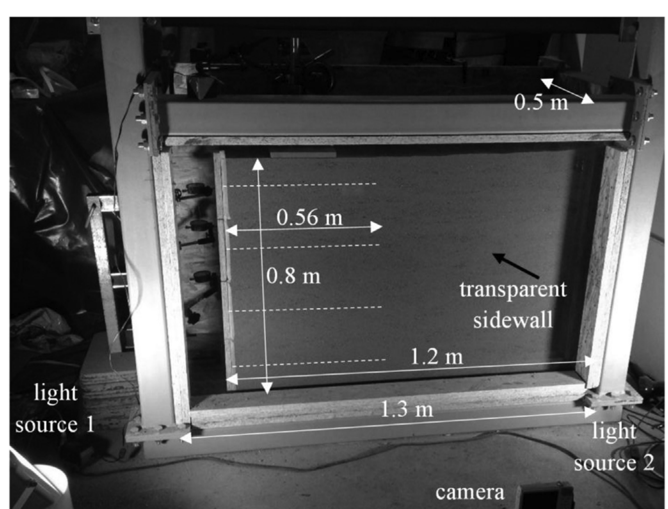

Fig. 1. Details of the physical model wall.