Staged Pullout Testing on Smooth-Metal-Strip Reinforcement Embedded in Sand

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Abstract

Axial pullout resistance of reinforcements embedded in fill materials is an important property in the design of mechanically stabilized earth walls. Commonly, minimum of three pullout tests are performed to develop the pullout factors considering the different levels of overburden stresses acting on the reinforcement. Pullout tests involve large-scale testing and performance of these tests is time consuming as well as sample preparation is labour intensive. Accordingly, in the present study, a staged pullout test is conducted on a smooth-metal- strip reinforcement embedded in sand and compared with conventional pullout test results. A large-size (0.9 m in length x 0.9 m in width x 0.6 m in depth) pullout box is used in the study, and normal stresses equivalent to 1 m, 3 m and 5 m overburden of sand at the reinforcement level are applied. The results of staged pullout testing on smooth metal strip embedded in sand are found to be in close agreement with the conventional pullout tests under the normal stresses considered in the study. Pullout resistance factors derived from conventional and staged pullout test results are presented in the study. Based on extensive pullout studies conducted in the study, it is found that staged pullout testing of metal-strip reinforcement placed in granular fill can be an alternative to conventional pullout tests performed on samples subjected to different normal stresses.

Keywords: Smooth metal strip, Retaining walls, Staged pullout, Pullout resistance

1. Introduction

Soil reinforcement technique gained much attention in the last few decades, for its ability to provide additional strength to the soil, and for the ease of construction associated with it. The reinforcement introduced in the soil reduces the settlements that occur within the soil and increases the load carrying capacity of the soil. The construction rate is rapid and the cost incurred for reinforced soil structures is much lower compared to conventional soil structures. For all of these benefits, the reinforced soil structures are widely adopted and executed across the world.

The stability analysis of reinforced soil structures includes external failure and internal failure. The overturning, sliding, and the bearing failure are the external failure mechanisms, which are studied by assuming the entire reinforced portion as one composite unit. The internal failure mechanism studies the interface shear and pullout failure of the reinforcement placed or embedded in the used reinforced fill material. Pullout resistance factor of the reinforcement is one of the important parameters considered in the design of reinforced soil structures.

In practice, metal strips and geogrids are widely used to reinforce the soils. Many pullout studies using geogrids (Cardile et al. 2015; Fannin and Raju 1993; Moraci and Recalcati 2006; Nayeri and Fakharian 2009), geotextiles (Artidteang et al. 2012; Weerasekara and Wijewickreme 2010), metal strips (Balunaini and Prezzi 2010; Esfandiari and Selamat 2012; Hariprasad and Umashankar 2018) are reported in the literature. Minažek and Mulabdić (2013) reported that the requires minimum of three pullout tests for three different normal stress conditions. It is challenging to prepare soil samples of volume 1-to-2 m^3 in the test box and also to prepare identical samples to perform pullout tests at different normal stress conditions. The practice of conducting three different tests consumes time as well as manual power.

In this regard, the conventional pullout testing is replaced with the staged pullout testing, in which one sample is tested under three different normal stresses, one after the other for a reduced axial pullout displacement. There are limited studies available on staged pullout testing. In the present study, conventional pullout tests and staged pullout test were conducted on smooth-metal-strip reinforcement embedded in Indian standard sand. Further, the difference in the pullout response observed between the conventional and staged pullout tests were quantified.

2. Materials

Sand

Indian standard (IS) Grade II sand was used in the present study as a fill material. Indian standard sand is popularly known as Ennore sand. Hereafter, IS sand (or) Ennore sand is called as sand. **Figure 1** presents the particle size distribution of the sand. The sand was classified as poorly-graded sand type, based on the gradation coefficients (C_u = 3.6 and C_c = 1.97). The maximum and the minimum dry unit weights of the sand were equal to 16.8 kN/m^3 and 15.3 kN/m^3, respectively.

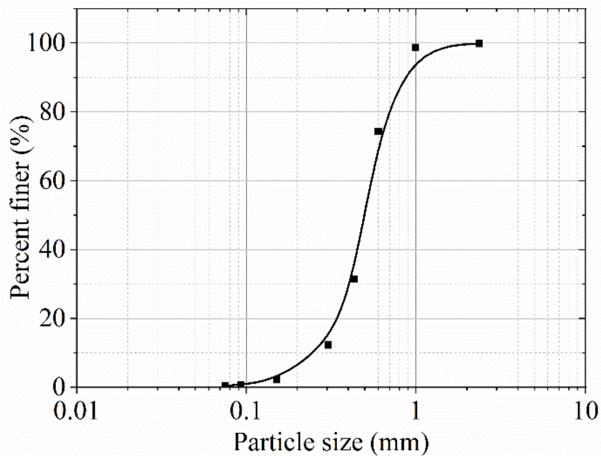


Figure. 1. Grain size distribution of Ennore sand

Smooth-metal-strip reinforcement

Metal strips used in the study are made of Grade 65 steel and galvanised with a zinc coating to avoid corrosion under service conditions. The top and bottom surfaces of the ribbed metal strip were smoothened. More details of the smooth-metal -strip reinforcement used in the study can be found in Hariprasad and Umashankar (2018). The dimensions of the strip used in the present study were equal to 750 mm long, 40 mm wide and 4 mm thick.

3. Experimental program

The experimental study comprises of three conventional large-scale pullout tests and one staged pullout testing on smooth-metal-strip reinforcement embedded in sand. The following sections details the sample preparation, and on conventional pullout testing and staged pullout testing procedures.

3.1 Sample preparation

Conventional and staged pullout testing were carried out in the pullout testing frame detailed in Hariprasad and Umashankar (2018). In order to perform axial pullout testing, axial pullout setup is included on to one side of the test box in the pullout test frame as shown in **Figure 2**. The main components of the axial pullout setup are the hydraulic actuator and S-shaped universal load cell each of capacity 100 kN, and the clamping plate to hold different reinforcements. The stroke of the hydraulic actuator was equal to 70 mm and the pullout tests were conducted to a maximum displacement of 60 mm. The level of the centre of the slit is equal to 520 mm from the bottom of the test tank. All the sand beds were prepared for a relative density of 85% using stationary pluviator. Details of stationary pluviator can be found in Hariprasad et al. (2016). The level of the sand bed layers was ensured using level tubes at different locations in the test box of size 0.9 m x 0.9 m x 1.0 m (In length, width, height).

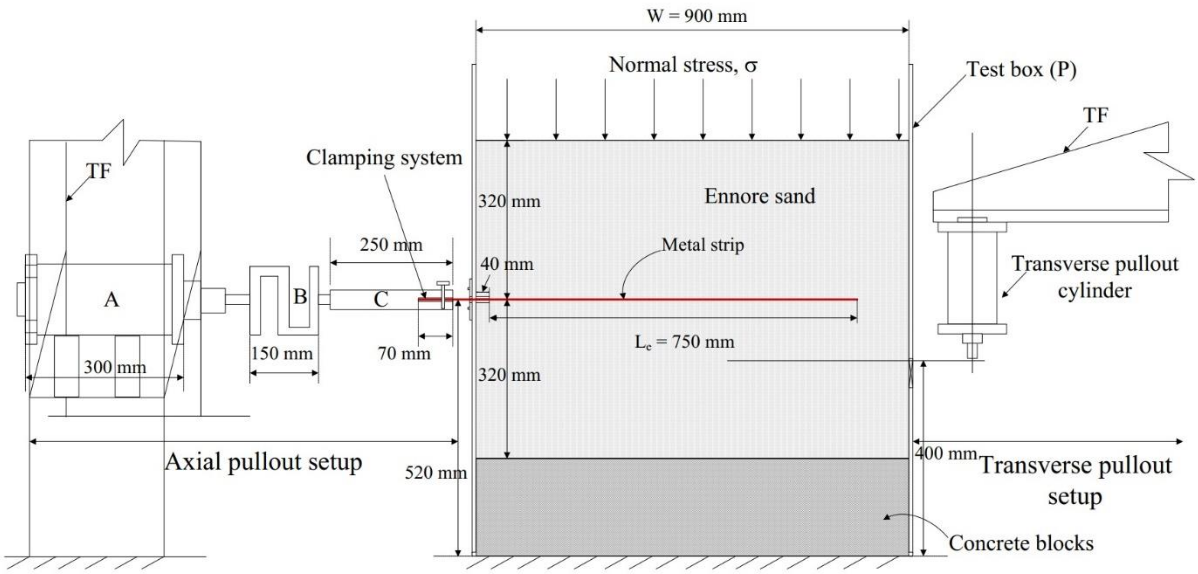


Figure. 2. Front view of the pullout testing frame with axial pullout setup

3.2 Conventional pullout testing (CPOT)

Three conventional pullout tests at normal stresses equal to 17 kPa, 52 kPa and 87 kPa were conducted on smooth-metal-strip reinforcement embedded in sand. The normal stress acting on the top of reinforcement is equal to applied normal stress on the surface plus the normal stress due to self-weight of the sand bed on top of the reinforcement. The flow of oil in the circuit was controlled using hydraulic needle valves.

3.3 Staged pullout testing (SPOT)

For inextensible reinforcements, the Federal Highway Authority (FHWA) recommends to consider the axial pullout resistance corresponding to 20 mm front-end displacement. In staged pullout testing, initially the smooth metal strip embedded in sand was pulled for an axial displacement of 20 mm under the normal stress equal to 17 kPa. Subsequently, the normal stress was increased to 52 kPa and 87 kPa, and pulled for a further axial displacement of 20 mm under each normal stress.

4. Results and discussion

Figure 3 shows the comparison of variation in axial pullout resistance force exhibited by smooth-metal-strip reinforcement embedded in sand under conventional pullout and staged pullout testing. The trends are close for the first two normal stresses, 17 kPa and 52 kPa. From the curves, it was observed that the smooth metal strip exhibited an increase in the axial pullout load with an increase in the normal stress. From the CPOT, peak pullout load of 1 kN, 2.1 kN and 3.7 kN were observed under normal stresses equal to 17 kPa, 52 kPa and 87 kPa respectively. From the SPOT, axial pullout loads were equal to 1 kN, 2.0 kN and 3.4 kN after correction for the length of reinforcement. Farrag et al. (1993) presented the effect of length of the pullout reinforcement. Lesser the length of reinforcement, lesser the pullout resistance of the reinforcement. The resistance force under 52 kPa and 87 kPa normal stress application differ by a percentage of 1% and 15%, lower values observed for SPOT. The difference in the pullout force from CPOT and SPOT was because of the decrease in the interface shear stiffness of the reinforcement with the increase in axial pullout displacement during SPOT. The behaviour could be attributed to the mobilization of shear stress along the entire smooth metal strip under the application of initial normal stresses and the degradation in the interface shear stiffness due to relative displacement between the metal strip and sand particles.

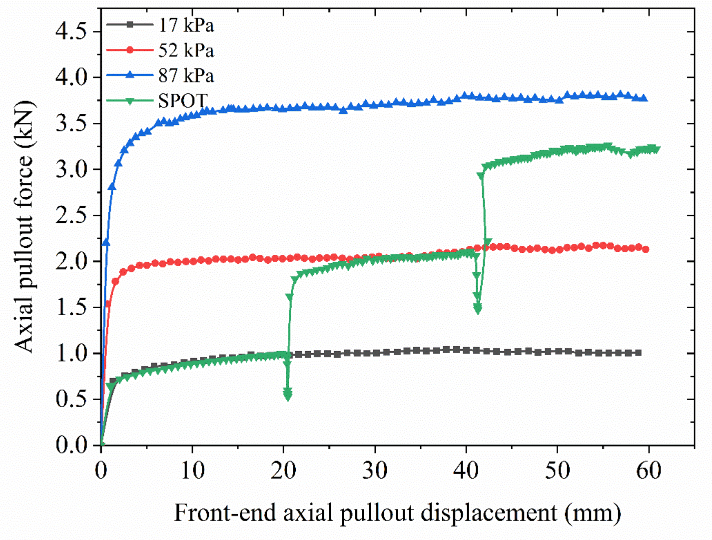


Figure. 3. Variation of axial pullout force with the front-end axial displacement in CPOT and SPOT

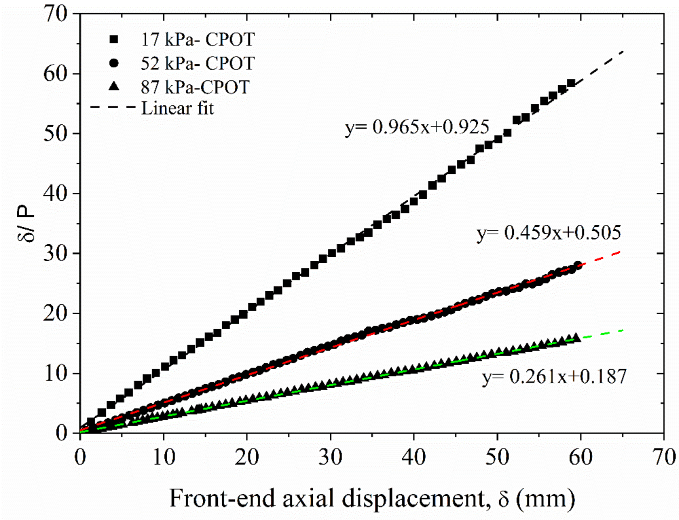
4.1 Analytical expression of pullout load vs displacement response

Hyperbolic function was used to estimate the pullout resistance (P_δ) at different pullout displacements. The equation to predict the pullout resistance, $P_\delta = \dfrac{\delta}{m+n.\delta}$ (1)

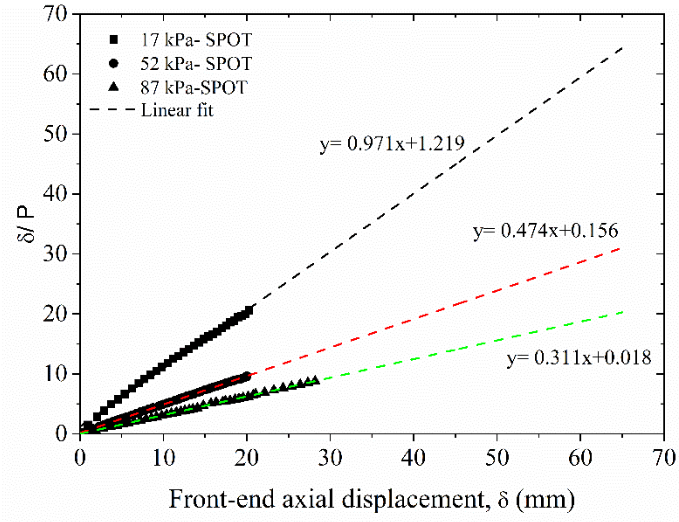
where, δ is the front-end axial pullout displacement, m and n are the hyperbolic constants. The hyperbolic constants are obtained from the linear fitting for the variation between δ/P_δ and δ. The intercept and slope of the linear fitting curves corresponds to m and n values, respectively. **Figure 4(a) and (b)** presents the variation of δ/P_δ along the front-end pullout displacement, δ for conventional pullout testing (CPOT) and staged pullout testing (SPOT), respectively. **Table 1** gives the values of hyperbolic constants, m and n for CPOT and SPOT tests under three different normal stresses applied.

Table 1: Hyperbolic constants for CPOT and SPOT

Normal stress (kPa)	CPOT		SPOT	
	m	n	m	n
17	0.925	0.965	1.219	0.971
52	0.505	0.459	0.156	0.474
87	0.187	0.261	0.018	0.311



(a)



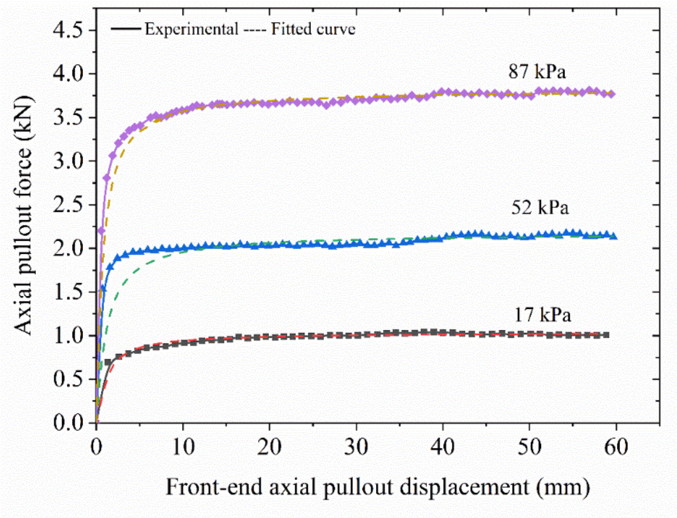
(b)

Figure 4. Variation of δ/P with the δ during (a) CPOT (b) SPOT

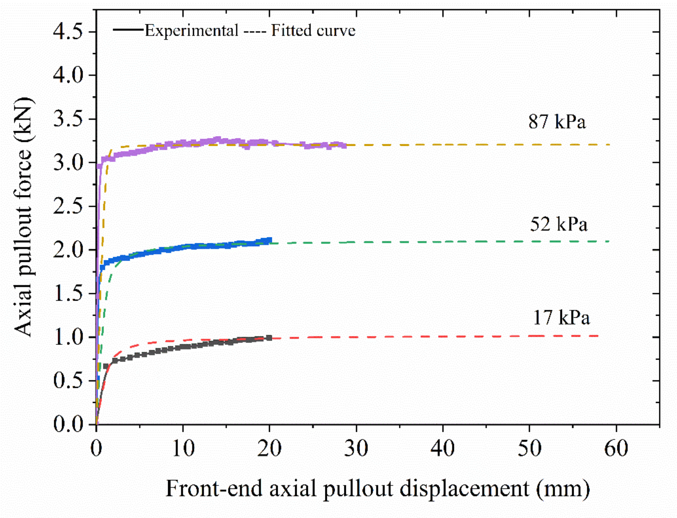
From the Table 1, it could be observed that the values of hyperbolic constant n from SPOT and CPOT are close to each other under 17 kPa for an axial front-end displacement of 20 mm. It was obvious for the reason the CPOT and SPOT samples and load application were similar. There was an increase in the value of ‘n’ under normal stresses equal to 52 kPa and 87 kPa. The behaviour could be attributed to the decrease in the pullout load in the staged pullout testing. However, the effect of the other hyperbolic constant ‘m’ was not significant on the estimation of pullout resistance.

4.2 Comparison of CPOT and SPOT

Figure 5(a) and (b) presents the experimental and estimated axial pullout resistance force along the axial pullout displacement for the smooth metal strip from CPOT and SPOT, respectively. The experimental and estimated (or) fitted curves for axial pullout force along the front-end axial pullout displacement were close enough barring the estimation for the initial displacements of 5-10 mm under the different normal stresses used in the study. Similar behaviour was observed for CPOT and SPOT trends. However, the pullout resistance corresponding to front-end displacement of reinforcement equal to 20 mm (as per FHWA guidelines) differs by less than 5% in both the CPOT and SPOT comparison.



(a)



(b)

Figure 5. Comparison of measured and estimated pullout resistance force with the axial displacement from (a) CPOT and (b) SPOT

Figure 6 presents the comparison of the estimated pullout resistance force with the axial displacement from CPOT and SPOT. The estimation of the pullout resistance for the initial displacements under the normal stresses 52 kPa and 87 kPa differs noticeably between the CPOT and SPOT fitting curves. However, there is no much difference under the normal stress 17 kPa as expected. The difference in the estimated pullout force for the initial displacements could be attributed to the weakened reinforcement or the loss of frictional force between the soil and reinforcement due to the earlier applied loads. The difference in the estimated curves for CPOT and SPOT under 52 kPa and 87 kPa were equal to 1% and 14%, respectively. The difference was equal to the difference observed between the experimental values obtained from CPOT and SPOT. Design charts for pullout resistance factors (F^*) were plotted for the different cases considered in the study.

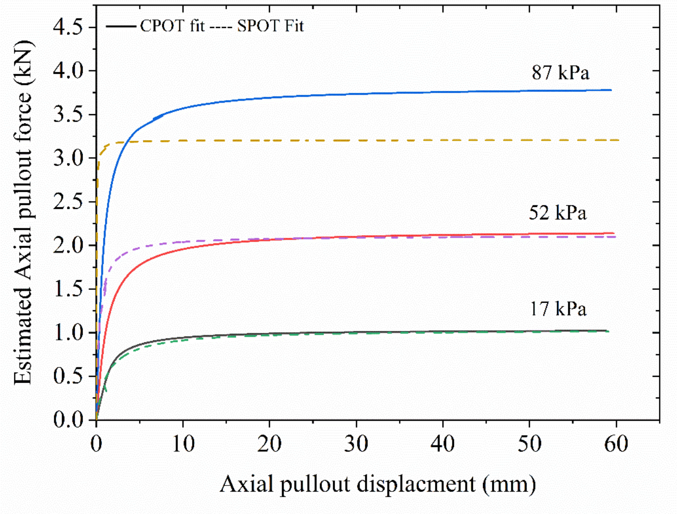


Figure 6. Comparison of estimated pullout resistance force with the axial displacement from CPOT and SPOT

Figure 7 presents the design chart for the smooth metal strip embedded in Indian standard sand. In this case, the pullout resistance factor was determined for the experimental and estimated hyperbolic fitting curves. It was observed that the pullout resistance factors between the CPOT and SPOT under normal stress 17 kPa are similar and varies under other two normal stresses. The decrease in the pullout resistance factor under higher normal stresses could be attributed to the reduced dilatancy. However, the estimated pullout resistance factor (F^*) are closer to the experimental values obtained from CPOT and SPOT. It was also observed that the F^* observed for the smooth metal strip tested in the study was higher than the AASHTO recommendation of F^* for inextensible reinforcements.

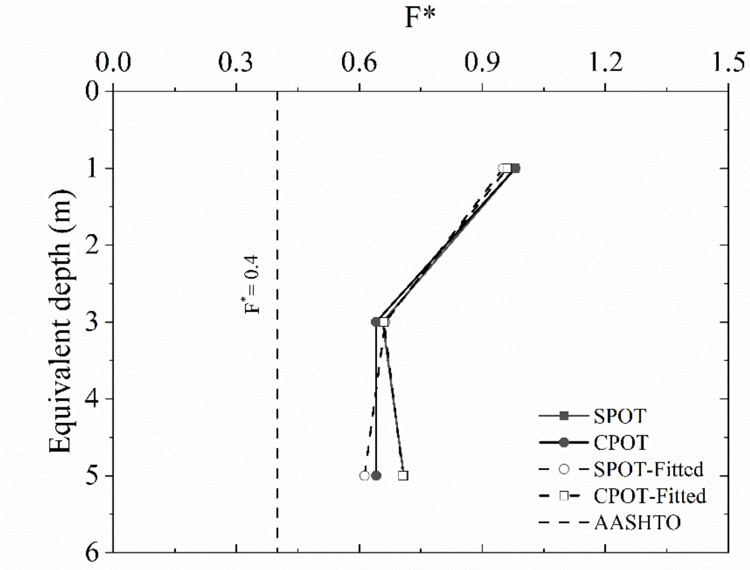


Figure 7. Axial pullout resistance factors (F*) for smooth metal strip in different cases

The results obtained from SPOT are satisfactory and can be adopted in the field to determine the pullout resistance factors for smooth metal strip embedded in sand.

5. Conclusions

The study was aimed at comparing the pullout resistance of metal-strip reinforcement based on staged pullout testing (SPOT) and conventional pullout testing (CPOT). The following conclusions are drawn from the study

1. The pullout resistance of reinforcement from CPOT and SPOT were found to differ by 1% and 15%, under normal stresses of 52 kPa and 87 kPa. respectively between SPOT can be done in a quick time

with much less effort. in sample preparation and testing when compared to CPOT. SPOT results are especially reliable under low normal stresses.

2. The estimated curves for CPOT and SPOT show a similar percentage of difference in the axial pullout forced under the normal stresses of 52 kPa and 87 kPa.
3. The pullout resistance factor (F^*) varies between 0.61-0.90, higher F^* was observed under low normal stress and lower F^* under high normal stress.

From this study, it can be recommended to adopt SPOT for inextensible reinforcement embedded sand to arrive at the pullout resistance factors. The proposed method reduces the time and effort involved in conventional pullout testing.

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