LABORATORY PULLOUT RESPONSE OF POLYESTER STRAP WITH UNANCHORED V-CONFIGURATION

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ABSTRACT

A series of laboratory pullout tests of polyester straps with unanchored V-configuration were conducted as part of research aimed to understand the behavior of mechanically stabilized earth walls reinforced by polyester straps with anchored V-configuration. The two soils [silty sand (SM) and sandy silt (MH)] and polyester straps used, as well as the test equipment and procedure, are described in details. A total of eight pullout test samples are evaluated, and the relationship between the pullout force and displacements along the strap is analyzed. The results for both soils include the following: (1) significant strain softening in force-displacement curves, (2) polyester strap extensible behavior, (3) “bonded” soil – polyester strap interface behavior at a low pullout force, and (4) increasing peak pullout force with an increase in vertical confining stress. The observed difference is in the relationship between the displacement at the peak pullout force and the vertical confining stress increases.

Keywords: Polyester strap, pullout test, MSEW, interface friction angle

INTRODUCTION

Mechanically stabilized earth walls (MSEW) reinforced by polyester straps with anchored V-configuration have been used for bridge approach ramps in Indonesia. A typical application of these straps is shown as Fig. 1. An extensive study is currently underway to understand the behavior of these walls. To verify the assumed behavior, a series of laboratory and field pullout experimental studies, as well as MSEW numerical studies, are being conducted. This paper reports the laboratory experimental study of polyester straps with unanchored V-configuration embedded in two soil types.

The technical literature dealing with the pullout response of polyester straps is very limited. Lo (1998) discussed the results of polyester straps laboratory pullout tests, and found that the average failure shear stress to average normal stress ratio increased with a reduction in the confining stress. He also found that the material grade of the straps has a little effect on the observed responses. Thamm et al. (1992) reported the extensive measurement results of a 3.2 m high full scale MSEW test using polyester straps with anchored V-configuration loaded to failure using surficial surcharges. In addition, Segrestin and Bastick (1997, in Gurung and Iwao 1999) compared the difference between the pullout behavior of extensible polyester straps and that of inextensible steel strips.

Fig. 1 Field installation of MSEW with anchored V-configuration polyester straps.

This paper discusses the soils and polyester straps used in the tests, followed by a discussion on the test equipment and procedure. A critical evaluation of the test results concludes this paper.

TEST MATERIALS

Soils

Two types of soils, from actual MSEW construction sites and referred to as Duku and Busung soils, were used in the current study. Soil Duku was silty sand with about 28% fines content (i.e. particles passing through a 75 µm sieve). Soil Busung was sandy silt with 27% clay fraction (i.e. particles size less than 2µm). The particle size distributions for both soils are shown as Fig. 2. The modified Proctor (ASTM D1557, 2002) compaction properties of both soils are shown as Fig. 3; soil Duku with less fines content has higher a maximum dry density, $\rho_{dry\text{-}max}$, and a lower optimum water content, w_{opt}. The soil friction angles for Duku and Busung soils were measured using direct shear tests in accordance with ASTM D 3080 (2004) and unconsolidated undrained triaxial tests in accordance with ASTM D 2850 (2003), respectively. The density of all soil specimens was compacted to about 100% of $\rho_{dry\text{-}max}$. The normal stress range adopted for the direct shear tests was 20 to 100 kPa, while the confining stress range adopted for the triaxial tests was 30 to 90 kPa. The physical properties of soils Duku and Busung are summarized in Table 1.

Polyester Strap

The high-tenacity polyester straps used were Kolotie 50 produced by Kolon, Korea. The typical surface and cross section are shown as Fig. 4. It consists of ten lanes of polyester yarns individually encapsulated in a high density polyethylene (HDPE). The polyester yarns are the load carrying elements, whereas the sheathing is for protection against construction damage. The sheathing has a textured surface to provide good interface soil – strap friction. The straps have nominal width and thickness of 90 mm and 2 to 3 mm, respectively. The nominal tensile strength is 50 kN, and this strength is reached at about 12% strain. The strap properties are summarized in Table 2.

Table 1 Physical properties of soils used

Property	Soils	
	Duku	Busung
Fines content (%)	28	63
Soil classification	SM	MH
Specific gravity	2.65	2.83
$\rho_{dry\text{-}max}$ (g/cm^3)	1.90	1.85
w_{opt} (%)	14.4	17.8
φ (°)	46.9	47.8

Note: $\rho_{dry\text{-}max}$ = maximum dry density & w_{opt} = optimum water content measured in modified Proctor tests, φ = soil friction angle.

Table 2 Properties of polyester straps.

Nominal Property	Value
Width (mm)	90
Thickness (mm)	2 – 3
Tensile Strength (kN)	50
Peak Strain (%)	12

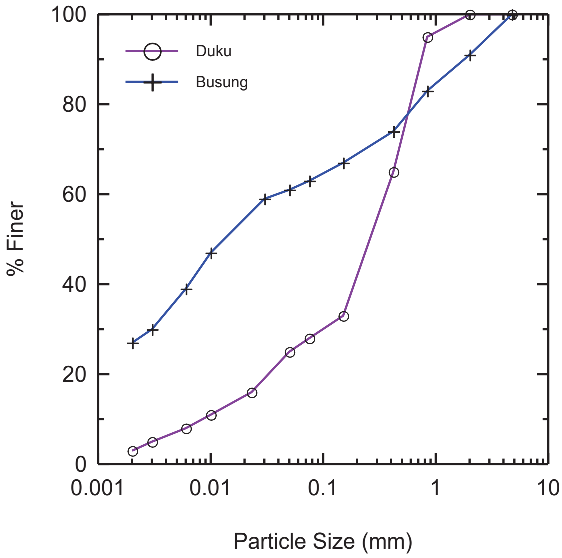

Fig. 2 Particle size distribution for Duku and Busung soils.

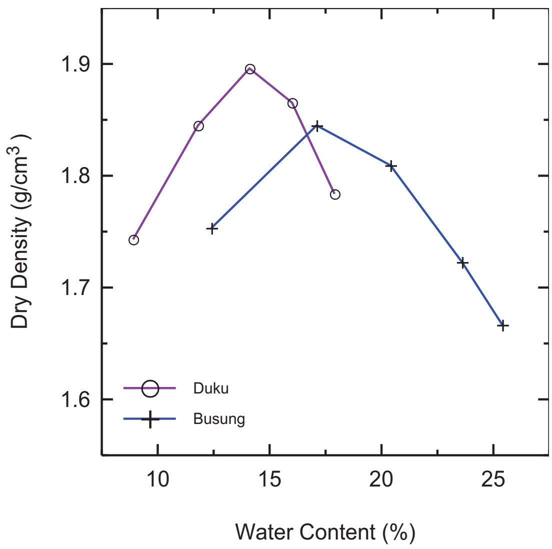

Fig. 3 Modified Proctor compaction properties for Duku and Busung soils.

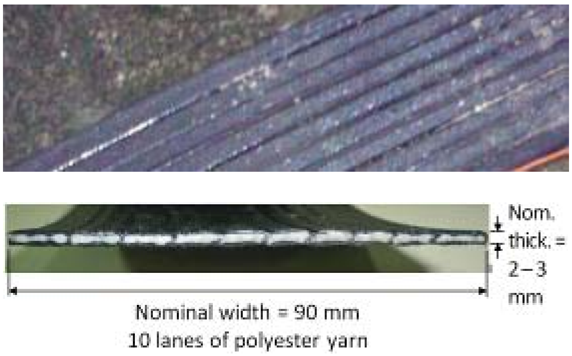

Fig. 4 Polyester strap surface and cross-section.

TEST SETUP

Pullout Test and Instrumentation Systems

The pullout test system used comprises a large steel pullout box, a vertical confining stress system, a clamping system, and a displacement-controlled pulling system. The overall pullout test system design is shown as Fig. 5.

The pullout box has inner dimensions of 2,200 mm long, 500 mm wide, and 500 mm deep. The front slot for the reinforcement and the back slot for the instrumentation are located about 200 mm above the bottom of the box. The total thickness of the soil sample to be accommodated is 400 mm, while the remaining 100 mm of the box is provided for the inflated air bag.

The vertical confining stress or the normal-to-reinforcement stress is applied to the top of the soil sample by a stress-controlled boundary comprising an air bag. During any test, the inflated rubber air bag was confined by the soil sample to the bottom, the pullout box steel walls to the sides, and the stiffened steel plate cover bolted to the pullout box walls to the top. Fig. 6 shows the air bag during installation and initial pumping.

The V-configuration of a polyester strap was achieved by folding the strap, with the strap placed within the soil sample and the strap fold clamped to the clamping system. To prevent slip, the connection between the strap fold and the clamping system was prepared with a 25 mm steel rod. This arrangement is shown as Fig. 7.

The displacement-controlled pulling system consisting of a 100 kN electrohydraulic system and the 100 mm in diameter hydraulic actuator are shown in Fig. 8. This system shown was attached to the reaction frame which is structurally connected to the pullout box.

The instrumentation system comprises a load cell and linear potentiometers connected to a digital data acquisition system. The position of this system relative to the pullout test system is depicted in Fig. 5. In addition, the vertical confining stress was measured using a pressure gauge attached to the air bag.

The load cell located between the hydraulic actuator and the clamping system was used to measure the applied force. Fig. 9 shows the load cell installed to the pullout test system.

The displacement of the strap specimen was measured using four (4) linear potentiometers placed externally in the back of the pullout box. These potentiometers were connected to the strap by inextensible nickel wires put inside copper tubes. For the Duku test series, the wires were fastened to the straps at 100 mm, 750 mm, 1,400 mm, and 2,050 mm from the strap exit at the front slot. For the Busung series, the wires were fastened at the exit and at 550 mm, 1,100 mm, and 1,600 mm from the strap exit.

Specimen Preparation

The soil was placed in the pullout box in 50 mm thick layers. Each soil layer was leveled and compacted at its optimum water content using a 640 N iron roller. The soil unit weight was controlled with the sand cone density test; it is noted that the achieved soil unit weight ranged only from 80 to 90 percent of the maximum dry density. When the soil level reached the pullout and instrumentation slots 200 mm above the pullout box bottom, the polyester strap was laid on the surface of the compacted soil and fixed to the clamps outside the box and subsequently the nickel wires were fastened to the strap. Finally, four 50 mm thick soil layers were placed, leveled, and compacted, resulting in a total soil thickness of 400 mm with the strap at the middle. Fig. 10 shows the strap and nickel wires installed on top of the compacted soil.

The polyester strap specimens were 4.5 m long. This specimen length was adequate for developing a strap with unanchored V-configuration and the required length for the clamping system, as shown in Figs. 7 and 10.

Testing Program

The testing program for the two soils is presented in Table 3. The vertical confining stress used was in the range of 38 to 142 kPa, representing typical vertical stresses for reinforcements in MSEWs. The displacement rate of the pullout test system was set to about 1 to 2 mm/minute. A test was stopped when there was continued displacement of the strap specimen at a value of essentially constant pullout resistance. A total of 8 tests are reported in Table 3.

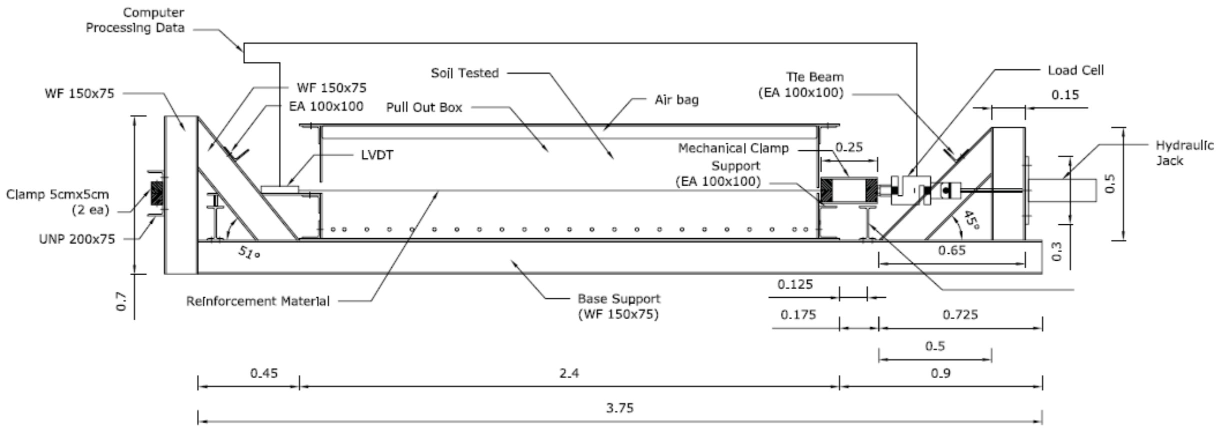

Fig. 5 Design of pullout box (unit in m).

Fig. 6 Air bag installation.

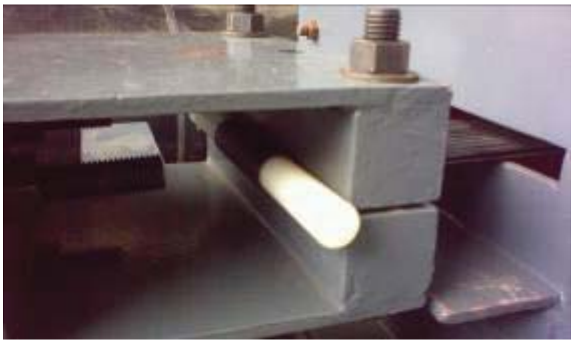

Fig. 7 Clamping system.

Fig. 8 Displacement-controlled pullout system.

Fig. 9 Load cell installed to clamping system and hydraulic actuator.

Fig. 10 Polyester strap with unanchored V-configuration in pullout box.

Table 3 Testing program.

No.	Soil	Vertical Confining Stress (kPa)
1	Duku	38
2		73
3		142
4a	Busung	50
4b		50
4c		50
5a		82
5b		82

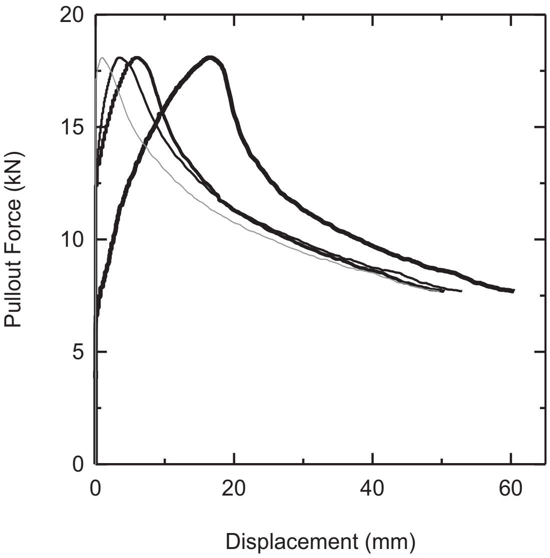

Fig. 11 Force – displacement curves for soil Duku (no. 2).

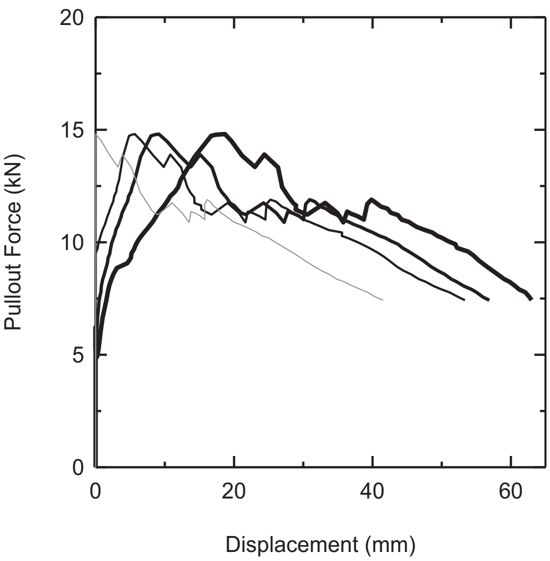

Fig. 12 Force – displacement curves for soil Busung (no. 4a).

TEST RESULTS

The typical applied pullout force versus displacement curves for soil Duku (silty sand, SM) are presented as Fig. 11. The curves for different wire fastener locations (100 mm, 750 mm, 1,400 mm, and 2,050 mm from strap exit) are shown with different line thicknesses; thicker lines represent closer locations. Overall, the displacement curves have significant strain softening behavior. At a given pullout out force, the displacement at a closer wire fastener location is greater; even at the peak pullout force, the displacement at 2,050 mm from strap exit was very small. All these indicate the extensible behavior of the polyester strap. In addition, the displacement started to occur at a certain pullout force; for sample no. 2, the displacement at 100 mm from strap exit started to occur at a pullout force of about 7 kN, indicating a "bonded" soil – polyester strap interface behavior at a low pullout force.

The typical applied pullout force versus displacement curves for soil Busung (sandy silt, MH) are presented as Fig. 12. The curves for different wire fastener locations (at exit and at 550 mm, 1,100 mm, and 1,600 mm from strap exit) are shown with different line thicknesses; the thickest line is for the response at strap exit and, for the others, thicker lines represent closer locations. The displacement curves have with significant strain softening behavior. Again, at a given pullout out force, the displacement at a closer wire fastener location is greater, indicating the extensible behavior of the polyester strap. Similar to the soil Duku samples, the curves indicate a "bonded" soil – polyester strap interface behavior at a low pullout force.

A general comparison between samples in soil Duku (silty sand, SM) and those in soil Busung (sandy silt, MH) shows that the pullout behavior of polyester straps in different soils is similar. Furthermore, the displacement pattern along the straps is consistent with that observed in other research (e.g., Segrestin and Bastick 1997, in Gurung and Iwao 1999). It is noted, the strain softening and extensible behavior of polyester straps with unanchored V-configuration is significantly different from the behavior of the Reinforced Earth steel strips which is practically tri-linear elastoplastic and inextensible (Harninto and Prakoso 2011).

The applied pullout force versus displacement curves for soil Duku samples with different vertical confining stresses are shown as Fig. 13. The curves are based on the displacement at location of 100 mm from strap exit. The strain softening and extensible, as well as "bonded" at low pullout force, behavior is observed in all confining stresses. It can be seen that the peak pullout force increases as the confining

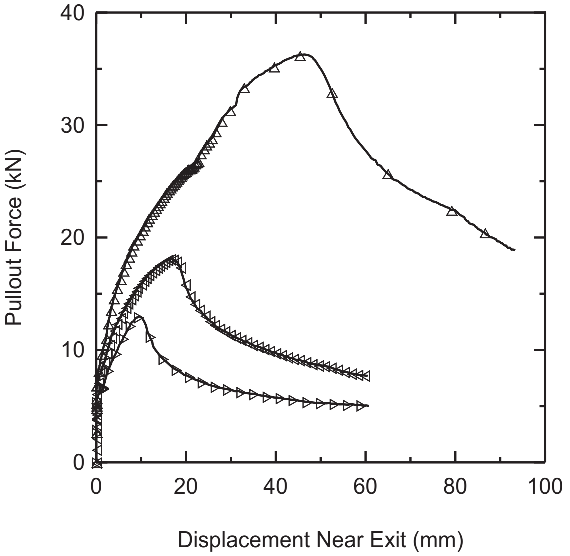

Fig. 13 Force – displacement curves for soil Duku with different vertical confining stresses (▷ = 38 kPa, ◁ = 73 kPa, △ = 142 kPa) (displacement at 100 mm from strap exit).

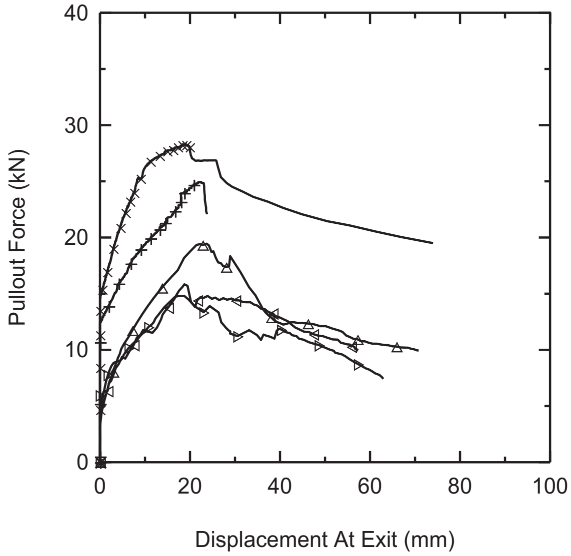

Fig. 14 Force – displacement curves for soil Busung with different vertical confining stresses (▷, ◁, △ = 50 kPa, +, ×= 82 kPa) (displacement at strap exit).

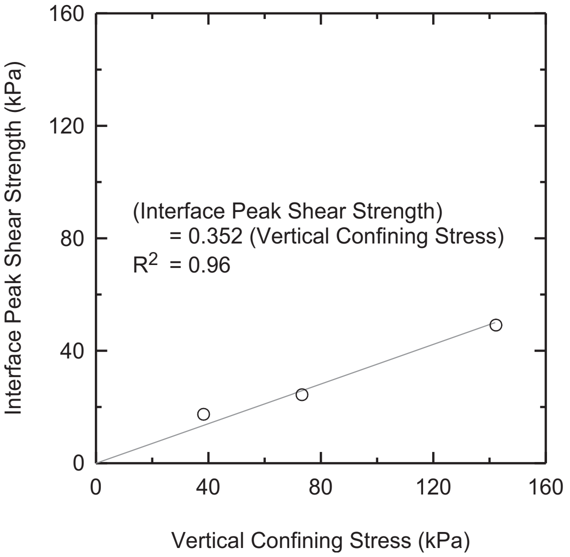

Fig. 15 Effect of vertical confining stress on interface peak shear strength for soil Duku samples.

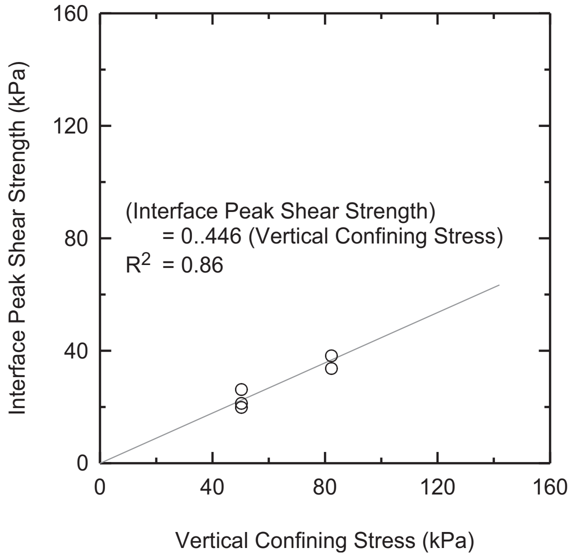

Fig. 16 Effect of vertical confining stress on interface peak shear strength for soil Busung samples.

stress increases and that the displacement at the peak pullout force increases as the confining stress increases as well.

The applied pullout force versus displacement curves for soil Busung samples with two different vertical confining stresses are shown as Fig. 14. The curves are based on the displacement at the strap exit. The previously observed three aspects of polyester strap pullout behavior are again observed in all confining stresses. It can be seen that the peak pullout force increases as the confining stress increases. However, it appears that the displacement at the peak pullout force does not change significantly for different confining stresses. It is noted that for each confining stress, there are variabilities in the curves that could be associated with the difficulties in preparing a large volume of soils for each sample.

The peak pullout forces are evaluated further to determine the interface peak shear strength. This implies that the pullout resistance is developed solely from the soil – polyester strap interface shear stresses; other mechanism, such as possible "passive resistance" due to the V-configuration is neglected in this paper. The interface area was about 0.734 m^2. The three data for soil Duku samples were analyzed and shown as Fig. 15. It is found that:

(Interface Peak Shear Strength) =
0.352 (Vertical Confining Stress) (1)

In terms of the interface friction angle δ, the value is 19.4°. The R^2 of Eq. (1) is high, indicating a strong relationship between the two parameters.

The five data for soil Busung samples were analyzed and shown as Fig. 16. It is found that:

(Interface Peak Shear Strength) =
0.446 (Vertical Confining Stress) (2)

The value of the interface friction angle δ is 24.0°. The R^2 of Eq. (1) is again high, indicating a strong relationship between the two parameters. Though the δ value of soil Duku is slightly lower than that of soil Busung, they are within the typical range for soil – HDPE interface friction angle (e.g., Bilgin and Shah 2010). It is noted additionally that the friction angle of both soils is relatively the same (See Table 3.).

The relationships between the displacement at interface peak shear strength and the strength itself were examined in Fig. 17 for both soils. Similar to previously discussed, for soil Duku (silty sand, SM), the displacement increases as the strength increase, while for soil Busung (sandy silt, MH), the displacement appears to relatively constant for the range of vertical confining stresses considered.

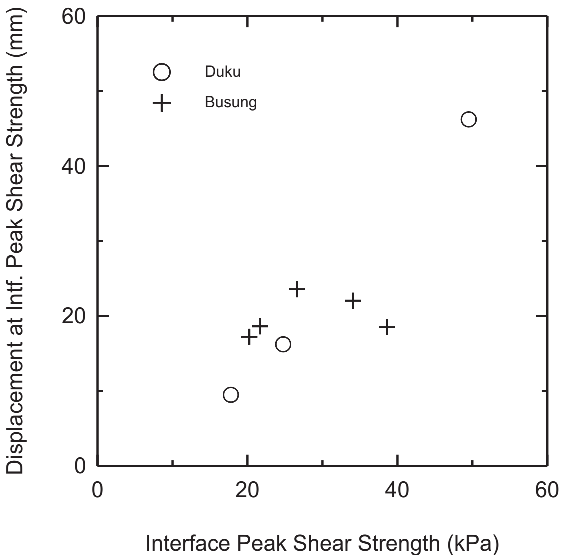

Fig. 17 Displacement at interface peak shear strength for soils Duku and Busung.

CONCLUSIONS

This paper discusses the laboratory pullout responses of polyester straps with unanchored v-configuration. The two soils [silty sand (SM) and sandy silt (MH)] and polyester straps used, as well as the test equipment and procedure, are described in details. A total of eight pullout test samples were evaluated, and for each sample, the relationship between the pullout force and displacements along straps was analyzed. The results include the following: (1) displacement curves with significant strain softening, (2) polyester strap extensible behavior, (3) "bonded" soil – polyester strap interface behavior at a low pullout force, and (4) increasing peak pullout force with an increase in vertical confining stress. The interface friction angle varies between 19.4° and 24.0°. The observed difference in behavior of polyester straps embedded in silty sand soil and in sandy silt soil is that the displacement at the peak pullout force increases as the confining stress increases for the former soil, while the displacement appears to be relatively constant for the range of vertical confining stresses considered for the latter soil.

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