Performance of hybrid lightweight slope system under seepage

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ABSTRACT: The behavior of a steep sandy slope remediated by a hybrid lightweight fill under seepage was investigated by using physical slope models. The fill was comprised of expanded polystyrene (EPS) blocks (geofoam blocks) with internal drainage channels and EPS bead - sand mixture. The dimensions of the geofoam blocks (density of the blocks were 20 kg/m^3) used in hybrid lightweight fill were 2.5-cm high, 5-cm wide, and 15-cm long. Two 0.5-cm wide and 15-cm long drainage channels were grooved along both top and bottom of these blocks. EPS bead content used in EPS bead - sand mixture of the hybrid lightweight fill system was 0.5% by weight. The hybrid lightweight fill was assembled to form an “embankment type configuration” at the toe of the sandy slopes. In this configuration, the geofoam blocks were placed along the slope face whereas the EPS bead - sand mixture was compacted to form the back-slope. In order to generate the hydrologic conditions within the slope, a laboratory lysimeter with dimensions of 60-cm high, 20-cm wide, and 200-cm long was constructed using 1-cm thick acrylic glass. Constant pressure heads of 25 cm-, 38 cm-, and 50 cm-H_2O were applied at the water reservoir compartment of the lysimeter during the tests. Two different embankment heights (15-cm and 22.5-cm) were used to investigate the effect of seepage on the dimension of the lightweight assemblage. The performance of the hybrid lightweight slope system was compared to that of non-remediated slopes.

Keywords: EPS beads, EPS bead – sand mixture, EPS block geofoam, seepage, slope stability.

1 INTRODUCTION

Expanded polystyrene (EPS) block (geofoam block) is a geosynthetic which is block or planner rigid cellular foamed polymeric material used in geotechnical applications (ASTM D4439). Geofoam blocks are made from styrene beads by expansion and molding. Apparent density of a geofoam block varies in between 11.2 and 38.4 kg/m^3 (ASTM D6817). Due to lightweight feature, approximately 50 to 200 times lighter than conventional compacted earth materials, geofoam blocks are used in geotechnical engineering for lightweight embankment fill over soft soil sites where primary consolidation is of concern. Using geofoam blocks in highway construction is a well established technology around the world (Farnsworth et al., 2008; Bartlett et al., 2011; Duškov, 2011; Aabøe, 2011; Korkiala-Tanttu et al., 2011; Kawashima et al., 2001). Various design guidelines have also been published for the use of geofoam in highway construction (NPRA, 1995; Stark et al., 2004).

Due to the lightweight feature, geofoam blocks can significantly reduce driving forces (mainly gravitational forces that cause slopes to fail) for slope stability and enhances the factor of safety. In addition, geofoam blocks have been gaining acceptance in slope rehabilitation projects as a lightweight fill due to their ease of installation. Following the use of geofoam blocks in slope remediation, a guideline sponsored by the National Cooperative Highway Research Program (NCHRP) has been published (Arellano et al., 2011). One of the drawbacks of slope remediation using lightweight fills is its vulnerability against horizontal driving forces (especially seepage forces). Seepage forces are one of the main causes of slope instability. The current design guideline requires implementation of a permanent drainage system which prevents the accumulation of pore water pressures above the bottom of the geofoam block assemblage (Arellano et al., 2011). On the other hand, this drainage system can be clogged due to maintenance issues and improper design. Therefore, the studies on the behavior of geofoam block slope systems susceptible to seepage flow had gained momentum in recent years (Akay et al., 2012; 2013; Özer et al., 2014; Akay et al., 2014a; 2014b; Özer and Akay, 2014; Koç, 2015; Akay, 2016; Özer, 2016).

In addition to the block form of EPS, the use of granular EPS (EPS beads) as lightweight inclusion into earthen fills such as sand and dredged waste has emerged in civil engineering applications. EPS beads mixed with dredge waste and cement has been implemented to recycle dredged materials (Satoh et al., 2001; Tsuchida et al., 2001; Yoonz et al., 2004). Stress-strain characteristics of dredged sand mixed with EPS beads and cement was studied by Miao et al. (2010). These studies showed that the EPS beads addition reduced the unit weight of the mixture whereas cement addition provided extra stiffness. On the other hand, to eliminate the cost of cement and to create noncementitious mixture, Deng and Xiao (2009 and 2010) studied shear strength characteristics of EPS bead – sand mixtures. Edinçliler and Özer (2015) performed triaxial testing program on various EPS bead – sand mixtures to investigate and model the effect of EPS beads grain size and content on the stress –strain behaviour of EPS bead – sand mixtures. These studies indicated that EPS beads reduced the unit weight of the sand however the strength of sand decreased with increasing EPS bead content. Even though the stress-strain characteristics of EPS bead –sand lightweight mixtures have been extensively studied and used in the field, their performances under seepage forces is still unknown.

Geofoam blocks are traditionally placed on the slope face as side-hill fill. The vulnerability of this configuration under seepage forces against global stability failure has been studied by Akay et al. (2012 and 2013) using laboratory physical slope models. To improve the performance of this traditional approach, Akay et al. (2014a and 2014b) proposed geofoam blocks with internal drainage channels. In addition, Özer and Akay (2014) proposed interlocked geofoam blocks and tested under seepage forces. However, neither geofoam blocks with internal drainage channels nor interlocked geofoam blocks improved the performance of slopes against deep seated global slope failure under seepage. Özer et al. (2014) proposed overburden stress concept in which geofoam blocks are placed at the toe of the slope as embankment type block layout where the slope applied overburden stress along the portion of the geofoam blocks buried inside the slope. This configuration significantly enhanced the performance of geofoam slope system under the seepage and prevented global slope failure (Özer et al., 2014).

The objective of this study is to enhance the traditional side-hill fill geofoam block configuration for slope rehabilitation under seepage by implementing a hybrid lightweight fill concept. Proposed hybrid lightweight fill comprised of geofoam blocks with internal drainage channels and EPS bead - sand mixture. Under the lights of overburden stress concept (Özer et al., 2014) hybrid lightweight fill was placed as embankment type configuration at the toe of the slope. Small scale laboratory physical slope models (1-g models) were used to achieve the objectives of the study.

2 MATERIALS AND METHODS

Following Akay et al. (2012, 2013), Özer et al. (2014), Akay et al. (2014a; 2014b), Özer and Akay (2014), Koç (2015), Akay (2016), and Özer (2016), a transparent Plexiglas model box was constructed with dimensions of 200 cm long, 20 cm wide and 60 cm high which composed of water and soil compartments (Figure 1). Slopes (45 degree slope faces and dry unit weight of 14 kN/m^3) with dimensions of 100 cm long, 20 cm wide and 55 cm high were constructed in 2.5 cm lifts in a controlled manner in the soil compartment of the box (Figure 2). Three different constant hydraulic heads (25 cm-, 38cm- and 50 cm-H_2O) were applied during the tests using the water compartment of the box (Figure 1). Models were equipped with 22 pencil size tensiometers coupled with pressure transducers (T1 – T22) installed on one side of the box to capture pore water pressures developed near the wall at 10 s intervals (Figure 1). The data logger collected and recorded the pore-water pressures (Figure 1).

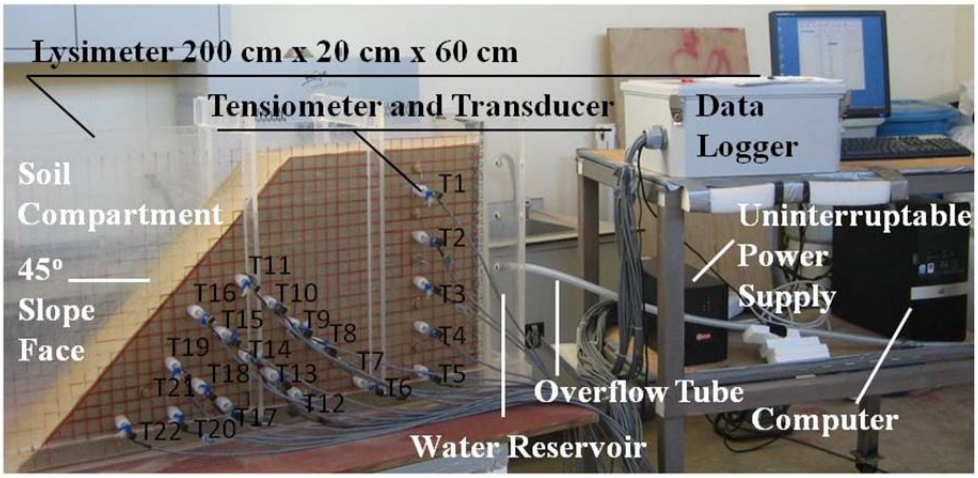

Figure 1: Experimental set-up

The first component of the hybrid lightweight slope was the geofoam blocks (type of geofoam is EPS 19 according to ASTM D6817) with internal dual drainage channels along the top and the bottom (Figure 2c). The second component was the EPS bead - sand mixture with an EPS bead content of 0.5% of the dry weight of the sand in the mixture (Figure 2b). Grain size of EPS beads used in EPS bead sand mixtures varied between 1 to 4 mm (Figure 2a). Physical properties of materials used in the slope models are summarized in Table 1.

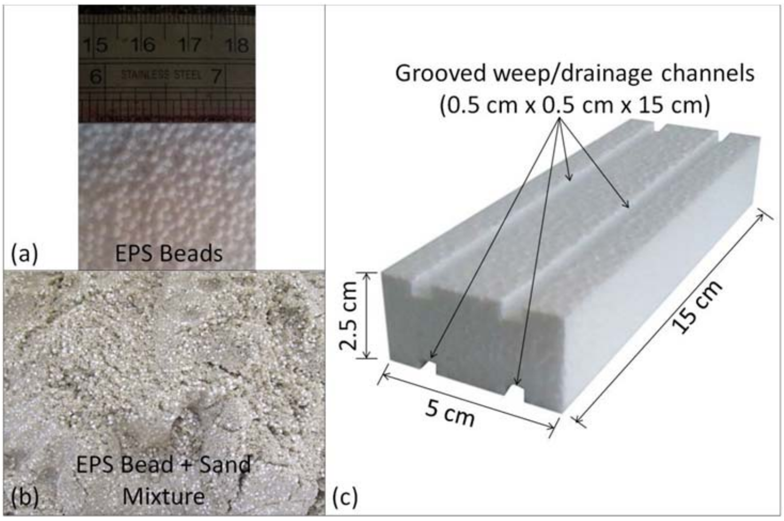

Figure 2: Lightweight fill materials (a) EPS beads, (b) EPS bead – sand mixtures, and (c) Geofoam blocks with grooved weep/drainage channels

Table 1. Physical properties of materials (Koç, 2015)

Property	Description and Unit	Value
Material: SAND		
Soil Classification	Unified Soil Classification System (USCS)	SP
Grain size distribution	Sand (%), Silt + Clay (%)	96.0, 4.0
Effective size	D_{10} (mm)	0.19
Uniformity Coefficient	C_u (-)	3.5
Coefficient of curvature	C_c (-)	1.2
Specific gravity	G_s (-)	2.65
Maximum void ratio	e_{max} (-)	0.89
Minimum void ratio	e_{min} (-)	0.56
Material: EPS beads		
Grain size variation	(mm – mm)	1.0 – 4.0
Effective size	D_{10} (mm)	2.0
Uniformity Coefficient	C_u (-)	1.6
Coefficient of curvature	C_c (-)	1.0
Specific gravity	G_s (-)	0.03
Dry unit weight	γ_{dry} (kN/m^3)	0.19
Material: EPS beads – sand		
Dry unit weight	γ_{dry} (kN/m^3)	11.6

A consolidated drained (CD) triaxial testing (ASTM D7181) and constant head permeability testing (ASTM D2434) program were carried out for both sand and EPS bead – sand mixtures by Koç (2015). The results of CD testing program were presented in Table 2. Based on a total of nine constant head permeability tests, the average saturated hydraulic conductivity for sand was measured as $1.8\text{x}10^{-4}$ m/s (with a standard deviation of $3.1\text{x}10^{-5}$ m/s), and based on a total of five constant head permeability tests, the average saturated hydraulic conductivity for EPS bead - sand was measured as $3.1\text{x}10^{-4}$ m/s (with a standard deviation of $5.8\text{x}10^{-5}$ m/s).

Table 2. Results of CD Tests (Koç, 2015)

Specimen	EPS Bead Content (By dry weight / By volume) (%)	Dry Unit Weight (kN/m^3)	Peak Deviatoric Stress (kPa)			Effective Mohr-Coulomb Parameters	
			Cell Pressure 50 kPa	Cell Pressure 100 kPa	Cell Pressure 200 kPa	c' (kPa)	Ø′ (degrees)
Sand	---	13.8	129.0	221.8	407.4	10.8	28.8
		13.8	103.9	204.2	424.6	8.0	29.7
		13.5	101.6	203.2	406.6	0	30.3
EPS bead - sand	0.5 / 19.6	11.3	110.8	214.2	360.0	11.7	26.7
		11.4	124.7	214.8	363.6	15.6	26.2
		11.3	132.0	224.6	378.0	17.0	26.7

Two different hybrid lightweight fill configurations were tested in this study: 15-cm and 22.5-cm high embankments (Figures 3b and 3c) in which the hybrid lightweight slope system comprised of geofoam blocks with dual drainage channels and EPS bead –sand mixtures were used as a lightweight fill. These configurations were used to remedy the sandy slope, referred to as the “Matrix” configuration (Figure 3a). While the geofoam blocks with internal drainage channels were placed along the slope face of the embankment type configuration, EPS bead – sand mixture were buried inside the slope (Figures 3b and 3c). Three different constant water heads (25 cm-, 38cm- and 50 cm-H_2O) were used in order to evaluate the performance of the hybrid lightweight fills under various hydraulic gradients. A total of nine physical slope experiments were conducted (3 configurations x 3 constant water heads). In order to distinguish the tests, a title name conventions for each test has been given. The title of an experiment included the geofoam block assemblage, constant water head level at the reservoir, and the date (ddmmyear), respectively. For example experiment title “15cmEmbankment38cmHead 28112013” represents the test of 15cm high hybrid lightweight fill assemblage under 38 cm-H_2O constant water head on 28.11.2013.

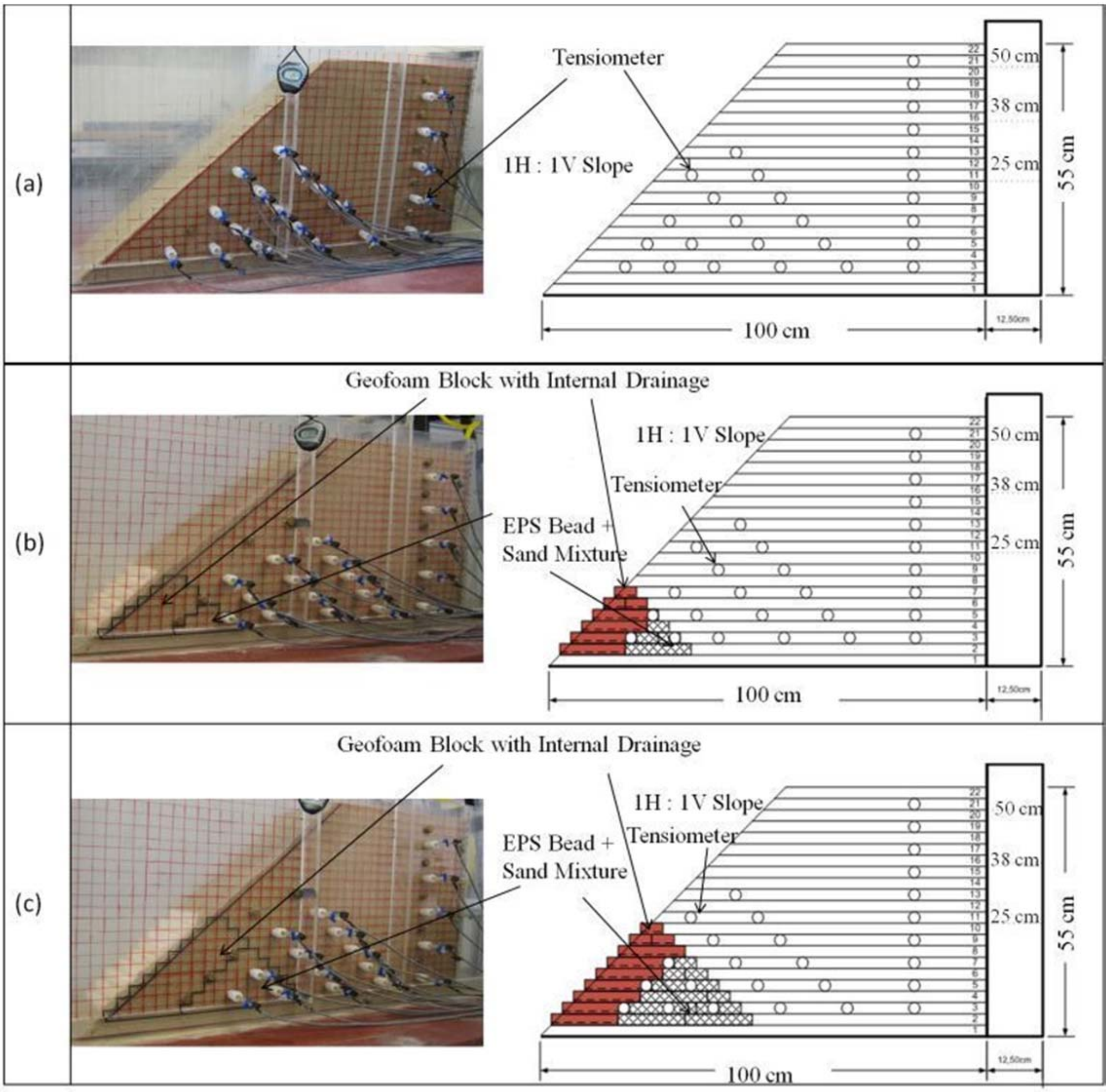

Figure 3. Physical slope experiments (a) Non-remediated slope (“Matrix” configuration), (b) “15cm Embankment” configuration, and (c) “22.5 cm Embankment” configuration

3 RESULTS AND DISCUSSIONS

Regardless of the magnitude of the applied constant hydraulic head, the final physical condition of the non-remediated Matrix sand slope reflected the detrimental effect of seepage on slope stability (Figure 4a). A shallow seated failure surface entering from the slope face and exiting at the toe was obtained under 25 cm-H_2O hydraulic head. Under both 38 cm- and 50 cm-H_2O constant hydraulic head conditions, a deep seated failure surface entering from crest and exiting at the toe was observed (Figure 4a). These failure surfaces were similar to that of the tests conducted by Akay et al. (2013) under the same physical boundary conditions. In addition, previous numerical modeling studies indicated unstable condition for these failure surfaces with factor of safety against global failure is well below 1.0 (Akay et al., 2013; 2014b). All of the tests were terminated when the steady state conditions were well established (Figure 5).

The physical conditions formed at the end of experiments of the “15cmEmbankment” hybrid lightweight fill assemblage are given in Figure 4b and the pore-water pressure head measurements were shown in Figure 5b. In addition, the physical conditions formed at the end of experiments of the “22.5cmEmbankment” hybrid lightweight fill assemblage are given in Figure 4c and the pore-water pressure head measurements were shown in Figure 5c. Regardless of the height of the hybrid lightweight fill assemblage, the failure surfaces obtained at the end of the tests were similar to that of non-remediated Matrix configuration. Contrary to embankment type configuration using conventional geofoam blocks (Özer et al., 2014) and geofoam blocks with internal drainage channels (Akay, 2016), the proposed hybrid lightweight fill assemblage were ineffective to prevent seepage induced failures.

Pore-water pressures within the slopes were similar (Figure 5). Contrary to the tests conducted using embankment type assemblage using geofoam block with internal drainage channels (Akay, 2016), the drainage channels in the hybrid lightweight fill assemblage were not active.

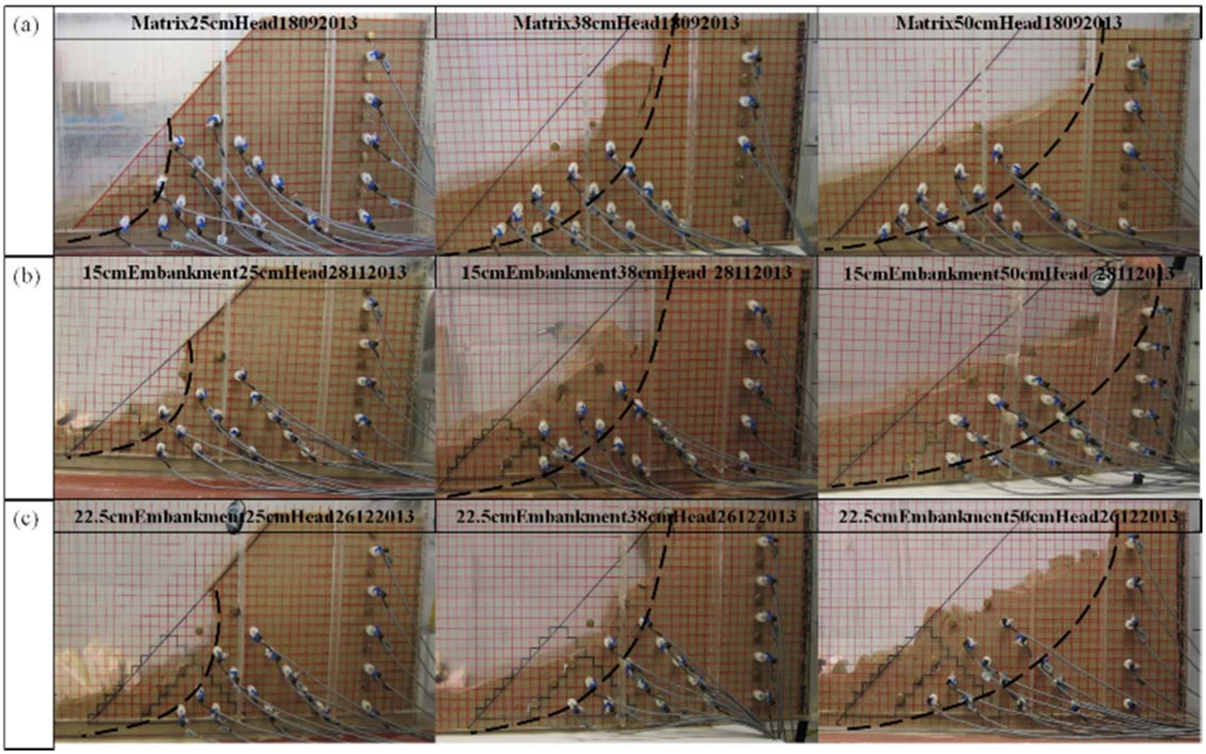

Figure 4. Physical condition of the slope during experiments at the end of the tests for configurations: (a) Matrix, (b) 15cmEmbankment, and (c) 22.5cmEmbankment.

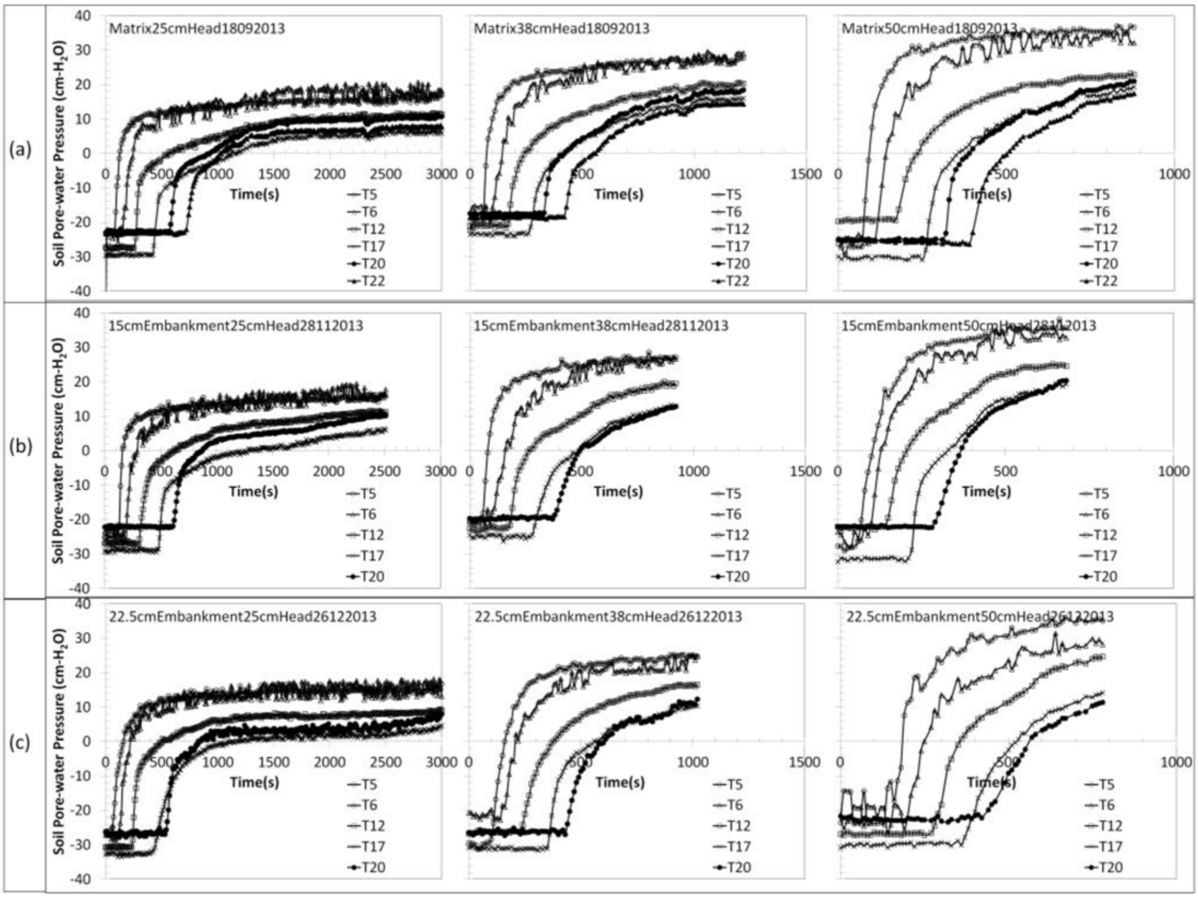

Figure 5. Pore-water pressure head measurements obtained from tensiometers (refer to Figure 1 for their locations) during laboratory lysimeter experiments (a) Matrix, (b) 15cmEmbankment, and (c) 22.5cmEmbankment.

4 CONCLUSIONS

This study investigated the impact of seepage on stability of a steep sandy slope remediated by hybrid lightweight fill comprised of geofoam blocks with an internal drainage system and EPS bead – sand mixtures. Even though EPS beads inclusions reduced the dry unit weight of the sand, it decreased the strength which made the lightweight fill system vulnerable against seepage induced failure. EPS beads addition increased the hydraulic conductivity; however, the proposed hybrid fill system was ineffective to dissipate the excess pore-water pressures. It was evident that the seepage conditions within the back-slope governed the global stability of the hybrid lightweight slope system. More elaborate EPS bead - sand mixtures with other subsurface drainage approaches could be incorporated in conjunction with the internal drainage system introduced in this study.

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