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Friction in reinforced earth utilizing fine grained backfills

Le frottement dans la terre armée réalisée avec des sols fins

On présente les résultats d'essais de laboratoire sur la valeur du frottement existant entre les armatures nervurées (du type couramment employé dans la réalisation des ouvrages en terre armée) et les sols fins. On donne également les résutats d'essais de fluage réalisés afin de déterminer l'influence de ce paramètre dans le choix du matériau de remblai pour terre armée. Tous ces essais ont été effectués dans une grande boite de chargement (90 x 90 x 45 cm) et ont comporté des essais d'arrachement d'armatures et des essais de fluage pour quatre sols cohérents à grains fins et un sol sans cohésion à granulométrie uniforme. Les résultats indiquent que le frottement sol-armature dans les sols fins est très inférieur à celui obtenu avec les sols grenus et que le fluage n'est pas un paramètre important dans le choix du matériau de remblai pour la terre armée.

Introduction

Reinforced Earth is a composite material of construction in which earth and linear tensile reinforcement are associated in a cohesive mass capable of withstanding both external and internal loads.

The key element in Reinforced Earth is the friction between the earth and the reinforcements. Through this friction, the earth transmits to the reinforcements the stresses which develop in the mass. The reinforcements are thereby placed in tension and the composite material gains an pseudocohesional strength which is directly proportional to the tensile strength of the reinforcements and acts in the direction of their placement. Traditionally, the earth component of the system has been restricted to cohesionless soils, characterized by purely frictional strength. Previous investigators (1) (2) (3) have studied and reported the complex phenomenon of soil-tie friction and the effects of various variables, such as density, width of reinforcements, overburden pressures, variation with length, etc., always using a cohesionless soil as their vehicle of study. The exception was an early study conducted by Schlosser (1) at the Laboratoire Central des Ponts et Chaussees (LCPC) designed to determine the effects of the fine fraction the angle of friction in a rapid shear test and its relationship to the coefficient of friction between the soil and smooth reinforcements. The results of these studies generally indicated that an important parameter is the relative volume of the fine grained portion to the granular portion, and that the friction developed decreases with increasing fine-grained portion. Further, these studies indicated that the critical grain size which separates purely frictional behavior is the 15μ size.

Based on these pioneering studies, Reinforced Earth backfills to date have been limited to cohesionless soils having no more than 15% by weight finer than the #200 mesh sieve (79μ), and recently, to no more than 15% by weight finer than the 15μ size.

Since significant economic advantages could be obtained by the utilization of fine grained backfills on projects in areas where cohesionless soils are scarce, a laboratory study was initiated to determine soil-tie friction and creep parameters of ribbed reinforcements in a variety of fine grained soils. This study concentrated on determining initially, the apparent coefficient of friction f* as a function of overburden stress on soils compacted in the range of 95% of their maximum density as determined by ASTM D-698 and near their optimum water contents. The effects of different degrees of compaction, moisture contents, saturation and other well known variables were not part of this study. Secondly, the magnitude of creep under loads less than peak representing a service load condition were measured to qualitatively assess whether this parameter not previously studied would impact on potential performance of Reinforced Earth structures constructed with fine grained soils.

Test Equipment

The methodology of testing consisted of performing pullout and creep tests in a large direct shear box (3 x 3 x 1.5 feet) as shown on Fig. 1. The lower half of the box is stationary and is attached to the reaction frame. The upper half is separated from the rest of the apparatus by one-inch diameter ball bearings. The normal pressure is applied by nine calibrated springs restrained between two rigid plates. Slots for the reinforcing strips were cut in both the upper and lower halves of the box at the approximate mid height of the sample.

The reinforcing strips were stressed by jacking against a reaction frame placed across the sides of the box at a deformation rate of approximately 0.10 inches per minute. The shear load was measured by a load cell positioned between the jack and the reaction frame, and normal pressures were checked at various positions in the box by pneumatic pressure cells.

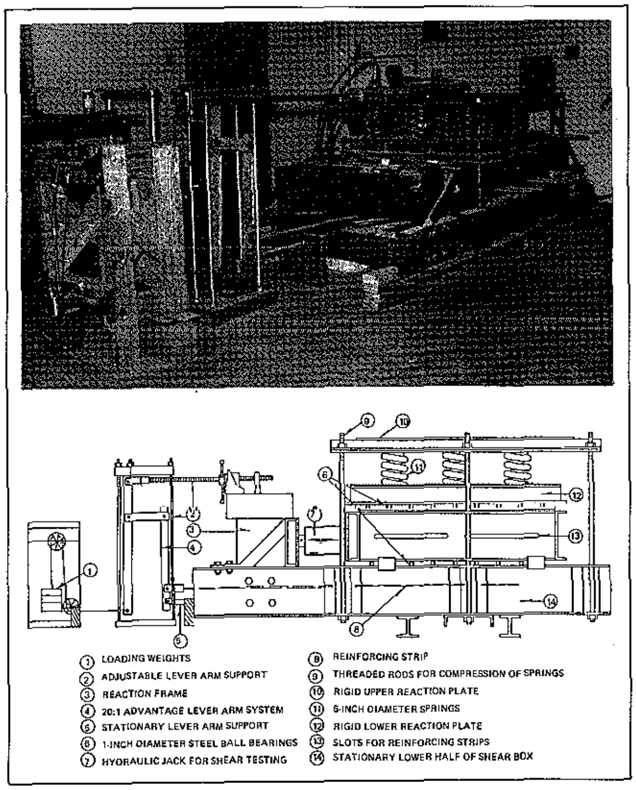

Fig 1: Large Direct Shear Box with Creep Test Setup

Ribbed reinforcing strips as presently designed and used by the Reinforced Earth Companies were used exclusively for this test program. Their general geometric configuration is shown in Fig. 2.

Sample Preparation

Samples were compacted at or near their optimum moisture contents, using a hand-held mechanical tamper similar to that used on construction sites to compact soils around retaining walls and footings where only limited access is provided. The top of each compacted 8-inch layer was scarified prior to placement of the next layer. The reinforcing strips were placed in two layers of four strips with care being taken to place the strips in a level horizontal plane. Foam rubber was placed around the portion of each strip adjacent to the shear box to reduce the potential to develop arching of the soil against the box during testing. The moisture content of each layer was checked prior to compaction to provide a uniform compaction of the sample.

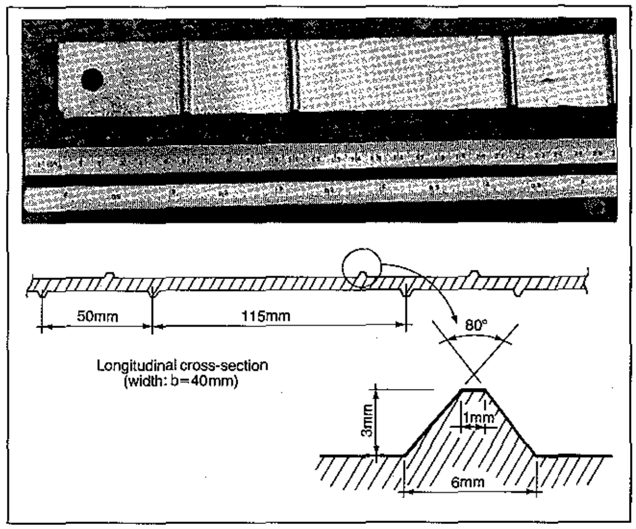

Fig 2: Ribbed Strips

A plastic liner was placed in the box prior to sample placement to reduce friction along the sides of the box and prevent moisture loss of the sample during testing.

Test Materials

Testing was conducted on five types of soils, two residual silts from the Piedmont geologic province of the United States, a silt from Orly, France, an aeolian sand from Wyoming, and a naturally occurring Kaolin clay. A summary of their engineering properties is summarized in Table 1 and Figs. 3 and 4.

All of the materials tested were either non-plastic or of low plasticity and exhibiting relatively large values of undrained shear strength, as tested in accordance with AASHTO 236.

SOIL NO.		1	2	3	4	5
SAMPLE DESCRIPTION		VIRGINIA RESIDUAL SILT	GEORGIA RESIDUAL SILT	FRENCH SILT	KAOLIN CLAY	WYOMING AEOLIAN SAND
Specific Gravity		2.68	2.81	2.73	2.66	2.63
Avg. Test Moisture Content (%)		21.9	28.4	22.9	22.7	11.1
Liquid Limit		44	63	35	36	23.0
Plastic Limit		35	NP	16	27	NP
AVERAGE TEST DENSITY (PCF)	DRY	98.3	86.8	103.2	94.1	101.2
	WET	119.9	111.4	126.9	115.4	114.2
DENSITY (% COMPACTION)		93.5	100.0	98.2	98.4	95.7
SHEAR STRENGTH	Cohesion (psf)	0	500	0	0	200
	Friction (deg.)	35	34	31	28.5	35

Table 1: Engineering Properties of Tested Soils

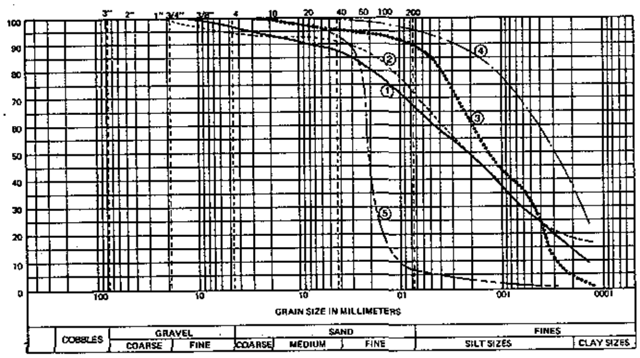

Fig 3: Grain Size Characteristics of Tested Soils

Frictional Resistance of Strips

The stress ratio coefficients, more commonly referred to as f*, apparent coefficient of friction, in the literature, of the materials tested was calculated by dividing the average peak shear stress along the strip by the average normal pressure on the strip. Occasionally, the average peak shear stress applied to the strip was not attained until after significantly large deflections had occurred. In general, however, the strip load versus deflection curves were nearly asymptotic to the ultimate strip load at 0.7 inches deflection. A deflection of 0.7 inches corresponds to approximately two percent strain along the shear surface which may be considered a reasonable level of deformation in a Reinforced Earth structure. Therefore, the stress ratio coefficients reported represent the maximum stress ratio corresponding to peak shear load or the load at 0.7 inches deflection, whichever occurred first.

The obtained load deflection curves are generally typical of results obtained in this apparatus for cohesionless soils (2) or for pullout tests in embankments previously reported by others (2) (3), with deflections in the elastic range to within 65 to 85 percent of the ultimate strip load for the soils tested.

The plastic range is somewhat dependent on confining pressure and it reaches 75 to 85 of ultimate load at the higher confining pressure or overburden loads. Typical developed stress strain data is shown in Fig. 5, where the circled numbers represent different strips pulled within the apparatus at the same confining pressure.

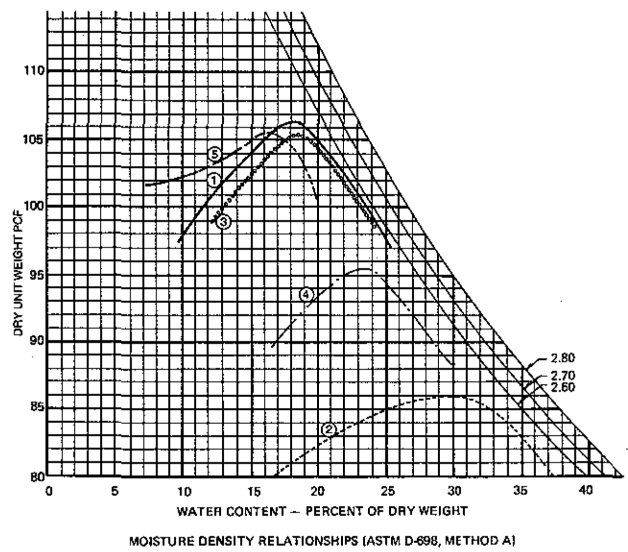

Fig 4: Compaction Characteristics of Tested Soils

As in all previous investigations of strip pullout capacity, f* coefficients decreased with increased normal pressure, becoming generally asymtotic to a constant value in the range of 2 to 3 KSF. However, this constant value is in all cases less than the drained angle of internal friction of the soil as measured by a direct shear test, a finding quite contrary to the case of well graded cohesionless soils.

Interestingly, the only cohesionless soil tested in this program, to provide a benchmark, the aeolian sand, also yielded at high normal stress a f* less than the drained angle of friction even though the material was well compacted at or near its optimum

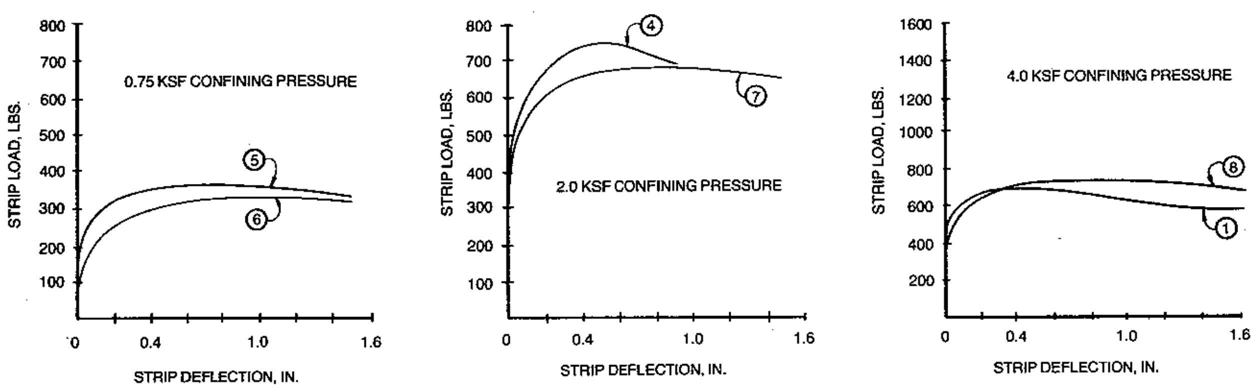

Fig 5: Stress Strain Relationship, Soil 3, Orly Silt

moisture content. This finding generally corroborates an earlier study in which a fine Ottawa sand with a similar uniformity coefficient of approximately 2 also yielded f* values at or just below the drained friction angle.

In fact, it appears that f* coefficients equal to the drained angle of internal friction may be justified only to a range of 0-1.5 KSF decreasing to approximately one-half of ϕ at the highest normal stress levels. In addition, the effects of molding or construction moisture content appears to be a significant factor in the developed friction. The lowest overall f* values was developed in the Orly silt, the only material compacted wet of optimum.

A summary of these results is graphically shown on Fig. 6, where the right hand ordinate of the scale is the drained angle of internal friction as obtained in a direct shear test.

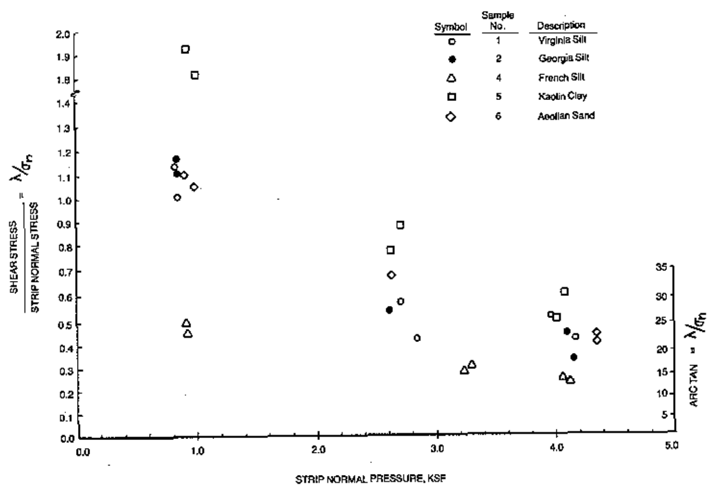

Fig 6: Summary of Results

Creep Testing

During the course of the pullout tests, one strip at each normal load was subjected to creep testing by modification of the pullout apparatus to exert constant level of stress for durations of up to 175 hours at which time creep had been reduced to a uniform and constant low level as a function of time.

The level of stress maintained for creep testing was chosen at approximately 50 to 60 percent of the ultimate strip load which should in general approximate service load conditions. Results for this type of testing never performed before indicate little or no tendency to creep at the load level tested for any of the typical soils used in this program. In fact, the largest creep rate measured (0.01 inches per log cycle of time) exhibited by the Orly silt compacted wet of optimum would translate roughly to only 0.06 inches of movement in 50 years. The control uniform cohesionless fine sand, Wyoming aeolian sand, exhibited approximately the same order of magnitude of creep while the natural Kaolin clay exhibited no creep at all.

Typical results are shown on Fig. 7.

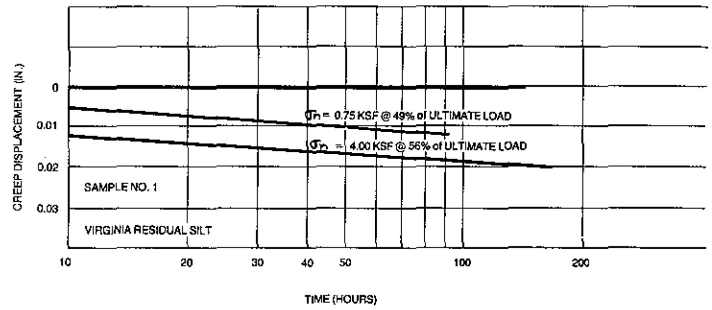

Fig 7: Typical Creep Test Results

Conclusions

1. This program observed the typical trend of decreasing f* with increased normal pressures for fine grained soils, as in the case of cohesionless soils.

2. The peak stress ratio or f* for ribbed reinforcing strips placed in fine grained soils is considerably less than for granular soils where a limiting and constant value at normal pressures greater than overburden heights of 20 feet (6m) can be generally approximated by the drained angle of internal friction.

3. It appears from these results that a limiting value of f* equal to 1/2 to 2/3 of the drained angle of friction may be used for all normal pressure greater than 1.0 to 1.5 KSF. For lower overburden pressures, it appears that a maximum f* value equal to the drained angle of friction may be warranted. It appears further that moulding water content plays a significant role in the development of f* and that for best results, fine grained soils should be compacted dry of optimum.

4. Significant additional work is necessary prior to the unrestricted use of fine grained soils in Reinforced Earth fill. The effects of saturation compaction water content, and other parameters must be studied in greater detail.

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