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Experimental study on geosynthetic reinforcement

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ABSTRACT: Systematic triaxial compression tests are made for the sand reinforced by geosynthetics. Comprehensive investigations into the interaction characteristics are also made between sand/lime fly ash and geosynthetics by direct shear tests and pull out tests. These national geosynthetics include needle-punched non-woven geotextiles (G_1), PE uniaxial oriented geogrids (G_2), PP biaxial oriented geogrids (G_3), PET fiber warp knitting geogrids (G_4), PE geonets (G_5), and glass fiber geogrids (G_6). On the basis of the experimental results, some useful conclusions are obtained, which help choosing geosynthetic type and comprehending the geosynthetic reinforcement mechanism.

1 INTRODUCTION

Though the use of reinforcement in soil structures dated back several thousand years, it was not until 1965 that Henri Vidal, a French architect, pioneered modern earth reinforcement techniques. Now, geosynthetic reinforcement mechanism is not very clear; design method is not maturated; and theoretical research lags behind engineering practice, therefore, it is necessary to make further researches on geosynthetic reinforcement.

Triaxial compression tests were first used by Schlosser and Long (1974) to investigate the effect of aluminium foil on the strength and deformation properties of sand. Afterwards, the triaxial compression tests were used by many researchers (Broms 1992, McGown 1997, Gray 1986, Moroto 1992, Atmatzidis 1984) to investigate the effect of geosynthetics on the strength and deformation properties of sand and gravel. The chosen geosynthetics are geotextiles and PP/PE oriented geogrids.

The interaction property between geosynthetics and fill material determines the internal stability of geosynthetic reinforcement structures; therefore it is the key technical index. Direct shear tests and pull out tests were used by many researchers (Holtz 1997, Myles 1982, Miyamori 1986, Ochiai 1992, Bergado 1992, Cancelli 1992, Koutsourais 1998) to investigate the interaction property. The chosen fill material are mainly sand and clay; the chosen geosynthetics are woven/non-woven geotextiles and PE/PP oriented geogrids. Hausmann & Clarke (1994) made preliminary researches on the interaction property between fly ash and oriented geogrids.

In this paper, consideration will be concentrated on the comparison of the reinforcement effect of different kinds of geosynthetics on sand/lime fly ash through triaxial compression tests, direct shear tests and pull out tests. On the basis of the experimental results, some conclusions are obtained, which help choosing geosynthetic type and comprehending the geosynthetic reinforcement mechanism.

2 TEST PROGRAM

2.1 *Test Equipment*

(1) Triaxial compression test: Materials Testing Machines (MTS). Specimen size is φ152.8×200mm (Diameter × Height). Maximum axial load is 98kN.
(2) Direct shear test: Shear box size is 150 × 150mm.
(3) Pull out test: Test box size is 500 × 240 × 300mm (Length × Width × Height).

2.2 *Testing Materials*

The materials used in the test program include six kinds of geosynthetics and two kinds of fill material. The geosynthetics are needle-punched non-woven geotextiles (G_1), PE uniaxial oriented geogrids (G_2), PP biaxial oriented geogrids (G_3), PET fiber warp knitting geogrids (G_4), PE geonets (G_5), and glass fiber geogrids (G_6), their technical indexes are summarized in Table 1. The fill materials are sand and lime fly ash. Their technical indexes are summarized in Table 2 and Table 3, respectively.

Table 1. Technical indexes of the geosynthetics

Geosynthetics		G_1	G_2	G_3	G_4	G_5	G_6
		PP	PE	PP	PET	PE	Glass fiber
Mass per unit area (g/m^2)		398	293	415	560	673	643
Tensile strength (kN/m)	Longitudinal	13.7	37.5	19.1	55.2	9.4	40.3
	Transverse	10.1		20.0	52.6	5.1	62.4
Elongation at failure (%)	Longitudinal	78.4	8.9	33.2	23.6	29.6	1.9
	Transverse	106.7		15.2	27.3	44.1	2.7
Dimension of opening (mm)				40×50	25×25	20	25×25

NOTES: G_1-needle-punched non-woven geotextiles; G_2-PE uniaxial oriented geogrids; G_3-PP biaxial oriented geogrids; G_4-PET fiber warp knitting geogrids; G_5-PE geonets; G_6-glass fiber geogrids.

Table 2. Soil parameters of the sand

Mechanical composition (mm)				Constrained diameter (mm)						Classification
2~0.50	0.50~0.25	0.25~0.10	< 0.10	d_{60}	d_{50}	d_{30}	D_{10}	C_u	C_c	
62%	25%	9%	4%	0.77	0.62	0.43	0.20	3.8	1.20	Coarse sand

Table 3. Technical indexes of the lime fly ash

Lime			Fly ash			Lime fly ash					
CaO	MgO	Loss-on-ignition	Fe_2O_3	Al_2O_3	SiO_2	Lime: fly ash (in dry weight)	Optimum water content, W_{op}	Maximum dry density, ρ_{dmax}, (g/cm^3)	Degree of compaction	Specimen dry density, ρ_d (g/cm^3)	pH
33%	17%	3.95%	8%	29%	49%	1:9	24.0%	1.27	90%	1.14	8.5

2.3 *Test Procedure*

(1) Triaxial compression test: Load speed is 1mm/min (1mm is 0.5 percent of specimen height). The confining pressure is 50, 100,150, 200kPa respectively. The geosynthetics are inserted horizontally in the middle of the sand sample.
(2) Direct shear test: The test is performed through moving the lower box at a constant speed of 0.5mm/min. The vertical pressure is 25, 50, 75, 100kPa respectively.
(3) Pull out test: The geosynthetics are pulled out at a constant speed of 1.0mm/min. The vertical pressure is 20 ~ 100kPa for fill material of sand and 20 ~ 50kPa for fill material of lime fly ash.

3 TRIAXIAL COMPRESSION TEST

3.1 *Effect of geosynthetics on the shear strength of sand*

It is discovered that (see Table 4): (1) Increased shear strength of geosynthetic reinforced sand is characterized by a substantial pseudo-cohesion; (2) At the failure of the reinforced sand, the computed tensile strength (α_F) of G_1 is 10.4kN/m corresponding to about 90% of elongation of strip tensile tests; the computed tensile strength (α_F) of G_3 is 4.5kN/m corresponding to about 2% of elongation of strip tensile tests; the computed tensile strength (α_F) of G_5 is 4.0kN/m (peak) and 4.9kN/m (residual) corresponding to about 30% of elongation of strip tensile tests, therefore the confining effect of fill material to act on different kinds of geosynthetics varies largely, which must be considered in geosynthetic reinforcement structures; (3) As to G_4 and G_5, the connection strength of strands at joint being weaker, the failure of the geosynthetics reinforced sand is controlled by the strength, hence the tensile strength of geosynthetics at the failure of the reinforced sand is much smaller than their tensile strength of strip tensile tests at failure, which must be improved recently.

3.2 *Effect of geosynthetics on the stress and strain of sand*

It is furthermore discovered that (see Figure1): (1) Geotextiles (G_1): the deviator stress and axial strain of the reinforced sand at the failure are increased and with the increase of axial strain, the deviator stress is increased gradually, that is, after the strain reaches a certain level, the reinforcing effect begins to show remarkably, hence they are likely to be suited for projects allowing high displacement; (2) PET warp knitting geogrids (G_4) and uniaxial/biaxial oriented geogrids (G_2/G_3): the deviator stress and axial strain of the reinforced sand at the peak stress are greatly increased and with the increase of axial strain after the peak stress, deviator stress tends to stability, therefore they are likely to be suited for projects allowing for medium displacement; (3) Glass fiber geogrids (G_6): the deviator stress of the reinforced sand at the peak stress is increased remarkable, but the axial strain at the peak stress is not increased and the deviator stress is decreased dramatically after the peak stress, so they are likely to be suited for projects allowing for low displacement; and (4) Geonets (G_5): the deviator stress of the reinforced sand at the peak stress is not greatly increased and the deviator stress is decreased dramatically after the peak stress, we think that they are likely to be suited for secondary projects.

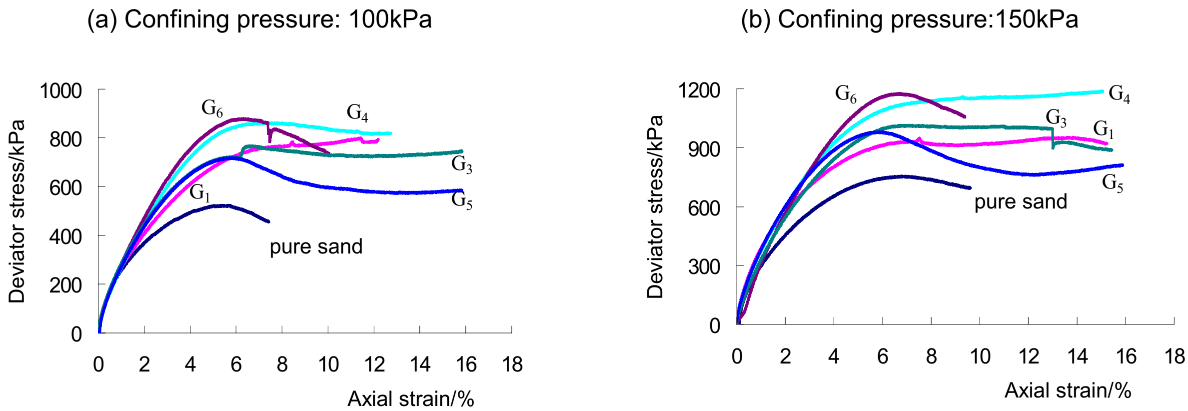

Figure 1. Axial strain – deviator stress curves

Table 4. Comparison of reinforcement effect of geosynthetics on sand

	Sand	G_1	G_3	G_4	G_5 (peak)	G_5 (residual)	G_6
Friction angle, φ (°)	45.6	43.9	48.4	50.3	47.2	44.5	50.8
Cohesion, c_R (kPa)	0	61.0	29.3	35.7	31.3	23.9	29.8
α_F (kN/m)	-	10.4	4.5	5.2	4.9	4.0	4.2

NOTES: (1) G_1-needle-punched non-woven geotextiles; G_3-PP biaxial oriented geogrids; G_4-PET fiber warp knitting geogrids; G_5-PE geonets; G_6-glass fiber geogrids. (2) α_F-force per unit width of reinforcement, $\alpha_F=2\Delta H c_R/(K_p)^{1/2}$; ΔH-spacing between reinforcements; K_p-coefficient of passive earth pressure (Gray 1986).

4 DIRECT SHEAR TEST

The fill materials are sand and lime fly ash, respectively. The geosynthetics include needle-punched non-woven geotextiles (G_1), PP biaxial oriented geogrids (G_3), PET fiber warp knitting geogrids (G_4), and PE geonets (G_5). The experimental results are summarized in Table 5.

It is discovered that (see Table 5): (1) The relatively high friction angle of lime fly ash make it attractive as a fill material; (2) C_{ds} is almost the same for various geosynthetics and fill materials; (3) The variation of C_{ds} is 0.77 ~ 1.00 and C_{ds} is smaller than 1.00, so the in-plane stability along geosynthetics must be checked and C_{ds}=0.70~0.80 is proposed in design.

$$C_{ds} = \frac{\tan\varphi_{sg}}{\tan\varphi_{ss}} \qquad (1)$$

Where C_{ds}=direct shear coefficient; φ_{sg}=friction angle at the soil-geosynthetic interface; and φ_{ss}=friction angle at a soil-soil interface.

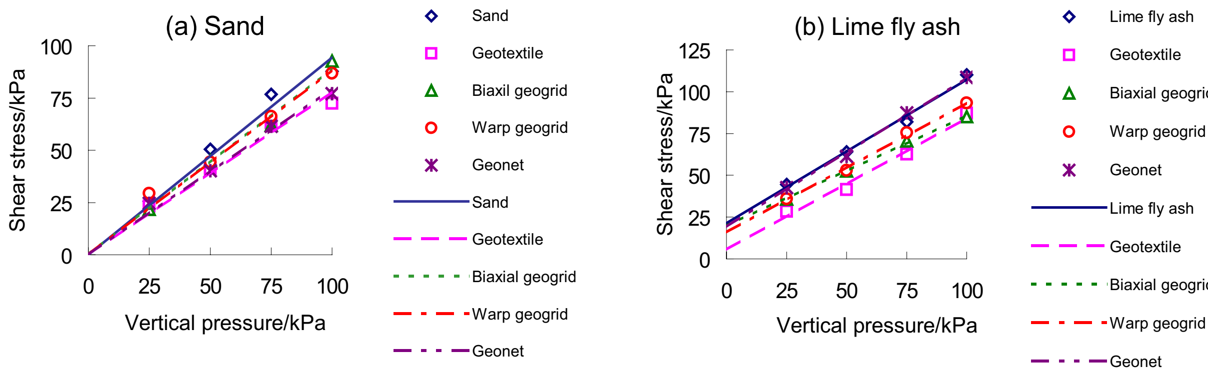

Figure 2. Shear stress – vertical pressure curves (direct shear test)

Table 5. Experimental results of direct shear tests

Fill material		Sand					Lime fly ash				
Geosynthetics		No Geosynthetics	G_1	G_3	G_4	G_5	No Geosynthetics	G_1	G_3	G_4	G_5
Friction angle, φ	(°)	43.3	38.0	41.7	41.5	38.5	40.6	38.3	33.5	37.8	40.0
Cohesion, c	(kPa)	0	0	0	0	0	21.5	5.5	19.6	15.9	19.1
C_{ds}	(-)	-	0.83	0.94	0.94	0.84	-	0.92	0.77	0.90	1.00

NOTES: (1) G_1-needle-punched non-woven geotextiles; G_3-PP biaxial oriented geogrids; G_4-PET fiber warp knitting geogrids; G_5-PE geonets.

5 PULL OUT TEST

The fill materials are sand and lime fly ash, respectively. The geosynthetics include needle-punched non-woven geotextiles (G_1), PE uniaxial oriented geogrids (G_2), PP biaxial oriented geogrids (G_3), PET fiber warp knitting geogrids (G_4), and PE geonets (G_5). The experimental results are summarized in Table 6.

It is discovered that (see Table 6): (1) C_{po} is 0.18 ~ 0.45 for fill material of sand and 0.35 ~ 0.85 for fill material of lime fly ash; (2) Cohesion is only 0 ~ 10.65kPa and unstable so that it may be neglected in determination of the anchor length of geosynthetics; (3) Geosynthetics are arranged in C_{po} from high to low: PET warp knitting geogrids, uniaxial/biaxial oriented geogrids, geonets and geotextiles; (4) The variation of C_{po} for various geosynthetics and fill materials is larger, therefore C_{po} must be determined through pull out tests for concrete geosynthetics and fill materials.

$$C_{po} = \frac{\tan\varphi_{sg}}{\tan\varphi_{ss}} \qquad (2)$$

Where C_{po}=pull out coefficient; φ_{sg}=friction angle at the soil-geosynthetic interface; and φ_{ss}=friction angle at a soil-soil interface.

Table 6. Experimental results of pull out tests

Fill material		Sand						Lime fly ash					
Geosynthetics		No Geosyn-thetics	G_1	G_2	G_3	G_4	G_5	No Geosyn-thetics	G_1	G_2	G_3	G_4	G_5
Friction angle, φ	(°)	43.3	9.6	14.3	19.3	22.9	9.7	40.6	16.7	24.9	25.5	36.1	22.4
Cohesion, c	(kPa)	0	0	2.20	1.99	10.65	7.16	21.5	3.25	7.02	4.36	0	0.96
C_{po}	(-)	-	0.18	0.27	0.37	0.45	0.18	-	0.35	0.54	0.56	0.85	0.48

NOTES: (1) G_1-needle-punched non-woven geotextiles; G_2- PE uniaxial oriented geogrids; G_3-PP biaxial oriented geogrids; G_4-polyester fiber warp knitting geogrids; G_5-PE geonets.

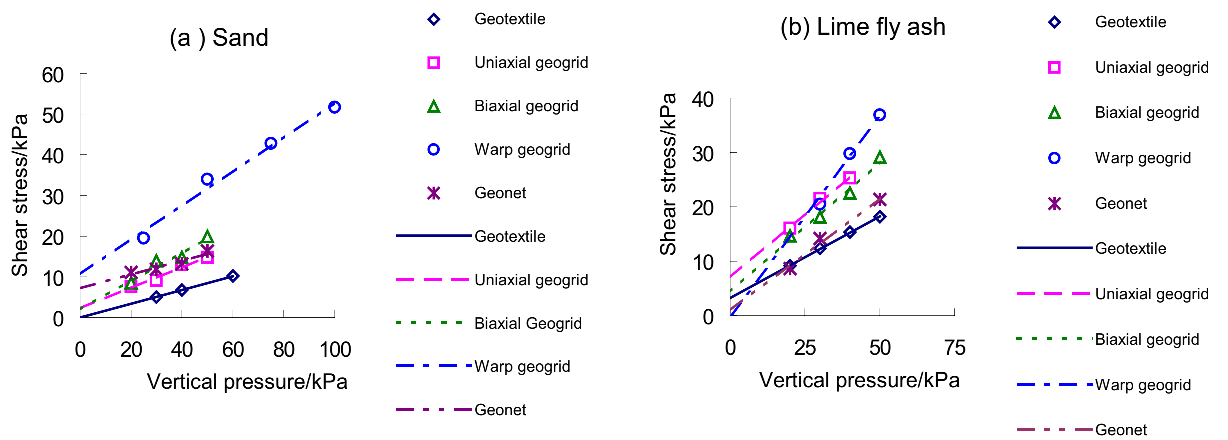

Figure 3. Shear stress – vertical pressure curves (pull out test)

6 CONCLUSIONS

The main conclusions are as follows:

- Tests indicate pseudo-cohesion for geosynthetic reinforced sand satisfying Mohr-Coulomb's equation.
- Geotextiles are likely to be suited for projects allowing high displacement, polyester warp knitting geogrids and uniaxial/biaxial oriented geogrids for projects allowing medium displacement, glass fiber geogrids for projects allowing low displacement and geonets for secondary projects.
- The confining effect of fill material to act on geosynthetics must be considered.
- Lime fly ash is light in unit weight, high in shear strength and its C_{po}, therefore, it is an ideal fill material.
- The in–plane stability along geosynthetics must be checked. C_{ds}=0.70 ~ 0.80 is proposed in design for national geosynthetics.
- Geosynthetics are arranged in C_{po} from high to low: PET warp knitting geogrids, uniaxial/biaxial oriented geogrids, geonets and geotextiles. C_{po} must be determined through pull out tests for concrete geosynthetics and fill materials.

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