Behaviour fibre reinforced silty sand during compression at critical state

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ABSTRACT: Oil palm empty fruit bunch (OPEFB) fibre used to study the stress path and critical state mechanics of fibre reinforced silty sand. Series of triaxial compression tests at confining pressures of 50 kPa, 100 kPa and 250 kPa were carried out on fibre reinforced silty sand specimens prepared with different fibre length of 15 mm, 30 mm and 45 mm. Effect of fibre content estimated by two different percentage of fibres which are 0.25% and 0.5% by weight of fibre and soil. Randomly distributed discrete fibre reinforced silty sand tested in both consolidate drained (CD) and consolidate undrained (CU) triaxial test condition. Triaxial test result used to develop the stress path relationship and volumetric changes due to static compression loads. It was found that the fibre reinforcement can restrain the volume dilation of soil which this dilation, fundamentally leads to increase in pore water pressure in undrained conditions and increase the deviator stress on drain condition. Angle of critical state line in p':q' plane increased with increasing the fibre length and fibre content. The effect of coated OPEFB fibres with acrylic butadiene styrene (ABS) thermoplastic on improvement of silty sand showed the higher increase than uncoated fibre. The results of these laboratory tests were shown the increase in critical state line angle. The results showed the increase in shear strength and relating shear strength to normal stress and specific volume.

1 INTRODUCTION

Soil reinforcement is a useful and reliable method for improve strength and stability of week soils. Randomly distributed fibre reinforced soils have recently attracted increasing attention in geotechnical construction. The fibres can provide isotropic increase in the strength of the soil composite without introducing continuous planes of weakness. The discrete fibres are simply added and mixed randomly with soil, much like cement, lime, or other additives (Yetimoglu and Salbas, 2003)

Some studies conducted on soils reinforced by plant roots were shown increase the shear strength of the soil due to fibre inclusions and, consequently, the stability of natural slopes (Prandini *et al.*, 1977, Wu *et al.*, 1979 and Fan and Su, 2008). With development of using polymeric fibre since the late 1980s, experimental tests have been conducted to study the effect of synthetic fibre-reinforcement on shear strength (Gray and Ohashi, 1983, Gray and Alrefeai, 1986 and Maher and Gray, 1990). Natural resources due to cost-effective and environment-friendly could be an alternative material for soil structure improvement (Prabakar and Sridhar, 2002).

Oil palm empty fruit bunch (OPEFB) fibre was used in this study due to its reliable strength and bulk availability in Malaysia. Oil palm belongs to the species *Elaeis* guineensis under the family *Palmacea*, and originated in the tropical forests West Africa. Major industrial in cultivation for Southeast Asian region such as Malaysia and Indonesia is the second largest plantation for the country (Sreekala *et al.*, 1997).

The shear strength of the fibre reinforced soil previously studied by under unconfined compression strength (UCS), direct shear tests and triaxial tests. The behaviour of fibre reinforced soil during the loading and critical states can provide practical information. This study was conducted using OPEFB fibres mixed with silty sand to determine the stress-path and critical state in the reinforced specimens.

2 MATERIAL AND METHODS

2.1 *Soil*

The silty sand soil classifies as SM according to the Unified Soil Classification System (USCS) ASTM used in the present experimental tests. Figure 1 shows gradation curve. The soil properties were summarized in Table 1.

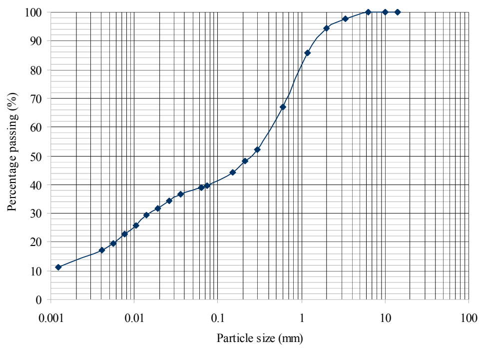


Figure 1. Gradation curve for soil Time

Table 1: Mechanical properties of Soil (Silty sand)

Property	Test Method	Value
Classification (USCS)	ASTM D2487	Silty Sand (SM)
Gs	ASTM D 854	2.575
LL %	ASTM D 4318	45
PL %		32.5
PI %		12.5
γ_{max} (kN/m³)	ASTM D698	16.67
γ_d (kN/m³)		14.50
Dr %	ASTM D4253	75

2.2 *Fibres*

OPEFB fibres used for reinforcing the soil mass are available in oil palm factories produced from Empty fruit bunch from palm-oil mill (Figure 2). The properties of OPEFB fibre were summarized in Table 2.

Table 2: Properties of oil palm empty fruit bunch fibre

OPEFB Fibre Properties	Value
Specific gravity	1.46
Linear density (denier)	1650
Average diameter (mm)	0.40
Elongation at break (%)	15.4
Breaking tensile strength (kPa)	2.83×10^5
Modulus of elasticity (kPa)	5500

2.3 *Coated Fibres*

The ABS thermoplastic used to protect the fibres from biodegradability. Natural OPEFB fibres have been coated with ABS thermoplastic to study the behaviour of fibre reinforced soil with protected fibre and effect of coating on performance of fibre reinforced soil mass.

2.4 *Sample preparation*

Fibre-reinforced silty sand prepared with three different percentages of fibre content of *f* = 0%, 0.25% and 0.50% by weight of dry soil. The tests were repeated at three different lengths *lf* of 15mm, 30mm and 45mm mixed with soil randomly used in the present study to carry out triaxial tests. The soil was initially prepared at the optimum water content and the mixing of soil with fibres was conducted until it reached approximately homogeneous mix of soil and fibres. Fibre silty sand mixed was compacted in three layers, with optimum moisture content (OMC) of 15.29% and a same dry density of 14.50kN/m³.

2.5 *Triaxial Test*

A series of hydrostatically consolidated undrained (CU) and consolidated drained (CD) triaxial shear tests were performed on both reinforced and unreinforced silty sand to evaluate their strength behaviour. All specimens were fully saturated with a minimum measured B value of 0.97. Axial load applied under strain-controlled condition with a strain

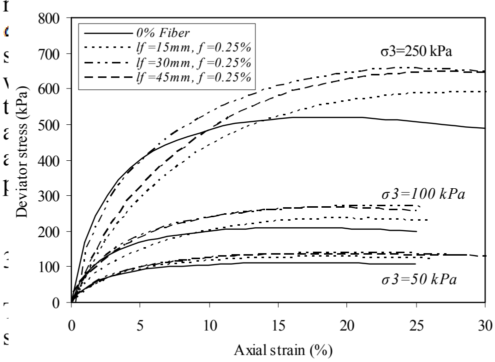
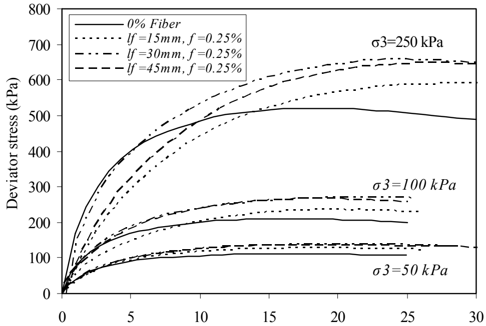


Figure 2 for stress-strain relation. Figure 3 shows the stress path is completely fixed in $p':q'$ space for drained compression test. Sample must follow a line of slope 3 from the initial state p'_0. The failures that found from the triaxial CD test was defined a single straight line, this single and unique line named as the critical state line. The slope of the critical state line increased with increase of the fibre length as the same matter of friction angle due to increase in deviator stress and critical state's failure points.



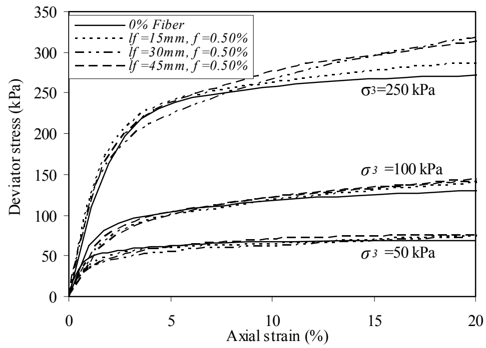


Figure 4 and Figure 5 represent the stress-strain relation and pore water changes in undrained condition. The effective stress pass is illustrated in Figure 6. The positive pore water pressure u has the effect of shifting the effective stress point to the left by distance equal to *u* from the total stress point. This effect was existence due to mix of silt and clay in to sand that increase the cohesion behaviour of the soil. The failure of sample in undrained condition describes the critical state line. Critical state line had the same increase with increasing the fibre length in compare with as drained test condition.

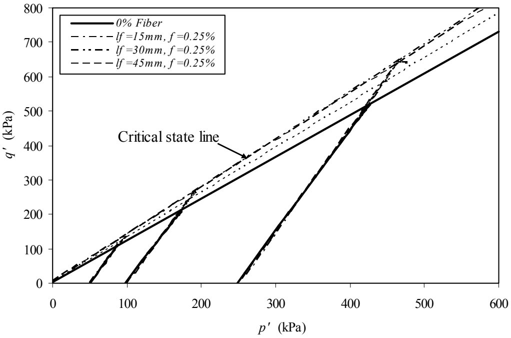


Figure 3: Test paths for drained compression test

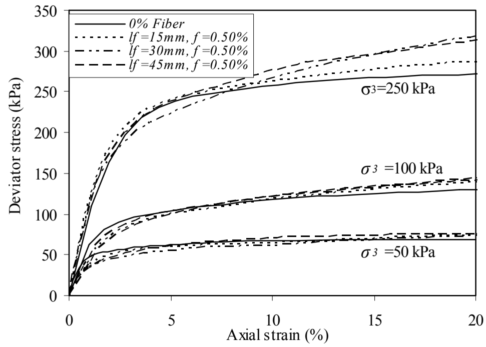


Figure 4: Typical stress-strain curves obtained from triaxial CU test on soil reinforced OPEFB fibres

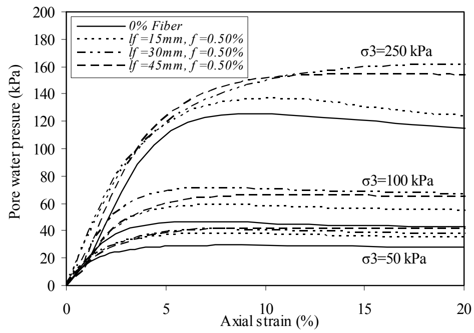


Figure 5: Excess pore water pressure curves obtained from triaxial CU test

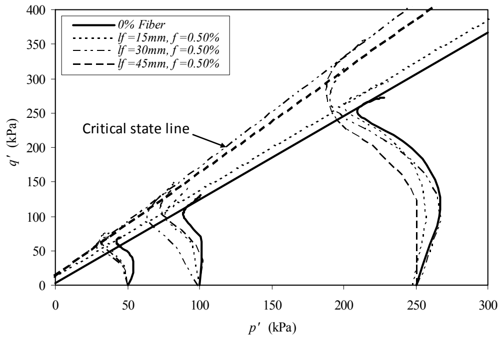


Figure 6: Test paths for undrained compression test

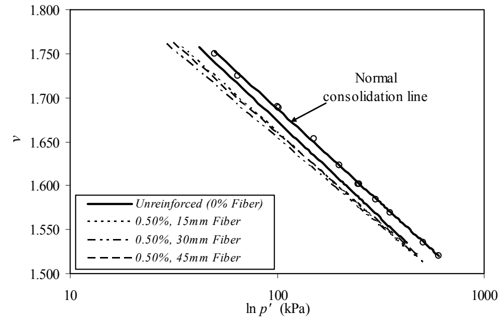


Figure 8: Changes of critical state line in $\nu : \ln p'$ space, for unreinforced silty sand and reinforced with OPEFB fibre

Figure 7 shows the failure state of drained and undrained triaxial compression tests with different fibre length and fibre content of 0.50%. Critical state line was found approximately the same for both drained and undrained test with the good correlation. A significant increase occurred with the raise of fibre length. A line in $\nu : \ln p'$ space defined from the drained and undrained test that is parallel to the normal consolidation line (Figure 8). The critical state line in $\nu : \ln p'$ space was shifted down and left. The specific volumes (ν) decrease substantially as fibre length increase due to decreasing the sample dilatation.

3.1 *Effect of coated fibres on stress path of reinforced soil*

Critical state line was found to have the same trend for silty sand reinforced with coated OPEFB fibres. The slope of critical state line in $p' : q'$ space was defined to increase with increase of fibre length and fibre content of coated fibre more than uncoated fibre (Figure 9). In addition, the specific volumes decrease with increase of the fibre content. Decrease of specific volumes by increasing the fibre length. The magnitude of the specific volume change is not too much but it still can describe the effect of fibre length and fibre content in control of dilatation of the soil sample.

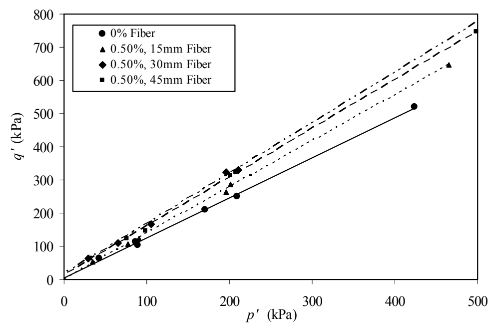


Figure 7: Changes of critical state line in $p' : q'$ space, for unreinforced silty sand and reinforced with OPEFB fibre

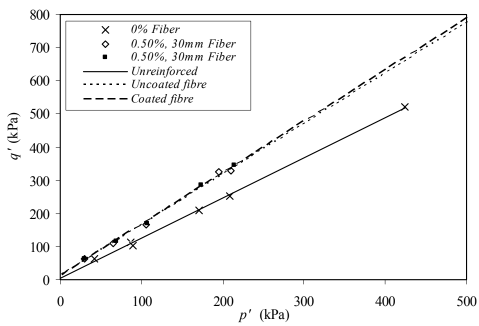


Figure 9: Comparison of critical state line for coated and uncoated fibre reinforced silty sand

The change on critical state line in $p' : q'$ plane was described by Atkinson and Bransby (1978):

$$q' = M.p'$$

where M is its gradient. The critical state line onto the $\nu : p'$ plane is curved. Other than if the critical state line redrawn on the graph with $\nu : \ln p'$, the critical state line fall close to straight line. The same as normally consolidate line the critical state was described by:

$$\nu = \Gamma - \lambda \ln p'$$

where Γ is the value of $p' = 1.0\ kN/m^2$ corresponding to on critical state line and λ is regarded to soil constants. The values of the critical state line parameter for fibre reinforced and unreinforced soil summarised in Table 3. The values of *M* in fibre reinforced soil shown increase due to increment of fibre inclusion (fibre content and fibre length).

Coated OPEFB fibres increased the shear strength of silty sand compared to uncoated fibres. Coated fibres shown higher interface friction between fibre and soil particles by increasing the surface area. Table 3 shows the increase in the *M* value and decrease in λ value of coated OPEFB fibre in compare with uncoated fibre.

The test path followed in standard triaxial tests may also be represented in $p' : q' : \nu$ space. Figure 10 illustrates the critical state line in $p' : q' : \nu$ space, the initial state of the sample, the test condition, and fibre inclusion (fibre length and fibre content) completely were determined the precise point on the critical state line at which the sample was failed.

Table 3: Critical state parameter obtained from triaxial compression series

Sample	Sample description	M	Γ	λ
OPEFB Fibre Reinforced soil	Unreinforced	1.214	2.115	0.096
	f = 0.25% , l_f = 15mm fibre	1.303	2.092	0.093
	f = 0.25% , l_f = 30mm fibre	1.378	2.080	0.091
	f = 0.25% , l_f = 45mm fibre	1.368	2.074	0.090
	f = 0.50% , l_f = 15mm fibre	1.376	2.073	0.090
	f = 0.50% , l_f = 30mm fibre	1.530	2.052	0.087
	f = 0.50% , l_f = 45mm fibre	1.474	2.064	0.089
ABS coated OPEFB fibre Reinforced soil	Unreinforced	1.214	2.115	0.096
	f = 0.25% , l_f = 15mm fibre	1.334	2.078	0.092
	f = 0.25% , l_f = 30mm fibre	1.418	2.066	0.088
	f = 0.25% , l_f = 45mm fibre	1.426	2.076	0.090
	f = 0.50% , l_f = 15mm fibre	1.405	2.071	0.090
	f = 0.50% , l_f = 30mm fibre	1.557	2.045	0.087
	f = 0.50% , l_f = 45mm fibre	1.512	2.053	0.087

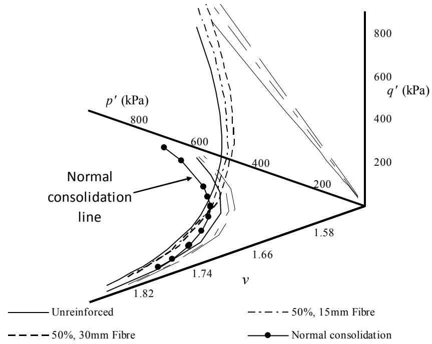


Figure 10: Comparison of the critical state line in $p' : q' : \nu$ space for fibre reinforced and unreinforced silty sand

4 CONCLUSION

Stress-path of the fibre reinforced silty sand soil was indicated the increase in shear strength by increasing the slope of critical state line in both drained and undrained condition. Effect of increase of pore water pressure in CU tests, change the stress path curves direction to the left. The trend of failure point was increased the critical state line. The limit of strength can describe by critical state line in $p' : q' : \nu$ space shifted by increasing the fibre length, fibre content and fibre aspect ratio. The coated OPEFB fibre increased the effects of fibres in improvement of shear strength of the reinforced soil.

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