EXPERIMENTAL STUDIES ON INGREDIENTS OF COMPOSITE SOIL FOR A HIGHER STRENGTH BACKFILL MATERIAL

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ABSTRACT

This article deals with experimental studies by lab tests for finding out a composite soil material with higher strength but lower unit weight. Soil from retreated site was broken, demoistured, crashed and then mixed with other materials including sand, cement as binder, shredded tires and water. Based on experimental procedure, a matrix for experiment design over percentage of ingredients was created and lab tests at different percentage (by weights) of ingredients were conducted in order to find out the reasonable proportion of ingredients which provided higher shear strength but lighter unit weight than that of in-situ soil. This composite soil material expects to contribute to effective material solution for mitigating soil instability.

***Keywords**: Backfill material, cement as binder, sand, water, shredded tires, higher shear strength.*

1. Introduction

Soil instability has always been a vast topic. Up to now, this topic attracts numerous researches in all aspects of scientific research, both including prediction studies, experimental and modeling and/or computational studies. Soil instability of riverbank is specifically a very complicated process of streambank retreat which related to many time variant factors such as hydraulic regime of river flows, hydrological condition of river section (longitudinal and transversal direction) geomorphological of river …etc. and inconsistently varied phenomena but also on its dynamic and/or multi-physical nature.

Firstly in agricultural aspect, there are researches on the vegetation factors affecting on riverbank and streambank stability. These researches concluded that vegetation increased resistance to erosion, but in many situations, especially along large watercourse, water eroded to a depth far below the rooting zones of vegetation. As such, specific kind(s) of vegetation with rooting depth planted to suitable density was necessary (Heede, 1980). Vetiver grass is such a suitable measure (Paul Truong, 2001; Vo Thanh Tan, 2000).

Secondly, during process of soil instability, many mechanisms which resulted in the slide of soil mass were postulated. The change of riverbed both in longitudinal and transversal direction resulted in a change of flow regime and then the new channel section, i.e due to the change of riverbed, subsequently caused hydraulogical regime and in turn, the riverbed varied accordingly. This process occurred endless from time to time, so what suitable measure to do for a strategy in reduction of riverbank instability therefore never well could be established (Duong Hong Tham, 2009).

Much effort was taken to find out some approach to tackle the problem. According to (Duong Hong Tham, 2010), there are generally three trends of approaches:

a. 2D or 3D analysis to compute safety factor of stability, withstand measures for it such as reinforced soil, using geogrid or other different structural elements (Duong Hong Tham, 2010).

b. Conducting analysis for Predicting riverbank soil instability. This trend focuses on conducting surveillance over river catchment together with built-in instrumentation for tracking and observing the slope movement. Data from many different station including hydrological data, geotechnical data, remote sensing data and manmade activities… were collected and predicting for soil instability was made (Osman & Barakabah, 2006; Lawler, Couperwaithe, Bulle & Harris, 1997).

c. Using light weight material for reducing the sliding weight of soil mass. This trend aims at using a light weight and stiff material for replacing the soil foundation and reducing the weight of soil mass as well. EPS Geofoam©, terra Lite© etc (Negussey, 1997).

Many studies were conducted both in analytical and experimental approach (Jason & Raymond Torres, 2006; Darby & Thorne, 1995; Chu Agor, ML, Wilson, G.V, Fox, GA, 2008; Le Thanh Ngoc, 2003). Overwhelming and effective solution is the one which considers many factors and takes several different alternatives into account as possible (Duong Hong Tham, 2012; Phu & Tran, 2012). Years after years, people lived in Mekong Delta actually suffer this natural hazard and view it as a natural phenomena. Their mere solution is to simply evacuate to the opposite bank of the river, zone of accretion.

However, up to now it seems that very few solution that focus on replicable material.

A question raised is that whenever a soil mass falls, how to reconstruct or re-build the bank to partly re-use the land area. Besides, what to protect the riverbank from being collapsed again by sliding together with boat wave attack, desiccation and twice a day water tide. Requirement for new material definitely has not only higher shear strength, easy to re-compact and lighter in weight as compared to in-situ soil. So a plan to study this specific problem: *how to prepare such a kind of soil* is carried out in lab, using soil from a recently failed riverbank.

Waste shredded tire was intended to play as a complimentary ingredient for backfill material. For how this material was used, during nearly 20 years from year of 90s to now, many experimental researches carried on shredded tires indicated this troublesome waste material could be used as a construction material. Mechanical properties of shredded tires which was not mixed with soil and had size from 2mm to 10mm 2- 40mm (Yan, Lohnes & Kjatanson, 2002) was postulated using confined compression, directi shear test and triaxial compression test. The research is a further study conducted grom synthesization of previous studies carried out in 90s by Bresset (1984), Benda (1995) and others. Results from these studies indicated that particle size did not affect shear strength and stress-strain response of shredded tires; moreover small size of shredded tires had lower compressibility than bigger one (Yan, Lohnes & Kjatanson, 2002).Experimental studies conducted by Salgado, R. et al. (1999) studied shredded tires up to 40% by weight mixed with Ottawa sand (Lee, Salgado & Lovell, 1999). Utilizing the rubber-sand material mentioned above intergrated with FEM analysing resulted in conservative design, i.e actual data was smaller than computed, especially active condition in retaining wall analysis ((Lee, Salgado & Lovell, 1999). Rubber-sand proved to be reasonably strong and lightweight backfill material. Recently, other experimental studies on model lab tests were conducted so as to evaluate the bearing capacity of medium dense river sand mixed with waste tire fibers at various fiber contents of 0.25%, 0.5%, 0.75% and 1% (Shiping Yang, Robert A. Lohnes & Bruce H. Kjartanson, 2002). The article indicated that bearing capacity increased at all fiber contents whereas 0.75% content might be an optimum content, beyond which settlement starts increasing (Shiping Yang, Robert A. Lohnes & Bruce H. Kjartanson, 2002).

However, should rubber be mixed with cohesive weak soil? What is our expectation for it, both in shear strength and compresibility? These questions would be partly answered by this experimental studies hereinafter.

2. Experiment design

Material used for experiment

Rubber. Small chips of waste shredded tires with size from 1 – 4mm diameter were used, a density 0.9 g/cm^3. There are three levels of rubber grains (percentage by weight): 10 %, 20% and 30%.

Soft soil. Peat soft clayey soil with high percentage of organic ingredients was taken near the soil surface, within the tidal zone (elevation -0.8 to -1.2m) and nearly collapsed. Falling soil broken from the riverbank cliff was crashed to remove natural humidity.

Table 1. Undisturbed soil at site underconsideration (collected by lab test)

Cohesion (kPa)	Angle of internal Friction	Void ratio e_o	Water content (%)	Plastic Limit/ Liquid limit W_P/W_L	Volume weight kN/m^3
4	7, 7^o	1,878	71,8	31,69/62,33*	15.8

(This limits at site under consideration was assumed to be the same as cited from (Tuan, Sang & Ngo, 2008) for the same area of sampling)*

Sand. Playing as a filler material. Medium sand which is about finer than 0.4-0.6 mm size was used to make compaction easier and to increase the internal friction angle of soil strength. Two levels of sand percentage by weight were used, 5 and 10%. This percentage of sand is commonly used by people in Mekong Delta. Sand for lab tes in this research is commonly used in construction.

Cement. As a binder, small percentage of about 5% and 10% was used for all trials. Like water, experiment was carried out with two different water contents, 15% and 20%.

At least three trials at a specific normal stress with respect to given percentage of rubber grains were conducted in standard direct shear stress to obtain shear stress, and three levels of normal stress were applied for each test. Soil strength line, i.e peak strength line was drawn to determine the cohesion and angle of internal friction for newly created soil.

Number of separate trials for lab experiment with each parameter of materials mentioned above would be 3 levels of normal stress x 2 sand percentage x 2 water content x 3 rubber percentage x 3 trials = 108 trials.

Matrix of tests

A matrix for collecting data was designed and aimed to reduce the number of trials as least as possible (Table 2). In this research, three trials for each experiment were conducted in order to ensure the best data collected (average values).

Table 2. Matrix of data in experimental design

		Water content 15%						20%					
		Rubber grains 10%		20		30		10		20		30	
		sand 5%	10	5	10	5	10	5	10	5	10	5	10
Trials at three levels of normal stress	σ1		1	3		5			2	4		6	
	σ2		1	3		5			2	4		6	
	σ3		1	3		5			2	4		6	
	σ1		1	3		5			2	4		6	
	σ2		1	3		5			2	4		6	
	σ3		1	3		5			2	4		6	
	σ1		1	3		5			2	4		6	
	σ2		1	3		5			2	4		6	
	σ3		1	3		5			2	4		6	

Note: Number in table denotes samples at specific ratio of mixing; three trials for each lab test.

Taguchi Method was applied in designing experiments. This is to determine the most dominated parameter(s) to concentrate in lab test and to rank the level of importance of each ingredient of mixture so that experiments could be necessarily carried out. Data collected from the direct shear test was calibrated by conducting an independent series of tests at a different laboratory. Results from these tests were compared to those of other lab results to ensure conformity (calibration).

Material mixing

Undisturbed soil samples were crashed and tested to determine physical properties. Then a mixture including dried soil grains, cement at very small percentage by weight, rubber grains and medium sand were mixed (Figure 1). Compaction in cylinder 90mm in diameter was done layer by layer of about 3-4cm thick.

Figure 1. Material mixing. a) Procedure of soil compaction ; b) Mixture prepare

Table 3. Taguchi experimental design: orthogonal array

TAGUCHI EXPERIMENTAL DESIGN ORTHOGONAL ARRAY FOR TARGET VALUE (SHEAR STRESS)

	# Sampl	Rubber (%)	Sand (%)	Cement as Binder (%)	Water content (%)	Shear stress (kg/cm2)			Mean	Stndard Dev. %	Sm1	St2	ST-Sm2	Ve1	SNi
						trial 1	trial 2	trial 3			(parameter are denoted as per [18])				
Normal stress 1	2	10	10	5	20	0.272	0.31	0.33	0.3	4.1	0.252126	0.252387	0.000261	0.000131	28.08062
Normal stress 1	3	20	5	5	15	0.28	0.3	0.32	0.3	2.8	0.3072	0.308	0.0008	0.0004	24.07674
Normal stress 1	6	30	5	5	20	0.3	0.24	0.26	0.64	2.9	0.252126	0.252387	0.000261	0.000131	28.08062
Normal stress 2	2	10	10	5	20	0.52	0.56	0.58	0.56	4.3	0.90761	0.912738	0.005128	0.002564	20.70616
Normal stress 2	3	20	5	5	15	0.52	0.48	0.5	0.5	1.4	1.008852	1.01403	0.005178	0.002589	21.12463
Normal stress 2	6	30	5	5	20	0.5	0.48	0.54	0.51	2.9	0.7203	0.727874	0.007574	0.003787	17.99808
Normal stress 3	2	10	10	5	20	0.7	0.76	0.7	0.72	0	0.3072	0.307578	0.000378	0.000189	27.33571
Normal stress 3	3	20	5	5	15	0.66	0.61	0.64	0.64	1.76	1.6428	1.646	0.0032	0.0016	25.3392
Normal stress 3	6	30	5	5	20	0.59	0.65	0.67	0.63	5.8	1.070421	1.078354	0.007933	0.003966	19.52432

effect of factors is calculated by the difference between the Max and Min value of SN

Shear stress of undisturbed soil

Direct shear stress conducted on undisturbed soil shows a cohesion about 4 kPa and frictional angle is 7-8^o. This is 3 kPa and 3,7^o respectively when tested by other laboratory for calibration (Fig. 2a).

3. Results

Consideration over recording of experiments

With a limited number of soil samples bored from site of eroded area, there were only 6 samples x 9 = 54 trials (three levels of normal stress, times three trials per lab test each normal stress, plus 9 undisturbed samples), so there were not enough soil samples for 108 experiments for this study, only half of required lab tests (Table 3).

Table 4. Groups of samples

Sample Number	Soil (%)	Rubber (%)	Sand (%)	Cement as Binder (%)	Water content (%)	Unit Weight (g/cm^3)
1	60	10	10	5	15	1.3
2	55	**10**	**10**	5	**20**	1.25
3	55	**20**	**5**	5	**15**	1.13
4	50	**20**	**5**	5	**20**	1.22
5	45	**30**	**5**	5	**15**	1.09
6	40	**30**	**5**	5	**20**	1.08

After applying Taguchi method for designing experiment [18], result indicates that

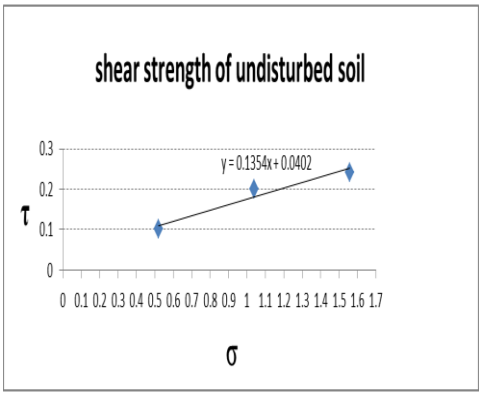
Normal stress 3 affects result of shear stress most as compared to the rest level of normal stress.

At the same cement percentage 5%, all % rubber together with % sand and water have equally importance in tests;

The nearly same value of effect factor, say *3,24* (for #sample 1, 4,5) and *3.50* (for #sample 2, 3, 6) indicates that group of samples with higher water content and and higher percentage of rubber grains (group 2, 3, 6) will result in clearer effect as compared to that of lower percentage of ingredients (group 1,4,5) as in Table 4. This method was used for determining necessary enough for lab tests and effective factor(s).

Soil mixed with supplementary materials

Three sets of soil samples were tested and results as ratio of direct shear stress τ over normal stress σ were built as normalized dimensionless parameters (Figure 2b).

a) 

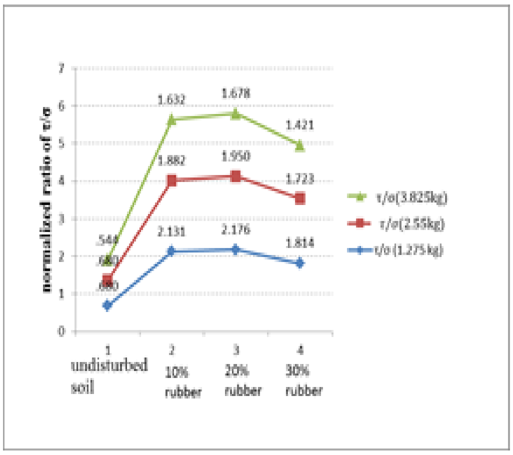
b) 

Figure 2. a) shear strength of undisturbed soil; b) normalized ratio τ/σ

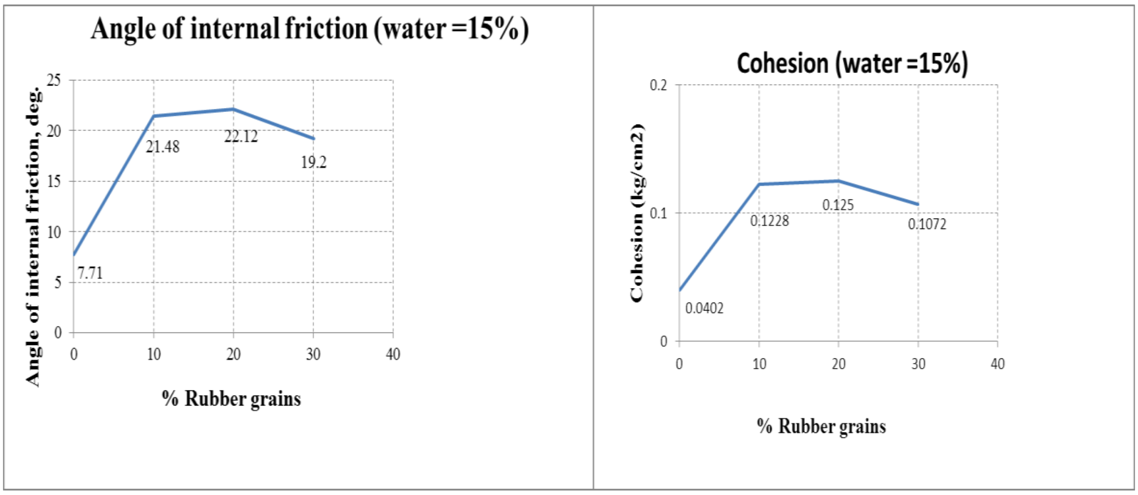


Figure 3. Parameters of shear strength of rubber-grain soil

- In phase 1, 15% by weight of waste shredded tires were used, mixed with various percentage of cement. Direct shear test results indicated that: At 10% by weight of cement, shear strength was determined to be the highest value, both in angle of internal friction and cohesion.
- In phase 2, Sand, Water and Grains were kept constant as % cement and soil changed.

Table 5. Phase 2 planned matrix of mixing

Sample	Cement (%)	in situ soil (%)	Sand (%)	Rubber grains (%)	water (%)
1	5	60	5	15	15
2	10	55	5	15	15
3	15	50	5	15	15

Soil Sample	Tan φ	φ (deg.)	Cohesion C (KPa)
1	0.6286	32.2	0.070
2	0.6673	33.7	0.131
3	0.5319	28.0	0.013

Percentage of cement greater than 15% resulted in a decrease in shear strength, having heavier volume weight as shown in Figure 3. So the suitable percentage of grains might lies between 10% and 15%.

4. Discussion

- The water content of mixed soil should be determined as a parameter for further studies.
- There is a similar trend of changing cohesion and internal friction angle to percentage of rubber grains (Figure 3).
- It was a decrease of shear strength as percentage of rubber grains increased, especially more than 20% rubber grains by weight.
- At 20% of water by weight, no significant value of shear strength was recorded. At 20% of water by weight, there was a good trend of shear strength, both in relation between cohesion and frictional angle versus % rubber grains and ratio τ/σ. Besides a peak of strength occurred between 15-20% waste rubber grains (see figure 3). For the phase 2 of research, 15% by weight of waste rubber grains will be chosen to conduct other series of direct shear tests to check which percentage of *cement* as binder shear strength will reach the highest value.

These mixture also had a lower unit weight less than undisturbed soil $\gamma = 15.8$ kN/m^{3}as shown in Table 5.

- Good percentage of admixture for soil under consideration could be of **55% soil, 15% water, 5% sand, 10% cement and 15% rubber**. At this percentage of ingredients, shear strength increases as compared to undisturbed soil shear strength.

5. Conclusion

A material for increasing riverbank soil stability could be made in laboratory. Experimental study for a lighter self-weight but higher shear-strength was postulated. Procedure is: In situ soil from retreated site was mixed with other materials including shredded tires in shape of chips grains 2-4mm of diameter, cement as binder, water at relatively suitable water content and sand (for cohesive soft soil). Effective factors of experiment were chosen to direct and focus main tests for experiement studies. That is percentage of filler (shredded tires and soil) and binder (cement). Series of lab tests were designed, conducted and compared to those of other laboratory as a calibration measure. Direct shear strength of lab made soil attained the highest value at 10% cement, together with 15% water, 5% sand and 15% rubber grains (% by weight). We strongly suggest that further studies in theoritical and experimental approach should be conducted in future. As collaborated with other additional measure in site, this suggested material expects an effective contribution for mitigating damages due to soil intability.

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