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STRENGTHENING SOFT SOIL FOR APPROACH ROAD AFTER ABUTMENT BY CEMENT AND FLY ASH

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Abstract. Approach road is an important structure of a bridge. Serviceability of a bridge is affected by the settlement of approach road, especially that on soft soil. One method that is usually applied for minimizing effect of settlement of approach road is to replace soft soil by hill soil. This method however may increase cost of projects in Mekong Delta area with a larger depth of soft soil. In this paper, soft soil strengthened by mixing it to cement and fly ash at different mix proportions was investigated. Test results from unconfined compression test and direct shear test of strengthened soft soil are compared to those of hill soil to determine the optimal mix proportion. Results showed that mixing 25kg cement and 75kg or 100kg fly ash to 1m^3 soft soil increased its unconfined compressive strength and shear strength and are higher compared to those of hill soil. Strengthening in situ soft soil by using fly ash, industrial waste from thermal power plant, reduces cost of project and at the same time contributes to solving environmental problems.

Keywords: soft soil, cement, fly ash, unconfined compressive strength, shear strength, direct shear test.

1. INTRODUCTION

Approach road after an abutment as shown in Fig. 1 [1] is an important part of bridge structures. An approach road is required for a smooth and harmonious transition from the road to the bridge (culvert). Settlement of approach road is quite common not only in Vietnam but also in the world [2]. Settlement gradually occurs and does not cause immediate danger. However, settlement of approach road after abutment may affect the safety of vehicles on the bridge, impact the top wall of abutment and deck adjacent abutment, and may cause discomfort for motorists using the bridge. There are many causes of settlement of approach road. Basically, settlement occurs when natural ground and backfill after abutment is consolidated. It comes from overload, increase in the number of vehicles, inadequate compaction work, poor quality of backfill soil and having soft soil of natural ground. Therefore, one of the ways that settlement of approach road can be avoided is by strengthening the natural ground and backfill soil of approach road.

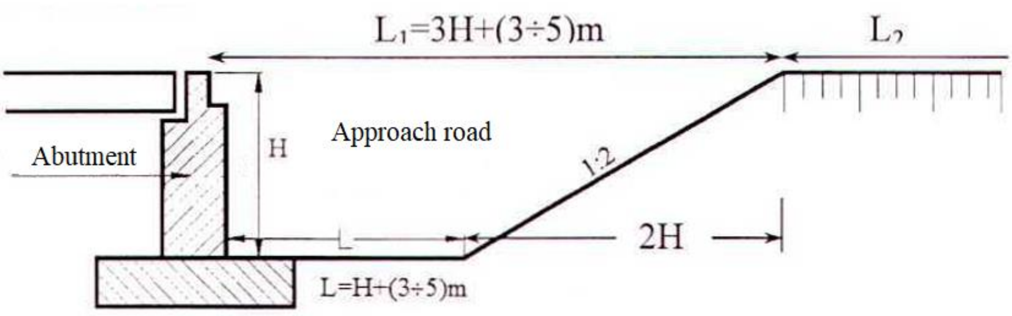


Figure 1. Approach road after abutment [1].

Table 1. Particle size distribution suggested for backfill [1].

No.	Opening	Finer (%)
1	90.0 mm	100
2	19.0 mm	75-100
3	4.75 mm	30-100
4	425 µm	15-100
5	150 µm	5-56
6	75 µm	0-15

Natural ground in Mekong Delta area is a product of sedimentary process with interaction with river and sea [3]. This type of natural ground is soft soil. This condition is a disadvantageous to construction of structures. Therefore, the foundation of structures needs to be strengthened. This is also true particularly for transportation projects such as road and approach road after abutment for safety vehicles and motorist. There are many methods for strengthening soft soil [4, 5] for approach road, such as: concrete slab combine with reinforced concrete piles; creating consolidated soft soil by geotextile tube under vacuum loading or sandbag combine loading; soil-cement deep mixing column; replacing soft soil with good backfill; or using approach slab etc. Good backfill to replace soft soil for approach road after abutment must satisfy some properties such as: a plastic index (PI) is lower than 15; particle distribution is shown in Table 1, and uniformity coefficient, C_u is larger than 3 as shown in Eq. (1), where D_{60} and D_{10} are diameter corresponding to 60% finer and 10% finer those are determined based on particle size distribution curve of soil.

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

However, transferring good soil as hill soil from other places to Mekong Delta area may increase construction time, which in turn will increase cost of project. Strengthening soft soil in projects in Mekong Delta area may be a good solution then as it may save construction time and cost of project.

Several studies have been conducted on the effect of fly ash on the capacity of soft soil. Moradi et al. [6] used bottom fly ash to enhance soft soil behaviour. Ozdemir [7] strengthened soft soil by adding fly ash up to 10% in content. Experimental results showed that increasing fly ash content did not increase unconfined compressive strength. In this paper, soft soil taken from a bridge project in Mekong Delta area is strengthened by mixing to both cement and fly ash, industrial waste from thermal power plant. The strengthened soft soil is compared to good soil like hill soil that is designed to replace soft soil and backfill after abutment. Different mix proportions are examined, and test results are evaluated and analysed to propose optimum mix proportion for the project.

2. MATERIALS

2.1. Soft soil and hill soil

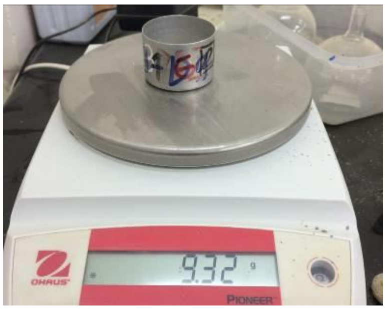


Figure 2. Electronic balance and sample container.

Figure 3. Test samples.

Figure 4. Dry oven.

Figure 5. Fly ash.

Soft soil was taken a bridge project in Mekong Delta area. Hill soil was designed to replace soft soil for the project. Both type of soils were put into nylon bags and moved to laboratory. Unit weights of both soft soil and hill soil were determined as 1677kg/m^3 and 2075kg/m^3, respectively. Water contents of both soils were also determined. To determine water content, soil sample containers and electronic balance with accuracy of 0.01g as shown in Fig. 2 were used. It was made sure that the sample containers were clean and dry before use. Wet soil and sample containers were put into dry oven as shown in Fig. 4 at 105°C in 24h until the weight did not change. Water content of soils was determined using Eq. (2) where w_1 is the weight of container, w_2 is the weight of wet soil and container as shown in Fig. 3, and w_3 is the weight of the dry soil and container. Water content of soft soil and hill soil is 49.49% and 22.6%, respectively.

$$w = \frac{w_3 - w_2}{w_2 - w_1} \times 100\% \quad (2)$$

2.2. Fly ash and cement

Fly ash is a by-product of the combustion of pulverized coal in thermal power plants. Its compounds includes silicon, aluminum, iron, calcium, and magnesium. Fly-ash particles are spherical with diameter ranging from less than 1 µm to 150 µm with particles retained on 45 µm seive size of about 10%. Because its small diameter, fly ash can be added to soft soil and fill the voids in soft soil. In this reasearch, fly ash was collected from Vinh Tan thermal power plant as shown in Fig. 5. The collected fly ash was kept in nylon bags to ensure its moisture content do not change during transport. The moisture content of fly ash was quite small. Fly ash is an admixture material for concrete exposed in brackish water, sea water and sulfate environment. So, fly ash mixed into soft soil in Mekong Delta area is suitable. In addition, it is predicted that the by-product of thermal power plants is about 25.4 millions tons in 2020 and up to 38.3 million tons in 2030. This requires a large storage area for fly ash, unless it is stored under the earth. Therefore, in this research fly ash added in soft soil contributes to solving some enviromental problems. The cement used in this research is PCB40 which is used in sulfate environment and is thus suitable for Mekong Delta area.

Table 2. Several mix proportions.

Name	**Weight / 1m^3 soft soil**		**Checking time**
	cement (kg)	**Fly ash (kg)**	
SS-C00-F00	0	0	Right after creating sample
HS-C00-F00	0	0	Right after creating sample
SS-C100-F00	100	0	5h after creating sample
			7 days after creating sample
			28 days after creating sample
SS-C50-F50	25	100	5h after creating sample
			1 day after creating sample
			28 days after creating sample
SS-C25-F75	25	75	5h after creating sample
			1 day after creating sample
			28 days after creating sample
SS-C25-F100	50	50	5h after creating sample
			1 day after creating sample
			28 days after creating sample

Note: SS is soft soil; HS is hill soil; C is cement; F is fly ash

3. EXPERIMENTS

In this research, soft soil and hill soil from the project were firstly compacted by standard Proctor test [8]. Unconfined compressive strength and shear properties were then compared. Next, soft soil was mixed with cement and fly ash at different mix proportions. Its testing properties were then compared to those of hill soil. In soil-cement deep mixing method, the amount of cement mixed to 1 m^3 soil is from 100kg to 240kg [9, 10]. In this research, 100kg, 50kg or 25 kg cement were mixed to 1m^3 soft soil. In addition, amount of fly ash of 0kg, 50kg and 75kg or 100 kg was added. Testing properties were conducted at 5h, 1 day or 7 days and 28 days. All mix proportions are listed in Table 2.

Figure 6. Proctor machine.

Figure 7. compaction test.

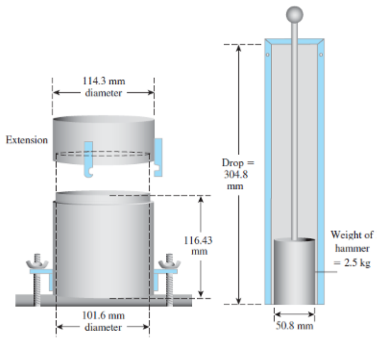


Figure 8. Standard Protor equipment.

a) Hill soil sample b) Soft soil sample

Figure 9. Compacted samples.

The density of subbase course is normally compared to the density of the compacted soil in laboratory via Proctor machine as shown in Fig. 6. Proctor test was conducted as shown in Fig. 7 to determine optimum water content in soil and maximum dry density of compacted soil that is applied for subbase layer of road structures or approach road. Information of Proctor test is shown in Fig. 8 [8]. Each sample, soil is separated into 3 layers and compacted by 25 blows in each layer. Soft soil and hill soil were molded as shown in Fig. 9. Extruder machine was used to remove a sample out of mold as shown in Fig. 10. Unconfined compression test was done with universal testing machine as shown in Fig. 11 to determine shear strength of soil, c_u. The loading speed applied for all specimens in unconfined compression test was 0.1kN/s.

Direct shear test was used to determine the shear properties of soil such as cohesion, c and friction angle φ. Shear ring was used to create samples as shown in Fig. 12 for direct shear test done by test machine as shown in Fig. 13. The loading speed applied for all specimens is 2mm/minute. The relationship of shear stress, τ and normal stress, σ based on Coulomb theory is expressed in Eq. (3).

$$\tau = \sigma \tan\varphi + c \quad (3)$$

Figure 10. Extrude equipment.

Figure 11. Universal Testing Machine.

a) Hill soil sample b) Soft soil sample c) samples for shear test

Figure 12. Using shear ring to create samples for direct shear test.

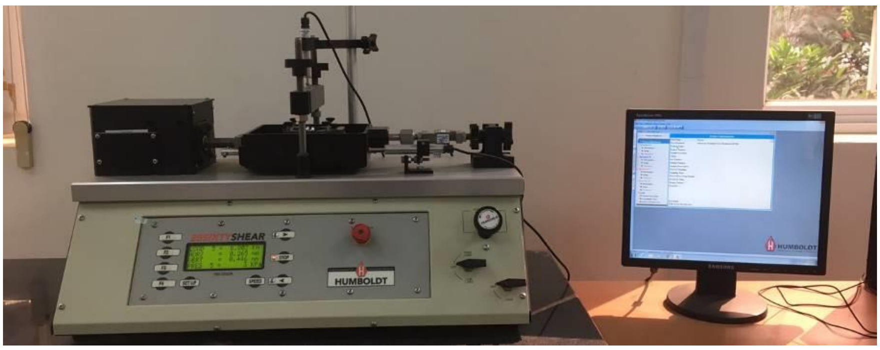


Figure 13. Direct shear test equipment.

Normally, normal stress applied for the test should not be larger than 1050 (KPa). However, for this test, the normal stress applied for soft soil was not larger than 45kPa to avoid failure in compression before failure in shear. After the soft soil was strengthened, normal stress may be larger.

Mixing cement and fly ash into soft soil can be made in construction site using excavator and soil mixer. In the laboratory, soil was mixed in containers. The amount of soft soil for one batch was first weighed. Amount of cement and fly ash was weighed based on mix proportion to soft soil, as well. Soft soil and cement with fly ash were mixed separately first before they were all mixed together as shown in Fig. 14 by using Rubimix 9 as shown in Fig. 15. Rubimix 9 has powerful 1200w motor, electronic regulator of 0 to 819 rounds per minute. In the mixing process, slow motion was selected to ensure adequate force for mixing. After mixing, compacting and molding, samples were kept in plastic box to avoid water evaporation as shown in Fig. 16. These samples were then subjected to unconfined compression test and direct shear test at different time schedules. For each mix proportion, 6 samples were prepared. The 6 samples were grouped in 3 pairs and each pair were tested in the same conditions.

a) Soft soil b) Soft soil, fly ash and cement

Figure 15. Rubimix 9

Figure 14. Mixing soil, cement and fly ash.

a) Sample in box b) Covering box to keep moisture

Figure 16. Boxes to keep samples.

4. RESULTS AND ANALYSIS

4.1. Comparison of soft soil and hill soil without strengthening

Firstly, samples of soft soil without strengthening and hill soil as shown in Fig. 17 were tested. Compressed hill soil samples are shown in Fig. 18. Relationship between load and displacement of the samples are shown in Fig. 19. Results show that unconfined compressive strength (q_u) of hill soil was larger than that of soft soil without strengthening. Maximum unconfined compressive strength of both soft soil samples was 0.3kN. Meanwhile, average unconfined compressive strength of both hill soil samples was 0.5kN. It means that the unconfined compressive strength of hill soil was larger than that of soft soil. Fig. 19 also shows that stiffness of hill soil was a little bit larger than that of soft soil. Therefore, replacement of soft soil by hill soil in subbase course of road or approach road after abutment can increase stability and reduces settlement.

4.2. Soft soil strengthened with 100kg cement

Previous results show that the bearing capacity of soft soil was smaller than that of hill soil. To reduce cost due to usage of hill soil and its transportation, soft soil can be used as subbase course instead. In that case, soft soil needs to be strengthened. Mix proportion of 100kg of cement to soft soil was prepared. Fig. 20 shows relationship between applied force and displacement of samples of the mix in unconfined compression test. The tested unconfined compressive strength of each pair at 5h and 7 days was quite similar, while the strengths of pair at 28 days were different. Unconfined compressive forces of the tested samples of this mix proportion are listed in Table 3. The average unconfined compressive forces at 5h was 1.475kN. This average value was much higher than that of hill soil, 0.5kN. At 5h, the strength of strengthened soft soil was 2.95 times larger than that of hill soil. Average unconfined compressive forces of soft soil strengthened at 7 days and 28 days was 3.15kN and 4.475kN, respectively. It means that, unconfined compressive forces of strengthened soft soil at 7 days and 28 days were 6.5 times and 8.95 times greater than that of hill soil, respectively. Fig. 21 shows failure of strengthened soft soil at 28 days. It is recognized that the sample failed in a brittle way, different from hill soil which failed in a plastic way as shown in Fig. 18. It can be confirmed from these test results that adding 100kg cement to soft soil for subbase layer of road or approach road after abutment improved the stability and strength of subbase course. Therefore, soft soil can be recycled to reduce cost of project.


Figure 17. Soft soil and hill soil.


Figure 18. Failure of hill sample.

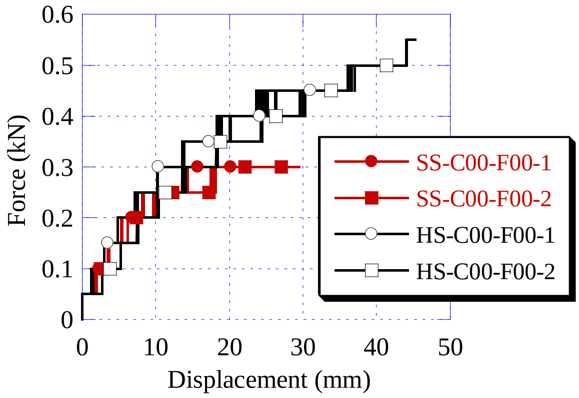


Figure 19. Relationship between applied force and displacement of soft soil and hill soil.

Table 3. Unconfined compressive force of SS-C100-F00 and SS-C50-F50.

No.	Checking time	Applied force (kN)			
		SS-C100-F00		SS-C50-F500	
		Each sample	Average	Each sample	Average
1	5h	1.35	1.475	1.05	1.05
2		1.60		1.05	
3	1 day	-	-	1.50	1.65
4		-		1.75	
5	7 days	3.00	3.15	-	-
6		3.30		-	
7	28 days	5.00	4.475	3.95	3.945
8		3.94		-	

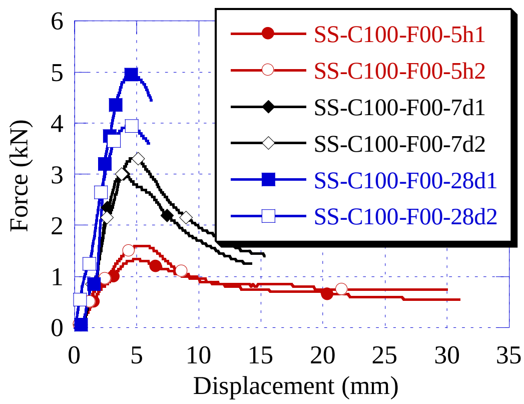


Figure 20. Unconfinement compression test of samples SS-C100-F00.

Figure 21. Failure of SS-C100-F00-28d.

4.3. Soft soil strengthened with 50kg cement and 50kg fly ash

Using 100kg of cement for 1 m^3 soft soil was proven to increase unconfined compressive strength of soil. The strength of strengthened soft soil was much higher than that of hill soil that was designed to replace soft soil. However, using 100kg of cement may be wasteful or costly. Reducing cement content and substituting a part of it with fly ash may reduce the cost of project. In this mix proportion, 50kg of cement and 50kg of fly ash for 1m^3 of soft soil were examined. Fig. 22 shows the results of the unconfined compression test. It seems that at 1 day, sample also failed in a brittle way. Fig. 23 shows relationship between applied load and displacement of samples in this mix proportion at different testing times. Unconfined compression forces are also listed in Table 3. At 5h, unconfined compressive strength was 1.05kN which was smaller than that of soft soil strengthened with 100kg cement. But it was still 2.1 times larger than that of hill soil. In this mix proportion, the sample at 1 day was tested, but not same at 7 days as SS-C100-F00. Average tested force at 1 day was 1.625kN, 3.25 times larger than that of hill soil. At 28 days, only one sample was tested. Another sample was broken in the moving process. However, at 28 days, unconfined compressive force of the mix proportion was 3.95kN, 7.9 times larger than that of hill soil. This value was about 88.3% of that of mix proportion using only 100kg cement. The strength of subbase course using 50kg cement and 50 kg fly ash for 1 m^3 soft soil, at 5h after constructing, might be higher than that of hill soil. Obviously, cost of 50kg fly ash is lower than that of 50kg cement. So, this mix proportion is cheaper than the mix proportion using 100kg cement only.

Figure 22. Failure of SS-C50-F50-1d.

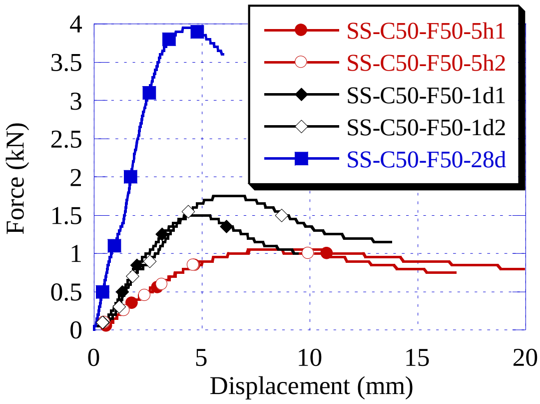


Figure 23. Unconfinement compression test of samples SS-C50-F50.

4.4. Soft soil strengthened with 25kg cement and 75kg or 100 kg fly ash

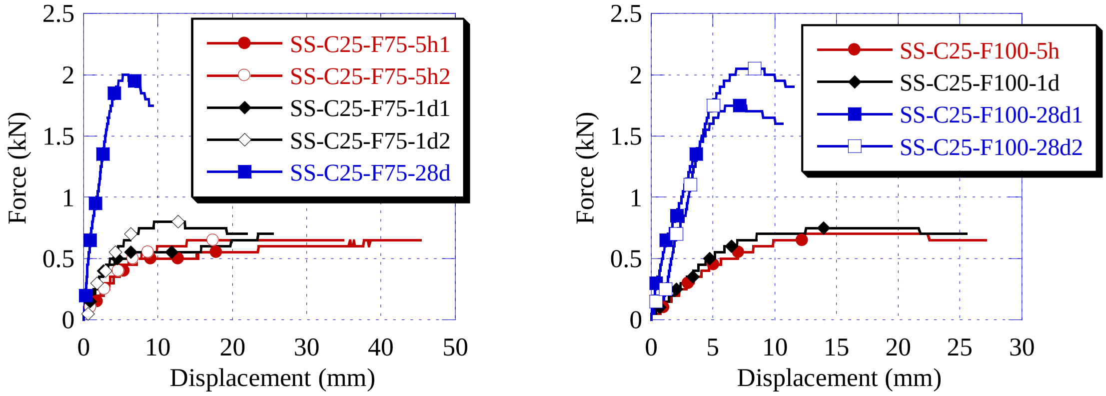
Sample SS-C50-F50 showed that its strength was still higher than that of hill soil. To reduce more cost, the weight of cement could be decreased, and the amount of fly ash could be increased. In this mix proportion, 25kg of cement and 75kg or 100kg of fly ash for 1m^3 soft soil were tested. Fig. 24 and Fig. 25 show failure of samples with 25kg cement and 75kg or 100kg fly ash under unconfined compression tests at 5h. Fig. 26 shows the relationship between applied load and displacement of these mix proportions. Maximum applied force of these specimens is listed in Table 4. Unconfined compressive force of these mix proportion was a little bit larger than that of hill soil at 5h and 1 day. However, at 28 days, tested unconfined compressive force was still approximately 4 times larger than that of hill soil. Test result of samples using 75kg fly ash was similar to 100kg fly ash. Reducing the amount of cement to 25kg also reduced unconfined compressive strength of strengthened soft soil compared to using 50kg or 100kg cement. However, the strength of samples using 25kg cement and 75kg or 100 kg fly ash was still higher than that of hill soil. The strength of samples using 100kg fly ash was a little bit larger than that using 75kg fly ash. Using 100kg fly ash increases the cost of the project to compare to 75kg fly ash. However, requirements of large storage for fly ash at a thermal power plant are currently a big challenge. Therefore, using 100kg fly ash has more environmental rewards aside from resulting to more improvement of the subbase course.

4.5. Analysis about unconfined compressive strength

In generally, adding cement and fly ash into soft soil increased its unconfined compressive strength. Percentage of strength increase depends on the amount of cement and fly ash. Testing results show that increase the amount of cement added to soft soil increases its strength.

Figure 24. Failure of SS-C25-F75-5h.

Figure 25. Failure of SS-C25-F100-5h.



a) Sample SS-C25-F75

b) Sample SS-C25-F100

Figure 26. Unconfinement compression tests of samples with 25kg cement.

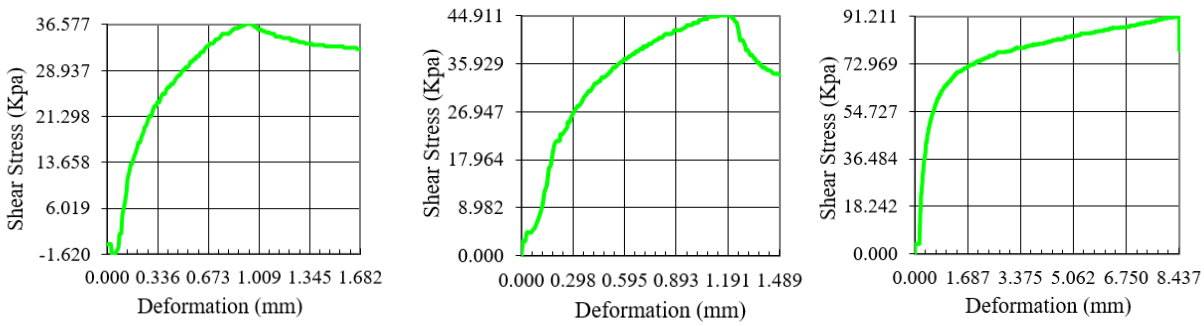
Table 4. Unconfined compressive force of SS-C25-F75 and SS-C25-F100.

No.	Checking time	Applied force (kN)			
		SS-C25-F75		SS-C25-F100	
		Each sample	Average	Each sample	Average
1	5h	0.65	0.65	0.70	0.70
2		0.65		-	
3	1 day	0.70	0.75	0.75	0.75
4		0.8		-	
5	28 days	1.5	1.5	1.75	1.90
6		-		2.05	

Unconfined compressive strength of the mix proportion using 25kg cement and 75kg or 100kg fly ash at 5h was larger than that of hill soil. The strength at 28 days was approximately 4 times higher than that of hill soil. Its stiffness was also higher than that of hill soil. The increase in strength and stiffness of strengthened soft soil is contributed by not only cement but also fly ash. Fly ash with small spherical particle size can fill the void in soft soil. Fly ash with larger surface area could absorb water in soft soil and contributing as aggregate in mortar with cement. Therefore, using 25kg cement and 100kg fly ash increases the strength of soft soil and reduces cost of the project.

4.6. Shear strength

Soil sample taken from construction site was tested as remold. After compacting, the subbase course was also tested for shear strength properties such as cohesion, c and friction angle φ. Test results showed that cohesion of soft soil and hill soil was zero due to consolidation. Friction angle of soft soil and hill soil was 31° and 68°, respectively. These values were quite large. Each type of soil, soft soil and hill soil, was tested by two normal stress values of 30kPa and 45 kPa. Therefore, the accuracy may not be high. For soft soil strengthened with 25kg cement and 75 kg fly ash, shear properties were tested at 1 day. Normal compressive stresses acting on samples were 30kPa, 45kPa and 60kPa, respectively. Relationships between shear stress and displacement at each normal stress are expressed in Fig. 27. Relationship between shear stress and normal stress Fig. 27. Relationship between shear stress and normal stress is shown in Fig. 28. Trendline passing through 3 points is created to determine shear properties. Trendline shows that cohesion, c is negative, but it is closed to zero. It is because accuracy of the test was not high. Theoretically, cohesion is zero because of consolidated soil. Friction angle was determined as 54.5°. To compare soft soil, friction angle of strengthened soft soil is much larger than that of unstrengthened soft soil. However, this value was still smaller than that of hill soil.



a) Normal stress σ = 30kPa b) Normal stress σ = 45kPa c) Normal stress σ = 60kPa

Figure 27. Direct shear test of SS-C25-F75-1d.

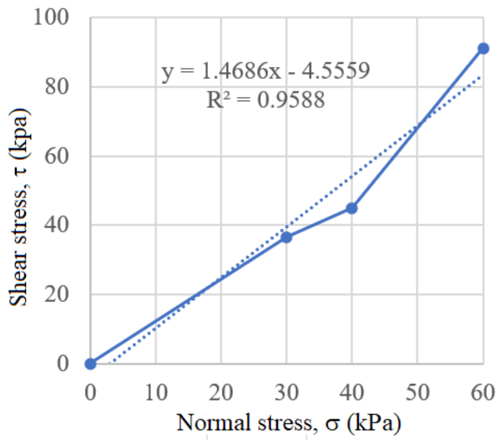


Figure 28. Predicting failure envelop line of SS-C25-F75-1d.

5. CONCLUSIONS

Recently, many construction projects have been carried out to improve infrastructure, especially in Mekong Delta area. The natural ground in Mekong Delta area has been formed from sedimentary process. This is mainly soft soil ground which needs to be strengthened before use in construction projects in this area, especially in road and approach road after abutment. There are many methods to strengthen soft soil. One of usual practice is to replace soft soil with good soil such as hill soil. However, this may increase cost of the project by transportation fee and cost of hill soil. To reduce project costs, soft soil at the project may be strengthened by mixing with cement and fly ash from thermal power plant. In this paper, several mix proportions were tested. The properties of strengthened soft soil such as unconfined compressive strength and internal friction angle increased when the amount of cement mixed into soft soil was increased. Larger content of cement could increase cost of projects. Results showed that the unconfined compressive strength of sample mixing 25kg cement and 75kg or 100 kg fly ash into $1m^3$ soft soil were a little bit larger than that of hill soil at 5h and approximately 4 times larger than that of hill soil at 28 days. In order to save money for storing fly ash, an industrial waste from thermal power plant, mix proportions of 25kg cement and 100 kg fly ash is recommended for projects with soft soil.

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