Chapter III

EXPERIMENTAL INVESTIGATION

1. Materials

1.1 Soils

Two sandy soils were used in this investigation.

1.1.1 Silty Sand. Soil sample was collected from road side of Det Udom-Buntharik highway in the North-East of Thailand. Its gradation and properties are shown in Figure 2 and Table 1, respectively.

1.1.2 Beach Sand. Beach sand used in this investigation was taken from Songkla Province which is located in the South of Thailand. Figure 3 and Table 2 show the gradation and properties of this soil sample.

1.2 Asphalt Emulsion

Emulsion selected to be used in this study was slow setting cationic emulsion (SS-K). It contained 60 % percent of asphalt resisdue. The emulsion properties are given in Table 3.

1.3 Lime

A commercially produced, high calcium hydrated lime was used in the investigation. Table 4 summarizes the properties of the hydrated lime.

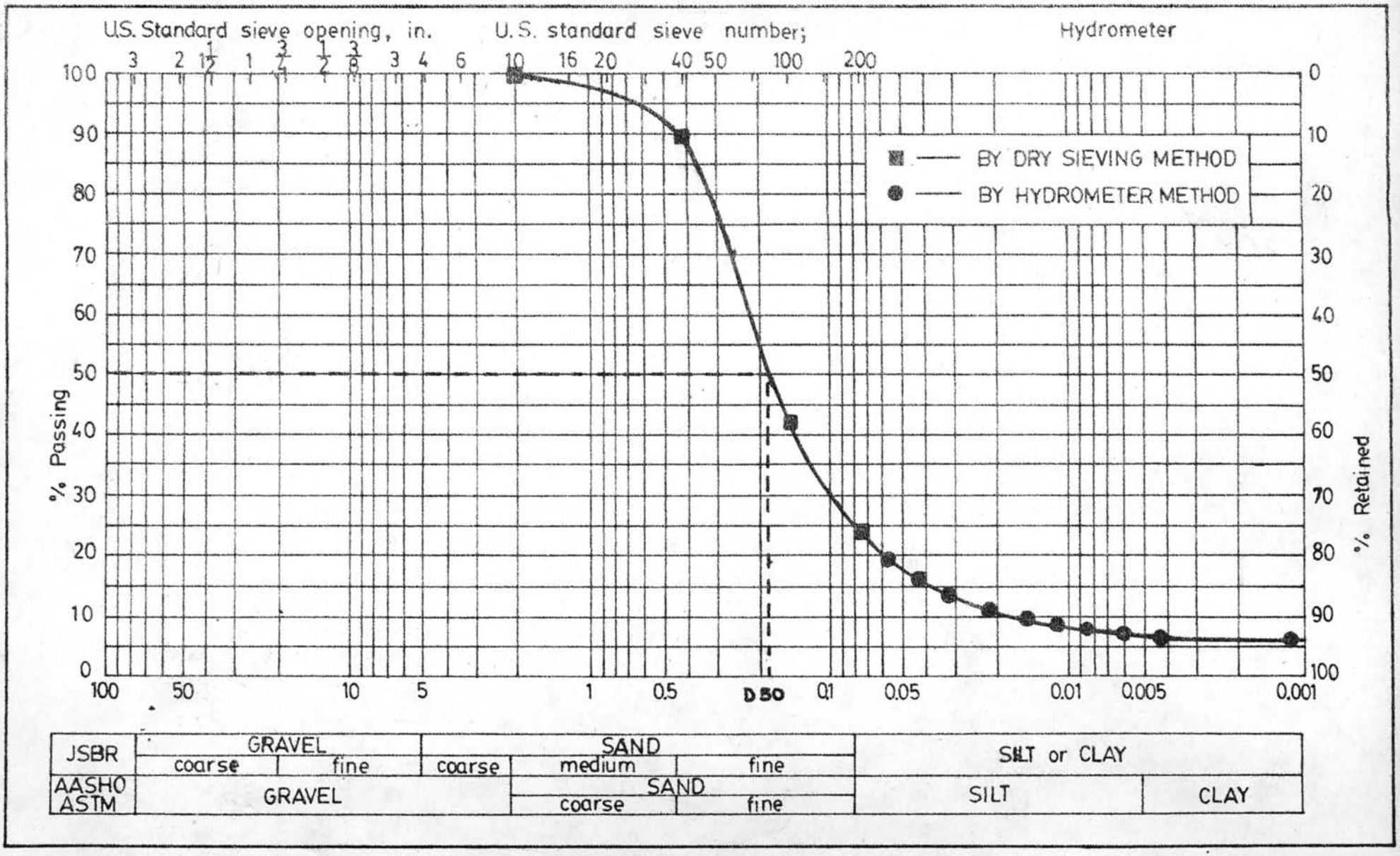

FIGURE 2. GRAIN SIZE DISTRIBUTION OF SILTY SAND

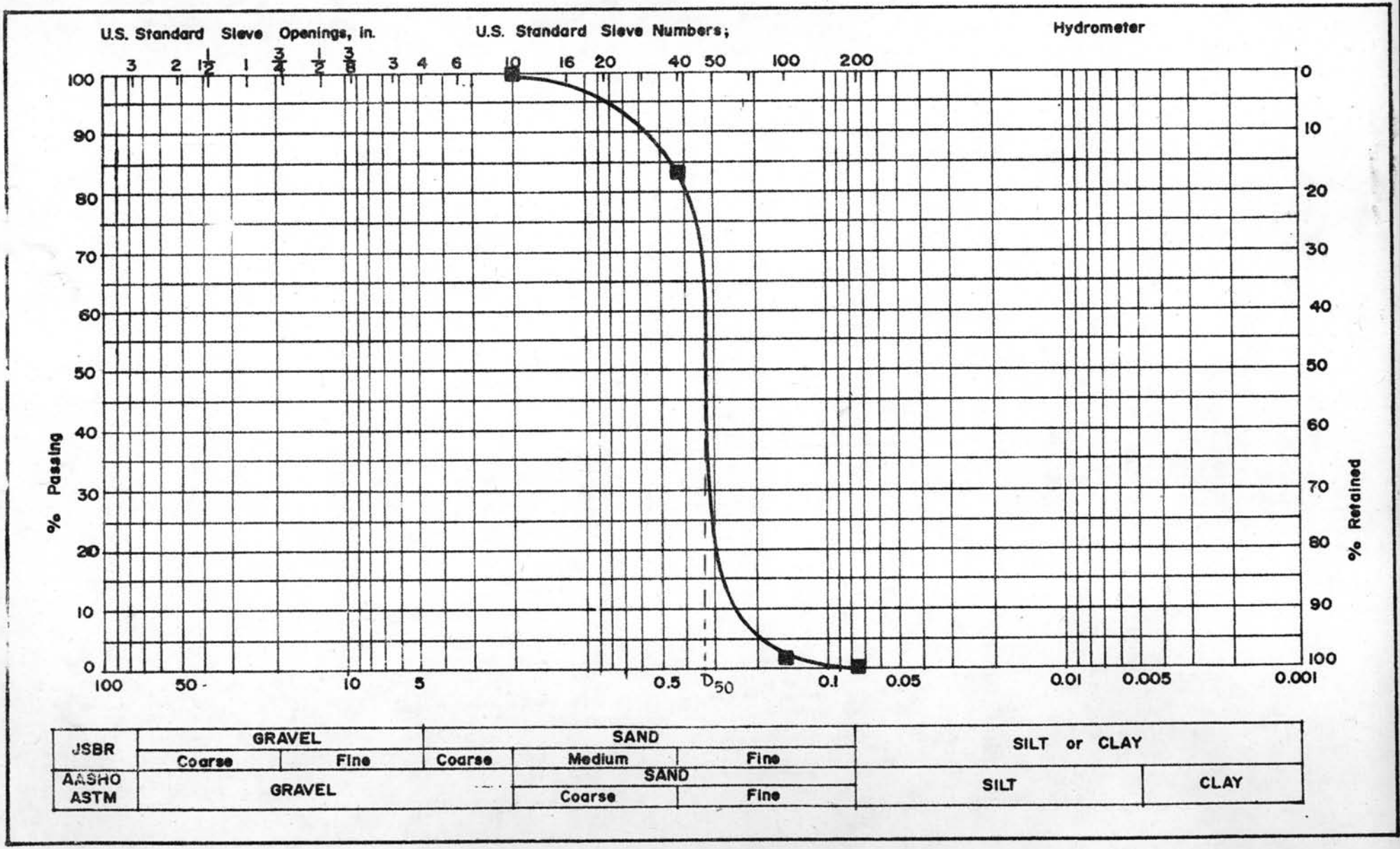

FIGURE 3. GRAIN SIZE DISTRIBUTION OF BEACH SAND

Table 1 - General Properties of Silty Sand

Property	Value
Texture Composition :	
Sand 2.000 - 0.074 mm.	76 %
Silt 0.074 - 0.005 mm.	17 %
Clay < 0.005 mm.	7 %
D50	0.19 mm.
Physical Properties :	
Atterberg's Limits	Non Plastic
Shrinkage Limits	17.4
Sand Equivalent	15
Specific Gravity	2.59
Engineering Properties :	
Maximum Dry Density *	117.7 lb/ft^3
Optimum Moisture Content *	12.75 %
Classification :	
U.S. Bureau of Public Roads	Sandy Loam
Mississippi River Commission	Silty Sand
AASHO	A-2-4
Chemical Composition :	
SiO_2	95.9 %
Al_2O_3	1.3 %
MgO	0.3 %
Fe_2O_3	0.2 %
CaO	1.1 %

* Kneading Compaction Using Harvard Miniature Compaction Method

Table 2 - General Properties of Beach Sand

Property	Value
Textural Composition :	
Sand 2.000 - 0.060 mm.	99.9 %
Silt 0.060 - 0.002 mm.	0.1 %
Clay < 0.002 mm.	0.1 %
D50	0.33 mm.
Physical Properties :	
Atterberg's Limits	Non Plastic
Specific Gravity	2.70
Engineering Properties :	
Maximum Dry Density*	96.9 lb/ft^3
Optimum Moisture Content *	14.50 %
Classification :	
U.S. Bureau of Public Roads	Sand
M.I.T. Classification	Sand
Chemical Composition :	
SiO_2	90.62 %
Al_2O_3	1.60 %
MgO	1.91 %
Fe_2O_3	2.84 %
CaO	2.10 %

* Kneading Comcation Using Harvard Miniature Compaction Method

Table 3 - Properties of SS-K Emulsion Used

Property	Specified	Measured
Test on Emulsion :		
Viscosity, Saybolt Furol, at 77°F., (25°C), sec.	20-100	37.0
Settlement, 5 days, %	5-	-
Storage stability test, 1 day, %	1-	-
Particle charge	Positive	Positive
Sieve test, %	0.10-	0.028
Cement mixing test, %	2.0-	0.02
Distillation, residue, %	57 +	65
Tests on Residue from Distillation Test :		
Penetration., 77°F, 100 g., 5 sec	100-200	133
Ductility, 77°F, 5 cm/min, cm	40+	Over 40
Solubility in Trichlorethylene, %	97+	99.9

Table 4 - Properties of Lime Used *

Analysis	Content
Calcium Hydroxide, $Ca(OH)_2$	> 90 %
Chloride, Cl	< 0.02 %
Aluminum, Iron and Acid-Insoluble	< 0.8 %
Sulphate, SO_3	< 0.5 %
Arsenic, As	< 0.0002 %
Lead, Pb	< 0.001 %

* Data based on average product, supplied by May and Baker, Ltd., Dagenham, Englnad

Table 5 - Properties of Type I Portland Cement Used **

Analysis	% by Weight
Silicon dioxide (SiO_2)	21.63
Aluminium Oxide (Al_2O_3)	5.09
Ferric Oxide (Fe_2O_3)	2.92
Megnesium Oxide (MgO)	0.91
Sulphur Trioxide (SO_3)	1.68
Loss on ignition	0.82
Insoluble residue	0.11
Tricalcium silicate ($3CaO.SiO_2$)	58.0
Tricalcium aluminate ($3CaO.Al_2O_3$)	8.6
Fineness Specific Surface (Blaine), average value	3000 cm^2/gm

** Data based on average product, supplied by the Siam Cement Company, Bangkok, Thailand.

1.4 Cement

Type I Portland cement produced by the Siam Cement Co., Bangkok, was used. The average properties of the cement are given in Table 5.

1.5 Water

Distilled water was used throughout the study in all mixtures of soil and stabilizers.

2. Sample Preparation and Testing

2.1 Preparation of Natural Soil Samples

Soil sample taken from the field were firstly air-dried at room temperature for 4 or 5 days in order to make it easy for handling. Soil samples were pulverized and then passed through a U.S. No. 10 seive to get rid of undesirable impurities, such as shells, roots, or hard lumps of soil. After pulverization and sieving, since it was found that completely air-dried soil samples were easy to be segregated during using, proper amount of distilled water was added to the soil and thoroughly mixed for 5 minutes. Moisture contents suitably used for this purpose were found to be about 4 % for silty sand and 1 % for beach sand. The mixed soils were then stored in sealed containers ready for further uses.

2.2 Grain Size Determination

The particle size distribution was determined by employing both wet and dry sieving methods. The soil samples after being soaked in distilled water for several hours with frequent stirring, were poured onto a No.200 sieve to separate the coarse and fine fractions.

The soils retained on the sieve were oven-dried for dry sieving. Hydrometer method, according to ASTM D 422-63, were carried out to analize the distribution of the fine fraction that passed through the No.200 sieve. Sodium metaphosphate at a concentrate of 40 gm/litre was used as dispersing agent.

2.3 Determination of Mixing Water Required to Produce a Uniform Mix

Trial and error method was employed to determine a minimum suitable water content to obtain a uniform stabilized mix (13).

In the case of soil-emulsion stabilization, soil particles has to be precoated with water before being mixed with emulsion. The minimum amount of mixing water required just to moisten the soil was added and thoroughly mixed with the prepared soil. Then, the various selected proportions of emulsion were added and incorporated with the moistened soil samples. By this method, the emulsion would be completely dispersed and the breaking time was prolonged. In order to obtain uniform mix, a Hobart mechanical mixer was used throughout the study for all mixing of soils and stabilizers. A uniform mixture was obtained when individual particles of soil were coated with asphalt. The quality of finished results could be judged by the uniformity of their colors, spottiness, stripping and balling denoting an unsatisfactory mix. With an amount of water added to soil, if the mixture was not uniform yet, a new sample would be prepared by using higher value of water content and quality again judged visually. Finally, after the uniform mix was obtained, the stabilized soil was oven-dried and the value of suitable minimum moisture content was then determined.

In the case of soil-lime-emulsion stabilization, lime was firstly mixed with dry soil and various selected percentages of emulsion were added later. It should be moted that the soil-lime mixture would be moistened before being incorporated with emulsion in order to obtain a uniform mix. The method of trial and error was carried out for this purpose as same as in soil-emulsion stabilization.

For soil-cement-emulsion stabilization, since the setting time of cement is the controlling factor the procedure was altered to ensure that all processing was completed before setting commenced. By this condition, soil would be uniformly mixed with emulsion before the cement was put. In mixing process of soil and various selected percentages of emulsion, the same method as in soil-emulsion stabilization was employed to find the minimum mixing moisture content. According to rather high value of mixing water content, the soil-emulsion mixture would be aerated in the oven at about 60°C to lower the water content to the required value for compaction. The soil-emulsion mixture was then mixed with cement and ready to be molded.

2.4 Compaction Curves

For determination of compaction characteristics of the soils and soil-stabilizers mixtures, several series of compaction were carried out for both silty sand and beach sand, viz., the raw soil, soil with emulsions (of various proportions), soil with emulsions and 3 % lime, soil with emulsions and 3 % cement. By using the mixing method deseribed above, the uniformly mixture of each mix were then separated into 4 or 5 batches of which the water contents

were lowered down to the different values by aerating in the oven at about 60°C. The quantity of the mixture contained in each batch should be suffecient to mold 2 specimens. The mixtures were then compacted in Harvard Miniature size mold, 1.313 in. in diameter and 2.816 in. height, in 3 layers, with a 40 lb spring tamper and 25 blows per layer. This compaction method was found to give compaction effort approximately equivalent to that of Standard Proctor (20). Specimens for unconfined compression test and triaxial compression test were also prepared by using this method of molding.

2.5 Relationship between Strength and Molding Water Content

The specimens for this study were of those prepared for compaction curve determination. After compaction, the specimens were extruded, weighed to nearest 0.01 gm and measured for diameter and height to the nearest 0.001 in. The specimens were then cured in sealed plastic bags for 1 day at room temperature. These cured specimens were tested for compressive strength by the unconfined compression test. The triaxial apparatus was employed for testing by using zero confining pressure. Load was applied at a rate of deformation of 0.03 in/min. until failure. The max. test load causing failure of the specimen was taken as its compressive strength. The test results reported are the average of two specimens.

2.6 ffects of Curing Time and Curing Type on Shear Strength of Stabilized Soils

All specimensfor this study were prepared by the following processes.

2.6.1 Mixing. A quantity of soil sufficient to mold 30 specimens for each mixture was mixed with selected quantity of emulsion, emulsion and 3 % lime, or emulsion and 3 % cement, by using the suitabe water content obtained from section 2.3. Both methods of mixing and lowering the water content to that for compaction, were the same as those for determining the compaction curves. Table 6 presents the proportions of stabilizers selected for mixing with silty sand and beach sand for each type of stabilization. The percentage of stabilizers shown in the table based on oven-dried weight of soil.

Table 6 - The Proportion of Stabilizers Used for Mixing with Soils

Soils	Stabilizers, %		
	Emulsion	Lime	Cement
Silty Sand or Beach Sand	5	-	-
	4	-	-
	4	-	3
	3	-	-
	3	3	-
	3	-	3
	-	3	-
	-	-	3

2.6.2 Molding. The specimens were molded by the same method as that for obtaining compaction curves. Thirty specimens of each type of mix were compacted by using only one value of water

content which was reasonably selected from the results of previous experiment of unconfined compression test. Also the same method of aeration was employed to lower the water content from the value for mixing to that for compaction.

2.6.3 Curing. After extruding, weighing and measuring their sizes, the specimens were cured in sealed plastic bags at room temperature for different curing periods of 1,3,7,15 and 30 days. For each type of mix, so, there would be six specimens for a period of curing.

For evaluating the effects of different curing methods, three series of stabilized silty sand, viz., silty sand with 5 % emulsion, silty sand with 3 % lime and 3 % emulsion, silty sand with 3 % cement and 3 % emulsion, were selected to be prepared and cured by two curing methods of which the first one was that as stated above, and the other was air-dried curing.

2.6.4 Testing. Two or three of six cured specimens were tested by unconfined compression test while the remainders were subjected to triaxial compression test. Both testing methods were carried out by using the same triaxial apparatus as that for unconfined compression test of section 2.5. All specimens were also deformed at a constant rate of deformation of 0.03 in/min. In the case of triaxial compression test, since the traffic load applied on the pavement structure is so rapid that most of fluid in pore can not escape and just little or no consolidation of compacted layer occurs, it is considered desirable to evaluate the strength envelope by the method of unconsolidated-undrained test without measurement of pore

pressure. Varying cell pressure (between 0 and 80 psi) were applied to identical specimens so that the apparent cohesion, Cu, and the angle of shearing resistance, ϕ_u, could be determined.

A dial gauge reading in $\frac{1}{1000}$ in. division was used to indicate strain, and at the end of each 25 division interval a reading on the load dial was taken. After 300 divisions of deformation the frequency was decreased to 50 division intervals, and later to every 100 division when the strain reading was more than 1,000 divisions. Load was applied to each specimen until failure or at least to about 15 % strain for such specimens that has no peak value of load readings.

Owing to the change in cross-sectional area of the specimen, the formula, $A = \frac{Ao}{1-\epsilon}$, was employed to compute the cross-sectional areas at various values of strain. After computing the deviator stresses, the stress-strain curves were plotted and the maximum deviator stress of each specimens was obtained. For some specimens having no peak no stress-strain curve the value at 12 % strain was considered to be the failure stress. Then, three of four Mohr circles were drawn and the straight lime that best fitted the results was taken for the purpose of determining Cu and ϕ_u