STITUTE OF TECHNOLOGY

APPLIED SCIENTIFIC RESEARCH CORPORATION OF THAILAND

COOPERATIVE RESEARCH PROGRAMME NO. 19

STABILIZED SOIL AS A MATERIAL OF CONSTRUCTION

RESEARCH PROJECT NO. 19/3

LABORATORY EXPERIMENTS IN THE STABILIZATION OF SOILS WITH CEMENT

REPORT NO. 1

CEMENT STABILIZATION OF SOME PLASTIC AND SILTY CLAYS

BY

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MATERIALS OF CONSTRUCTION GROUP

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CEMENT STABILIZATION OF SOME PLASTIC AND SILTY CLAYS

By Milan M. Pajevic,* Chin Yun Pin* and Preecha Disthatian*

SUMMARY

An experimental investigation on the response of two selected soils to stabilization by Portland cement is reported. Effects of sand content in the mix and cement concentration were investigated. Some effects of moisture content and density at compaction were also observed and further studies recommended.

Results showed that Bangkok clay mixed with sand in proportion of 41.5 per cent of clay and 58.5 per cent of sand by weight and silty clay of the type prevailing in the north-eastern part of Thailand can be economically stabilized.

INTRODUCTION

A. Objective of the study

The solution of the housing problem in developing countries depends in the first place on the wide-scale construction of low-cost dwellings. The most important component of the construction cost is the cost of material and special efforts are therefore needed in introducing now, cheaper, locally available materials.

One of the materials to be considered in this context, particularly in the case of "self-aid" schemes, rehabilitation programmes, and other similar projects based on free or very cheap labour, is stabilized soil.

Use of soil as a construction material dates from more than twenty centuries ago. Simple compacted soil is however vulnerable to moisture and to the erosive effect of natural agents, and the contemporary use of soil for housing construction is therefore almost entirely based on stabilized soil. The preparation of stabilized soil involves: classification, selection, and preparation of components; mixing of the components; compaction of the mixture; and drying and curing. Manufacturing and testing techniques are very simple and easy for anyone to learn, and the equipment inexpensive.

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Cement-stabilized soils, although used for a very long time in many countries, have not so far been used on a larger scale for housing in Thailand. One of the reasons for this is the poor quality of soil found in Bangkok and the densely populated central plain of Thailand. Plastic, shrinkable clays with a low sand content are not suitable for soil stabilization. In the Bangkok area the price of cheap sand differs very little from that of clay, and an attempt has therefore been made in this investigation to find the optimum mixture of these two materials.

The use of stabilized soil for low-cost housing construction has the best chances for success in the less developed north-eastern Thailand. The second soil selected for this investigation was therefore silty soil found to be prevalent in this area.

With the above mentioned matters in mind, the following are outlined as the primary objectives of this study:

(1) To investigate the physical behaviour of sand-clay mixes and silty clay stabilized with Portland cement.

(2) To study whether the selected soils can be stabilized with economical amounts of cement.

(3) To examine the suitability of cement treated sand-clay mixes and silty clay for use in manufacture of blocks in low-cost housing constructions in Thailand.

B. Mechanism of soil-cement stabilization

Stabilization of soil with cement consists in adding Portland cement to a moistened pulverized soil, and permitting the mixture to harden. It is necessary that the soil be cured so that the hardening process can take place. During the curing process, the material must be kept moist, and evaporation held at a minimum.

There are two general categories of soil-cement. These are characterized by the presence or absence of a skeleton of gravel and sand or sand-size materials. With such a skeleton present, the stabilized soil is akin to concrete. In a system lacking a course granular skeleton, the particles that are cemented are secondary, natural or artifical structural units that consist of aggregates of clay, silt, and even sand particles. With cohesive soils, an important part of the mechanism may be the hardening of the clay aggregation due to the presence of lime liberated as a result of the hydration of cement.

In fine-grained, silty, and clayey soils, the cement on hydration develops strong linkages among the mineral aggregates and the soil aggregates to form a mould that encases the soil particles. In this way the particles are fixed; they can no longer slide over each other, and, as a result, the shear strength increases. The chemical effect of cement on their surface reduces the water affinity and thus the water holding capacity of clayey soils. The combination of reduced water holding capacity, reduced water affinity and strong matrix provide an encasement of the larger unpulverized raw aggregates. Because of its strength and reduced water affinity, this encasement serves to protect the aggregates and to reduce the swelling and softening due to absorption of the moisture (Davidson 1961). The chemical properties of soil are the main factor that affects the degree of reaction between the hydrating cement and the soil component (Handy 1958; Herzog and Mitchell 1963).

C. Factors affecting cement stabilization

The structural properties of soil-cement mixtures depend on many factors. These factors can roughly be divided into two groups: those dependent on materials and those dependent on processing methods.

Among the most important are:

- Physical and chemical properties of soil and cement.
- Cement content of the mixture.
- Moisture content of the mixture at the time of compaction.
- Density of the compacted mixture.
- Method of curing and age of specimens.

MATERIALS

A. Soils

(1) Soil quality requirements

Montero (1961) states that any clay which has both a liquid limit greater than 40 per cent and a shrinkage limit less than 12 per cent, or any clay with a liquid limit greater than 60 per cent, is a material of high potential expansiveness.

According to Indian Standard IS:1725-1960, soils satisfying following requirements will produce good quality soil-cement blocks:

(a) The soil should have a plasticity index between 7 and 12.

(b) The fraction of soil passing through IS sieve 40 and retained on IS sieve 8 should not be less than 33 per cent of the total fraction passing through IS sieve 40.

(b) The fraction retained on IS sieve 200 should not be more than 20 per cent and the maximum size of the granular material should not exceed 20 mm.

(d) The sulphate content of the soil, expressed as sodium sulphate, should not be more than 0.2 per cent.

(e) The organic matter should not exceed 0.3 per cent.

The paper "Soil-cement, its use in building" (United Nations 1964), recommends as the optimum proportion for soil-cement, 75 per cent sand and 25 percoent silt and clay. The content of clay included in the latter percentage should not be less than 10 per cent. Broadly speaking, the soils considered su suitable for soil-cement construction work are those containing a minimum of 45 per cent sand with 55 per cent silt and clay and a maximum of 80 per cent san with 20 per cent silt and clay.

Soil containing a percentage of clay higher than a certain limit has, when dried a strong tendency to crack and shrink with variations of moisture Stabilization of clayey soil is possible but costly for the following reasons:

- A greater amount of cement is needed.
- Pulverization of clay is a very slow process.
- It is difficult to moisten the mixture of clay and cement owing to the formation of clods.

One way of overcoming these difficulties is to add a carefully measured amount of sand to the clayey soil. The resulting mixture can meet the criteria for ideal soils.

(2) Selected soils

Two types of have been selected for this investigation. The first one designated BC is a Bangkok clay. Bangkok clay, which is found in the central plain area of Thailand as well as in many other South-east Asian regions, is a fine grained clay of brownish black colour with a high plasticity index. The sample was obtained at the site of the Heavy Duty Laboratory of ASRCT from a depth of about 0.5 metre.

The second chosen soil, designated SC is silty clay belonging to the A-4 group occurring prominently in north-eastern Thailand (Anuphan Bunnag, unpublished data, 1966). The sample was obtained in the Don Muang area from the depth of about 0.5 metre.

The properties of two soils are given in Table 1. The data on grain-size distribution of the soils are shown in Figures 1 and 2.

TABLE 1

PROPERTIES OF SOILS STUDIED

Soil properties	Bangkok clay BC	Silty clay SC
Textural composition :		
Sand (2.0-0.074 mm), %	5.2	11.5
Silt (0.074-0.005 mm), %	34.8	62.5
Clay (0.005 mm), %	60.0	26.0
Classifications:		
Textural (USBPR)	Clay	Silty clay
Engineering (AASHO)	A-7-6(8)	A-4 (8)
Physical properties:		
Liquid limit, %	64.0	25.2
Plastic limit, %	30.8	22.4
Plasticity index, %	33.2	2.8
Specific gravity, g/cm^3	2.76	2.85
Activity *	1.95	0.07
Optimum moisture content, %	25.9	14.8
Max. dry density, g/cm^3	1.50	1.68
Chemical properties:		
pH	5.4	4.2
Organic matter content, %	1.12	1.24
Soluble sulphates, %	0.25	0.07

$$\text{* Activity} = \frac{\text{Plastic Index}}{(-2\,\mu)\ \text{Clay content}}$$

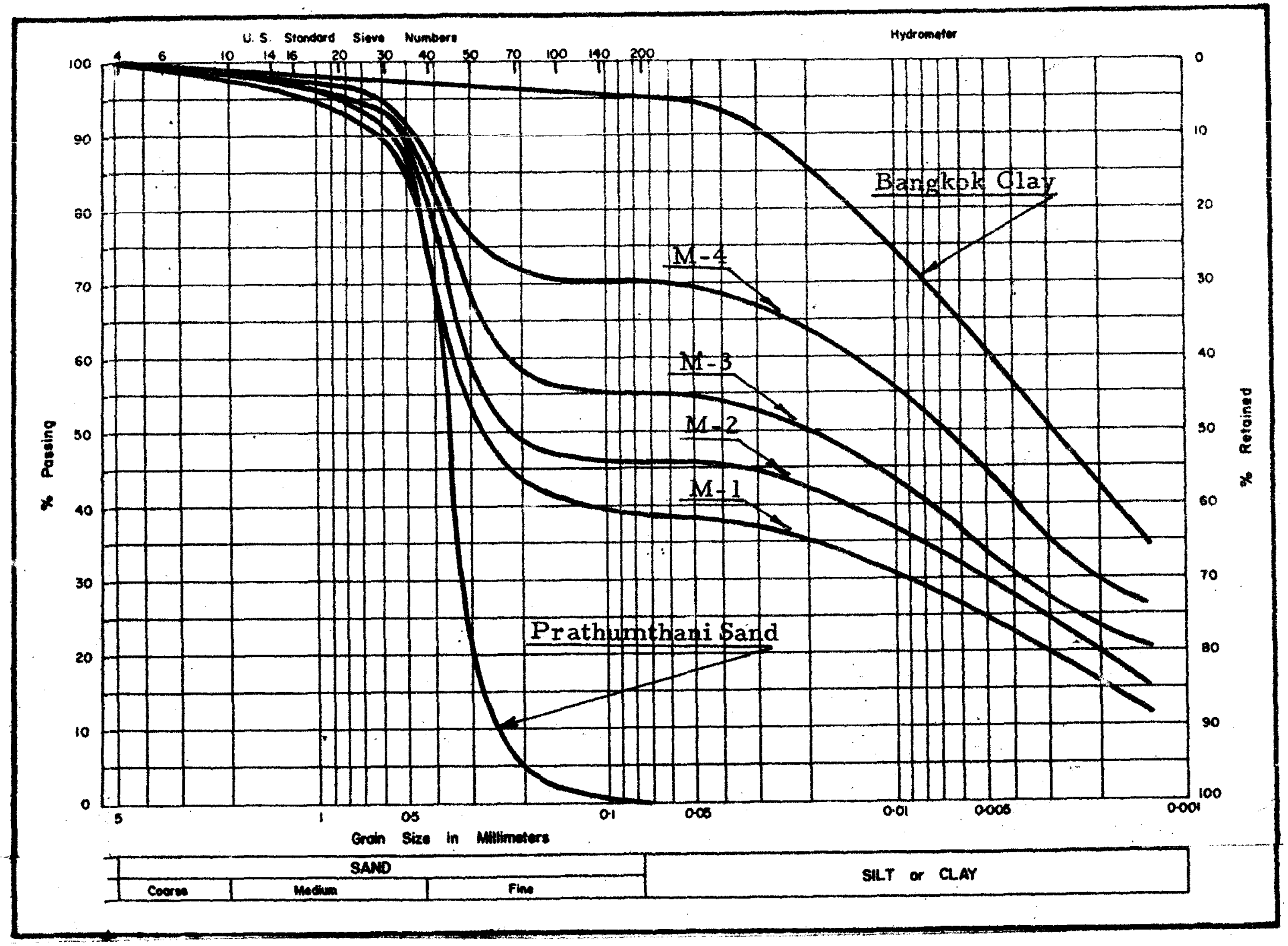

Figure 1. Grading curve of Bangkok clay mixed with and without Pathum Thani sand.

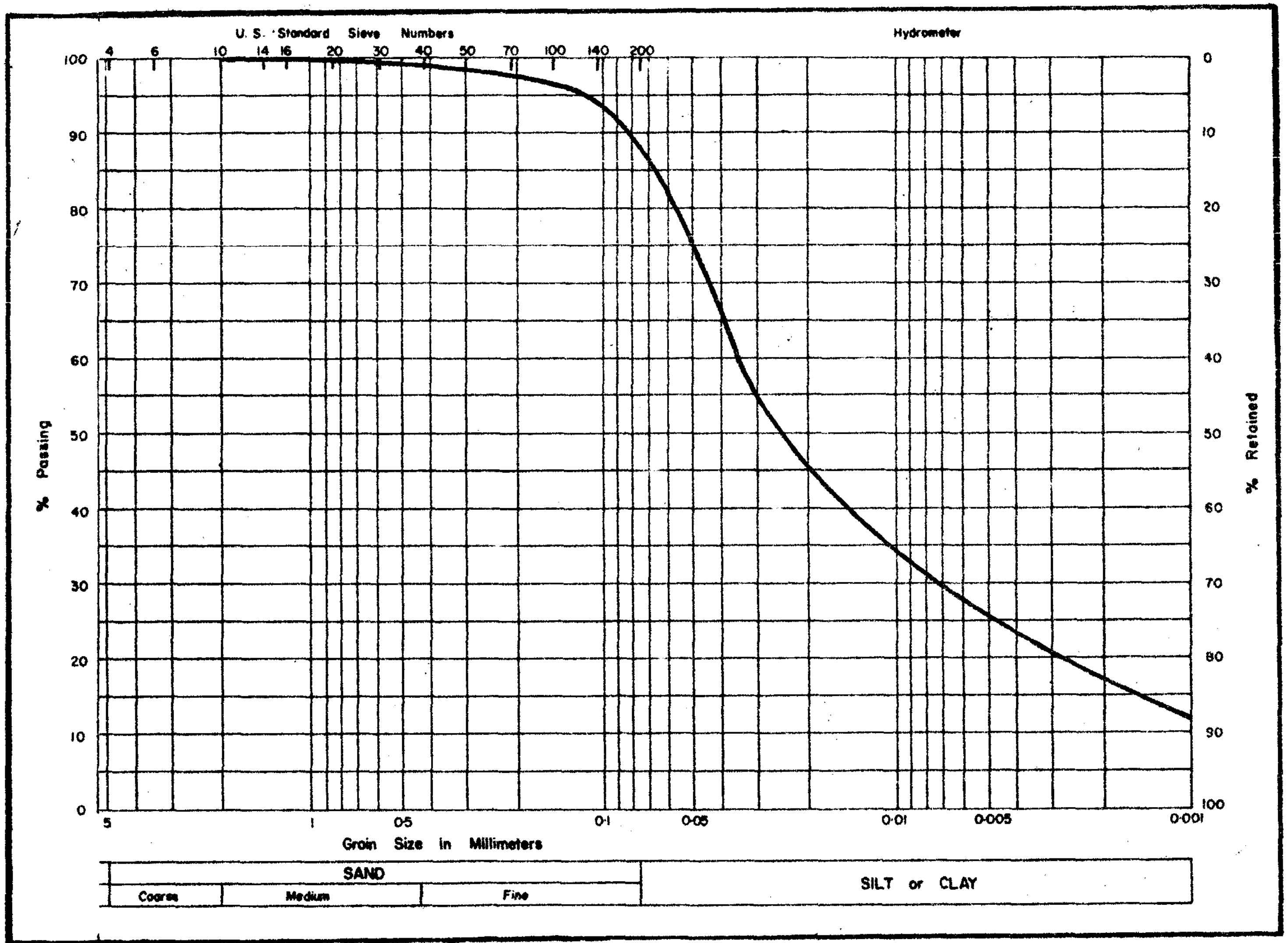

Figure 2. Grading curve of Don Muang silty clay.

(3) Soil-sand mixes

The composition of the soil-sand mixes was based on volume ratio rather than weight ratio, with the thought that the batching will in practice, in the greatest number of cases, be done by using measuring boxes, i.e. by volume. For the sake of accuracy, however, the volume ratios have been expressed as their weight equivalents.

Four soil-sand mixes were selected for study:

Designation	Soil-sand ratio by volume	Soil-sand ratio in % by weight
M-1	3 : 4	40.8 : 59.2
M-2	1 : 1	53.0 : 47.0
M-3	3 : 2	43.8 : 57.2
M-4	3 : 1	73.8 : 26.2

B. Sand

For the purpose of this investigation, commercially available sand from Pathum Thani, designated PS, was selected as stabilizer No. 1 for the Bangkok clay. Main reason for the selection of this sand was its low price. The cost of this sand (which is mainly used for filling) is between 25 and 30 baht per cubic metre, while the cost of soil of purchased in the Bangkok area amounted to about 20 baht per cubic metre. Sieve analysis for the Pathum Thani sand is given in Table 2 and is graphically presented in Figure 1.

TABLE 2

SIEVE ANALYSIS OF PATHUM THANI SAND

U.S. standard sieve no.	Sieve opening mm	Per cent retained	Cumulative per cent retained	Per cent finer
4	4.760	0	0	100.0
8	2.380	1.3	1.3	98.7
16	1.190	3.8	5.1	94.9
30	0.590	3.0	8.1	91.9
50	0.297	72.6	80.7	19.3
100	0.149	16.4	97.1	2.9
200	0.074	2.5	99.6	0.4

F.M. = 1.92 Sp. gr. = 2.62

C. Cement

The Siam Cement Company's "Tiger" brand cement was used throughout all the tests. Results of physical and chemical tests are shown in Table 3. Until required for use, cement was stored in sealed steel drums. Four different percentages of cement were tried with the soils used, i.e. 2, 6, 10, and 14 per cent by dry weight of soil or clay-sand mix.

TABLE 3

CHEMICAL AND PHYSICAL TESTS OF CEMENT *

Chemical analysis, %	
Loss	1.32
SO_3	1.53
MgO	0.86
SiO_2	40.54
Al_2O_3	4.33
Fe_2O_3	2.43
CaO	44.88
Na_2O	0.11
K_2O	3.61
Physical tests:	
Autoclave expansion, %	0.05
Initial set +, h:min	2:25
Final set, h:min	3:20
Compressive strength ‡, kg/cm^2	
3 days	96
7 days	138
8 days	190
Flexural strength, kg/cm^2	
3 days	26
7 days	33
28 days	42

* Siam Cement Co. "Tiger" brand, silica cement.

\+ Vicat method

‡ RILEM-CEMBUREAU method

PREPARATION OF TEST SPECIMENS

A. Preparation of soils

Soil samples were first air-dried in shallow layers. The clods were then broken up and the soil pulverized with a wooden hammer. Pulverized soil was screened through the U.S. standard screen No. 4 consisting of a 4.76 mm wire mesh in a wooden frame (Figure 3). The screened material was stored after quartering in 200-litre steel drums. The moisture content of the air-dried soil was determined prior to using the sample contained in each drum.

B. Manufacture of soil-cement blocks

Dried and screened soil or sand-clay mix in a proportion selected on the basis of trial mixes, sufficient to produce twenty blocks of the size 9 x 14 x 29 cm, was first measured and spread out in a thin layer on the "mixing base". The measured quantity of cement was then sprinkled uniformly over the layer of soil and mixed until all the material has taken a uniform colour (Figure 4). When the dry soil and cement was thoroughly mixed, the mixture was again spread in a shallow layer and water sprinkled on it from a watering can until the moisture was distributed uniformly. The amount of water added was determined from preliminary experiments as that needed to give maximum unit weight.

The mixture of soil-cement, moistened with a proper amount of water was compacted in the CINVA-RAM mechanical moulder. The CINVA-RAM block press is a simple, low-cost, portable machine. It is made entirely of steel. The press has a mould-box where a hand-operated piston compresses a mixture of soil and cement. The press was developed by the Housing Research Centre (CINVA)* of the Organization of American States in Bogota, Colombia and has gained considerable popularity during the last decade. According to an article in the Reader's Digest of May 1964 (Anon. 1964), until 1964 about 12,000 of these presses were in operation. Figure 5 shows some of the soil-cement masonry elements which can be made by using the CINVA-RAM press.

The block making process was started by inserting some loose, moist soil-cement mixture into the moulder (Figure 6). The cover was than closed, the lever swung into its vertical position, and the catch was raised to enable compaction to begin (Figure 7). As the lever of the moulder was lowered, the piston slid part of the way up, producing its maximum pressure with the lever in a horizontal position (Figure 8). When the block was completed, it was

* Centro Interamericano de Vivienda.

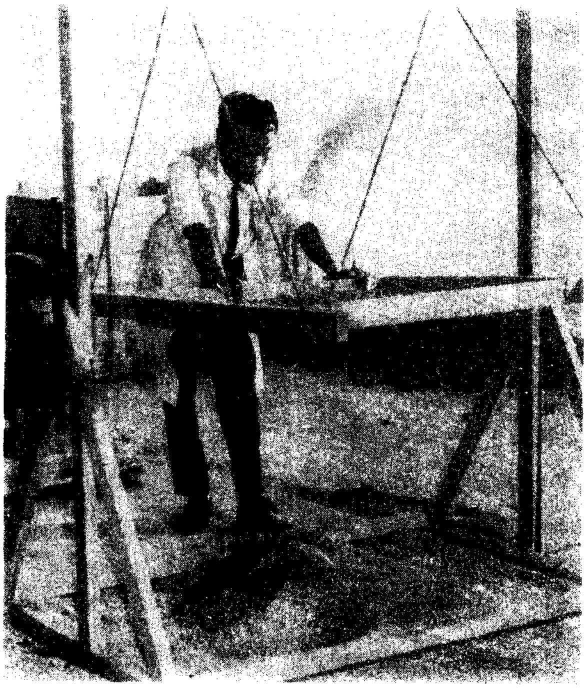

Figure 3. Screening pulverized soil.

Figure 4. Mixing cement and soil.

Figure 5. Some soil-cement masonry elements.

Figure 6. Inserting cement-soil mixture in moulder.

Figure 7. Swinging moulder lever to vertical position to allow compaction to begin.

Figure 8. Lowering lever to horizontal position for maximum pressure.

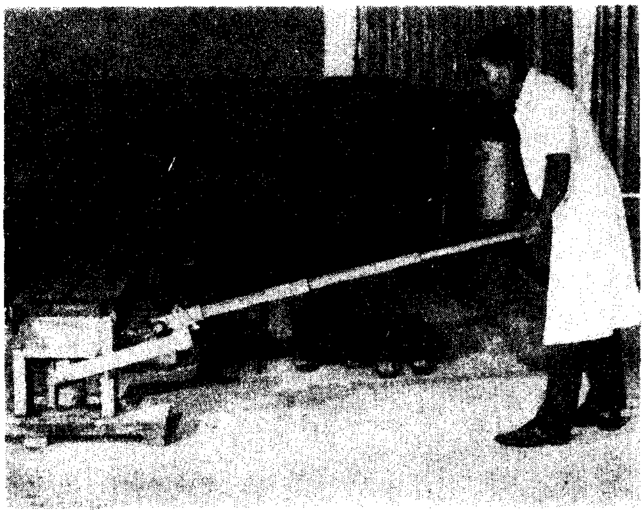

Figure 9. Swinging lever to opposite horizontal position to release block.

Figure 10. Removing block from moulder.

Figure 11. Watering blocks after first 24 hours.

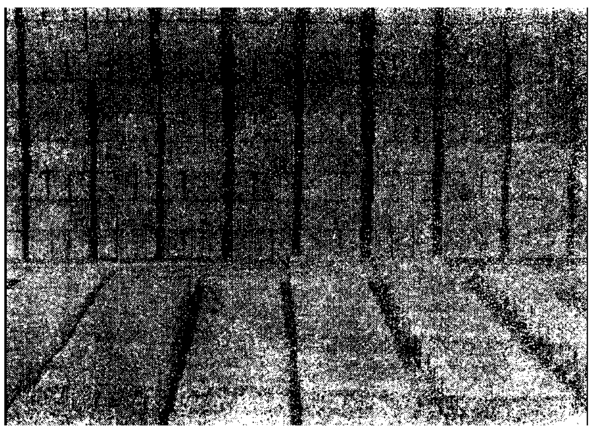

Figure 12. Blocks are stacked on third day for further spraying.

it was removed from the mould by turning the lever in the oposite direction until it was again horizontal, but on the other side (Figure 9). In this position, the piston has reached its maximum height pushing the block upwards and releasing it on top of the moulder box.

C. Curing of blocks

Immediately following removal from the press (Figure 10), the blocks were weighed and the unit weight recorded. All blocks were then stored in the heavy duty hall at 27° ± 5°C. During the first twenty-four hours the blocks were covered with jute bags and sprinkled with water at frequent intervals to prevent sudden loss of moisture. After the first twenty-four hours, the blocks were uncovered and watered regularly with a watering can (Figure 11). On the third day after they are made, the blocks were stacked and spraying was continued until the end of eight days (Figure 12).

When made in practice the blocks are after the eighth day air-cured until the twenty-first day, when they can be used for construction. In this investigation however, after the eighth day the blocks were air-cured until the twenty-sixth day and then damp-cured for a period of at least 48 hours prior to testing which was always twenty eight days after making of the blocks. (Indian Standard IS:1725-1960).

In order to study the effect of curing conditions two additional series of blocks were made and cured under conditions different from those already described. The blocks of the first series were instead of 48 hours damp curing, completely immersed in water for 24 hours prior to testing and tested wet. Curing conditions of the third series were modified in such a way, that the blocks were after air-curing oven-dried and then immersed in the water for 24 hours prior to testing.

TEST PROCEDURE

A. Soil gradation

The percentages of gravel, sand, and silt were determined by using the standard procedure, i.e. by sieving for the larger grain sizes and by the sedimentation process for finer particles. Gradation of soils passing the screen No. 200 (0.074 mm) was determined by using a hydrometer (ASTM Standard D422-63).

B. Atterberg limits

The Swedish scientist Atterberg established "limits" between the states of soil consistency. He gave the name "liquid limit" to that separating the liquid and plastic states; "plastic limit" to that between the plastic and soft solid; and "shrinkage limit" that separating the soft solid from the hard state. For the purpose of this investigation only liquid and plastic limits were determined.

The liquid and the plastic limit were determined using standard ASTM methods, described for liquid limit in ASTM Standard D423-66 and for plastic limit in ASTM Standard D424-59.

C. Specific gravity

The specific gravity of soils was determined using the method described in ASTM Standard D854-58 (1965).

D. Compaction

This test, also called the moisture-density relation of soil-cement mixtures, is used to determine the relationship between the moisture content and the density of soil-cement mixtures. The moisture content corresponding to the peak of the curve obtained by plotting different densities and corresponding moisture contents is termed "optimum moisture content", under the compaction prescribed in the standard method. The dry unit weight, in grammes per cubic centimetre of the soil-cement mixture at "optimum moisture content" is termed "maximum density".

The compaction test was carried out in accordance with the ASTM Standard D559-57 (1965) method.

E. pH-value

The pH-value of soils was determined using the standard electrometric method described in B.S. 1377:1961, Part 3, Section 3.

F. Organic matter content

The determination of the percentage by weight of organic matter present in examined soils was carried out in accordance with the standard chemical method described in B.S. 1377:1961, Part 3, Section 1.

G. Sulphate content

The water-soluble sulphate content of soils was determined by using the B.S. 1377:1961 chemical method (Test 8).

H. Moisture absorption

The moisture absorption of soil-cement blocks was determined using Indian Standard IS:1825-1960 test method. For each determination, five blocks were oven-dried at $110^{\circ} \pm 5^{\circ}C$ for 24 hours and weighed. Specimens were then completely immersed in clean water at room temperature and allowed to remain in this state for 24 hours. After immersion specimens were taken out, wiped with a damp cloth and weighed. The percentage water absorption was calculated from the difference in weights of the specimens after 24 hours immersion and dry specimen.

I. Compressive strength

The compressive strength was determined for all soil-cement blocks at the age of 28 days. Ten 9 x 14 x 29 cm blocks were used as a sample for each determination.

The specimens, which were prepared for test by pressing and curing described in Sections 3 B and 3 C, were placed between 2 three-ply plywood sheets each approximately 3 mm thick and centred between the plates of the 60-tonne compression testing machine. The rate of loading was about 14 kg/cm^2 per minute. The specimens were loaded until failure.

5. RESULTS AND DISCUSSION

A. Basic property tests

(1) Plasticity

The increase of sand content in the soil-sand mixture resulted in the decrease of liquid limit and plastic limit as well as in the decrease of the plasticity index as shown in Tables 4, 5 and Figures 13 and 14. This phenomenon can be explained by the fact that the sand stabilizer is a non-plastic material.

According to the Indian Standard IS:1725-1960, in order to produce good quality soil-cement blocks the soil should have a plasticity index between 7 and 12. From Figure 14 one can see that only mix M-2 consisting of 48.5 per cent sand by weight or a proportion 1:1 by volume satisfies this requirement.

TABLE 4

PROPERTIES OF THE BANGKOK CLAY-PATHUMTHANI SAND MIXES

Mix properties	M-1 BC % 41.5 PS % 58.5	M-2 BC % 48.5 PS % 51.5	M-3 BC % 58.5 PS % 41.5	M-4 BC % 73.8 PS % 26.2
Textural composition: %				
Sand (2.0-0.074 mm)	60.3	54.0	44.5	29.8
Silt (0.074-0.005 mm)	15.7	16.5	21.5	25.7
Clay (0.005 mm)	24.0	29.5	34.0	44.5
Classifications:				
Textural (USBPR)	sandy clay loam	sandy clay loam	clay	clay
Engineering (AASHO)	A-4 (1)	A-4 (4)	A-6 (11)	A-6 (10)
Physical properties:				
Liquid limit, %	27.7	30.7	38.6	40.5
Plastic limit, %	21.6	22.4	25.5	23.7
Plasticity index, %	5.1	8.3	13.1	16.8
Specific gravity, g/cm^3	2.68	2.69	2.71	2.73
Max. dry density, g/cm^3	1.78	1.74	1.68	1.62
Optimum moisture content, %	16.0	17.3	18.0	18.8
Activity	0.33	0.42	0.57	0.56

TABLE 5

EFFECT OF CEMENT CONTENT ON PLASTICITY INDEX OF SILTY CLAY

Soil properties	Cement content %				
	0	2	6	10	14
Liquid limit, %	25.2	26.0	26.0	25.0	24.8
Plastic limit, %	22.4	21.4	22.1	22.2	21.7
Plasticity index, %	2.8	4.6	3.9	2.8	3.1

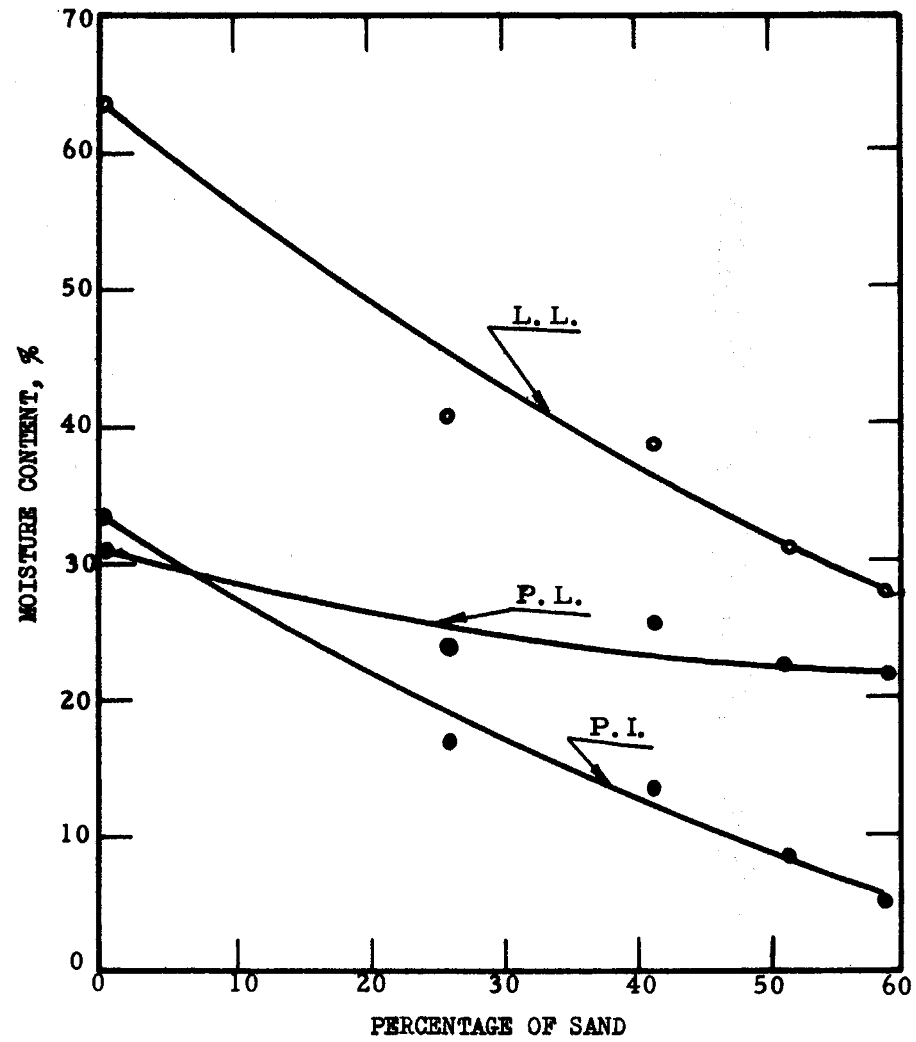

Figure 13. Relationship of liquid limit, plastic limit, and plasticity index v. percentage of sand. (Bangkok clay - Pathum Thani sand)

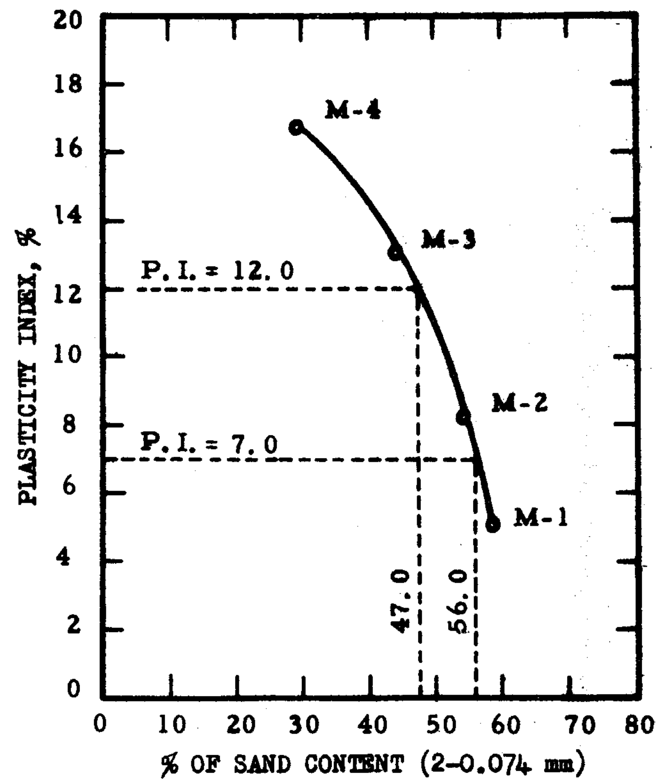

Figure 14. Effect of sand content of Bangkok clay-Pathum Thani sand mixture on plasticity index.

Other mixes containing sand in the range between 47 to 56 per cent by weight would also satisfy this condition. Mix M-2 was therefore selected for further experiments in soil-cement block making.

The dry density of the silty clay practically did not change upon addition of cement. The addition of 14 per cent of cement resulted in only 2 per cent decrease of the dry density of non-stabilized clay. The addition of cement caused only a slight increase of the optimum moisture content (Figure 15).

(2) Activity

The term "activity" is defined as the ratio of the plasticity index of a soil to the per cent clay content (2-micron clay). Since the activity reflects the physico-chemical properties of soil, it may be expected that the higher the activity, the lower will be the strength of a mixture at a given cement concentration (Bjerrum 1954; Moh 1967).

From Table 4 one can see that the mix M-1 (41.5 per cent clay and 58.5 per cent sand by weight) has the lowest activity. Mix M-1 also gives the highest dry density for the optimum moisture content (Figure 16). This mix was, therefore, also selected for further investigation on soil-cement blocks.

B. Soil-cement block testing

(1) Effect of cement content on compressive strength

One of the objectives of this investigation was to find the amount of cement needed to stabilize effectively soil-cement blocks. As a criterion for the compressive strength requirement the study has adopted a minimal strength of 18 kg/cm^2 at 28 days after casting, as recommended by the Indian Standard IS:1725-1960, "Specification for soil-cement blocks used in general building construction". Based on this criteria, cement contents of 2, 6, 10 and 14 per cent by dry weight of soil were used in this study. Soil-cement blocks were compacted in the CINVA-RAM press to maximum dry density and optimum moisture content and moist cured for 8 and 28 days after pressing. Table 6 and Figure 17 show the effect of cement content on the compressive strength of stabilized soils. It is noted that compressive strength increases with the cement content. The gain in strength also varies with the properties of the soil. The minimum amount of cement required for soil-cement block manufacture could be estimated from Figure 17. Minimum cement requirement of silty clay, sand-clay mix M-1 and sand-clay mix M-2 pressed at optimum moisture content

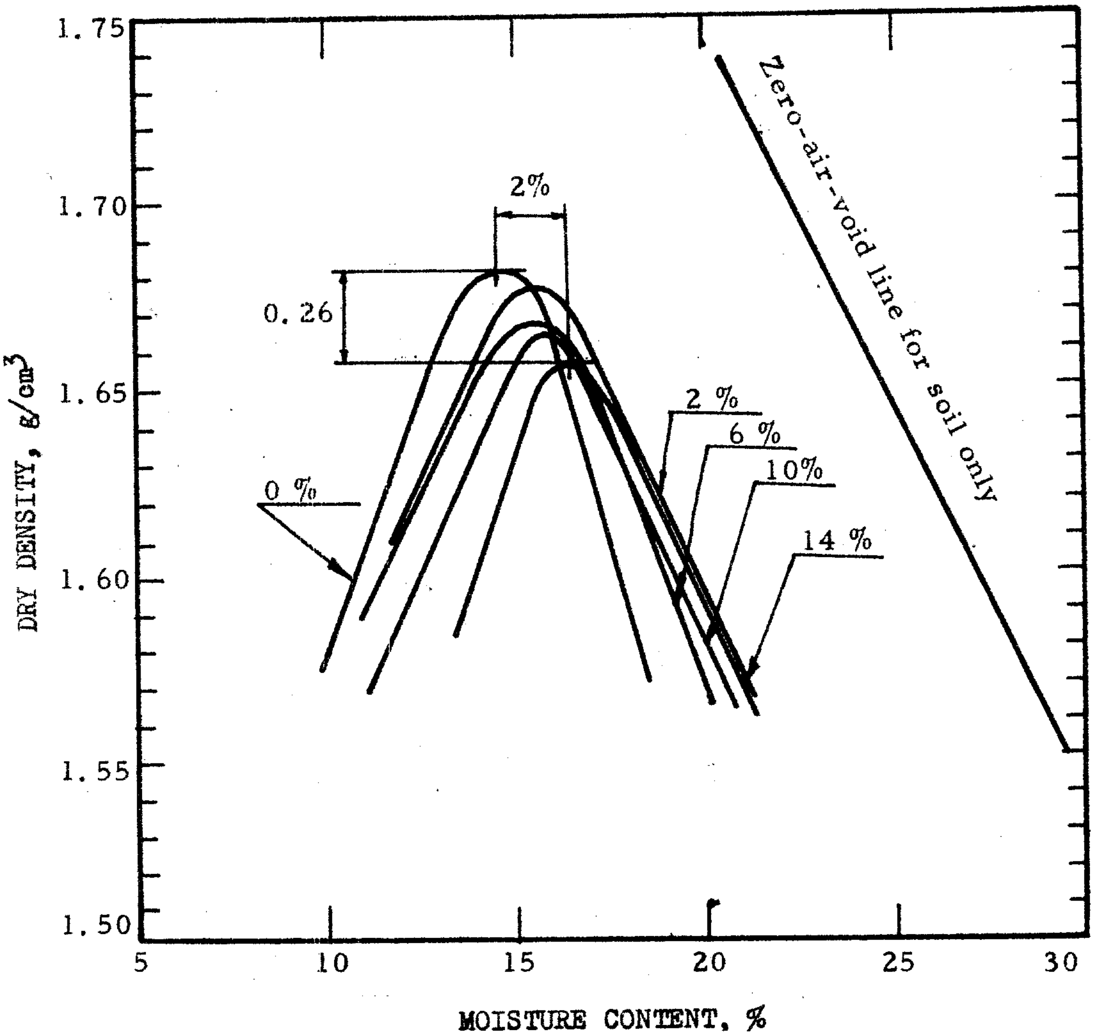

Figure 15. Effect of moisture content on dry density of silty clay stabilized with cement and unstabilized.

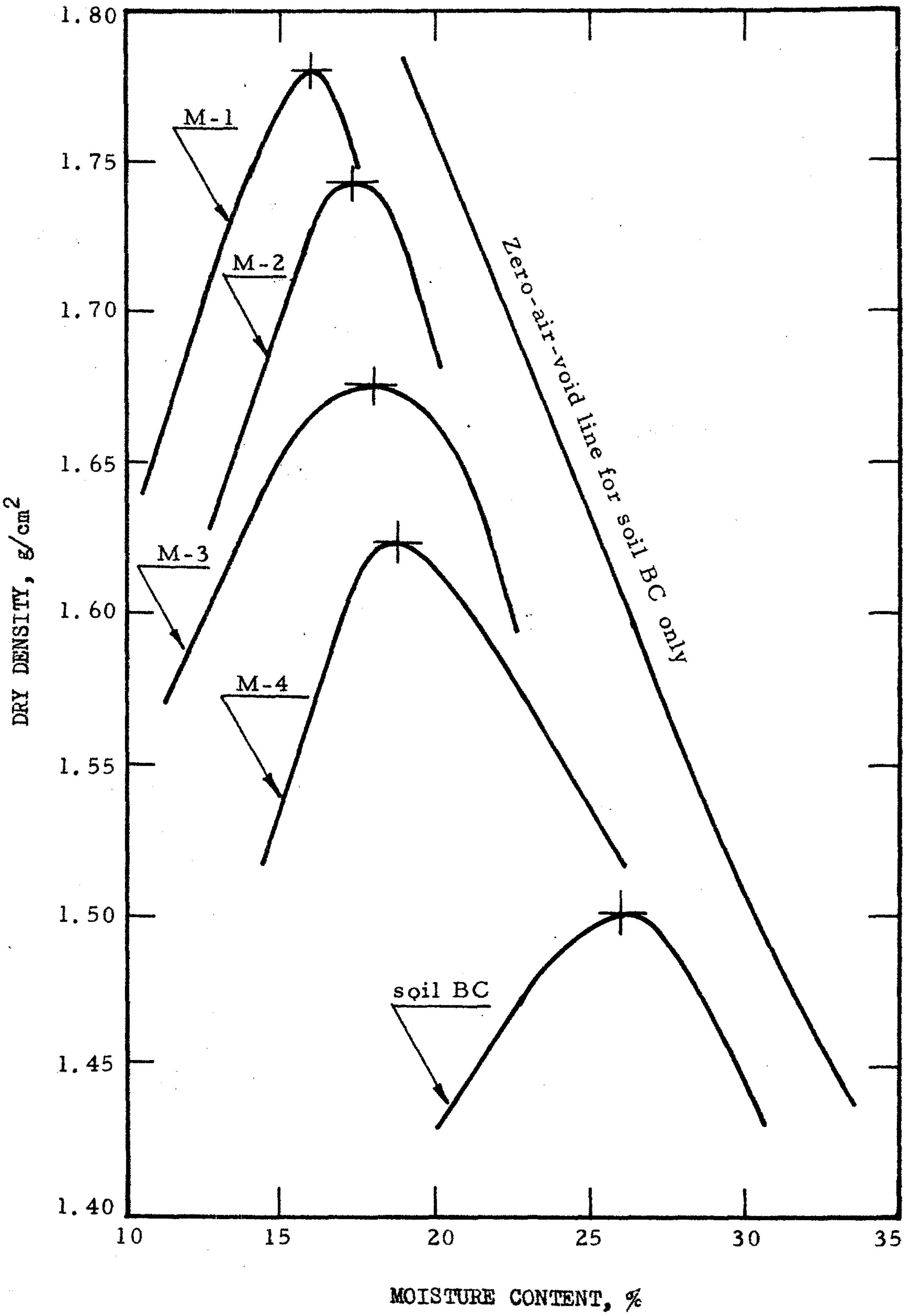

Figure 16. Effect of moisture content on dry density of Bangkok clay mixed with Pathum Thani sand and unmixed.

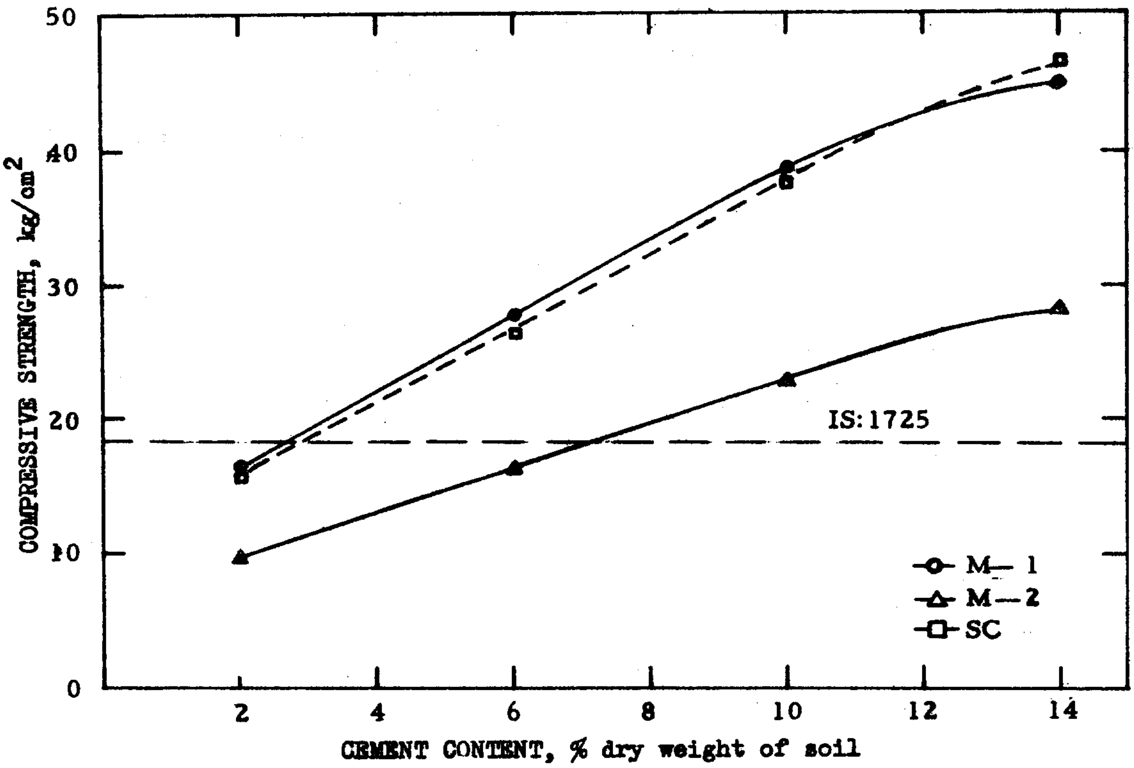

Figure 17. Effect of cement content on compressive strength at optimum moisture content.

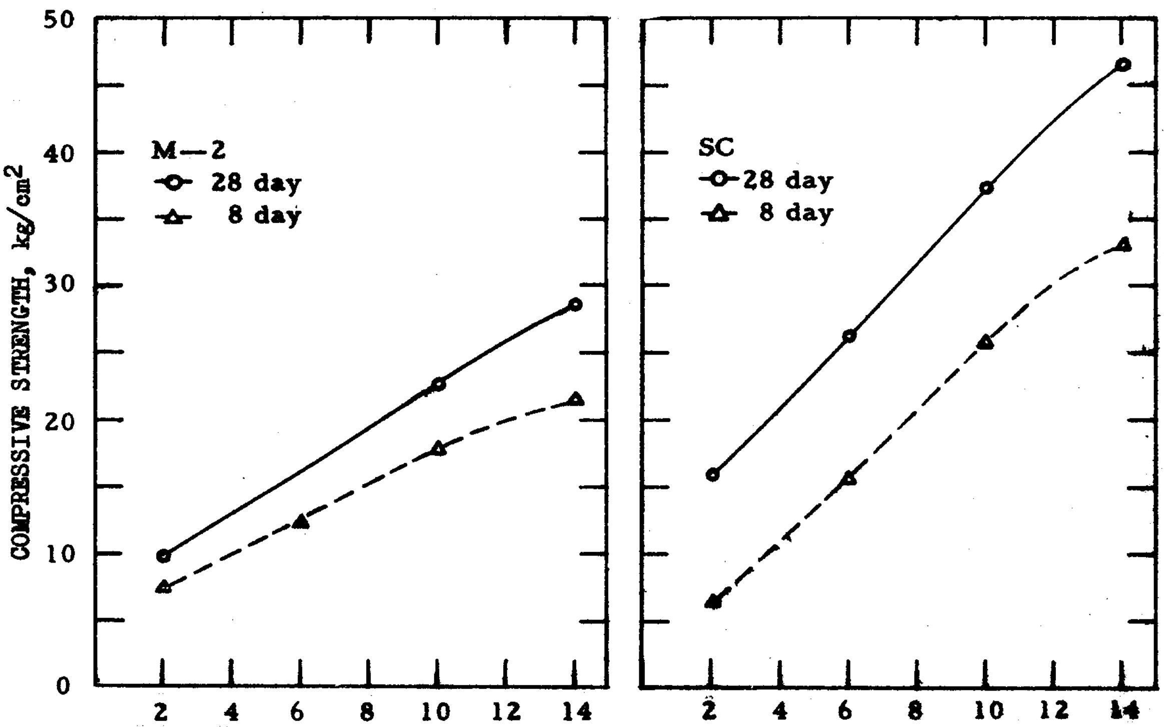

Figure 18. Effect of curing time on compressive strength at optimum moisture content.

TABLE 6

EFFECT OF CEMENT CONTENT ON RATE OF STRENGTH DEVELOPMENT

Soil	Cement content	8-day strength Actual (kg/cm²)	% of 28-day strength
SC	2	6.4	40
	6	8.6	33
	10	25.7	68
	14	33.1	70
M-2	2	7.5	76
	6	12.2	74
	10	16.5	73
	14	21.8	76

TABLE 7

EFFECT OF MOISTURE CONTENT OF SOIL-CEMENT BLOCKS DURING CURING ON 28-DAY COMPRESSIVE STRENGTH

Soil	Cement content %	28 - day compressive strength A* kg/cm²	A* %	B+ kg/cm²	B+ %	C‡ kg/cm²	C‡ %
M-1	2	17.8	100	--	-	-	-
	6	27.6	100	4.9	18	7.1	26
	10	37.8	100	13.2	35	20.6	55
	14	45.4	100	20.3	45	16.5	36
M-2	2	9.8	100	-	-	-	-
	6	16.4	100	2.5	15	3.8	23
	10	22.6	100	7.3	33	8.9	39
	14	28.8	100	10.0	35	12.6	44
SC	2	15.8	100	-	-	-	-
	6	26.2	100	4.3	16	4.0	15
	10	37.5	100	10.9	29	13.4	35
	14	46.7	100	11.2	24	19.8	42

* 8 days moist, 18 days air-cured, 2 days damp.

+ 8 days moist, 19 days air-cured, 1 day immersed in water.

‡ 8 days moist, 19 days air-cured, oven-dried, 1 day immersed in water.

and maximum dry density is 2.8 per cent, 2.5 per cent and 7 per cent respectively.

(2) <u>Effect of curing time on compressive strength</u>

The study of the effect of curing time was carried out on two soils only, sand-clay mix M-2 and silty clay. The compressive strength of blocks made of these two soil-cement mixtures continued to increase with curing time (Figure 18). Results obtained on the rate of strength development are not conclusive.

(3) <u>Effect of curing of moisture content of the blocks on compressive strength</u>

The type of curing has a marked effect on the development of compressive strength. Data given in Table 7 illustrate the effect of varying moisture content dependent on the curing method on the 28-day compressive strength of soil-cement blocks (Figure 19). The strength of blocks completely immersed in water for 24 hours prior to testing, amounts between 18 to 45 per cent of the strength of blocks damp cured for 48 hours prior to testing. The strength of blocks oven-dried before immersion in water for 48 hours prior to testing is on the whole higher, and amounts to between 15 and 55 per cent of the strength of damp-cured blocks. With only a few exceptions, the difference in compressive strength between the results obtained for three mentioned curing methods, decreases with the increasing cement content.

TABLE 8
SUMMARY OF TEST DATA FOR SOIL-CEMENT BLOCKS

Soil	Cement content %	Standard Compaction O.M.C.* %	Standard Compaction d g/cm^3	Compaction at molding M C.+ %	Compaction at molding d g/cm^3	Absorption %	28-day compressive strength kg/cm^2
M1	2	16.2	1.77	18.0	1.75	-	17.8
	6	16.0	1.76	15.5	1.72	18.16	27.6
	10	16.7	1.72	15.8	1.70	18.40	37.8
	14	17.3	1.72	14.7	1.73	15.30	45.4
M2	2	17.0	1.72	16.7	1.84	-	9.8
	6	17.5	1.71	17.9	1.71	18.3	16.4
	10	18.0	1.70	18.2	1.73	18.2	22.6
	14	18.1	1.75	20.4	1.71	15.6	28.8
SC	22	15.6	1.68	16.8	1.73	-	15.8
	6	15.8	1.66	14.7	1.69	20.1	26.2
	10	15.6	1.67	13.8	1.73	19.40	37.5
	14	16.4	1.66	14.8	1.69	19.30	46.7

* Optimum moisture content.
+ Moisture content.

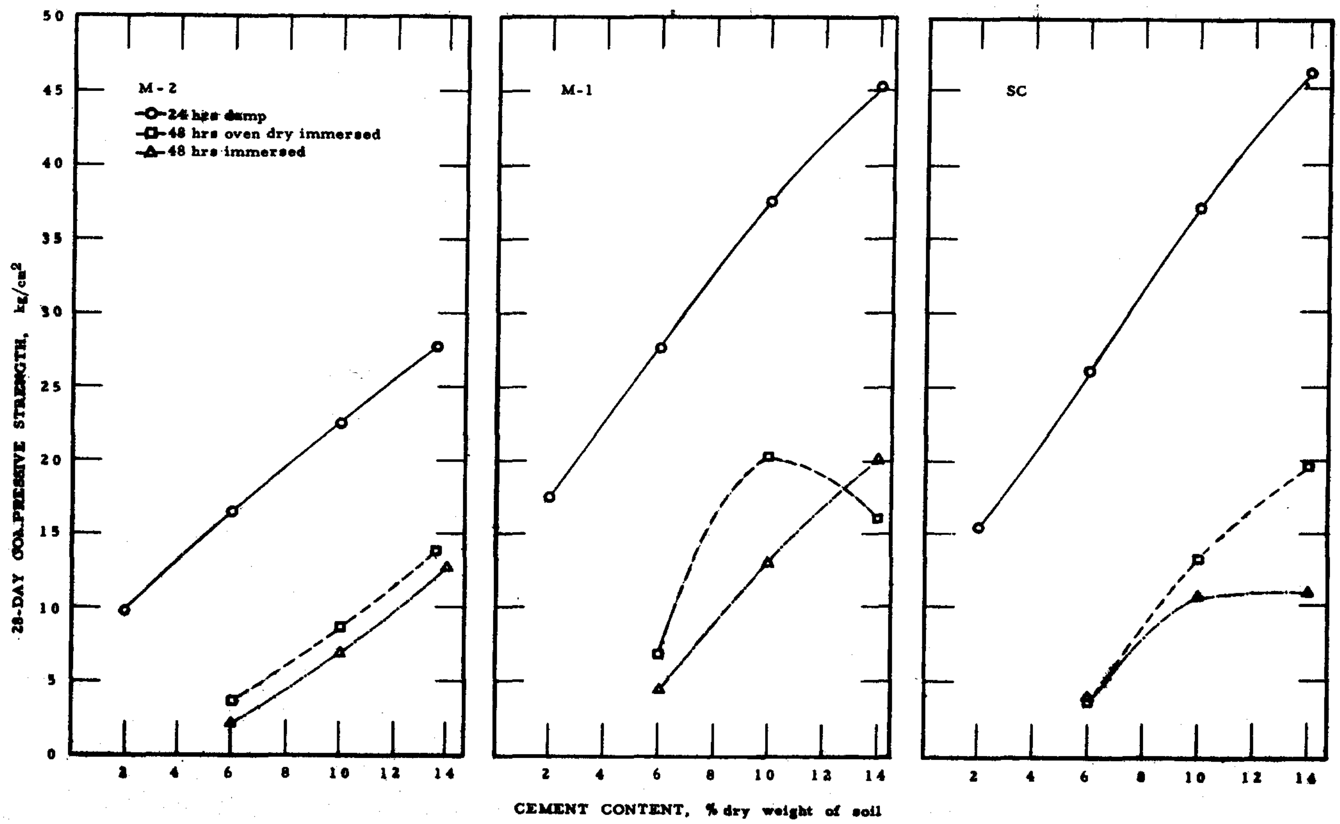

Figure 19. Effect of moisture content during curing on strength development.

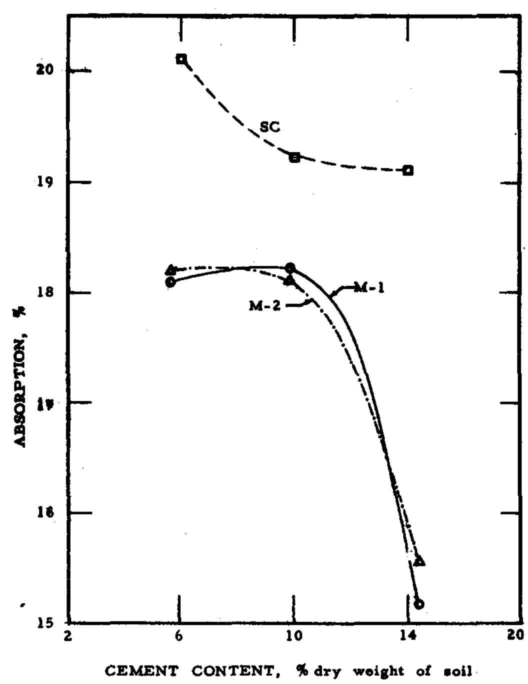

Figure 20. Effect of cement content on water absorption.

(4) Effect of cement content on moisture absorption

Data given in Table 8 and Figure 20 illustrate the effect of cement content on water absorption of the soil-cement blocks. With 2 per cent cement content all blocks disintegrated after being completely immersed for 24 hours in water. The water absorption was reduced for specimens stabilized with 6, 10, and 14 per cent of cement. It is noted that water absorption slightly decreases with cement content. None of the cement contents, however, met the requirement specified by the Indian Standard IS:1725, i.e. that moisture absorption should not exceed 15 per cent.

(5) Effect of activity on compressive strength

The expectation that the higher the activity the lower will be the strength of a mixture at a given cement concentration was fulfilled. From Figure 17 one can see that for the same cement content the less active soil-sand mix M-1 has given always higher compressive strength than mix M-2.

6. RECOMMENDATIONS

A. Compacted density

The compacted dry density has an important effect on the compressive strength of soil-cement mixtures. Moh (1967) has found that a decrease of 5 per cent in the dry density at compaction resulted in a reduction of 25-40 per cent in the 7-day and 27-day strength. This effect was noticed also during some of the soil-cement block making experiments carried out after the completion of the experimental work for this report. Specific recommendations regarding the required cement content can be made only after a series of additional tests is made with the purpose to establish the relation between the maximum dry density obtained under strictly controlled laboratory conditions and those when using CINVA-RAM press under field conditions. The results of this investigation should therefore only be regarded as guidance for future work and not as recommendations for practical application.

B. Moisture content at compaction

All experiments in this study have been carried out using the optimum moisture content. Various investigators have found that variations of moisture content at the time of compaction have a marked effect on the strength development. In his paper "Cement stabilization of lateritic soils", Moh and co-authors

(1967), found that in some cases the 2 per cent increase of moisture above the optimum moisture content can even bring up to a 45 per cent reduction of the 27-day compressive strength.

The determination of the optimum moisture content is made in practice by a field test. An investigation into the deviation of moisture content determined by the field test from the optimum moisture content and correlation of these data with resulting variations in the strength development appears to be necessary at this stage.

C. Drying of soil

The preparation of the Bangkok clay sample, i.e. drying and crushing, required as a result of the high moisture content and plasticity during the rainy season more effort than normally expected. This may have an unfavourable effect on the total time required for the manufacture of blocks and also increase the cost.

The use of Bangkok clay for the manufacture of soil-cement blocks is therefore recommended only during the dry season.

7. CONCLUSION

The experimental data obtained in this investigation indicate that inorganic clay of high plasticity prevailing in Bangkok and the Central Plain area of Thailand can be stabilized with an economical amount of cement in the range between 6 and 10 per cent when used in the form of a mix containing 41.5 per cent clay and 58.5 per cent sand (3:4 by volume).

The mix containing 48.5 per cent clay and 51.5 per cent sand (1:1 by volume) can also be used for the manufacture of soil-cement blocks when stabilized with a minimum of 10 per cent cement and moulded at optimum moisture content and maximum dry density.

Silty clay prevailing in the north-eastern area of Thailand can be economically stabilized with an amount of cement in the range from 6 to 10 per cent.

It must be emphasized, however, that results obtained in this investigation should be accepted only as a guidance for further studies, pending additional data correlating the results of investigations obtained under optimal laboratory conditions with those obtained by using field tests and methods.

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