CONSOLID SYSTEM IN SOIL STABILIZATION

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Abstract : This paper deals with a laboratory investigation of soil stabilisation using the 2-component consolid system. Three soils were selected for investigation and two components of the consolid system investigated were Consolid-444 and Conservex. The amounts of these additives investigated covered the ranges recommended by the manufacturer. The parameter used to characterise strength was CBR values and the influence of curing time on strength development was investigated. The test programme was devised to determine the amount of Consolid-444 that needed to be added to soil compacted to standard maximum dry density in order to optimise strength. The same criterion was used to optimise the amount of Conservex added to the soil prepared at optimum Consolid-444 content. Addition of Consolid-444 did not improve significantly the resistance to water of any of the of the soils investigated; a significant improvement was observed when Conservex was added.

Key words : stabilisation, consolid, conservex, curing time, strength.

1. INTRODUCTION

The quality and thickness required of pavement layers is influenced to a great extent by the strength properties of the sub-grade. There are many circumstances involving both construction and service life of pavement which make it necessary or desirable to stabilise soils. Stabilisation, as applied to pavement construction, can be defined as a means of treating soils and/or base materials to increase their strength and bearing capacity and decrease their water sensitivity and volume change during the wet-dry cycle. Stabilisation of soil sub-grade will increase its strength thereby permitting reduction of overall pavement thickness. The term soil stabilisation means improving the stability or bearing capacity of the soil by the use of controlled compaction, and/or the addition of a suitable admixture or stabiliser. Soil stabilisation deals with physical, physico-chemical and chemical methods to make the stabilised soil serve its purpose as a component material of the pavement. The basic principles in soils stabilisation may be stated as follows :

i. Evaluating the properties of a given soils
ii. Deciding the method of supplementing the lacking property by an effective and economical method of stabilisation
iii. Designing the stabilised soil mix for intended stability and durability values.
iv. Considering the construction procedure by adequately compacting the stabilised layers.

Soil condition in many locations in Indonesia are very variable and various solutions are needed in order to comply with compaction requirements and the provision of a satisfactory pavement foundation. In accordance with developing technology, there are many alternative methods of stabilisation and types of stabiliser to choose from in order to improve the soil sub-grade or to improve the local soil for use as sub-base/base. One alternative is the Consolid System. This system requires the addition of two stabilisation components.

The first of these is added in liquid form and is known as CONSOLID-444 (C-444). The choice of the second component is dependent upon soil type and moisture condition and may be either CONSERVEX (Cx), which is a liquid, or SOLIDRY (Sd), a powder with a filler consisting of cement and hydrated lime. CONSOLID 444 is the basis of the Consolid system. These products were developed over many years of theoretical and empirical experimentation. In this respect it is important to understand that the Consolid System was specifically developed for soil stabilisation and impermeabilisation with a view to being applicable to a wide range of materials. The objectives of this investigation were :

i. to characterise soil samples at 3 locations in Indonesia namely soil-A from Tanjung Sari (West of Java) and the other two called Soil-B from Semen Api and soil-C from Pasir Merah, both are in Palembang (South of Sumatra)
ii. to evaluate the influence of varying amounts of CONSOLID-444 and of CONSOLID-444 plus CONSERVEX (Cx) at varying curing times on soil characteristics
iii. to identify soil suitable for treatment by the Consolid System

2. SOIL TESTS AND CONSOLID MATERIALS

2.1. Unconfined Compressive Strength (UCS) Test

The UCS test is commonly required for roads, and this test is a special case of a triaxial compression test in which the all round pressure $\sigma_3 = 0$. Test is carried out only on samples which can stand without any lateral support. The unconfined compression tests is one of the simplest and quickest test used for the determination of the shear strength of soils. The test can also be performed in the field using simple loading equipment..

2.2. California Bearing Ratio (CBR)

The CBR of soil is determined from a penetration test developed by the California Division of Highway as a method for evaluating the stability of soil sub-grade and other flexible highway materials. The test result has been correlated with flexible pavement thickness requirements. The test may be conducted in the laboratory or in the field. The laboratory CBR apparatus consists of a mould, 15 cm diameter, with a base plate and a collar, a loading frame with the cylindrical plunger of 5 cm diameter and dial gauges for measuring the expansion on soaking prior to testing and the penetration value. The test consists of causing the plunger to penetrate a pavement component material at 1.25 mm/minute. The load for 2.5mm or 5mm penetration is recorded. This load is expressed as a percentage of a standard load value to obtain the CBR value. The standard load value was obtained from the average of a large number of tests on different crushed stones. The CBR usually selected is that at 2.5mm penetration. If the CBR at 5mm is greater than that at 2.5mm, the tests should be repeated. If the check tests gives a similar result, the value for 5mm penetration is used in defining CBR (KHANNA and JUSTO, 1973)

2.3. Compaction

The purpose of soil compaction as to improve the qualities of the soil used either as a subgrade material for roads or in the fills of dams. The properties of the material that are important in construction are high shear strength, low permeability and water absorption and also little tendency to settle under repeated loading. For the above mentioned properties the objectives of compaction are to increase the soil strength, decrease the voids in the soil and reduce the compressibility and permeability of the soil. The are several advantages which occur through compaction detrimental settlement can be reduced or prevented, soil strength is increased and slope stability can be improved, bearing capacity of pavement sub-grade can be improved and undesirable volume changes, caused by swelling and shrinkage may be controlled. Compaction of soil is measured in terms of the dry density of the soil, which is the weight of soil solids per unit volume of the soil bulk. The factors that affect compaction are moisture content of the soil, and compactive effort.

Compactive effort is defined as the amount of energy imparted to the soil. With a soil at a given moisture content, increasing the amount of compactive effort results in closer packing of soil particles and increased dry density. For a particular compactive effort there is only one moisture content which gives the maximum dry density. The moisture content that gives maximum dry density is called the optimum moisture content. If the compactive effort is increased, the maximum dry density also increases but the optimum moisture content decreases. The compactive effort in the field during the construction is imparted by mechanical rollers. Rollers of different types and sizes are used in practice according to requirements. Whether the soil in the field has attained the required density is determined by carrying out appropriate tests on the compacted soil (MURTHY, 1993). The target density in the field is determined from laboratory tests. The laboratory tests that are normally used for determining the optimum moisture content and the maximum dry density of a given soil are standard proctor test and modified proctor test. Proctor established that compaction is a function of four variables like dry density, water content, compactive effort, and soil type (gradation, presence of clay minerals, etc.)

2.4. Consolid System of Soil Stabilisation

Consolid-444 (C-444) + Conservex (Cx), for use mainly with dry soil and in unflooded areas; meanwhile Consolid-444 (C-444) and Solidry, for use mainly with wet soil and flooded areas.

a. Consolid-444 (C-444)
Consolid-444 is a chemical and is one component of the Consolid System. It acts by releasing the adhering water film surrounding the soil particles. This allows the natural binding power of the soil fines to be enhanced and results in an irreversible agglomeration of the fines by exchange of the electrochemical loading on the soil particles. In this way there is a reduction in the active soil surface. Through this action, a limited hydrophobic reaction due to a pole reversal and ion exchange on the particle surface, and a general reduction in the sensitivity of the treated soil against the capillary rise of water occurs. Because the process operates interactively on the physico-chemical boundary, the same stabilising effect can be achieved by using the same dosage rate of chemical (in practical terms) for the majority of soil types.

Typically Consolid-444 is applied in the field at a rate of 400 to 800 cm per cubic meter of soil. To achieve this low application rate (200cc/m^2) to a depth of 250mm), an effective mixing with the soil to be treated is achieved by diluting the Consolid in water, preferably in the ratio of at least 15:1 to 20:1. It should be appreciated that a dilution ratio of 20:1 corresponds to adding only approximately one percent moisture to the soil. Therefore it rarely has an adverse effect on construction moisture conditioning requirements.

b. Conservex (Cx)
Conservex is a product which is soluble in water. This material acts like a bitumen and fills the pores among the grains, thus rendering the treated soil more dense and waterproof and preventing the seepage of surface water into deeper layers. Conservex in the amount of 10-20 liter/m^3 (0.5-1% by weight of the soil) is mixed with water, and is mixed to a depth of 50-100mm thickness with soil already containing Consolid-444. Although a treatment with Consolid alone provides some strength gain and a reduction in capillary rise, the degree of hydrophobic behaviour achieved is not sufficient to prevent unacceptable loss of strength or seepage if the treated soil is inundated or subject to free surface water. Conservex is a bitumen-based liquid which is completely dispersible in slightly acidified water.

c. Solidry (Sd)
Solidry acts in much the same way as Conservex. Available as a powder, it achieves the same effect as Conservex when added in the amount 1-2% by weight of the soil. Solidry as an additive in the Consolid System is used mainly for wet soil and flood inflected areas. The Consolid System is said to have the following advantages :

i. decreases permeability and capillary rise
ii. increases CBR
iii. increases water resistance
iv. decreases softening of soil by water.

3. LABORATORY WORKS

3.1. Materials

Soil samples were taken at three locations that are sample-A from Tanjung sari (West Java) and samples-B and C from Palembang (South Sumatera); Consolid-444 and Conservex were obtained from PT. Lahan Asprindo Lestari, Jakarta

3.2. Laboratory Tests

Laboratory tests for determining the properties of the natural or untreated soils are Grain size analysis, Atterberg limit tests, Specific Gravity tests, Standard Proctor Compaction test, CBR test, UCS test, Permeability test. For the treated soil, before mixing with Consolid System materials, the soils were at Optimum Moisture Content (OMC) as determined by Standard Proctor Test. Various amounts of Consolid System materials were added as follows :

i. Consolid-444 was added in four concentrations :
   a. Soil + 400cc Consolid-444 per m^3
   b. Soil + 550cc Consolid-444 per m^3
   c. Soil + 650cc Consolid-444 per m^3

d. Soil + 800cc Consolid-444 per m^3

From these four concentrations, an optimum amount of Consolid-444 was determined for each soil type, by CBR and UCS tests at 7 days.

ii. Concentrations of Consolid-444 + Conservex investigated were as follows :
a. Soil + Opt. C-444 + 10 lt Cx per m^3
b. Soil + Opt. C-444 + 13 lt Cx per m^3
c. Soil + Opt. C-444 + 17 lt Cx per m^3
d. Soil + Opt. C-444 + 20 lt Cx per m^3

These concentrations were chosen on the basis of the manufacturers specification where Conservex content is specified to be in the range 10 - 20 lt per m^3. From these four concentrations, an optimum combination of Consolid-444 + Conservex were determined by CBR and UCS tests at 7 days.

3.3. Effect of Curing Time

The influence of curing time was investigated only for soils treated with the optimum amounts of the Consolid components as determined before. Curing times investigated at 1, 3 and 14 days (curing for 7 days was used to choose the optimum amount of Consolid system components).

3.4. Mixtures Preparation

The soils were air dried and passed through a No. 4 sieve. The predetermined amount of water for untreated samples and a mixture of water and Consolid System materials for treated samples were added to the air-dried soil. Fluids and soil were mixed by hand, until a uniform mixture was obtained. The mixture was then placed in a plastic bag and allow to stand for approximately 12 hours.

3.5. Standard Proctor Compaction

The Standard Proctor test was carried out in accordance with ASTM D 698-66, in order to obtain the Optimum Moisture Content (OMC) of the soil from each site. Generally 5 samples were used to determined the and Maximum Dry Density (MDD) of untreated soil. The OMC thus obtained provided a basis for testing soil treated with the components of the Consolid System.

3.6. California Bearing Ratio (CBR) Tests

Samples for the CBR test were prepared at OMC and material was compacted in the standard CBR mould in accordance with ASTM designation D 698-66. Untreated and treated samples were soaked for 4 days prior to test. Before soaking treated samples were cured for periods of 1, 3, and 14 days. (7 days curing was the basis for determining the optimum content of Consolid Materials).

3.7. Unconfined Compressive Strength (UCS) Test

The UCS test was carried out in accordance with ASTM Designation D 2166-85 for both untreated and treated samples. The soil samples treated with Consolid-444 and Consolid-444 + Conservex were tested after curing periods of 1, 3, 7, and 14 days. Following compaction of untreated/treated material in the standard compaction mould, 3 samples were extruded for the UCS test. A thin walled tube was pushed manually into the material and the UCS sample obtained by subsequent extrusion from the tube. Visual inspection of samples following extrusion indicated that in the majority of cases considerable sample disturbance had occurred. Cracking and crumbling of the samples was evident. The UVS test was carried out in a compression machine at a constant rate of strain of 0.5% per minute. The strength of a particular sample was taken as the average of two or three measurement.

3.8. Permeability Test

Samples of untreated soil for the permeability test were prepared at OMC; for soil tested with Consolid System component, sample were prepared at optimum Consolid System content and compacted in the permeability test mould. All the permeability tests were carried out by Falling permeability test after a curing time of 7 days.

3.9. Durability Test

Soil samples at OMC and MDD were made and compacted in a mould with dimensions of 5cm in diameter and 10cm in high. The samples of untreated soil and of soils treated with Consolid-444 and with Consolid-444 + Conservex and cured for 7 days were placed on their end in a water bath containing water 3cm deep and than observed for a period of 24 hours.

4. RESULTS AND DISCUSSION

4.1. Soil Properties

Analysis of the chemical and mineral composition of soil-A, soil-B and soil-C were done in the central for Research and Development on Mineral Technology, Bandung as shown in Table 1. The physical properties of Soils A, B and C are summarised in Table 2. From the Atterberg Limit tests and Grain Size Analysis, the three soils are classified into : Soil-A is A-7,CH; Soil-B is A-4,SC; and Soil-C is A-3,SM.

Table 1
Chemical and Mineralogical Analysis and Mineral Composition of Soils A, B and C

Chemical Composition	Soil-A	Soil-B	Soil-C
SiO_2	37.90	73.60	87.60
Al_2O_3	31.66	17.64	7.41
Fe_2O_3	13.41	0.56	1.52
TiO_2	1.72	0.38	0.18

Table 1 (continued)			
Chemical Composition	**Soil-A**	**Soil-B**	**Soil-C**
CaO	0.12	0.05	0.02
MgO	0.12	0.15	0.05
K_2O	0.03	0.65	0.06
Na_2O	0.00	0.07	0.20
LOI	14.35	6.28	2.80
Mineral Composition	Halloysite	Quartz Kaolinite	Quartz Kaolinite

Table 2 Physical Properties of Untreated Soils A, B and C

Properties	Soil-A	Soil-B	Soil-C
Specific Gravity	2.68	2.67	2.76
Liquid Limit, %	96.05	30.39	-
Plastic Limit, %	45.50	21.92	-
Plasticity Index, %	50.55	8.47	Non Plastic
Grain Size Analysis			
% passing # 4	100.00	100.00	100.00
% passing # 10	100.00	100.00	100.00
% passing # 20	99.90	72.58	96.87
% passing # 40	99.80	49.78	88.76
% passing # 80	99.34	39.48	34.44
% passing # 100	99.24	38.42	25.48
% passing # 200	98.66	38.12	16.64
Classification			
USCS	CH	SC	SM
AASHTO	A-7	A-4	A-3

4.2. Compaction and Permeability Characteristics

Compaction characteristics and the permeability at optimum moisture content of soil A, B and C are shown in Table 3 and the compaction test results for the untreated soils are illustrated in Figure 1, for samples prepared in a Standard Proctor mould. OMC and MDD of Soil-A are 44% and 1.2 gr/cm^3; Soil-B are 13.5% and 1.82 gr/cm^3 and Soil-C are 12% and 1.88 gr/cm^3.

Table 3 Compaction and Permeability Characteristics of Soils A, B and C

Properties	Soil-A	Soil-B	Soil-C
Compaction Characteristics			
MDD (gr/cm^3)	1.20	1.82	1.88
OMC (%)	44.00	13.50	12.00
Permeability Values (cm/sec)			
sample-1	6.74 E -07	7.90 E -07	3.03 E -05
sample-2	6.63 E -07	1.59 E -06	2.44 E -05
sample-3	7.48 E -07	2.21 E -06	2.45 E -05
Average Value	6.95 E -07	1.53 E -06	2.64 E -05

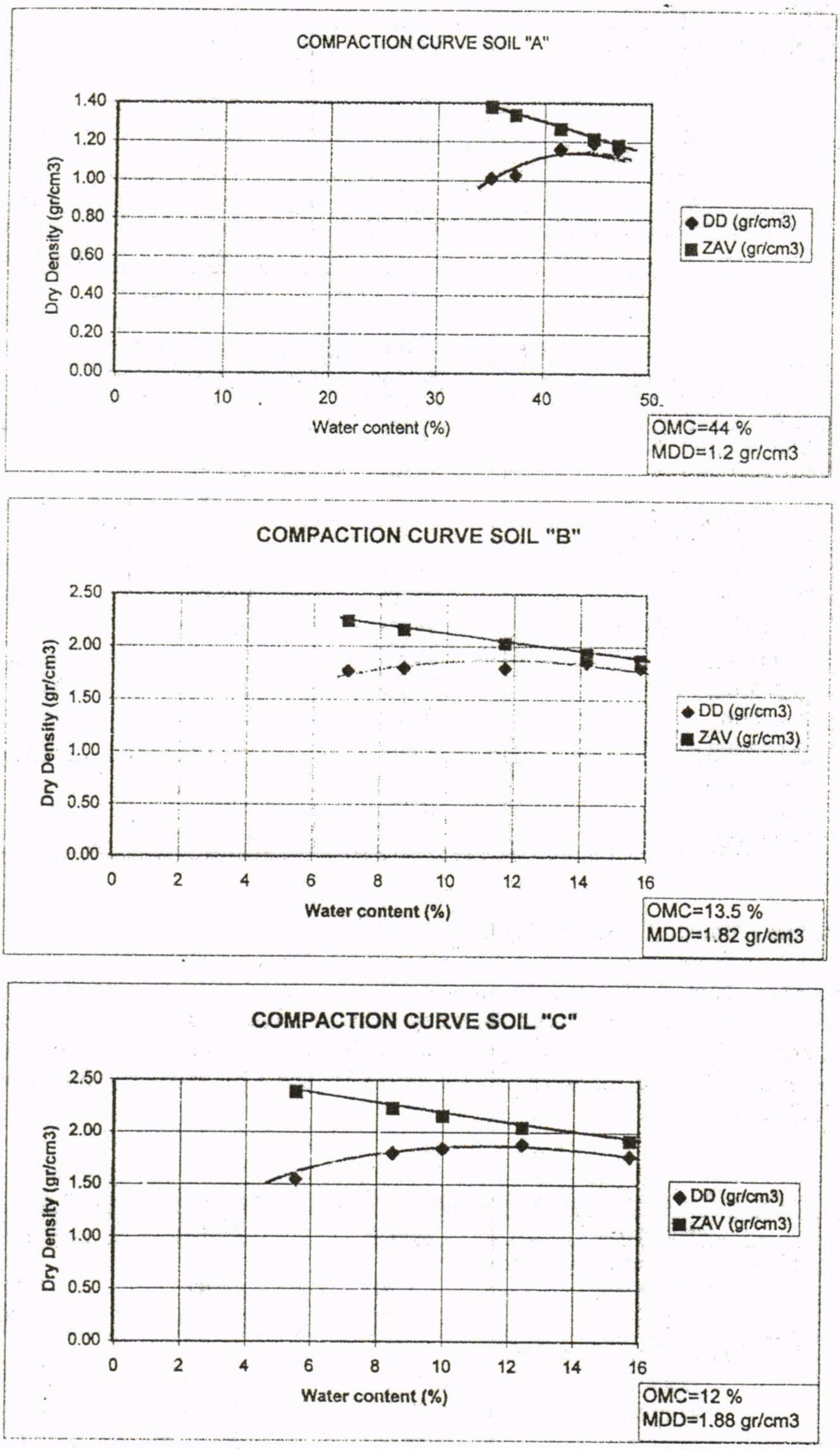

Figure 1 Moisture - Density Relationships for Untreated Soils.

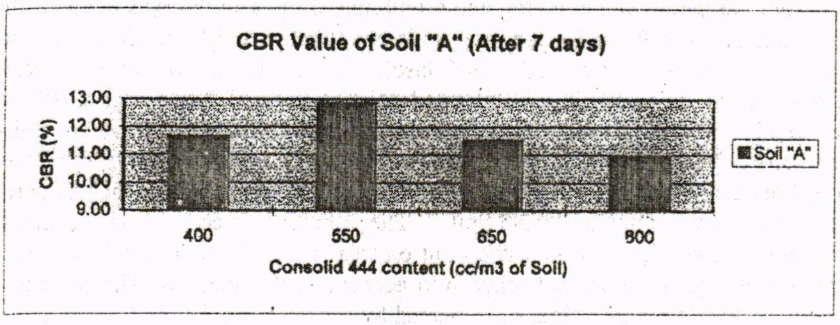

Figure 2 CBR Value of Soil A Treated with Consolid 444 after curing for 7 days.

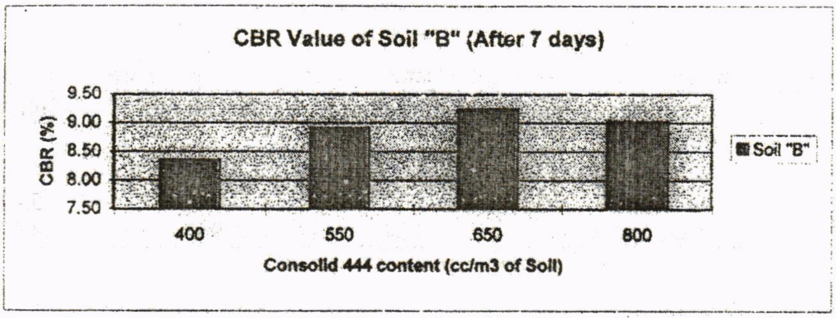

Figure 3 CBR Values of Soil B Treated with Consolid 444 after curing for 7 days.

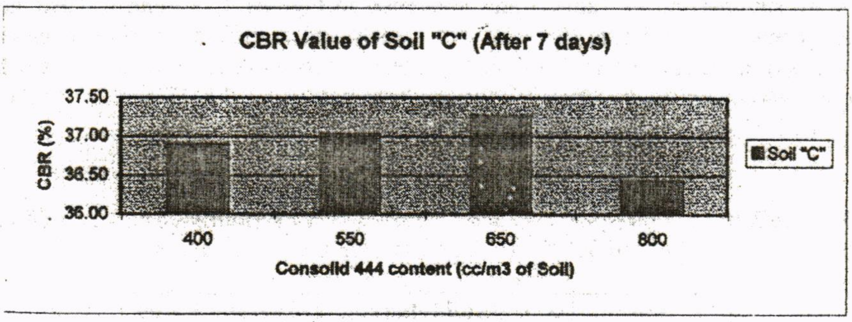

Figure 4 CBR Values of Soil C Treated with Consolid 444 after curing for 7 days.

4.3. Strength Characteristics of Untreated Soils

Data on the strength of untreated soils A, B and C as indicated by the CBR test are summarised in Table 4. For UCS, sample disturbance once occurred during removal of samples from the mould and cracking and crumbling of the samples was evident; the UCS test is not considered suitable for the three soils investigated. CBR and UCS test results for untreated soils, and for soils treated with Consolid-444 and Consolid-444 + Conservex, do not correlate well; for example the untreated soils say Soil C has a high CBR value as opposed to a lower value for Soil-A; the corresponding UCS values are low for Soil-C and high for Soil-A. A similar lack of correlation is evident in a comparison of the Soil-A and Soil-B test results, although in this case it is not so severe. There is also lack of correlation between the test results for Soil-B and Soil-C. The same lack of correlation continues into a comparison of the results of tests carried out on treated samples and for these reasons the UCS test results are therefore not taken into account in the analysis. The untreated soils have relatively high strength values as indicated by soaked CBR, i.e. soils A, B and C have CBR values of 4.84%, 6.69% and 34.92%, respectively. Soil-B and Soil C exhibited no swelling after 4 days soaking but Soil-A exhibited a little swelling after 4 days soaking (0.45%).

Table 4 Summary Data on Strength Characteristics of Untreated Soils A, B and C

Property	Soil-A	Soil-B	Soil-C
CBR (%)			
sample-1	4.55	6.71	34.41
sample-2	5.12	7.21	35.42
Average Value	4.84	6.96	34.92

4.4. Strength Characteristics of Soil Treated with the Consolid System

The results of CBR tests on soils treated with Consolid-444 at 4 concentration and cured for 7 days are summarised in Table 5 and illustrated in Figures 2, 3, and 4. CBR data for samples prepared at optimum Consolid-444 content and at different curing times (1, 3, 7 and 14 days) are presented in Table 6. CBR test results from samples made at optimum Consolid-444 content plus Conservex (at concentration of 10, 13, 17 and 20 lt/m^3 of soil) are summarised in Table 7 and illustrated in Figures 5, 6 and 7.

Table 5 CBR Results for Soils A, B and C Treated with Consolid-444 content of 400, 550, 650 and 800 cc/m^3 of Soil and Curing Time 7 Days

Soil	Consolid-444 C	Average Value
A	400	11.64
	550	12.86
	650	11.51
	800	10.94
B	400	8.35
	550	8.90
	650	9.24
	800	9.02

Table 5 (continued)		
Soil	Consolid-444 C	Average Value
C	400	36.90
	550	37.03
	650	37.26
	800	36.44

Table 6 CBR Values of Soils A, B and C at Optimum Consolid Content (with different time of curing)

Curing Time (days)	SOIL-A (550 cc)	SOIL-B (650 cc)	SOIL-C (650 cc)
1	11.01	7.08	34.92
3	11.48	7.97	35.56
7	12.86	9.24	37.26
14	13.09	9.11	38.90

For treated soils, this investigation was concerned with 4 concentrations of Consolid-444 (400, 550, 650 and 800 cc/m^3 of soil) and also 4 concentrations of Conservex (10, 13, 17 and 20 litre/m^3 of soil) plus the optimum content of Consolid-444 and four curing time were investigated.

Treated with Consolid-444 alone, Soil-A achieved its highest CBR value (13.09%) at a concentration of 550 cc/m^3 Consolid-444 and at a curing time of 14 days. Both Soil-B and Soil-C achieved their highest CBR values (9.24% and 38.90, respectively) at a Consolid-444 concentration of 650 cc/m^3 and at a curing time of 7 and 14 days, respectively. However, as shown in Table 5, variation in Concolid-444 concentration, in the range 400-800 cc/m^3, does not appear to influence significantly the CBR values of the soils investigated.

Table 7 CBR Results for Soils Treated with Optimum Content of Consolid + Conservex and Curing Time 7 days

SOIL	Optimum Consolid-444 (cc/m^3 soil)	Conservex (lt/m^3 soil)	Average Value (%)
A	550	10	16.37
		13	15.88
		17	15.50
		20	15.05
B	650	10	8.86
		13	8.05
		17	7.80
		20	7.38
C	650	10	41.97
		13	39.18
		17	35.97
		20	36.06

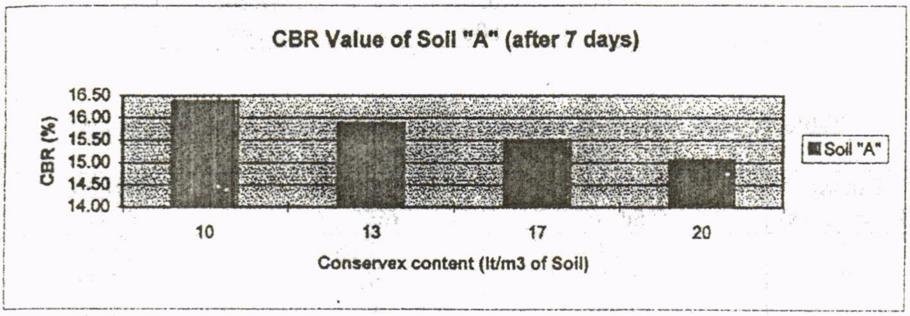

Figure 5 CBR Value of Soil "A" treated with opt. Consolid 444 + Conservex (10. 13, 17 and 20 lt/m3 of Soil) after curing for 7 days.

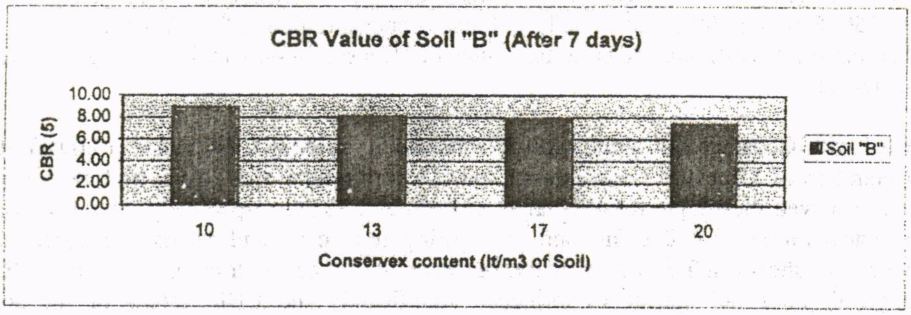

Figure 6 CBR Value of Soil "B" treated with opt. Consolid 444 + Conservex (10. 13, 17 and 20 lt/m3 of Soil) after curing for 7 days.

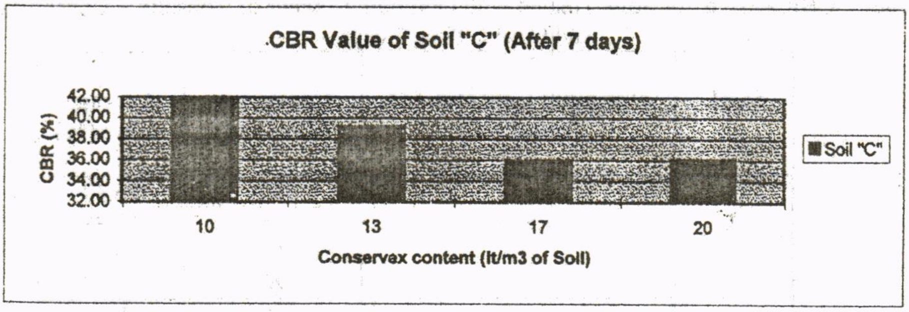

Figure 7 CBR Value of Soil "C" treated with opt. Consolid 444 + Conservex (10. 13, 17 and 20 lt/m3 of Soil) after curing for 7 days.

The optimum of Consolid-444 content of Soil-A (550 cc/m^3 of soil) is lower than that of Soil-B and Soil-C (650 cc/m^3 of soil). This may be due to the fait that the Plasticity Index of Soil-A is very high (50.55%) and its optimum moisture content is also very high (44%); the Plasticity Index of Soil-B is low (8.47%) and Soil-C in Non Plastic and the optimum moisture contents of Soil-B and Soil-C are relatively low (13.5% and 12% respectively). The influence of curing time on the CBR of soils treated with optimum Consolid-444 content is summarised in Table 6. In general, the CBR values of the soils investigated increase with increase in curing time. However, the increase is not significant: the CBR value of soils A, B and C after 14 days curing in 18.9%, 29% and 11.4% higher respectively than the value at 1 day curing. When treated with optimum Consolid-444 content plus Conservex, the highest CBR value is obtained after curing for 14 days at optimum Consolid-444 content and 10 litre/m3 of Conservex i.e. Soil-A, 16.32%; Soil-B, 9.24% and Soil-C, 42.19%. These values are marginally higher than those achieved when the soil are treated with Consolid-444 only. As shown in Table 7 and in Figures 4.7, 4.8 and 4.9, in general the trend is for CBR value to decrease with increase in Conservex content.

Table 8 CBR Values of Soils at Optimum Consolid-444 and Conservex

Curing Time (days)	Soil-A (550cc C444 + 10 lt Cx)	Soil-B (650cc C444 + 10 lt Cx)	Soil-C (650cc C444 + 10 lt Cx)
1	13.85%	8.73%	38.84
3	15.75%	8.98%	39.72
7	16.37%	8.86%	41.97
14	16.32%	9.24%	42.19

4.5. Permeability Characteristics of Soils Treated with Consolid System

Permeability test results at optimum Consolid-444 content and at optimum Consolid-444 + optimum Conservex content, after a curing time of 7 days, are presented in Table 9; a comparison of permeability values for untreated and treated soils is given in Table 4.11. With reference to Table 3 and Table 9, addition of the optimum amount of Consolid-444, as determined from CBR test data, decreases the permeability of Soils A and B by 21.3% and 18.3% respectively but has negligible affect on the permeability of Soil-C. the addition of Conservex to soil treated with Consolid-444 makes soil-A impermeable and makes Soils B and C highly impermeable.

Table 9 Permeability Values of Soils at Optimum Consolid-444 and Optimum Consolid-444 + Conservex

SOIL	Coefficient of Permeability (cm/sec)		
	Untreated	Treated	
		Optimum Consolid-444	Optimum Consolid + Conservex
A	6.95 E-07	5.47 E-07	0.00
B	1.53 E -06	1.25 E-06	1.01 E-08
C	2.64 E-05	2.58 E-05	1.35 E-08

4.6. Durability Characteristics of Untreated and Treated Soils

The durability of soil A, B and C, untreated and treated at optimum Consolid-444 content and optimum Consolid-444 content + Conservex content and cured for 7 days, was investigated by visual observation over a 24 hour period. The soil sample were made and compacted at Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). Sample size was 5 cm in diameter and 10 cm high. The samples of soils, untreated and treated with Consolid-444 and with Consolid-444 plus Conservex and cured for 7 days, were placed on their end in a water bath containing water 3 cm deep. Sample condition was then observed at intervals over a period of 24 hours. Samples of Soil-A, untreated and treated only with Consolid-444 collapsed after 2 minutes but the soil treated with Consolid-444 plus Conservex remained intact for 24 hours.

In the case of Soil-B, after 2 minutes soaking the untreated sample and that treated with Consolid-444 only were partially collapsed; after 20 minutes soaking the untreated soil collapsed and after 4 hours the soil treated with Consolid-444 plus Conservex remained intact up to 24 hours. The untreated sample of Soil-C and that treated with Consolid-444 did not collapsed. Nevertheless disintegration of the bottom of the samples was clearly evident over the 24 hours period. Soil treated with Consolid-444 plus Conservex remained intact up to 24 hours.

5. CONCLUSIONS

Based on the results of the investigation described in this paper, the following conclusions may be drawn :

1. The soils investigated represent a reasonable range in soil type as indicated by classification and CBR values. Soils A, B and C are classified as CH/A-7, SC/A-4 and SM/A-3, respectively; the corresponding CBR values are 4.84, 6.96 and 34.92%.
2. The amounts of Consolid-444 investigated covered the manufacturers recommended range (400-800 cc/m^3 of soil) and CBR after 7 days curing was chosen as the basis for selecting the optimum content. Using this criterion, the optimum Consolid-444 content for Soil-A was determined to be 550 cc/m^3, that for Soil-B and Soil-C was 650 cc/m^3.
3. Selection of an optimum amount of Consolid-444 was necessary in order to implement subsequent stages of the investigation. However the data suggest that increasing Consolid-444 content over the range recommended by the manufacturer does not improve significantly the CBR value of the soil. For practical purposes the minimum content (400 cc/m^3) could realistically have been chosen as the optimum.
4. The average CBR value of Soil-A, containing 550 cc/m^3 of Consolid-444 and cured for 7 days, was 12.86% and represents an increase of 166% on the value for untreated soil (4.84%). Increase recorded for Soil-B and Soil-C, 650 cc/m^3 of Consolid-444 and 7 days curing, were 32.8% and 6.7% respectively.
5. Samples prepared at optimum Consolid-444 content and cured for periods of 1, 3, 7 and 14 days exhibited some increase in CBR value with increase in curing period. The increase however cannot be regarded as significant.
6. There was a marginal reduction in the permeability of samples of Soil-A and Soil-B treated with Consolid-444; there was negligible effect on samples of Soil-C. There was no improvement in the durability (as defined in this investigation) of samples of Soil-A treated with Consolid-444; the performance of samples of Soil-B was marginally better. Samples of Soil-C treated with Consolid-444 appeared to be able to resist collapse but it

should be noted that a similar performance was observed for untreated samples of Soil-C.

7. The manufacturer's recommended range for the additive Conservex (10-20 litre/m^3) was investigated and CBR after 7 days curing was again chosen as the criterion for identifying an optimum. The optimum identified was the same for the three soils i.e. 10 litre/m^3. In general CBR value decreased as the amount of Conservex was increased above 10 lt/m^3.
8. At 7 days curing, the CBR of Soil-A containing optimum amounts of Consolid-444 and Conservex was 16.37%; the CBR values for Soil-A containing Consolid-444 only and for untreated soil were 12.86% and 4.84% respectively. The addition of Conservex to Soil-B treated with Consolid-444 reduced 7 days CBR value from 9.24% to 8.86%; 7-days CBR value of Soil-C increase somewhat, from 37.26% to 41.97%.
9. In general, the CBR values of soils containing Consolid-444 and Conservex increased with increase in curing time. However with the possible exception of Soil-A (13.85% at 1-day to 16.32% at 14-days) the influence of curing was not significant.
10. The resistance to water damage of the three soils investigated improved significantly when Conservex was added to the soils already containing Consolid-444.
11. In summary, of the three soils investigated, only Soil-A can be considered a viable candidate for stabilisation using the Consolid-444 System from consideration of strength improvement alone. If durability is a major concern, then all 3 soils are viable.

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