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MECHANICAL PROPERTIES OF A CEMENT STABILISED COASTAL SOIL FOR USE IN ROAD CONSTRUCTION

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ABSTRACT: Mechanical properties of a coastal soil stabilised with 1%, 3% and 5% cement have been evaluated. A clayey silt of low plasticity (liquid limit = 30, plasticity index = 7), collected from the Chittagong coastal belt of Bangladesh, has been used in this investigation. Experimental results showed that considerable increase in unconfined compressive strength (q_u), California Bearing Ratio (CBR), flexural strength and flexural modulus has been observed due to stabilisation. Durability test indicates that percentage loss in soil-cement decreases with the increase in cement content. It has been found that q_u (cured for 28 days) and CBR of samples stabilised with 3% and 5% cement fulfil the requirements of soil-cement road sub-base and base subjected to light traffic. Analyses using CIRCLY computer program were conducted to estimate the thickness of soil-cement base for paved and unpaved rural roads having a maximum width of 2.5 m and subjected to anticipated design traffic loading of Light Cross County Vehicle (LCCV), i.e., jeep. It has been found that at a given CBR of subgrade and modulus of soil-cement, thickness of soil-cement base increases with increasing load repetitions and that at a particular CBR and load repetitions, thickness of soil-cement base decreases as modulus increases.

KEYWORDS: Cement stabilisation, compressive strength, CBR, flexural strength, road, soil-cement base

INTRODUCTION

In connection with road construction, stabilisation is referred as means by which the engineering properties of subgrade and pavement materials can be improved in order to withstand traffic loading and weather effects. An increasing emphasis has been placed on the use of stabilised pavement materials in recent years. Through the use of stabilising agents, low-quality materials can be economically upgraded to the extent that they may be effectively utilized in the pavement structure. There are a number of methods of soil stabilisation for use in road works. The additives which are commonly used are granular materials, Portland cement, Lime Lime-flyash, bitumen and tar. Full use of the potential of stabilisation requires an awareness of the various methods available, their preferred applications and limitations, their properties and means of evaluation and their construction requirements. Cement stabilisation is widely recommended for construction of roads (Ingles and Metcalf, 1972; NAASRA, 1986; Hausmann, 1990; Bell, 1993). The major engineering benefits of cement

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stabilisation are increased strength and stiffness, better volume stability and increased durability.

The existing roads in the coastal areas of Bangladesh are mostly earthen roads and hardly water bound macadam roads not easily accessible for light traffic. Almost all the coastal regions of Bangladesh are affected by cyclone, storm surge, flood every year due to the geographical location of these regions. The roads are severely damaged due to flood, currents and wave action. This situation needs maintenance of these roads every year and due to financial constraint it is practically impossible. With regard to the above circumstances, it is very essential to find a realistic solution of this type of problem. The usual practice of constructing the rural roads in the coastal regions is to dump the loose soil over the road formation and to render a nominal compaction of soil. These roads are subsequently exposed to rain, monsoon flood and wave actions. These adverse effects together with inadequate compaction significantly impair the durability of these roads. The ultimate effect is comparatively low subgrade strength and eventually higher pavement thickness if paved roads are to be constructed. On the basis of this context, some treatment of locally available materials has become necessary for satisfactory and economic construction of road in these regions. Cement stabilised bases may be provided in the construction of rural roads in the coastal areas for low volume, light traffic movement.

The present study has been aimed at evaluating the mechanical properties of a cement stabilised coastal soil of Bangladesh to examine its suitability for use as a base coarse in road construction. Attempt has also been made for design of cement stabilised unpaved and paved rural roads for light traffic movement.

SOIL USED AND REGIONAL GEOLOGY

Disturbed soil from Anwara of Chittagong coastal region was collected for the present investigation. The Eastern coastal area of administrative unit of Anwara is a tidal plain situated as a narrow strip between the Chittagong hilly uplands and the Bay of Bengal. The surface environment of this area are mainly controlled by shallow sea water and the flood plain activities of the rivers, Karnafully, Halda and Shangu. The subsoils are mainly composed of very soft to medium stiff clay silts and fine grained silty sands with some decomposed organic material near the surface. Tectonically the site is a part of the folded flank of the Bengal Basin. The area is located in the zone of medium seismic activity. The design magnitude of ground acceleration due to earthquake in this region is 0.05.

Liquid limit, plastic limit and plasticity index of the soil were 30, 23 and 7, respectively while the fractions of sand, silt and clay of the soil were found to be 34%, 62% and 4%, respectively. According to Unified and AASHTO Soil Classification System, the soil belongs to ML group and A-4 group, respectively.

LABORATORY TESTING PROGRAMME

A laboratory investigation programme was undertaken to evaluate the mechanical properties of the untreated soil and soil stabilised with ordinary Portland cement. The soil was stabilised with cement contents of 1%, 3% and 5% by weight of soil. The following tests were carried out on samples of untreated and stabilised soil:

(i) Modified compaction test
(ii) Unconfined compressive strength test on compacted samples
(iii) California Bearing Ratio (CBR) test
(iv) Flexural strength test using simple beam with third point loading system
(v) Repeated wetting and drying test

RESULTS AND DISCUSSIONS

Moisture-Density Relations

The moisture content-dry density relationships of the untreated and stabilised samples of the soil were investigated by carrying out Modified Compaction test which was performed following the procedure outlined in ASTM D1557 (ASTM, 1989). The moisture-density relations of the samples are shown in Fig. 1. From the plots shown in Fig. 1, the maximum dry density (γ_{max}) and optimum moisture content (w_{opt}) of the samples were determined which are presented in Table 1. Table 1 shows that with the increase in cement content, γ_{max} increases while w_{opt} decreases. Compared with the untreated sample, the values of γ_{max} increased up to 8% while w_{opt} reduced up to about 9% for the sample stabilised with 5% cement content. Ahmed (1984) also found increase in maximum dry density with increasing cement contents for local sandy soils.

Table 1. Moisture-density relations of untreated and cement stabilised samples

Moisture-Density Parameters	Cement Content (%)			
	0	1	3	5
Maximum Dry Density (kN/m^3)	17.10	17.38	18.21	18.50
Optimum Moisture Content (%)	16.4	15.5	15.0	14.9

UNCONFINED COMPRESSIVE STRENGTH

Unconfined compressive strength tests were performed on compacted samples of 71mm diameter by 142 mm high. The mould used for compaction was fabricated which comply with the requirements of ASTM D1632 (ASTM, 1989). The moisture content and compacted dry density of the samples were equal to w_{opt} and γ_{max} obtained from the Modified Compaction tests. The treated samples were cured under moist condition for 7, 14 and 28 days. Finally, the samples were tested under compression up to failure. The unconfined compressive strength (q_u) of the untreated sample has been found to be 710 kN/m^2.

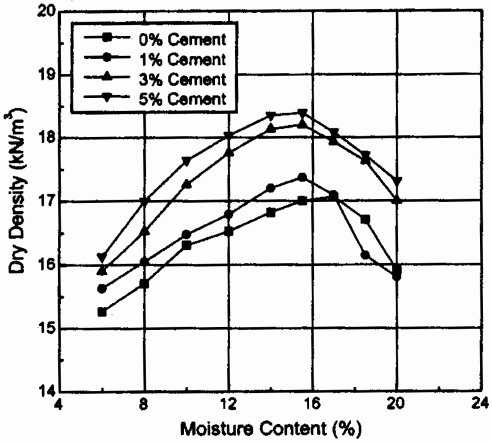

Fig 1. Moisture-density relations of untreated and cement stabilised samples

The q_u-values of the stabilised samples are shown in Table 2. Table 2 shows that compared with the untreated sample, the values of q_u of treated samples increased remarkably, depending on the cement content and curing age. Similar results were also reported by Hossain (1986) and Serajuddin (1992) for fine-grained soils of Bangladesh for use in road construction. Portland Cement Association, PCA (1956) recommended that the values of q_u of soil-cement cured for 7 days and 28 days for soils belonging to ML and A-4 group should be in the range of 250 to 500 psi (i.e., 1723 to 3445 kN/m^2) and 300 to 900 psi (i.e., 2067 to 6201 kN/m^2), respectively. Table 2 shows that q_u-values of samples stabilised with 5% cement and cured for 14 and 28 days fulfil the requirements of PCA (1956). Ingles and Metcalf (1972), however, recommended that the values of q_u of soil-cement road sub-base and base for light traffic should be in the range of 100 to 200 psi (689 to1378 kN/m^2). Table 2 also shows that for all cement contents and curing age, the values of q_u of stabilised samples fulfil the requirements of soil-cement road sub-base and base for light traffic as proposed by Ingles and Metcalf (1972). The increase in q_u with cement content is shown in Fig. 2. Fig. 2 shows that at a given curing age, q_u increased with increasing cement content and that at a particular cement content, q_u increased with the increase in curing age. Value of q_u of the sample treated with 5% cement and cured for 28 days has been found to be 6 times higher than the strength of untreated sample. The rate of strength gain with curing time was evaluated in terms of the parameter strength development index (SDI) as defined by the following expression (Uddin, 1995):

$$SDI = \frac{Strength\ of\ stabilised\ sample - Strength\ of\ untreated\ sample}{Strength\ of\ untreated\ sample} \quad (1)$$

A plot of SDI with curing age is shown in Fig 3 which shows that SDI increases with increasing curing time and cement content. This figure clearly demonstrates the relative degree of strength gain resulted due to increasing cement content and curing age. Uddin (1995) also reported an increase in SDI with increasing curing time and cement content for samples of Rangit clay of Bangkok treated with 5% to 40% and cured for 1 to 40 weeks.

Table 2. Unconfined Compressive Strength of Cement Stabilised Samples

Cement Content (%)	Unconfined Compressive Strength, q_u (kN/m^2)		
	7 Days	14 Days	28 Days
1	785	1391	1729
3	1267	2325	3431
5	1634	3013	4304

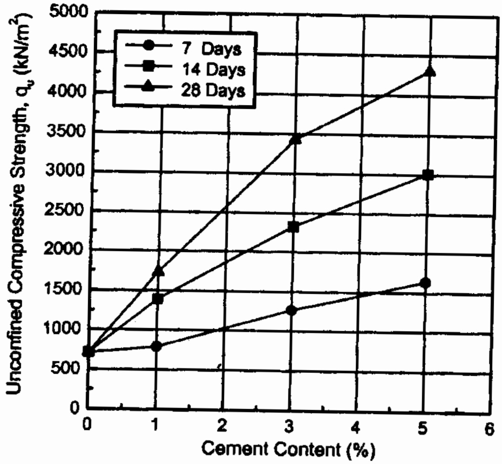

Fig 2. Effect of cement content on unconfined compressive strength

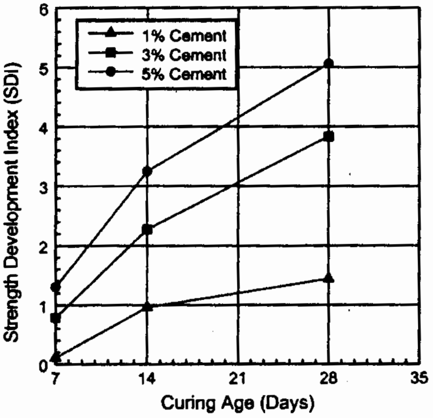

Fig 3. Effect of curing age on strength gain

CALIFORNIA BEARING RATIO (CBR)

CBR tests were carried out on untreated and stabilised samples compacted according to Modified Compaction test using three levels of compaction energies. Each sample was soaked for 4 days and finally bearing test on the sample was performed following the procedure outlined in ASTM D1883 (ASTM, 1989). Summary of CBR test results is presented in Table 3. It can be seen from Table 3 that compared with the untreated sample, CBR values of the stabilised samples increased considerably. The variation of CBR with cement content is shown in Fig. 4 while Fig. 5 presents the CBR versus dry density plots for the samples. Figs. 4 and 5 show that at all levels of compaction, CBR increased sharply with increasing cement content and dry density, respectively. CBR for sample stabilised with 5% cement increased up to 5 times that of the untreated sample. Ingles and Metcalf (1972) recommended that four-day soaked CBR of soil-cement road sub-base and base for light traffic should be in the range of 50 to 150. It can be seen from Table 3 that CBR of samples stabilised with 3% cement and compacted with medium and high energy and that CBR of samples stabilised with 5% cement and compacted with low to high energy fulfil the criteria proposed by Ingles and Metcalf (1972).

FLEXURAL PROPERTIES

Flexural strength test using simple beam with third point loading system were performed on compacted untreated and stabilised samples in accordance with the procedure outlined in ASTM D1635 (ASTM, 1989). The mould used for sample preparation was fabricated which comply with the requirements of ASTM D1632 (ASTM, 1989). The mould has inside dimensions of 76.2 by 76.2 by 285.8 mm for preparing samples of the same size.

Table 3. CBR Test Results of Untreated and Cement Stabilised Samples

Cement Content (%)	Dry Density (kN/m^3)			Soaked CBR		
	Compaction Effort			Compaction Effort		
	Low	Medium	High	Low	Medium	High
0	15.57	16.31	17.12	11	16	24
1	15.93	16.69	17.42	27	34	44
3	16.44	16.85	18.24	40	63	92
5	16.54	17.22	18.61	51	90	120

Note : low compaction effort = 10000 ft-lb/ft^3; medium compaction effort = 25000 ft-lb/ft^3 and; high compaction effort = 56000 ft-lb/ft^3

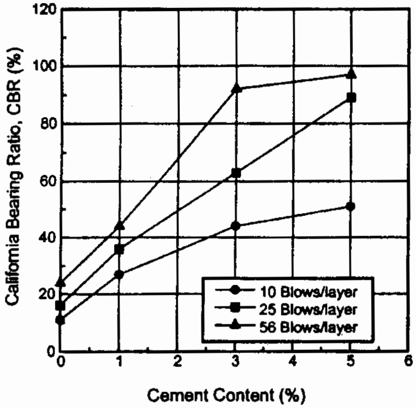

Fig 4. Effect of cement content on CBR

The design moisture content and dry density of the samples were approximately equal to their respective w_{opt} and γ_{max} achieved in the Modified Compaction tests. The stabilised samples were cured for 7 and 28 days before being tested. The fracture occurred within the middle third of the span length of the sample and the flexural strength (R) and flexural modulus (E) of samples were calculated using the following expressions:

$$R = \frac{PL}{bd^2} \tag{2}$$

$$E = \frac{23PL^3}{1296I\Delta} \tag{3}$$

where, P = total applied load; L = span length of sample; b = average width of sample; d = average depth of sample; I = moment of inertia of the beam section; and Δ = deflection of the beam in the mid span.

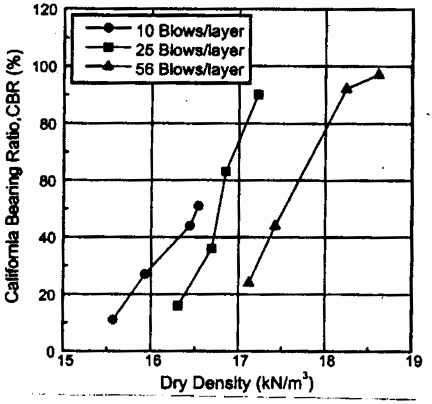

Fig 5. CBR versus dry density curves of samples

The flexural strength, flexural modulus and deflection (Δ) of the untreated samples were found to be 67.5 kN/m^2, 49.8 MPa and 0.2 mm, respectively. The flexural properties of the stabilised samples are shown in Table 4. Table 4 shows that compared with the untreated sample, the flexural strength and modulus of the stabilised samples increased significantly depending on the cement content and curing age. Compared with the untreated sample, flexural strength and flexural modulus of sample treated with 5% cement and cured for 28 days are about 4 times and 2.7 times higher. The effect of cement content on flexural strength and flexural modulus are shown in Figs. 6 and 7, respectively. Figs. 6 and 7 show that flexural strength and modulus increase with increasing cement content. It is also evident that curing age has got insignificant effect on increase in flexural strength and modulus.

Table 4. Flexural Properties of Cement Stabilised Samples

Cement Content (%)	Flexural Strength (kN/m^2)		Deflection (mm)	Flexural Modulus (MPa)		
	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days
1	80.8	84	0.147	0.152	80.1	80.9
3	101.3	128	0.180	0.216	82.0	86.8
5	248.0	267	0.328	0.292	110.6	133.3

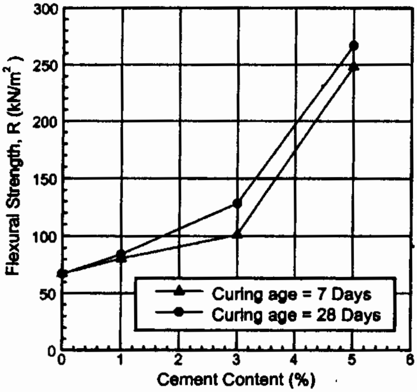

Fig 6. Effect of cement content on flexural strength

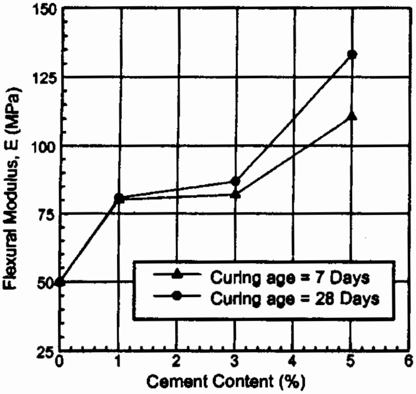

Fig 7. Effect of cement content on flexural modulus

DURABILITY

Durability of compacted soil-cement mix samples was evaluated by performing repeated wetting and drying tests in accordance with the *procedure outlined in ASTM D559 (ASTM, 1989)*. Compacted samples of 101.6 mm in diameter and 116.4 mm high were prepared following the procedure outlined in ASTM D698 (ASTM, 1989). Soil-cement losses in repeated wetting and drying tests for compacted soil-cement mix samples stabilised with 1%, 3% and 5% cement are 25.8%, 20.4% and 16.5%, respectively. The results indicate that the percentage loss in soil-cement decreases with the increase in cement content, as can be seen from Fig. 8. Similar results were also reported by Hossain (1986), for two regional soils.

PCA (1956) suggested that a maximum of 10% loss of soil-cement in the wet and dry test is allowable for this type of soil. Compendium 8 (1979), however, mentioned that in tropical and sub-tropical conditions, where freeze and thaw tests are not essential, a q_u-value of 150 psi (1034 kN/m^2) at 7 days curing is adequate to withstand 12 cycles of wetting and drying. A sample withstanding 12 cycles of wetting and drying satisfies the weathering conditions in the tropics. Table 2 shows that the values of q_u of samples stabilised with 3% and 5% cement and cured at 7 days fulfil the requirement as proposed by Compendium 8 (1979).

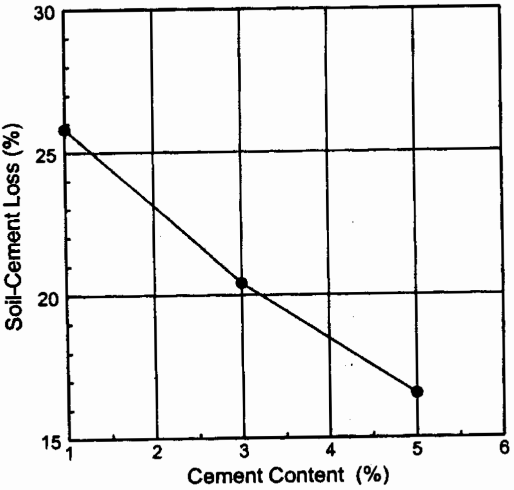

Fig 8. Effect of cement content on soil-cement loss for treated samples

ANALYSIS OF SOIL-CEMENT RURAL ROADS

Unpaved (i.e., continuous soil-cement base directly over natural subgrade) and paved (i.e., continuous soil-cement base overlying the natural subgrade and underlying an asphalt wearing surface) rural roads of width of 2.5 m and subject to wheel loads were modelled using the computer program CIRCLY (Wardle, 1977). The CIRCLY program is based on linear elastic theory for anisotropic materials in a horizontally layered system subject to multiple circular loads. The unpaved and paved roads have been assumed to subject design traffic loading of Light Cross County Vehicle (LCCV), i.e., jeep. LCCV is a single axle vehicle with an axle load of 24 kN which is supported by two tyres at the rear end having a contact pressure of 280 kPa in each tyre. The radius of the contact area of each tyre is 116.8 mm. In summary, the mechanistic design procedure consisted of the following steps (NAASRA, 1987):

(1) Selection of pavement structure and design pavement loading.

(2) Estimation of the elastic parameters of asphalt, soil-cement base and subgrade.

(3) Adopting the fatigue criterion for the asphalt, soil-cement base and subgrade.

(4) Determination of strains at the following critical locations in the pavement:
   - The tensile strain in microstrain (ε_1) at the bottom of the asphalt layer
   - The tensile strain in microstrain (ε_2) at the bottom of the soil-cement base
   - The compressive strain in microstrain (ε_3) at the top of the subgrade

(5) Determination of the number of allowable load repetitions (N_{all}) before unacceptable rutting or fatigue cracking occurs using the relationships for the fatigue criterion for the asphalt, soil-cement base and subgrade.

Input Parameters for Pavement Layers

The asphalt and the soil-cement layers were assumed to be homogeneous, elastic and isotropic. In each analysis of paved road, the values of thickness, flexural modulus and Poisson's ratio of the asphalt were equal to 38 mm, 750 MPa and 0.4, respectively. For both unpaved and paved roads, analyses were carried out with flexural modulus of soil-cement base equal to 300 MPa, 500 MPa and 750 MPa. Poisson's ratio of soil-cement base was taken as 0.2. The natural subgrade has been assumed to be homogeneous, elastic and anisotropic. The elastic parameters required for anisotropic layer are three moduli (vertical, horizontal and shear modulus) and two Poisson's ratio (vertical and, horizontal and cross). For the subgrade, the CBR values have been taken as 5 (an equivalent value for 80% compaction of subgrade) and 15 (an equivalent value for 95% compaction of subgrade). The vertical modulus (E_v) of the subgrade in MPa was estimated from its CBR and was assumed to be equal to 10 times the CBR value. A degree of anisotropy of 2 was assumed and accordingly the horizontal modulus (E_h) of the subgrade was set equal to half the E_v. The value of Poisson's ratio (ν) of subgrade was taken as 0.45 and the shear modulus is equal to $E_v/(1+\nu)$. The pavement interface layers were assumed to be rough.

Fatigue Criteria for Pavement Layers

The limiting strains at the pavement interface layers are related to the allowable number of load repetitions to fatigue (N) for the asphalt, soil-cement layer and subgrade. The following fatigue criteria have been used (NAASRA, 1987):

Asphalt fatigue criteria: $$N_{all} = \left[\frac{K}{\varepsilon_1}\right]^5 \quad (4)$$

K = 7245 for asphalt modulus = 750 MPa;

Soil-cement fatigue criteria: $$N_{all} = \left[\frac{K}{\varepsilon_2}\right]^{18} \quad (5)$$

K = 370, 360 and 340 for soil-cement modulus = 300 MPa, 500 MPa and 750 MPa, respectively.

Subgrade fatigue criteria: $$N_{all} = \left[\frac{8511}{\varepsilon_3}\right]^{7.14} \quad (6)$$

Analytical Results

For a particular CBR of subgrade and modulus of soil-cement base, a number of analyses were performed with varying thickness of soil-cement base (t). Using the fatigue criteria as shown in Equations 4, 5 and 6, the allowable number of load repetitions to fatigue (N_{all}) for each thickness of soil-cement base were estimated. The minimum of the three allowable load repetitions (N_{all}) as determined using Equations 4, 5 and 6 has been taken as the number of load repetitions to fatigue (N) for use in design.

Thickness of soil-cement base (t) versus number of load repetitions to fatigue (N) plots for subgrade CBR values of 5 and 15 for the unpaved road are shown in Figs. 9 and 10, respectively. Figs. 11 and 12, however, show the thickness of soil-cement base (t) versus number of load repetitions to fatigue (N) plots for subgrade CBR values of 5 and 15, respectively, for paved road. It can be seen from Figs. 9 to 12 that for each modulus, t increases with increasing N and that for any particular value of N, the values of t decreases as modulus of soil-cement base increases. Comparing Fig. 9 with 10, it can be seen that for each modulus, as CBR increases from 5 to 15, the thickness of soil-cement base decreases at any particular value of N. For example, it has been found that for unpaved road at N = 10^4 repetitions and modulus = 300 MPa, as CBR increases from 5 to 15, the thickness of soil-cement base decreases markedly from 275 mm to 175 mm (i.e., 36.4% reduction thickness of soil-cement base). Comparing Figs. 9 and 10 with Figs. 11 and 12, it is also evident that for all values of modulus, CBR and N, the thickness of soil-cement paved road is less than that for unpaved road. For example, at modulus = 750 MPa, CBR = 15 and N = 10^7 repetitions, the thickness of soil-cement base of unpaved road decreases from 225 mm to 200 mm for paved road (i.e., 11.1% reduction in thickness of soil-cement base).

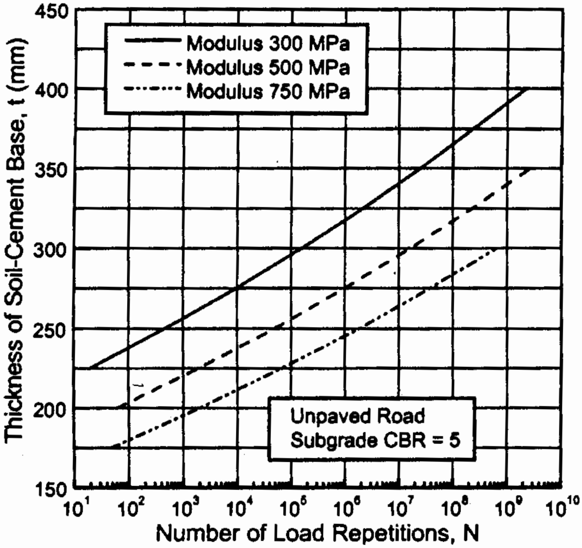

Fig 9. t versus N plots for unpaved road (subgrade CBR = 5)

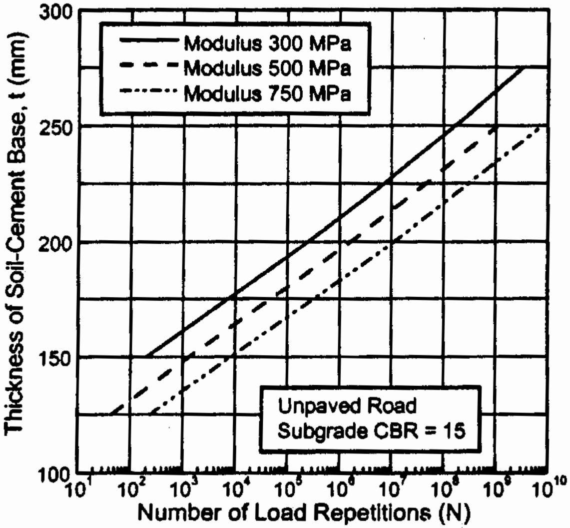

Fig 10. t versus N plots for unpaved road (subgrade CBR = 15)

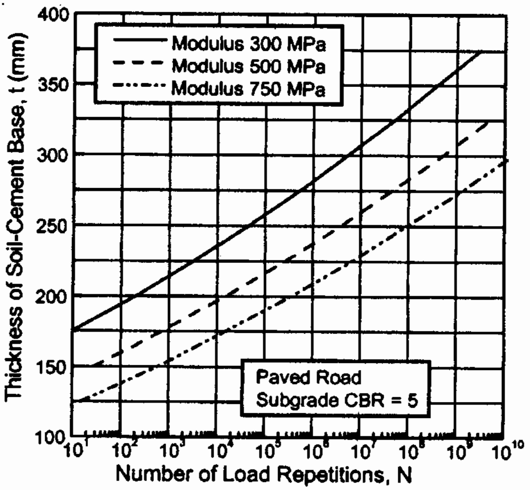

Fig 11. t versus N plots for paved road (subgrade CBR = 5)

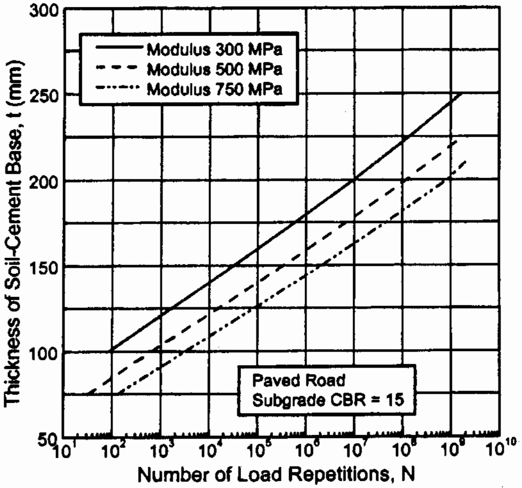

Fig 12. t versus N plots for paved road (subgrade CBR = 15)

CONCLUSIONS

Mechanical properties of a cement stabilised soil for use as base material in rural roads of coastal area have been investigated. Test results indicated that with the increase in cement content maximum dry density increased while optimum moisture content reduced.

Compared with the untreated sample, unconfined compressive strength (q_u) of stabilised samples increased significantly depending on the cement content and curing age. For all cement contents and curing age, the values of q_u of stabilised samples fulfil the requirements of soil-cement road sub-base and base for light traffic as proposed by Ingles and Metcalf (1972). CBR of stabilised samples increased sharply with increasing cement content. CBR of samples stabilised with 3% cement and compacted with medium and high energy and CBR of samples stabilised with 5% cement and compacted with low to high energy fulfil the criteria proposed by Ingles and Metcalf (1972). Flexural strength and modulus of stabilised samples increased with increase in cement content. Results of durability tests indicated that percentage loss in soil-cement reduced with the increase in cement content. According to the criteria proposed by Compendium 8 (1979), it has been found that samples of the soil stabilised with 3% and 5% cement and cured for 7 days will be able to withstand 12 cycles of wetting and drying which satisfies the weathering conditions in the tropics.

Paved and unpaved roads with soil-cement bases and subjected to a design traffic loading of Light Cross County Vehicle (LCCV), i.e., jeep, have been modelled using CIRCLY computer program. It has been found that for both paved and unpaved roads the thickness of soil-cement base depends markedly on subgrade CBR, modulus of soil-cement base and allowable number of load repetitions to fatigue (N), i.e., design life. It has been found that for both paved and unpaved road, at a particular CBR of subgrade and modulus of soil-cement base, the thickness of soil-cement base increases with increasing N and that at a particular CBR of subgrade and N, the thickness of soil-cement base decreases with the increase of modulus of soil-cement base. It was also found that as CBR of subgrade increases, thickness of soil-cement base decreases. For a given CBR of subgrade, modulus of soil-cement base and N, it has been found that the thickness of soil-cement base for the paved road is less than that for unpaved road.

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NOTATION

CBR	California Bearing Ratio (CBR)
d	average depth of soil-cement beam sample
b	average width of soil-cement beam sample
E	flexural modulus of soil-cement
E_v	vertical modulus of subgrade
E_h	horizontal modulus of subgrade
I	moment of inertia of soil-cement beam
K	fatigue constant
L	span length of soil-cement beam
LCCV	light cross county vehicle
N_{all}	allowable number of load repetitions to fatigue
N	number of load repetitions to fatigue for use in design

P	total applied load on soil-cement beam sample
q_u	unconfined compressive strength
R	flexural strength of soil-cement
w_{opt}	optimum moisture content
Δ	deflection of soil-cement beam sample at mid span
γ_{max}	maximum dry density
ε_1	tensile strain in microstrain at the bottom of the asphalt layer
ε_2	tensile strain in microstrain at the bottom of the soil-cement base
ε_3	compressive strain in microstrain at the top of the subgrade