Fourth Australia - New Zealand
Conference on Geomechanics,
Perth, 14-18 May 1984

Experimental Cement-stabilisation in Kuwait

S.N. DOSHI
Highway Research Engineer, Road Research Centre, Ministry of Public Works, Kuwait
M.S. MESDARY
Director, Road Research Centre, Ministry of Public Works, Kuwait
and
H.R. GUIRGUIS
Executive Vice President, Resource International Limited; Road Research Centre, Ministry of Public Works, Kuwait

SUMMARY This paper reports results of a laboratory and field study of the application of cement-stabilised subbase and base courses to permit reduction of thickness of highly temperature-dependent asphalt pavements. The results of various laboratory tests on a typical stabilised soil and for a range of cement contents are reported and their significance is discussed. Statistical relations among unconfined compressive, indirect tensile and flexural strengths of soil-cement are presented. The paper gives a description of trial pavement sections, construction procedures, field monitoring of test sections during and after construction, and discussion of results.

1 INTRODUCTION

In the summer climate of Kuwait, excessively high temperatures are induced in asphaltic pavements which cause substantial reductions of effective stiffness modulus. The resulting loss of load-spreading characteristics and pavement stability lead to distress such as excessive permanent deformation, surface corrugations and fatting-up.

An urgent need exists to reduce the thickness of asphalt layer or minimize its temperature susceptibility, either by binder modification or by development of improved asphaltic mixtures. This need provided the stimulus for extensive research programs by the Road Research Centre (RRC), Kuwait, including a program to explore the possible application of cement-stabilised sub-base and base courses to permit reduction of thickness of highly temperature-dependent asphalt pavements.

The initial phase of the research program was a laboratory study on the properties and behaviour of cement stabilised soils. Various laboratory tests were conducted, such as moisture-density, CBR, compressive strength, indirect tensile strength, modulus of rupture, and dynamic modulus, for a range of cement contents and curing times. The results of these tests are reported and their significance is discussed.

Based on the laboratory studies, an experimental project was constructed in April-May 1980, on an ongoing road project (Salmi Road), linking Kuwait and Saudi Arabia.

The paper gives details of the preliminary laboratory study, a description of trial pavement sections, construction procedures, field monitoring of test sections during and after construction, and discussion of results.

2 LABORATORY STUDIES

The soil used in the laboratory investigation was obtained from the proposed site of field trial pavement sections. The physical properties of the soil are summarised in Table I.

The cement used was Type I. Cylindrical specimens 101.6 mm in diameter by 116.4 mm high for moisture-density, unconfined compression, indirect tension and dynamic modulus tests, were compacted in accordance with AASHTO T 134-76, Method A. Flexural strength test specimens, 50.8 by 50.8 by 305 mm, were prepared following the procedure prescribed in AASHTO T 126-76. The specimens, after extrusion from the moulds, were sealed in plastic bags with no water added throughout the specified curing periods. The specimens were stored in a closed chamber at room temperature which varied from 18 to 25°C. Laboratory tests and major results are presented below.

TABLE I

ASTM No.	Openings (mm)	% Passing
4	4.76	100
10	2.00	98
30	0.59	87
40	0.42	73
50	0.297	54
100	0.149	26
200	0.074	18
Liquid limit		24
Plastic limit		19
Plasticity index		05
AASHTO classification		A-2-4
Bulk specific gravity		2.53
Maximum dry density, kN/m^3		17.90
Optimum water content, %		10.50
Soaked CBR, %		21.00

2.1 Moisture-Density Relationships

Dry density-moisture content relationships, for the typical A-2-4 soil used in this study with different cement contents, are shown in Figure 1. Appreciable increase in density is noted with increase in cement content. However, no significant change is observed in the optimum moisture content for compaction.

2.2 California Bearing Ratio.

Limited CBR tests at optimum moisture content were conducted for a range of cement contents and curing times. Although large variations in test results were noted, the CBR values obtained were generally very high. It was found that, with the addition of 9 percent cement by weight, a soaked CBR of at least 400 percent can be obtained at seven days.

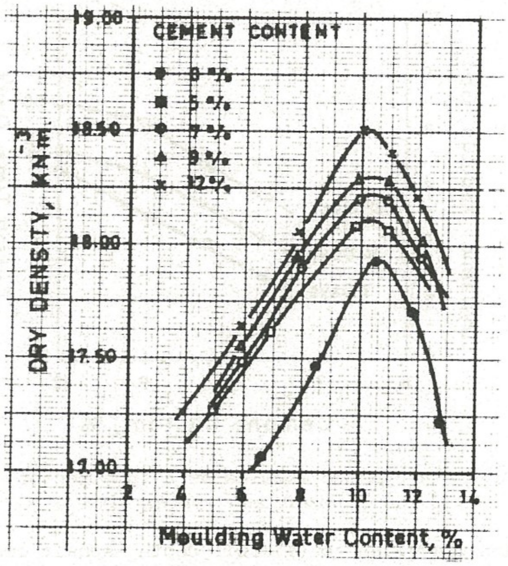


Figure 1 Moisture-density relations

2.3 Compressive, Tensile and Flexural Strength

Sufficient evidence has been reported in the literature to indicate that tensile or flexural strength is more significant than compressive strength, with regard to the behaviour of cement stabilised materials used in roads. It has been shown that both tensile and flexural strengths are related to compressive strength which is the most easily determined property. This explains why the unconfined compression test is so widely used even though failure typically occurs in tension.

In this study, all three strength test methods were applied to laboratory soil-cement specimens prepared with various cement contents and curing times. Cylindrical specimens, for unconfined compression and indirect tension tests, were compacted at the optimum moisture content. The unconfined compression tests were conducted at a strain rate of 1.3 mm m^{-1}. The indirect tension tests followed the method described in Transportation Research Board's Special Report 162 (1975). The indirect tension tests were performed at a constant deformation rate of 0.847 mm s^{-1}. The flexural strengths of specimens, prepared at optimum moisture content, were determined by testing simple beams subjected to a load applied at a rate of 200 N m^{-1}. The cured cylindrical and beam specimens were soaked in water at 25°C for four hours before testing. All speciments were tested at a temperature of 25°C.

The relationships between curing time and compressive strength, tensile strength, and flexural strength are shown in Figure 2 for various cement contents.

The interrelations between unconfined compressive, indirect tensile and flexural strengths are found to be sensitive to the cement content and the curing time and considerable scatter is observed. Theindirect tensile strengths are found to range between 5 and 20 percent of the corresponding compressive strengths, and between 19 and 95 percent of the corresponding flexural strengths. Flexural strengths are found to range between 19 and 45 percent of the corresponding compressive strengths.

Statistical analysis of the test results established correlations for estimating indirect tensile and flexural strengths from unconfined compressive strength. As an approximation, the following

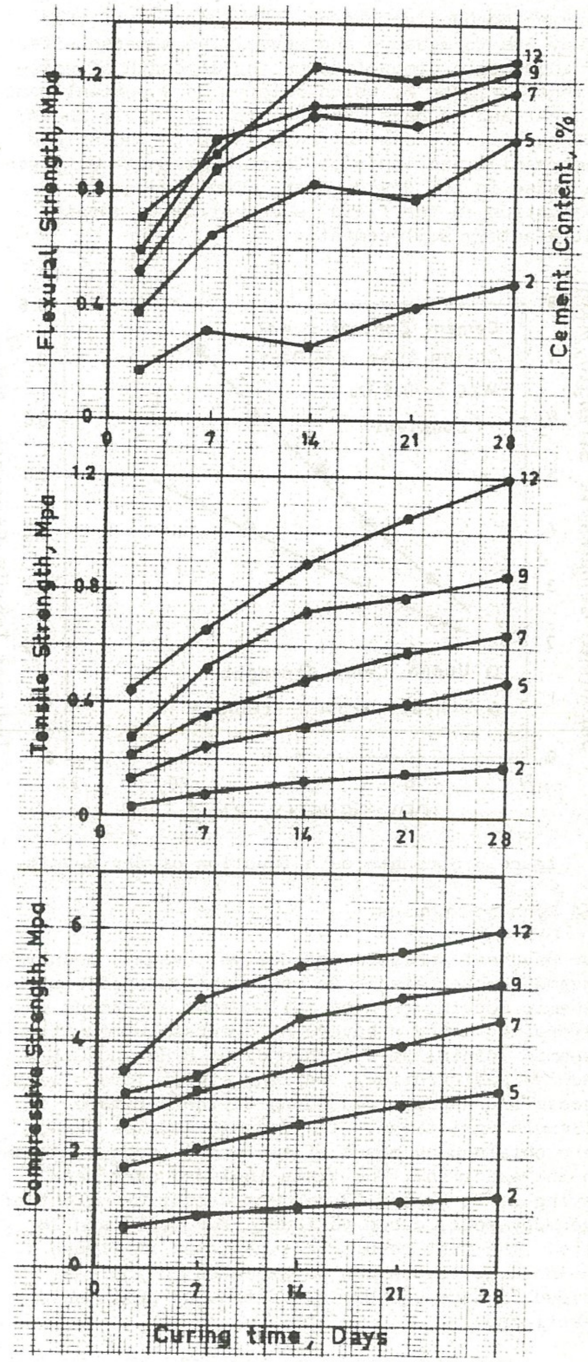


Figure 2 Variation of strengths as a function of curing time and cement content

relationships are suggested (Doshi and Guirguis, 1983):

$$S_t = 4.529 \times 10^{-3} (q_u)^{1.418} \quad (1)$$

$$f = 0.875 (q_u)^{0.845} \quad (2)$$

where:

S_t = Indirect tensile strength in kN m^{-2}
q_u = Unconfined compressive strength in kN m^{-2}
f = Flexural strength in kN m^{-2}

2.3.1 Effect of density

The effect of inadequate compaction on unconfined compressive and indirect tensile strength of soil-cement was studied in the laboratory by testing specimens moulded at optimum moisture content and varying compactive effort. The purpose of this study was to measure and reveal the adverse effect of inadequate compaction on the strength of soil-cement. Figure 3, which relates to 9 percent cement content and 14 days curing time, typically shows substantial decrease effected in both unconfined compressive and indirect tensile strength with small decrease in the dry density. Thus, adequate compaction in the field is essential to obtain satisfactory soil-cement.

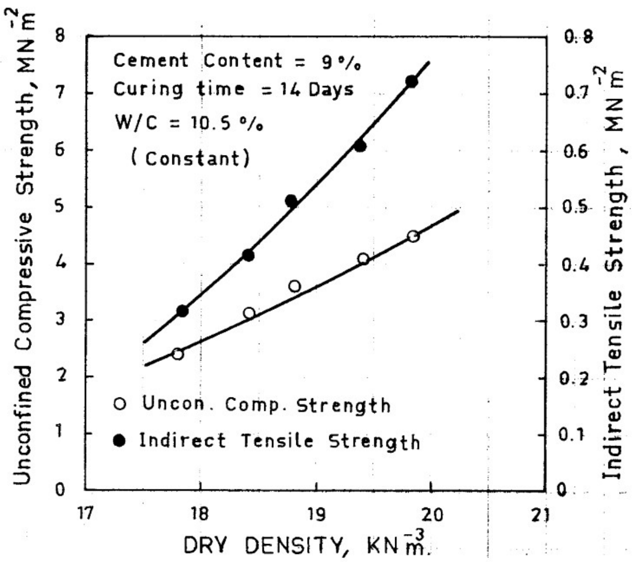


Figure 3 Strength as a function of dry density

2.4 Dynamic Modulus

For pavement analysis and design, dynamic modulus of pavement materials is an essential characteristic. Dynamic modulus (E*) of soil-cement specimens was determined using a haversine compression function of dynamic loading at a frequency of 8 Hz and 0.125 second load duration. Various stress levels were chosen and applied according to the ultimate strength variations. The dynamic modulus values were obtained by means of two strain gauges attached to the specimen. The tests included specimens having 5, 7, 9, and 12 percent cement by weight of oven-dry soil, cured variously for 7, 14 and 28 days. The test results are depicted in Figure 4. The modulus values can be expected to increase beyond 28 days age due to continuing pozzolanic reactions.

3 FIELD STUDIES

Using the guidelines established by theoretical analysis and laboratory research, two experimental road sections were designed with soil-cement layers in the structures. Construction of soil-cement layers was carried out in April-May 1980 as a part of road construction work in progress for Kuwait-Saudi Arabia Road.

3.1 Description of Test Pavements

Kuwait-Saudi Arabia Road is about 80 km long. The pavement thickness of this road except for the test sections is 25 cm, comprising all asphaltic layers, locally designated as sand-mix (sub-base course), asphalt concrete Types I (base) and II (binder or levelling course), each 7 cm thick, and Type III surface 4 cm thick. The subgrade soil was a typical local sandy soil with a CBR of at least 15.

In the design of experimental sections, consider-

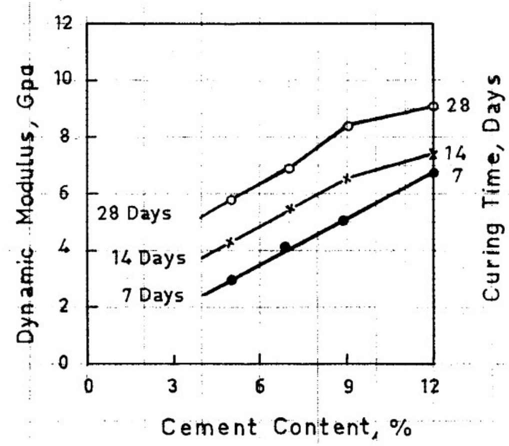


Figure 4 Dynamic modulus as a function of cement content and curing time

ation was given to (i) full depth asphalt construction overlying a soil-cement layer and (ii) an unbound granular layer placed between asphalt concrete and soil-cement layers. Figure 5 shows a schematic presentation of layer composition of the trial pavements. A uniform thickness of 15 cm was adopted for soil-cement layers in both trial sections. The amount of cement to be mixed (9% by weight of dry soil) was determined mainly on the basis of compressive and tensile strength requirements.

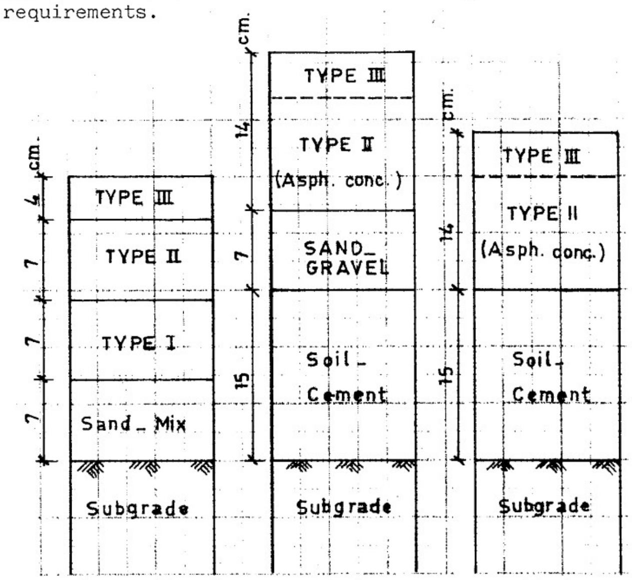


Figure 5 Layer composition of trial pavements

The experimental sections were planned in such a manner that the major emphasis was placed on "sandwich" design (Section I, Figure 5). Section I is 3.6 km long and Section II is 1.0 km long. "Sandwich" or "upside-down" construction can minimize or eliminate the risk of propagation of cracks from the cement-stablised layer to the surface through the asphaltic layer. This type of construction has been applied with considerable success in Japan (Yamanouchi, 1965), Switzerland (Vogt, 1973; Scazziga, 1982) and South Africa (Otte et.al., 1976).

3.2 Construction of Soil-Cement Layers

The embankment and subgrade preparation for the test area, to the required level and grade, was carried out according to Kuwait standard specifications. The subgrade was tested by both Dynaflect and nuclear density gauge and found to be satisfactory.

Soil, cement, and the required quantity of water were mixed in a stationary plant. The mixed material was transported to the site in trucks as quickly as possible, unloaded into the paver and spread on the subgrade. Breakdown rolling was performed immediately behind the paver with two coverages of single drum, self-propelled vibratory roller. Intermediate rolling was performed with no vibration for two coverages and the final rolling was done with six coverages of a pneumatic-tired roller. This pattern of compaction produced acceptable density. It was necessary to limit the length of construction unit to ensure completion of the compaction process before initial set of cement. Normally, a 150-m long section of soil-cement was constructed each day. Dust storms hampered construction on occasion.

As the paver used had a maximum width of 4.5 m, the work was carried out one lane at a time with a longitudinal construction joint. Compaction of one lane was concurrent with processing of the adjacent lane.

Water curing was begun within two hours of compaction and was maintained for 7 days. Then further curing was achieved by means of bituminous emulsion applied at a rate of about 1.0 litre m^{2}.

Trials were undertaken to investigate the possible advantages of "deliberate pre-cracking" as a solution to reduce the risk of reflection cracking in the pavement surface. Extensive small cracks were deliberately induced in the soil-cement by applying a heavy steel wheel roller to recently laid material. This additional rolling was performed on a 250-m long stretch in Test Section II.

For Section I, a layer of unbound sand-gravel was constructed over the stabilised layer. Construction of the 7-cm thick sandwich layer of sandgravel was in accordance with Kuwait general specification requirements.

Construction of asphalt levelling course (Type I) and the wearing course (Type III) was in accordance with the particular specifications of the contract. No special problem was encountered during the field construction.

3.3 Evaluation During Construction and Curing

3.3.1 Delayed compaction

The dry density and strength of soil-cement are functions of time lapse between mixing and compaction. The adverse effect of time lag between mixing and compaction on the density and strength of soil-cement was studied. Soil-cement mixtures taken from the mixing plant were moulded at various time intervals between mixing and compaction, ranging from 10 minutes to 4 hours. Dry density tests revealed profound effects of delayed compaction. The samples were cured for 14 days and then tested for unconfined compressive strength. Figure 6 shows the mean results of these tests.

3.3.2 Variation in compressive strength

In a study of the variability in compressive strengths of in-place soil cement mixtures, the data indicated significant variation in strengths of laboratory and field specimens. It was found that a difference of 500 kPa between identical laboratory

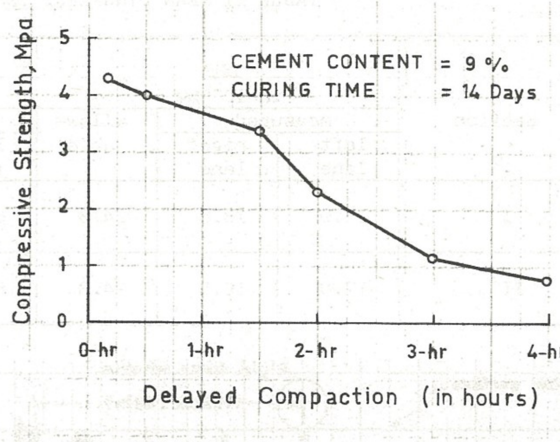


Figure 6 Effect of delayed compaction

specimens could occur, even for repeated tests under strictly controlled conditions.

Specimens of plant-mixed material in the field were prepared and cured both in the laboratory and in the field. Strengths of specimens prepared in the field and cured in the laboratory were also evaluated. It was observed that field-moulded and field-cured soil-cement specimens had, at 14 days curing, only 50 percent of laboratory design strength. However, this difference could become smaller at prolonged age.

3.3.3. Field moisture and density

The moisture content of the soil-cement mix was checked at the plant as frequently as practicable. Moisture adjustments were applied as and when necessary. However, some fluctuations in the moisture content during compaction were noted, perhaps due to climatic factors.

Moisture and density measurments of compacted soil-cement were obtained by nuclear and traditional methods. Speedy moisture and sand replacement tests were employed as conventional methods. The nuclear gauge was used more extensively as it is more convenient and provides prompt and accurate results.

Tests were carried out at 20-m intervals, at least 2 hours after completion of the compaction work. In general, compaction was higher than the specified 95 percent of maximum dry density.

3.3.4 Cement content

To study the uniformity of the plant mixing operation, samples were obtained during the compaction operation for cement content analysis by AASHTO method T 144-74. Cement contents were found to be generally higher than specified by 5 to 15 percent.

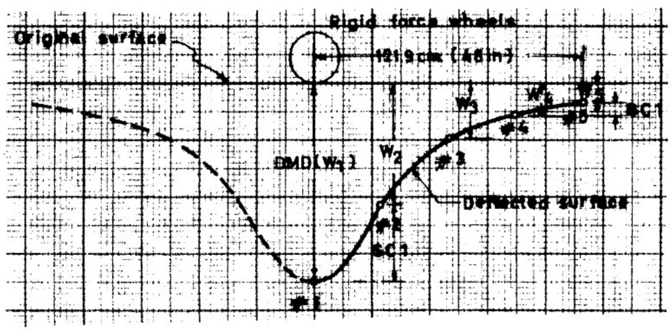
3.3.5 Dynamic deflection

Construction quality of soil-cement layers was also checked by dynamic deflection measurements using the Dynaflect equipment. The Dynaflect unit consists of a dynamic force generator, control unit, sensor assembly, and a calibration unit. The deflection measurements are made using five motion sensing geophones suspended from the towing arm of the trailer. The deflection basin parameters associated with Dynaflect measurements are shown in Figure 7.

Dynaflect measurements were conducted at 25-m intervals on the experimental sections, 2 days and 7 days after their completion. The deflection results

TABLE II MEAN DYNAFLECT TEST RESULTS FOR SOIL CEMENT AT 2 DAYS

Section	DMD in 10^{-3} mm			SCI in 10^{-3} mm			SP (%)		
	measured		allow-able	measured		allow-able	measured		allow-able
	left lane	right lane		left lane	right lane		left lane	right lane	
I	17.0	18.8	24.8	6.3	6.0	6.8	46	48	45
II	17.0	16.5	24.8	6.8	5.8	6.8	42	45	45



DMD = Dynaflect maximum deflection (W1)
SCI = Surface curvature index (W1-W2)
BCI = Base curvature index (W4-W5)
Sp = Spreadability $\frac{(W1+W2+W3+W4+W5)}{5W1}$

Figure 7 Dynaflect deflection basin parameters

were analysed by a computer program which lists all five deflection values and the basin parameters. The program also calculates the mean and the standard deviation of these parameters.

Tables II and III give the mean deflection data. Allowable Dynaflect parameters, estimated using mathematical simulation of structure response, are also shown. Based on the allowable limits for each performance parameter (MDD, SCI, Sp), the measured deflections indicate satisfactory soil-cement construction.

3.4 Post construction evaluation

Since construction, the experimental pavement sections have been continuously evaluated. Periodic field tests and condition surveys will be continued for a number of years. Some of the results obtained to date are presented below.

3.4.1 Dynamic deflection tests

From a study of the results of Dynaflect tests carried out at 28 days, it was observed that the deflection values were greater than those measured during the wet curing period. This was due to the development of cracks at 28 days. When these cracks were sealed with expansive cement and the soil-cement layer tested thereafter, the results showed considerable improvement. The variation in results for left and right lanes was found to be insignificant.

3.4.2 Crack survey

The results of the crack survey are briefly presented in two main sections:

1. Shrinkage cracking of soil-cement before placement of a bituminous cover.

2. Cracking in the pavement surface under traffic.

1. The phenomenon of cracking of soil-cement layers, which occurs even in the absence of wheel loads, indicates the importance of stress due to changes in the moisture content and ambient temperature during and after the curing period. Research studies of the shrinkage of soil-cement under various conditions have been reported by George (1968); Pretorius and Monismith (1971); Wang (1973); Bhandari (1973); Bofinger et.al (1978).

Cracking behaviour of the experimental sections in this study was carefully surveyed and mapped periodically. After 28 days curing, shrinkage cracks in Section II were extensive, with transverse cracks at regular intervals of about 5 m, as wide as 15 mm, and longitudinal cracks along the construction joint. Shrinkage cracks in Section I occured only at isolated places with transverse cracks 25 to 30 m apart having widths generally smaller than 4 mm. No further change in crack frequency and width was noted after this period. It is pertinent to note that the soil characteristics, cement content in the mix, compaction and the method and time of curing for both sections were identical. The only variable parameter was the compaction moisture content. In Section II, moisture content during compaction was about 2 percent more than optimum whereas in Section I, the moisture content was close to optimum. This shows that the moisture

TABLE III MEAN DYNAFLECT TEST RESULTS FOR SOIL-CEMENT AT 28 DAYS

Section	DMD in 10^{-3} mm		SCI in 10^{-3} mm		SP (%)		E in MPa	
	cracked	cracks sealed	cracked	cracks sealed	cracked	cracks seals	cracked	cracks sealed
I	19.5	19.0	6.8	6.3	42	45	3050	3450
II	22.0	18.1	9.2	7.1	41	43	1800	2750

content at which soil-cement was compacted had a profound effect on shrinkage cracking. This finding is consistent with the laboratory results reported by George (1968) and Bofinger et.al. (1978). This study has provided sufficient information on the effect of compaction moisture content on shrinkage cracking to justify compaction of soil-cement at or below, but never above, the optimum moisture content. However, the target moisture content should be the optimum and not below, so that other criteria for acceptable dry density and air voids are also satisfied.

2. Since the placement of a bituminous cover, a periodic survey of surface cracks has been made. The first cracks to develop in the pavement surface were recorded in Section II in February 1982. These cracks were less than 3 mm wide. No cracks developed in Section I at that time. Since no cracks developed in Section I with a sand-gravel sandwiched base, it is assumed that the cracks in Section II were a result of the upward propagation of shrinkage cracks in the soil-cement base. The portion of Section II where deliberate pre-cracking was induced in the soil cement base had little reflection cracking in the wearing surface. No subsequent cracking has been observed since they first developed. The field survey made in April 1983 revealed that many of the surface cracks in Section II noted earlier have closed and are no longer visible.

4 SUMMARY AND CONCLUSIONS

Laboratory tests showed a substantial decrease effected in the strength properties of soil-cement with small decrease in the dry density. The importance of adequate compaction in the field is stressed.

Statistical analysis of laboratory strength results established correlations for estimating indirect tensile and compressive strength. There is little object in carrying out all three strength tests.

The overall condition of the test pavements constructed with soil-cement layers in the structures is good. Periodic field tests and condition surveys are to be continued. The major observations made to date are as follows:

There can be a significant variation in strengths of laboratory and field specimens and this should be accounted for in the design stage, so that the final desired density and strength can be achieved. It is essential that soil-cement mixture be compacted as quickly as possible.

Dynaflect tests carried out at 28 days showed greater deflections than those measured during the wet curing period. This was due to the development of cracks at 28 days. When these cracks sealed and the soil-cement layer re-tested, the results showed considerable improvement. It is thus better to allow the soil-cement to crack and then seal these cracks before laying the asphalt courses.

The moisture content at which soil-cement is compacted is found to have a profound effect on shrinkage cracking. Soil-cement should be compacted at or below, but never above, the optimum moisture content. However, the target moisture content should be the optimum and not below, so that other criteria for density and air voids are also satisfied.

Crack survey of the pavement surface under traffic indicated that full depth asphalt construction overlying a soil-cement layer will show reflection cracking. This can be minimised either by "delibrate pre-cracking" or sandwich layer system. The long term performance of sandwich structure must await further observations. However, there is some indication that it is a better solution.

The successful construction of trial pavements and subsequent field tests have shown the feasibility of the application of cement stabilised sub-base and base courses to permit reduction of thickness of highly temperature dependent asphalt pavements.

5 ACKNOWLEDGEMENTS

The authors wish to express thanks to V.R. Kumar for his help in the field studies. Thanks are also due to Moawad Ali Samaha and Ahmed Sabry who carried out preparation and testing of laboratory samples.

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