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A Comprehensive Evaluation of Pavement Design Parameters for Kuwaiti Soils

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SUMMARY The paper briefly describes some of the salient results of a comprehensive study to investigate the part played by subgrade soil materials as are available in Kuwait. It also examines the correlations if any found to exist between laboratory measured resilient modulus, laboratory measured CBR values, peak shear stress ratio on a shear box at 10 kN/m^2 vertical stress and results from a simple impact hammer test developed in Australia. The results demonstrate the inherent difficulty of predicting the dynamic response from the results of static tests.

1 INTRODUCTION

The development of improved design procedures for flexible pavement structures requires a knowledge of the mechanical characteristics of the component material. During the last decade the Ministry of Public Works (MPW) in the state of Kuwait constructed, a significant part of the country's road network in accordance with the national policy for social and economic development. Unfortunately the active program of road construction during this period allowed little opportunity to adequately characterize the subgrade soil. The lack of such information made it impossible to identify adequately the effect of factors and factor interactions often encountered in the hot and dry climate of the region affecting subgrade soil support and inturn its influence on pavement design and overlay thickness requirements.

The MPW and Kuwait University are placing increasing emphasis on the development and standardization of the design and evaluation procedures suitable for local conditions. The fact that Kuwait is one of the fortunate countries that enjoys one of the very good subgrade soils made subgrade soil a potential candidate for its investigation and subsequent use in the design and evaluation studies of road pavements.

Improved methods of subgrade soil characterization require that these materials should be characterized in terms of fundamental parameters. However, there is no simple, inexpensive and practical method available for determination of the structural action, strength and deformation modulus of these materials. The most commonly used CBR method of testing and design which is based on an arbitrary strength property of material has inherent shortcomings mainly due to the confining boundary effects of the mould. The paper briefly describes results from some of the testing techniques being used to investigate the part played by subgrade soil materials. The equipment used and modified includes not only simple, practical and inexpensive bearing test, impact hammer test, direct shear box test, but also a repeat load triaxial test machine. A prime aim of investigation is to degermine the existance of any correlation between the complex stress-strain relationships obtained from a repeat-load triaxial test and the simple static type of tests.

2 AN APPRAISAL OF SUBGRADE SOILS IN THE STATE OF KUWAIT

As per AASHTO classification four types of soils viz A-1-b, A-3, A-2-4 and A-4 are generally encountered in Kuwait. However, A-2-4 is the most common type of soil. The road subgrade foundation soil locally known as 'Gatch' is found almost every where below varying depths of wind blown sand. Gatch is predominantly calcareous sand and contains sufficient fines to give a measure of cohesion when watered and rolled. Properly compacted Gatch having a CBR in excess of 100 percent provides an excellent base provided it is kept dry. Fines content of Gatch has a low plasticity index and moisture content during rolling is critical. For the best Gatch it varies from 7 to 12 percent depending on the degree of compaction being exerted. However, a small moisture variation due to temporary flooding or percolation through hair cracks in the surfacing causes a slurry formation and results in road failure.

Surface wind blown natural desert sands are in general too fine and are difficult to compact even if this contains a little material passing 75 micron sieve. It gets readily broken up by traffic and once in loose state can not be recompacted with normal rollers. However, such materials can provide a very firm and stable platform for road construction when compacted and confined by the pavement layers above. Occurrances of coarser varieties of clean sand are limited. They are found in the form of thin lenses which are reasonably clean and well graded but beneath about one meter of finer overburden and overlying Gatch.

Other characteristic feature of Kuwait's arid region is the presence of evaporite salts in the ground close to the surface, especially in locations where the ground water level is high, near the sea for example. The effect of these salts (namely gypsum, salts of calcium, magnisium and sodium sulphate in varying proportions) on the durability of a road pavement is an important consideration in arid regions. It has been found that the cementing effect of salts in the crystalline state may render certain otherwise weak materials highly suitable for road construction.

3. CHARACTERISATION OF SOILS

The current Kuwaiti specifications for soils for use in pavement construction were derived from AASHTO and BS specification. In the current specifications, the stability of the soil is implied rather than measured, for the only strength test referred to in the Ministry of Public Works standard is the CBR. The soil characteristics of importance in evolving a design and maintenance strategy for pavement structures (by integrating parameters such as traffic, material resources, climate and maintenance policy) are relationships between applied stress and the resultent resilient and permanent strains. The necessary insitu testing to obtain this information is not only very complex and expensive but in any event is not possible at the design stage. This has led to the need for development of suitable laboratory test procedures which aim to reproduce insitu conditions as closely as possible both in regard to the condition of the material, and the stress pattern applied during the test.

The reproduction of all aspects of insitu stress conditions in the laboratory requires very complex equipment and this even for research purposes has not yet successfully been done. In all earlier works simplifications have been applied by reproducing those aspects of insitu situations which are likely to be of most significance.

4 RESEARCH OBJECTIVES

Several individual research studies investigating the dynamic response of soil materials using repeat load triaxial test apparatus have been reported in the past. Most of the above studies were directed towards a specific soil type, or investigation of a particular parameter upon the resilient modulus (Mr) response for a given material. However, the results shown in Fig. 1 of a recent study (Doshi, 1983) on comparison between CBR ranges for Kuwaiti soils and general soils having same AASHTO classification show an appreciable variations. This is primarily because of the reason that Kuwaiti soils are generally calcareous in nature and contain gypsum, salts of calcium, magnesium and sodium sulphates in varying proportions, (Bissada, 1974). With Kuwaiti soils, specifications need to recognise that different soil types will possess different salts and carbonate sediments by different amounts. This in turn indicates the need for development of suitable performance test methods of the soils in respect of degradation, permeability and bearing capacity.

In order to give more latitude and encouragement in the use of local soil materials there is also need to establish acceptance criteria for (a) low grade but otherwise sound soil materials and (b) soils which are apparently sound in conventional laboratory testing but which deteriorate in service and to evolve methods of improving soils which would normally be unsatisfactory in service. This particularly applies where soils deteriorate in the presence of water and would involve means of reducing their sensitivity to water and/or preventing water from having access to soils in question. The acceptance criteria for such materials must in all cases be related to the category of pavement and traffic for which the material is considered for use.

The main objectives of this research have been:

(i) to determine if typical resilient modulus (Mr) relationships exist for the typical soil types found in the state of Kuwait.

(ii) to investigate the factors and factor interactions affecting the modulus response in respect of the soil types chosen for test.

(iii) to determine any correlations found to exist between laboratory measured resilient modulus, laboratory measured CBR values, peak shear stress ratio on a shear box at 10 kN/m^2 vertical stress (Pike 1972) and results from a simple low cost impact hammer test developed in Australia, (Clegg, 1980).

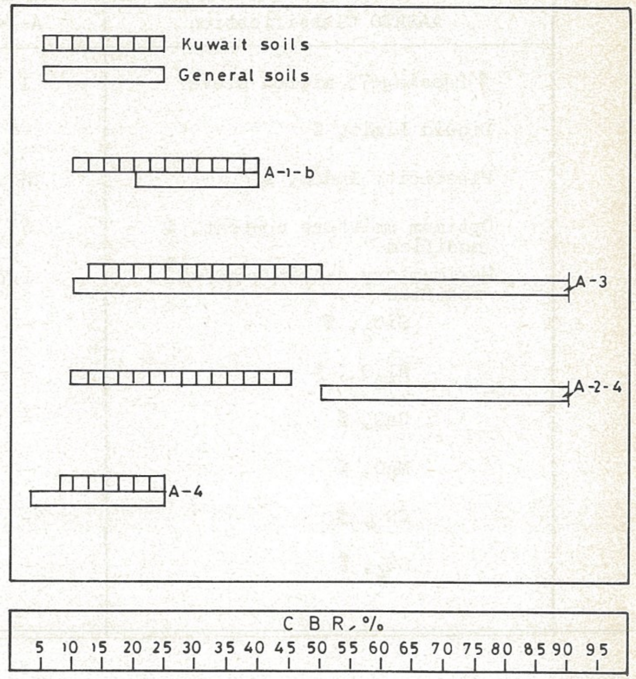

Figure 1 Comparison between CBR ranges for Kuwaiti soils and general soils having same AASHTO classification (After - Doshi 1983)

5 SELECTION OF MATERIALS, TESTS AND TESTING PROCEDURES

The soil types studies have included four of the most common types of soil material, viz. A-1-b, A-2-4, A-3 and A-4 as are commonly available in the state of Kuwait. Samples obtained from different locations showed minor variations in plasticity, physiochemical characteristics and percentage passing 0.075 mm sieve. Thus, a representative sample was used in this study. The grain size distribution and the corresponding pertinent properties of the soils are summarized in Table I.

The following laboratory tests were carried out:

1. Repeat load triaxial,
2. California Bearing Ratio (CBR)
3. Peak Shear Stress Ratio (PSSR), (Pike, 1977)
4. Impact hammer, (Clegg, 1980)

Compaction was carried out by vibration technique

TABLE I

SOIL PROPERTIES

AASHTO Classification	A-1-b	A-2-4	A-3	A-4
% Passing 75 micron sieve	1	3	5	49
Liquid Limit, %	-	-	-	28
Plasticity Index, %	NP	NP	NP	9
Optimum moisture content, % modified	6	9	7.50	15.5
Maximum dry density, gm/cm^3 modified	1.79	1.9	1.82	1.79
SiO_2, %	-	83.6	88.7	47.1
Al_2O_3, %	-	3.3	3.1	9.9
CaO, %	-	2.3	2.0	14.3
MgO, %	-	1.6	1.1	8.5
CO_3, %	-	7.6	0.7	8.8
SO_4, %	-	0.3	0.1	3.0

for granular soils and by falling hammer technique for others so as to produce densities comparable with those obtained on site. The maximum proportion of volume occupied by solids (MPVS) was then determined as a measure of the combined effects of particle shape and surface texture, initial grading and degradation of the compaction achieved.

6. RESULTS

Laboratory tests on the four selected soil types each compacted to maximum dry density show wide differences in engineering properties.

6.1 Compaction Characteristics

Typical results of compaction tests (Fig.2) show that most A-3 granular soils five comparable values of maximum dry density when compacted dry or compacted at initial moisture contents at or slightly above that required to saturate the soils. This further indicates that, if results are transposed to a volumetric basis, the maximum proportion of volume occupied by solids (MPVS) for a granular soil when compacted to refusal in a dry state may be taken as a measure of laboratory compactability. Also the water required to saturate the soil at this MPVS has been found to correspond with the optimum moisture content (OMC). This OMC could be given by the following expression:

$$OMC = \frac{100(100-MPVS)}{MPVSxRD} + WA$$

where RD = owen dry relative density of soil
and WA = water absorption value of soil (percent)

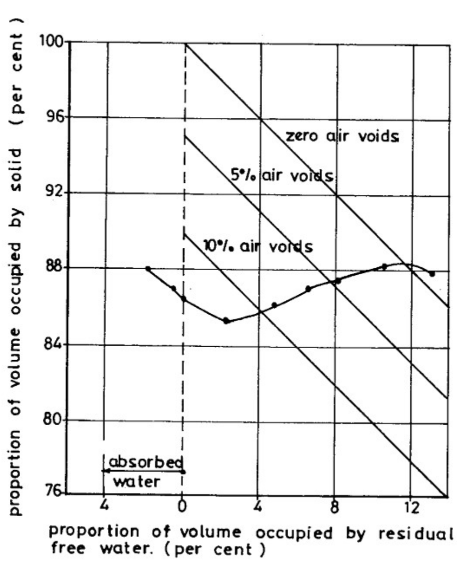

FIG. (2) TYPICAL COMPACTION CURVE

This observation of a higher density at zero moisture content is similar to the one reported by Dynapac's research department, (Forssblad,1980) indicating the potential of dry compaction technique as an effective and very economical method in desert regions where water is in short supply and expensive.

6.2 CBR Test Results

CBR results of soils indicate that CBR values increase as the penetration increases. Also, for almost all tests, the CBR values obtained from the top surface were lower than those obtained from the bottom surface. The tests on the bottom faces (which were smooth and dense because they had been compacted against the face of the base plate of the CBR mould) did not provide a clear distinction between effects due to various factors and factor interactions. It would however, probably be unwise to rely on the tests carried out on the top surfaces of CBR samples compacted with a table vibration technique. The lower results obtained for these cases were probably attributable to the disturbed surfaces produced due to trimming the top to a reasonable level surface before testing. The trimming process can introduce local variabilities of particle packing. Such disruption is not repeatable even after trying several modifications of the method.

6.3 Direct Shear Test Results

The laboratory test results on soil mixes using a 60 mm circular shear box revealed that the well-known Mohr-Coulomb Theory that relates two elements of shear strength (internal friction and apparent cohesion) linearly to confining (normal) stress is inapplicable to well-graded, well-compacted, non-plastic materials. This deviation from linearity of the Mohr-Coulomb failure envelope has been observed by Enderby as long ago as 1940. Similar observations have been reported recently by Pike, Acott and Leech (1977). Tests have been carried out in the present research to determine the Peak Shear Stress Ratio in the manner advocated by the TRRL/SAGA workers. These results show that average Peak Shear Stress Ratio for most soils having CBR of more than 20 were between 3 and 4.6 respectively. The comparative trafficking trials at TRRL have shown that a stable subbase should have a threshold value of about 3. This shows most of the soil mixes when compacted to refusal (as in the present laboratory study) give a mix capable of forming a stable sub-base.

6.4 Triaxial Test Results

Using repeat load triaxial apparatus under constant confining stress, it was observed that both the resilient axial and radial strains vary not only with the repeated axial stress, but also with the confining pressure indicating that the resilient response of most granular soil materials is significantly non-linear. Hence for the pavement structures in Kuwaiti conditions overlying granular soil-subgrade whose response primarily dictates the overall behaviour of the road, a non-linear approach to analysis is necessary for accurate prediction of primary, limiting and functional response. The preliminary findings from the factorial analysis of triaxial test results indicate that resilient properties of soil materials are also affected to a lesser extent by such factors as soil type, density, grading and moisture content than by stress level and confining pressure. It was also observed that permanent strain for soil mixes tends to reach an equilibrium value after about 10^4 load applications. This indicates that well-graded, well-compacted unbound soil mixes well-protected from water may give good performance in field conditions after efficient early compaction by rollers and construction traffic.

Predictive equations to relate the primary variables influencing the resilient modulus response of these four different soils so far studied are given in Table II.

These equations use : (bulk stress), for a constant test moisture Sr (saturation) and density. Analysis of the results of over 40 dynamic triaxial tests in-indicates that similar inverse correlations exist between K_1 and K_2 for all granular soil materials. For the range of test conditions investigated, permanent deformations accumulated rapidly under the early few load applications but the rate of accumulation decreased considerably after about 200 load applications. At this stage the level of permanent deformation recorded was in all cases less than 2 per cent and generally less than 1.25 per cent.

6.5 Impact Tester Results

The Impact Tester used is a simple, low cost, convenient, portable and reliable device, similar in design to the Impact Soil Tester developed in Australia. The test is based upon measurements of the decelerations of a 4.5 kg hammer when dropped upon a sample of compacted soil. The correlation presented earlier by Lees and Bindra (1982) indicated the relationship between CBR and Impact value is of the form CBR = $2.5\ I_4 - 25$ (for CBR > 30%) where I_4 is the Impact value at the 4th blow. As a general rule, it appears that the CBR value over the full range of CBR values is equal to $0.07(I_4)^2$. With a view to confirming the validity of CBR values predicted by using this correlations additional actual tests were performed. Good agreement was observed between the CBR predicted from the established correlations and that measured by these additional check experiments.

7 CONCLUDING REMARKS

The factorial design experiment for analysing the effect of factors and factor interactions from different combinations of types of soil, compaction moisture condition, density and compaction effort at two levels, has revealed widely varying results between and within both static and dynamic tests on nominally identical specimens. These results demonstrate the difficulty of predicting the dynamic response from the results of static tests.

Comparison of resilient modulus and conventional CBR values on nominally identical specimens relating these variables is a function of stress level. For typical bulk stress values anticipated under highway pavements the coefficient is significantly lower than the value of 10(M_r = 10 CBR) suggested by Henkelom & Foster (1960). This could be due to the fact that CBR values are determined when deformations are considerable, whereas the dynamic elastic modulus is derived from measurements made with very small deformations and relatively high frequencies. There is, therefore, no necessary direct relationship between the two.

Using a 60 mm shear box it was found that shear tests carried out at a normal stress of 10 kN/m^2 on soil mixes compacted to refusal can be used to distinguish stable from unstable sub-bases. A threshold value of Peak Shear Stress Ratio (PSSR) of about 3 is suggested for stable sub-bases as a result of comparative trafficking trials at TRRL, U.K.

The need for maximum effective use of subgrade support has been outlined and some details of how characterisation can be tackled have been given. The paper discusses some of the main results obtained in relation to their application in the field of flexible pavement design.

TABLE II

RESILIENT MODULUS RESULTS

(SUMMARY OF K_1-K_2 STATISTICS BY SOIL TYPE USING $Mr=K_1(\text{BULK STRESS } \theta)^{K^2}$ PREDICTIVE EQUATIONS, WHERE Mr IS IN MN/m^2 AND θ IN KN/m^2)

AASHTO Classification	K_1 Parameter			K_2 Parameter			Range of F Values Mr =F(CBR)
	Mean	Std. Dev.	Range	Mean	Std. Dev.	Range	
A-1-b	35	19.9	7.5-152	0.52	0.19	0.23-0.78	2.1-11.4
A-2-4	27	11.1	6.4-108	0.45	0.11	0.27-0.58	1.6- 6.9
A-3	43	16.3	8.2-139	0.57	0.21	0.29-0.81	2.3- 9.8
A-4	--	--	--	--	--	--	6.9-14.3

These relationships are applicable only for bulk stress levels as are generally encountered at subgrade level i.e., less than 100-150 KN/m^2.

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