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The effect of wetting and drying on the performance of stabilized subgrade soils

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ABSTRACT

Stabilization methods are often utilized to improve the performance of road pavement subgrades which are weak or susceptible to small changes in moisture content. However, although a variety of performance models for natural materials have been developed and incorporated within road pavement design methodologies little research attention has been given to the characterization of similar performance models for stabilized subgrade soils. To address this, the research reported herein describes and discusses the results of a laboratory testing programme, incorporating cycles of wetting and drying, for a number of stabilized subgrade soils to determine the resilient behaviour and permanent deformation characteristics of the soils. The results from the experiments were used to characterise six models of subgrade soil permanent deformation performance identified from the literature and from these to develop a new improved model of performance which incorporates resilient behaviour. A comparison of the existing models of permanent deformation showed that those which consider stress state in addition to the number of load repetitions are better able to predict permanent deformation than those which consider the number of load cycles only. Samples subject to wetting and drying exhibited significantly greater permanent deformation and had lower values of resilient modulus than those which were not subject to wetting and drying. The usefulness of the results for analytical road pavement design are demonstrated by using a back-analysis procedure to determine appropriate resilient modulus values to characterise an analytical model of a road pavement together with the performance models to predict road pavement subgrade performance under cumulative applications of traffic load. Accordingly, the results show the importance of adequately replicating material behaviour in field conditions. In particular, the design process must utilize resilient modules values and deformation models which are determined in conditions which take into account in-situ stresses and cycles of wetting and drying.

1. Introdcution

Analytical pavement design consists of two main processes. One is associated with development and characterization of numerical models to enable actual stresses and strains at any point within a road pavement to be determined. This requires the resilient modulus, Poisson's ratio and material density to be characterized and utilized within the model.

It is important to determine the resilient modulus value(s) to be used with a numerical model under the variety of conditions to which the road pavement is likely to be subjected. The resilient modulus may be affected by many factors such as stress level, soil type, amount of stabilization and moisture fluctuations [1–4]. The moisture within a road pavement fluctuates according to the immediate environment and its influence on resilient modulus is most apparent when spring thawing is followed by a period drying during the summer months. Such a repetition of prolonged wetting and drying can adversely affect the performance of the road pavement structure.

The second process within analytical road pavement design is associated with empirical studies to ascertain the number of load cycles to which the materials within the pavement can undergo before failure, i.e. the development of so called performance models. The design is formulated by setting limits to the stresses, strains and deformations at critical locations within the theoretical model. Usually such limits are applied to prevent fatigue cracking at the bottom of the bituminous layer, limit permanent deformation (rutting) within the subgrade [5] and or limit surface deflection [6–8].

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For fatigue cracking the limit is set to control the tensile strain beneath the bituminous layer whereas for rutting it is usual to set a limit on the compressive strain at the top of the subgrade or a rut depth limit at the surface of the road pavement. However, each layer in a pavement structure contributes to the total surface rutting development, i.e. the rut is the sum of the permanent deformation of all layers of the pavement structure. As far as stabilized materials are concerned, pavement design standards such as the AASHTO pavement design guide, MEPDG [9] specify that pavements with one or more stabilized layers should be designed for fatigue cracking alone, but not for rutting (since it often assumed that permanent deformation is zero in these standards). However, research by Wu et al. [10,11] and others show that permanent deformation can occur in stabilized soils.

Several researchers have related the accumulation of permanent deformation in the subgrade to the number of load repetitions [12,13], others have linked permanent deformation to the applied stresses [14,15] and others have produced modified versions of these models through introducing different soil properties such as moisture content and measures of strength [16–18]. However, the literature associated with permanent deformation development in stabilized base and/or subgrade layers is limited [see for example [10,19–21]].

To address the apparent lack of stabilized subgrade soil performance models and their use within analytical pavement design, research was carried out to (i) determine how representative values of resilient modulus for stabilized subgrade soils can be obtained by laboratory experimentation, and (ii) identify suitable models of stabilized subgrade material performance which accurately replicate in-situ permanent deformation behaviour under cumulative load. The developed model is demonstrated via an analytical pavement design procedure.

2. Laboratory testing program

Three different types of subgrade soils were used. The soils are representative of subgrades which may be found in Kurdistan. The index properties and moisture-density relationships of the soils were determined using standard laboratory tests and are shown in Tables 1 and 2. Three soils were stabilized with cement and a combination of cement and lime as follows: 2%CC, 4%CC, 2%CC + 1.5%LC and 4%CC + 1.5%LC (CC and LC denote Cement and Lime Contents respectively).

A number of laboratory tests were performed on the samples as follows:

(1) **Permanent deformation tests:** There is no widely accepted standard specification procedure for a permanent deformation test for subgrade soils. For this research, therefore it was decided to use a process based on both AASHTO T307 [22] and BS EN 13286-7 [23]. The stress levels specified to determine the resilient modulus of subgrade soils in AASHTO T307 together with the specified apparatus were used in combination with the procedure mentioned in BS EN 13286-7. The number of loading cycles was chosen to be 50,000 cycles.

Table 2
Maximum dry density and optimum moisture contents for stabilized and unstabilized soils.

Soil type	MDD (gm/cm^3)	OMC (%)	Standard used
Untreated			
A-4	1.913	10.3	BS1377-4:1990 section 3
A-6	1.889	11.0	
A-7-5	1.485	21.5	
Treated 2%CC			
A-4	1.853	12.3	
A-6	1.862	13.0	
A-7-5	1.48	23.0	
Treated 4%CC			
A-4	1.847	13.2	
A-6	1.845	13.5	BS1924-2:1990 Section 2
A-7-5	1.465	23.5	
Treated 2%CC + 1.5% LC			
A-4	1.845	13.0	
A-6	1.847	13.4	
A-7-5	1.472	24.0	
Treated 4%CC + 1.5% LC			
A-4	1.838	14.0	
A-6	1.842	14.0	
A-7-5	1.463	24.5	

(2) **Resilient modulus tests:** For the resilient modulus test the procedure of AASHTO T307 was followed [24]. The test requires the preconditioning of a soil sample with 500–1000 cycles with a confining pressure and deviatoric stress of 41.4 kPa and 27.6 kPa, respectively. The test requires different combinations of confining pressure and deviatoric stresses to be applied for 100 cycles for 15 sequences. The results from the last five cycles were averaged to obtain the resilient modulus of a specified stress combination.

(3) **Wetting and drying tests:** Wetting and drying consists of cycles of wetting the soil sample by submerging it in water at room temperature for a period of time followed by drying in an oven. The ASTM D 559 [25] procedure specifies that a cycle should consist of submerging the sample for 5 h and thereafter drying the sample in an oven at a temperature of 71° ± 3° for a further 42 h. Twelve such wetting and drying cycles are specified during which soil losses, volume and moisture changes are recorded. Chittoori et al. [19] adapted ASTM D 559 by using 21 cycles of wetting and drying to compare the strength of the stabilized soils in terms of the Unconfined Compressive Strength (UCS) after 3, 7, 14 and 21 cycles. For this research, it was therefore decided to use 25 wetting and drying cycles after which the resilient modulus value of the three soils were determined according to AASHTO T307.

3. The model development

Six models of material performance were identified from the literature for the purposes of comparing their suitability to predict the development of plastic strain of stabilized soils. The models identified are as follows:

Table 1
Index properties of the soils.

Index limits	Soil type			Standard used
	A-4	A-6	A-7-5	
Liquid limit LL (%)	21	35	51	BS1377-2:1990 sections 4 and 5
Plastic limit PL (%)	14	21	31	
Plasticity index PI (%)	6	14	20	