JOURNAL OF MATERIALS SCIENCE LETTERS 14 (1995) 302–304

Dynamic flexure tests of soil–cement beams

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A wealth of empirical information has been accumulated on aspects contributing to the successful performance of stabilized soil–cement pavements. In many areas where a rapid increase in heavy traffic was noticed, it was realized that these empirical methods suffered some drawbacks. Failure due to extensive cracking of pavements, which was not accompanied by any apparent permanent deformation, led to the recognition that resilient deformation under transient heavy loading is of major importance. It is essential therefore to design the soil–cement pavement to withstand the dynamic action of traffic loads with longer fatigue life.

The traffic load applied on the pavement causes compression at the upper layer and tension at the underside. This condition can be simulated by flexure tests in the laboratory.

The aim of this investigation was to determine the dynamic modulus of rupture (MOR) for soil–cement beams with 6 and 10% content. The beam specimens were prepared in accordance with the ASTM D 1632 – 63 [1] standard test method for flexural strength of soil–cement. The specimen size 76.2 × 76.2 × 285.8 mm was selected because it ensures the failure in flexure. It was found that smaller beams may fail in shear rather than in flexure due to the small distances between the supports and points of loading.

The soil selected for the tests was red marl from Abergavenny, South Wales, which can be found in the red sandstone originating from the Devonian age. Red marl is a silty clay representing typical subgrade material in pavement structure. The stabilizer used was ordinary Portland cement manufactured by Blue Circle Cement Company and supplied in sealed containers.

The red marl was air-dried, mechanically pulverized to a maximum 2 mm diameter clod size, and well mixed before testing. The soil suitability was assessed by the criteria used for stabilized road pavements. The Proctor Compaction test was carried out to determine the dry density/moisture content relationship of the soil using a 2.5 kg rammer according to B.S. 1377:1975: Test 12 [2]. The optimum moisture content and the maximum dry density were found to be 15% and 1.85 mg m^{-3} respectively. The soil–cement mixture was dry-mixed and a predetermined amount of distilled water was added and mixed thoroughly using an electric mixer for exactly 11 min. The moisture content of the mix was adjusted prior to moulding.

To minimize friction all specimens were prepared by two-end static compaction in an oil-lined mould. Sufficient mixture was placed in the mould so that the two rams did not reach the end of their travel when the full compaction pressure was applied by means of a hydraulic press. The soil–cement–water mixture was compacted in three equal layers with an equal number of taps applied to each layer. The top plate was placed on the specimen surface and the mould moved to the compaction rig (see Fig. 1).

Pressure was then generally applied to the specimen by a hydraulic jack, until the gap between the corner plates and the mould's sides closed; this pressure was sustained for 5 min and then released. The specimen was removed by dismantling the mould, and wrapped with polythene sheet and an outer sheet of aluminium foil to ensure constant temperature distribution around the specimen. The specimens thus prepared were stored inside a controlled-environment curing chamber at 25 °C and constant relative humidity of not less than 98%. The dynamic flexure tests of Fig. 2 were carried out on an Instron 1251 testing machine capable of a wide range of load control and load repetitions from 0.001 to 1000 Hz. The built-in transducer simulated the ram

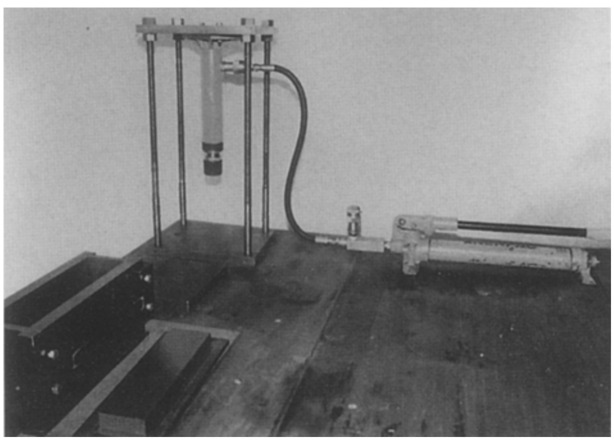

Figure 1 Mould for preparation of 76 × 76 × 286 mm long prismatic specimen and compaction accessories.

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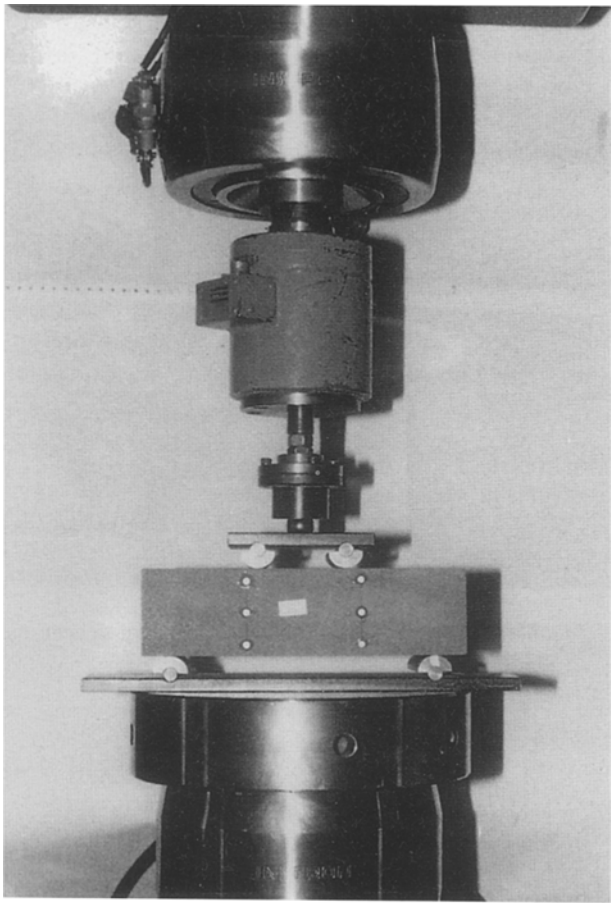

Figure 2 Four-point loading flexure test.

movement, hence the specimen's deformation was monitored fairly accurately. The machine was set up for sinusoidal loading changing from almost zero to a load level less than that which would cause failure in static mode. The frequency of 5 Hz was chosen to simulate traffic loading and the number of load repetitions was monitored on a cycle counter. The automatic chart recorder was used to monitor maximum and minimum load applied, deformation and time. The oscilloscope provided on the Instron console was used to indicate the waveform, frequency and the load applied.

Ten beam specimens were prepared for each cement content and tested to failure. The MOR evaluated from ASTM D 1632-63 [3] is calculated according to the type of beam failure. If the fracture occurs in the middle third of the span the MOR is calculated from

$$R = PL/bd^2 \quad (1)$$

and for the fracture occurring no more than 5% of the span length outside the middle third from

$$R = 3Pa/bd^2 \quad (2)$$

where R is modulus of rupture, N/mm^2, P is maximum applied load, N, L is span length = 228.6 mm, b is average specimen width = 76.2 mm, d is average specimen depth = 76.2 mm, and a is distance between the line of fracture and the nearest support, measured along the centre line of the bottom surface of the beam. If the fracture occurs by more than 5% of the span length outside the middle third, this is generally indicative of influence from the supports or of damage to the soil–cement specimen caused during handling or by non-uniform mixing of materials.

The test results for the 6 and 10% cement content beam specimens are summarized in Table I. It should be noted that these values are averages from all tests carried out. The results show a substantial drop in strength due to fatigue effects in flexure. For example, for 6% cement content and 28 days curing time the static strength fell from 830 to 470 N after 60400 load cycles, a reduction of about 43%. It was further noted that the fatigue failure of soil–cement beams in flexure was caused by the development of tension cracks at the underside of the beam specimens.

Table 2 gives results carried out in dynamic compression [4] so the direct comparison of strength reduction under dynamic flexure and compression can be made. As can be seen the specimens under the dynamic compression (6% cement) indicated that the drop in strength under 100000 cycles was of the order of 14.7%. Table I and Fig. 3 show the variation of the dynamic MOR (also known as the bending tensile strength) with $\log_{10}$ (number of cycles of failure). It can be seen that the MOR

TABLE I Dynamic flexure test results for 6 and 10% cement content at 28 days curing time

Cement (%)	Load applied (N)	Load (%)	Cycles to failure	$\log_{10}$ cycles to failure	MOR ($N\,mm^{-2}$)
6	780	93.98	1	0	0.403
6	790	95.18	1	0	0.408
6	830	100.00	1	0	0.429
6	620	74.70	11	1.041	0.320
6	670	80.72	60	1.778	0.346
6	580	68.67	950	2.978	0.300
6	470	56.63	60400	4.781	0.242
10	1160	100.00	1	0	0.600
10	1150	99.14	1	0	0.594
10	1030	88.79	8	0.903	0.532
10	980	84.48	20	1.301	0.506
10	930	80.17	42	1.623	0.481
10	980	84.48	90	1.954	0.506
10	640	55.17	71000	4.851	0.331

TABLE II Dynamic compression test results for 28 days curing time

Cement (%)	Stress ($N\,mm^{-2}$)	Stress (%)	Cycles to failure	$\log_{10}$ cycles to failure
6	2.99	100.00	1	0
	2.80	93.73	64	1.81
	2.67	89.47	1100	3.04
	2.67	89.47	1750	3.24
	2.55	85.21	100000	5
10	4.20	100.00	1	0
	4.07	96.99	46	1.67
	3.82	90.93	224	2.35
	3.57	84.87	415	2.62
	3.31	78.80	100000	5

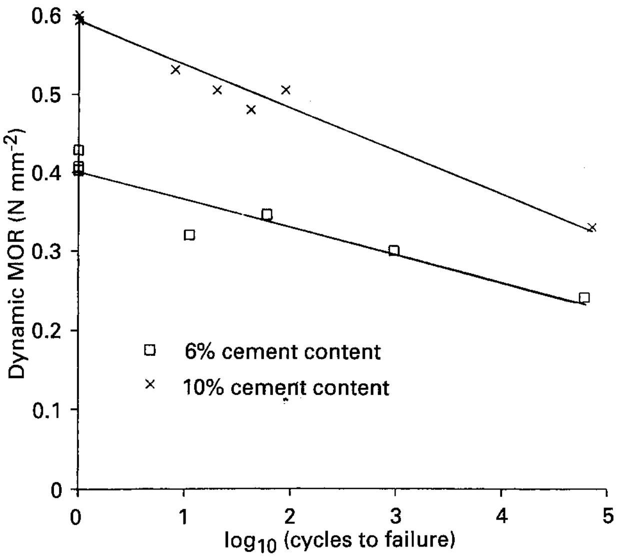

Figure 3 Dynamic flexure tests for 28 days curing time – MR variation.

decreases by about 44%, again a considerable reduction in strength.

In conclusion it can be said that the dynamic flexure mode was found considerably more critical than the dynamic compression mode. It was demonstrated that as much as 44% reduction in strength can occur when soil–cement beams are subjected to dynamic flexure.

The stresses generated by traffic loading are flexural in nature. The tensile stress at the bottom of the cement-treated layer is an important design parameter and should be used as a design criterion. Ironically, it remains one of the least well defined material properties. This results from lack of experimental techniques that are rigorous enough from a continuum mechanics viewpoint. Flexural fatigue tests are easier to carry out but involve uncertainties regarding the extreme fibre stress induced during flexural fatigue testing. It is clear that more experimental research is necessary to obtain the representative value for the MOR.

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Received 12 March
and accepted 2 December 1993