can be graded to the sides after the first pass of the roller.

14) It is now recognised that bases to be surfaced with bituminous materials must be primed. Thus if the cost of the primer at the site cannot be kept low, cement stabilisation may be uneconomical even though the actual stabiliser is readily available.

15) Soil-cement construction cannot be developed extensively in Britain until an adequate supply of suitable plant is available. This is not the case at present, and, in the absence of existing American plant, the British plant will have to be developed. This involves encouragement of manufacturers which in turn necessitates an increased interest on the part of users. To achieve this, further experiments and demonstrations on the lines described herein will be required.

FUTURE WORK.

Further lines of development include:

1) Demonstrations of the economic value of soil-cement construction.
2) Encouragement of the design of suitable British plant, particularly better soil-mixers with improved control of working depth for dealing with soils having relatively high clay or stone content; also mechanical methods of spreading cement.
3) Use of travel-mixers (when available).
4) Use of the plant-mix method.

SUMMARY.

Given suitable equipment, satisfactory results should be obtainable with all soils of the types used except that for the heavy clay and large gravel without soil binder, found in patches on two sites, it would be necessary either to balance the grading with suitable granular or clayey soil respectively, or to excavate and replace by suitable soil. The four experiments indicate that the use of soil-cement mixtures in Britain promises to provide an economical form of road construction.

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ACKNOWLEDGEMENTS

Acknowledgement is due to Mr.H.E. Aldington, C.B. M.I.C.E. Chief Engineer, Ministry of Transport for permission to submit the paper, and to Mr. H.L. Kerr B.Sc. A.M.I.C.E. Borough Engineer, Dartford for the use of the photographs.

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IX c 4

SOIL STABILIZATION TESTS USED IN GREAT BRITAIN

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SUMMARY

In Great Britain a crushing test has found wide acceptance both for determining the suitability of a soil for stabilization with cement and for checking the quality of the processed soil in the field. The reasons for adopting this test are discussed, and its application to the construction to two experimental stabilized roads is described.

The crushing test is made on 4-in. (10.2 cm) cubes compacted to a bulk density and at a moisture content generally determined by a laboratory compaction test. The cubes are cured in a damp atmosphere for 7 days before being crushed.

The data obtained from the experimental roads support general experience that a crushing strength of 250 lb./sq.in. (17.6 Kg./sq.cm) is a suitable criterion for soil-cement in Great Britain. A comparison of the crushing strength of field and laboratory processed soil from one of the experiments using mix-in-place work showed that the efficiency of modern rotary tillers in processing soil-cement may exceed 75% of that of laboratory mixing.

For the waterproofing stabilization of soil the Rapid Water Absorption test and the Capillary Water Absorption test have been developed by the Road Research Laboratory to determine the suitability of soils for stabilization and to check the quality of field processing. In the former test samples are completely immersed and the weight of water absorbed after 16 hours' immersion determined. In the other test the weight of water absorbed by capillarity is determined for periods up to 28 days.

From a consideration of results obtained with these tests in the construction of an experimental road stabilized with 'Vinsol'-resin it is concluded that the tests correlated quite well with the subsequent performance of the road and that suitable acceptance criteria for stabilization with waterproofing materials would be water absorption test and not more than 6 gm. after 28 days' absorption in the Capillary Water Absorption test.

INTRODUCTION.

This paper describes tests used in Great Britain in connexion with the stabilization of soils in road construction. For the cement stabilization of soil a crushing strength test has found wide acceptance both for determining the suitability of a soil for stabilization and subsequently for checking the quality of the processed soil. For methods of stabilization which aim at preventing the soil from absorbing water (waterproof stabilization) the Rapid Water Absorption test and the Capillary Water Absorption test have been found of value.

The suitability of the crushing test for soil-cement has been confirmed by experience on a number of jobs with which the Road Research Laboratory has been concerned, notably the construction in 1944 of an experimental road in collaboration with the Ministry of Transport at Abingdon in Berkshire and an experimental road constructed in 1947 near Guildford in Surrey. Experience with the absorption tests was also gained during the construction of the road at Abingdon.

THE CRUSHING TEST FOR SOIL-CEMENT.

Discussion -

The crushing test for soil-cement is used as a criterion of quality in much the same way as for concrete. Advantages that this test possesses over the durability tests used in the U.S.A. and elsewhere are that it can be completed in 7 days instead of 31 days and further that the actual crushing strength is a more convenient numerical criterion than the data given by the durability tests. Nevertheless, it is recognised that soil-cement in road construction rarely fails in compression but from deterioration due to the action of water or frost. Experience in Great Britain has shown that the durability of soil-cement is to some extent related to the strength of the soil-cement as determined by a crushing test, although, as in the U.S.A. no exact relationship has been found

As a result of investigations made in Great Britain together with a study of American test data, a strength for laboratory prepared soil-cement of 250 lb./sq.in. (17.6 Kg/sq.cm.) after damp curing for 7 days has been accepted as a suitable criterion for soil-cement construction in Southern England. Where a more severe climate is experienced, a crushing strength of 400 lb./sq.in. (28.2 Kg./sq.cm) has been tentatively suggested.

The same crushing strength test is used in both preliminary laboratory work and as a control test during construction, although naturally a somewhat lower strength is obtained in the latter case. The relation between the two strengths depends on the method used in the field to pulverize the soil and mix in the cement. When agricultural equipment is used, field strengths may be not more than 50 to 75% of the corresponding laboratory strength, whereas when more efficient methods are used e.g., rotary tillers or travel plant), a figure greater than 75% may be achieved. Although the criterion of a 250 lb./sq.in. (17.6 Kg./sq.cm.) crushing strength was adopted when agricultural plant only was available, no change has yet been introduced since better mixing plant come into use.

Test Procedure -

The first stage in the test procedure is to determine the density/moisture relationship for the soil-cement being studied, using the draft British standard compaction test (similar to the standard A.A.S.H.O.compaction test but employing material passing the ¾-in. (1.9 cm) B.S. sieve). The results of this test give the moisture content required for optimum compaction in the laboratory, and the corresponding density obtained. Sometimes, particularly with very sandy soils, it is found necessary to make field trials with the compaction plant to be used on the full-scale work to determine the values of density and moisture content corresponding to the adequate compaction of the soil-cement.

The crushing strength test is usually made on 4-in. (10.2 cm) cubes. The most satisfactory method for preparing these cubes has been found to be to compact the soil-cement in a constant volume mould (Fig. 1) to obtain the required density. An alternative method that has been used for field work is to compact the processed material into the mould in three layers by placing a 4-in. (10.2 cm) square plate over the admixture and applying 28 blows of a Proctor rammer (5½ lb.(2.5 Kg.)) to each layer through this plate. The cubes are cured in a damp atmosphere for 7 days and then crushed at a rate of approximately 250 lb./sq.in.(17.6 Kg./sq.cm) per minute, the dry density of the cubes being checked before crushing.

Constant Volume Mould for Preparing Soil-Cement Cubes.

FIG.1

TESTS FOR WATERPROOF STABILIZATION.

Introduction -

Two methods of tests have been developed at the Road Research Laboratory in connexion with the stabilization of soil with waterproofing materials. The first test used was the Rapid Water Absorption test, but for laboratory work this was subsequently superceded by the Capillary Water Absorption test.

Rapid Water Absorption test -

In this test, cylindrical specimens 4 in. (10.2 cm) diameter and 1½ in. (3.8 cm) thick were prepared in a Proctor mould by compacting treated soil at a moisture content about 2% below the optimum with 25 blows of the rammer, a cylindrical metal block being placed in the mould to limit the thickness of the specimen to 1½ in. (3.8 cm). The specimens were cured for 24 hours in a damp atmosphere, and then immersed in water for 16 hours, and the weight of absorbed water determined as a percentage of the dry weight of the specimen. The low initial moisture content was chosen as being a condition in which an ineffectively treated soil would be able to absorb water rapidly.

Capillary Water Absorption test -

In this test cylindrical specimens 3 in. (7.6 cm) long and 2 in. (5.1 cm) diameter are compacted in a constant volume mould (Fig. 2) to a density and moisture content corresponding to a 10% air voids content on the compaction curve of the treated soil. The choice of the large air voids content was made so that ineffectively treated soil in this condition would be able to absorb water rapidly. It is also possible to differentiate between water absorbed into the air voids and water causing the specimen to swell. After preparation the specimens are first cured for three days in a damp atmosphere, and their sides are then coated with paraffin wax, taking care to remove any wax from the ends of the specimens. The specimens are allowed to absorb water by capillary action by standing in a humid atmosphere in a 2 mm. depth of water for periods of 1, 3, 7,14 and 28 days, the amount of water absorbed being determined by weighing. The test is described in more detail in another contribution 1) to the Conference.

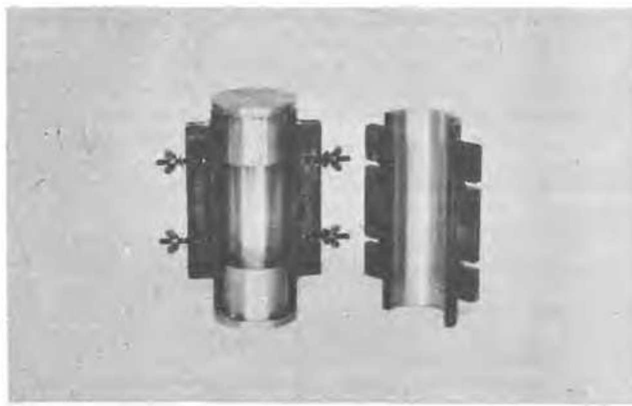
Acceptance Criteria

On the basis of experience in the laboratory during the development of the tests, it was estimated that for the Rapid Water Absorption test a water absorption not exceeding 10% of the dry weight of the specimen at 16 hours was a suitable criterion for accepting a soil as being suitable for soil stabilization with the particular stabilizer being examined, while for the Capillary Water Absorption test a water absorption of 6 to 8 gm. at 28 days was chosen (weight of specimen 300 to 320 gm).

PRACTICAL APPLICATION OF THE TESTS.

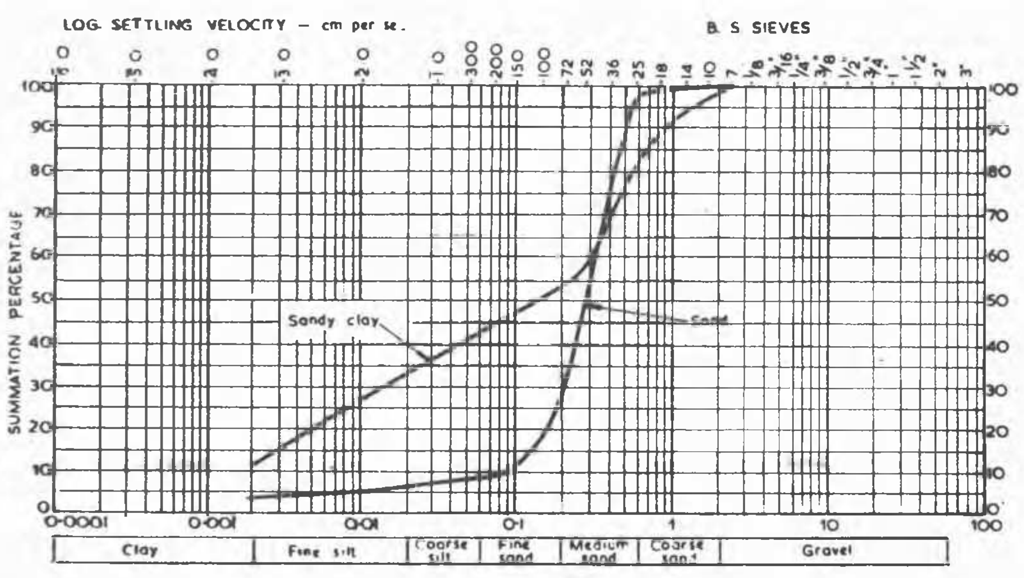
The practical application of the tests described in the earlier part of this paper will now be illustrated by means of data obtained during the construction of the two experimental roads previously mentioned with which the Road Research Laboratory was concerned.

1) Abingdon, Berkshire - This road, constructed in the autumn of 1944, was 4,000 ft.(1220 m) long, and the soils used in the construction were a sand and sandy clay (Fig. 3).Half the length of the road was constructed in soil-cement, a quarter with 'Vinsol'-resin and the remaining quarter with a mixture of sodium rosinate and aluminium sulphate. Mix-in-place construction with agricultural plant was used throughout. A general view of the pulverized soil is shown in Fig. 4 and a view of a sec-



Constant Volume Mould for Preparing Capillary Water Absorption Cylinders.

FIG.2



Typidal Gradings of the Soils stabilised at Abingdon.

FIG.3

Abingdon:- A view of part of the road during construction.

FIG.4

Abingdon:- A view of part of the completed road.

FIG.5

tion of the completed road is shown in Fig.5.

2) Hatchlands, Guildford, Surrey - This road, constructed in June, 1947 was 2,000 ft. (610 m) long and was on a site where the soil consisted of a sandy clay (Fig. 6). The entire length of this road was constructed in soil-cement using mix-in-place with a modern rotary tiller specially designed for soil-cement work. A cement content of 10% was used throughout, and the road was divided into five 400 ft.(122 m) lengths, each of which was constructed at a different moisture content ranging from 12% to 22% in order to determine the effect which adverse weather conditions during construction can have on the performance of a soil-cement road. A view of the processing in progress is shown in Fig. 7., and a view of a section of the completed road is shown in Fig. 8.

SOIL-CEMENT CRUSHING TEST.

Results obtained at Abingdon - In Table 1 the results are given of crushing tests made on cubes prepared from the processed soil on two of the soil-cement sections at Abingdon.

Section (1), where a sand was processed, was covered with 3 in. (7.6 cm) of tarmacadam and as is shown by the photograph taken in 1947 (Fig. 9) was still in good condition 3 years after construction. Although the strength of the soil-cement was much higher than is required by the British criterion for soil-cement it should be mentioned that this part of the road was constructed on 3 to 4 ft. (about 1 m) of fill overlying a peat bog and that heavier vehicles (up to 16 tons (16,260 Kg.) in weight) have used the road than was anticipated when it was built.

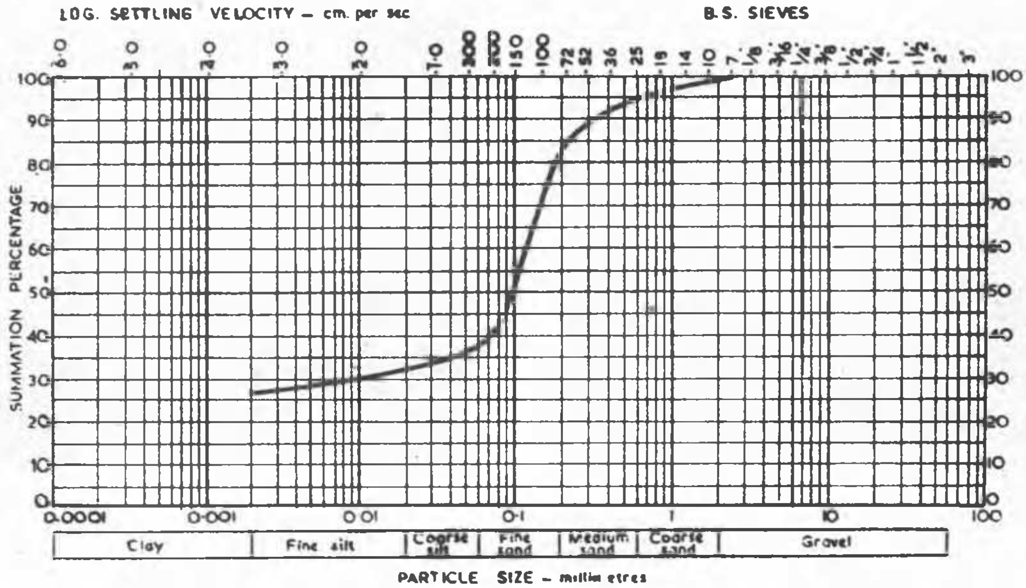
Section (2) which was only surface-dressed remained, except for minor defects, in good condition for two years until 1946 when it was reconstructed in the course of re-grading certain sections of the road.

Results obtained at Hatchlands - The crushing strength/moisture content relationships obtained with both laboratory and field processed soil-cement in the case of the Hatchlands experiment are shown in Fig. 10. Unfortunately, the density of the cubes prepared in the field was somewhat less than that

TABLE I

Mean moisture contents, dry soil densities and compressive strengths after 7 days curing of test cubes of soil-cement

Soil	Chainage (ft.)	Chainage (m.)	Moisture content when compacted (%)	Dry soil density (lb./cu.ft.)	Dry soil density (Kg./cu.m.)	Breaking stress (lb./sq.in.)	Breaking stress (Kg./sq.cm)
Sand	300	91.5	9	115	1840	416	29.2
	400	122	8	116	1856	438	30.9
	500	152.5	9	115	1840	376	26.4
	600	183	10	116	1856	456	32.1
Sandy Clay	1,250	381,25	17	106	1696	380	26.7
	1,500	457.5	24	99	1584	189	13.3
	1.750	533.75	19	106	1696	289	20.3



Typical grading of soil used at Hatchlands, near Guildford.

FIG.6

Hatchlands:- Work in progress.

FIG.7

Hatchlands:- Part of the completed road.

FIG.8

TABLE 2

Results of Rapid Water Absorption tests (single samples) on mixed materials taken between chainage 2.000 ft. and 3.000 ft. ('Vinsol' section)

Stabilizer	Chainage (ft.)	(m.)	Distance from east edge of road (ft.) 2 (0.6 m.)	6 (1.8 m.)	10 (3.0 m.)	14 (4.3 m.)
			water absorbtion			
1% 'Vinsol'	2,100 2,200	640.5 671.0	1.8 4.0	2.7 2.6	2.7 3.4	7.1 11.6 x)
1% 'Vinsol' 0.5% $Al_2 (SO_4)_3$	2,300 2,400	701.5 732.0	7.9 15.0 x)	5.0 4.6	14.6 x) 4.4	5.2 10.3 x)
2.2% 'Vinsol' 1% $Al_2 (SO_4)_3$	2,600 2,800	793,0 854.0	7.8 7.8	6.6 9.0	8.9 7.5	12.6 x) 8.4

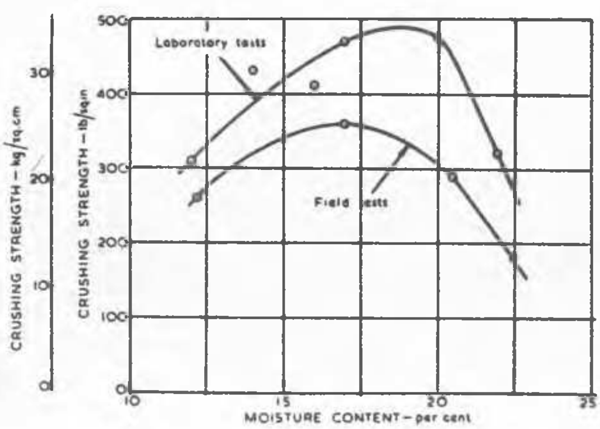
x) Failures had occurred at these points by 8th February, 1945.

Abingdon:- Part of the soil-cement section as it was in 1947. (N.B. The marks on the road are caused by oil).

FIG.9

Abingdon:- Part of the "Vinsol" section in the early spring of 1947.

FIG.11



Crusging strength/moisture content relations at Hatchlands

FIG.10

of the cubes made in the laboratory, but nevertheless the results show the general form of the relationship between crushing strength and moisture content and, if allowance is made for the different densities, indicate that when modern efficient mixing plant is used in the field, crushing strengths comparable with those obtained in the laboratory may be reached.

WATER ABSORPTION TESTS

Results with Rapid Water Absorption test - Table 2 gives results of Rapid Water Absorption tests made on samples of processed soil taken from the section of the Abingdon experimental road that was treated with "Vinsol"-resin and surface-dressed. (Parts of the section were also treated with aluminium sulphate).

The results indicate that towards the edges of the road, the processing was much less efficient than at the centre: This conclusion was confirmed by the subsequent behaviour of the section which by the end of the first winter after construction had failed along parts of the edges of the road (Fig. 11). The general behaviour of the road considered in relation to the test results indicated that the criterion for satisfactory waterproofing should be rather less than the 10% water absorption chosen as a result of laboratory tests, a figure of 8% being a more suitable value.

Results with Capillary Water Absorption test - The results obtained with capillary water absorption tests made on the processed soil taken from the same experimental section at Abingdon as were the Rapid Water Absorption test specimens gave a similar degree of agreement with the behaviour of the road, the amounts of water absorbed varying from 3 to 18 gm. after 28-days' water absorption. In general, the results confirmed the selection of 6 gm. as the upper limit of water absorption for satisfactory soil waterproofing.

Discussion of water absorption tests - It has not yet proved possible to obtain further field experience with the water absorption tests, but subsequent laboratory research has shown that with the Rapid Water Absorption test misleading results may sometimes be obtained through air being entrapped in the soil. This defect does not occur in the Capillary Water Absorption test. Further, in the latter test the conditions and rate of water absorption are more in keeping with practical conditions. For these reasons the Capillary Water Absorption test is now used in laboratory studies, and the Rapid Water Absorption is now confined to control work in the field.

REFERENCE.

1) K.E. CLARE: Some laboratory experiments in the waterproofing of soils: Contribution to the Conference.

ACKNOWLEDGEMENT.

This paper was prepared at the Road Research Laboratory of the Department of Scientific and Industrial Research and is presented by permission of the Director of Road Research.

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