compaction machinery and obtain densities considerably in excess of those possible a decade ago. Complementary to this the "Heavy Proctor" has been introduced into the Laboratory. 2) This utilises a 10-pound rammer dropped through 18-inches instead of a 5½-pound rammer dropped through 12-inches.

It may be necessary to modify the Dietert technique to correspond to this test and further work will then be required to correlate the two.

By using the method described of compacting in the shear box, it will be possible to allow samples to swell or consolidate under given overburden loads, and it will be interesting to compare results of such tests with the softening tests carried out on the 1½-inch cylindrical samples.

In general, the approach to compaction problems is still largely empirical, but there is now no reason why estimates of stability should not be based on shear strength calculations as well as previous experience.

ACKNOWLEDGEMENTS.

The work described was carried out in the Laboratory of Messrs. Soil Mechanics, Ltd., and the author wishes to express his thanks to his Assistant - Mr. T.G. Clark - who carried out most of the tests, and to the Directors for permission to publish the results.

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## SOME LABORATORY EXPERIMENTS IN THE WATERPROOFING OF SOILS

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SUMMARY.

The note points out the value of reducing the ability of moisture to enter soil, as for instance, in the case of road subgrades, and it deals in detail with two waterproofing agents which have been investigated at the Road Research Laboratory. These are "Vinsol"-resin, which is a solid in powder form, and a waxed fuel oil. Both these materials have surface-active properties, that is, they can spread over the surface of water in thin films. It is suggested that the waterproofing of soils when admixed with these materials is due to the formation of such films at the air/water interfaces in the pores of the soil.

A description is given of the Capillary Water Absorption test developed at the Road Research Laboratory for evaluating the waterproofing properties of such stabilizers. Results obtained with this test in the case of a sandy clay soil are given, indicating, that under ideal laboratory conditions, 1 per cent of the resin and 3 per cent of the waxed oil by weight of the soil impart a maximum degree of waterproofing to the soil.

In the Capillary Water Absorption test, account is taken, in preparing the specimens, of the influence of the waterproofing agent on the compaction properties of the soil. Laboratory compaction tests made on mixtures of the sandy clay and the two stabilizing agents referred to, show that both reduce the maximum dry soil density.

Attention is drawn to the importance of the pH of the soil-water in the waterproofing of soil with resinous materials. Curves are given showing that the water absorption is greater in alkaline soils than in soils having an acidic reaction. However, some very alkaline soils and also chalk can be waterproofed using sodium stearate or tall oil emulsions.

A study has also been made of the soil waterproofing properties of several resins from tropical areas. Of these, only a Manila Copal resin was found to have an effect of the same order as "Vinsol"-resin. The waterproofing properties of Wallaba resin from British Guiana were found to be considerably improved by treating the resin with acetyl chloride.

In spite of the pH effect, the addition of "Vinsol"-resin appears to impart to chalk some resistance to damage by frost, to which chalk is particularly susceptible. Experiments are described in which cylindrical specimens of powdered chalk were frozen from the top downwards, while in contact with a source of free water. After 16 hours, ice-lenses were formed in specimens of the untreated material, while specimens containing resin were unaffected.

Box shear test results obtained with the sandy clay soil are given, showing that the addition of resin does not increase the natural stability of the soil, by increasing either the cohesion or the angle of internal friction.

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INTRODUCTION

In road engineering it is important that bases and subgrades constructed of cohesive soils should have an adequate stability when laid, and that this stability should be subsequently maintained. Such soils are stable if well compacted at suitable moisture contents, but they may become less stable owing to the ingress of water. While the provision of an impermeable road surfacing will prevent the entry of water from above, moisture content increases may occur from water rising from a water-table. A method of reducing and delaying such moisture content increases is to mix waterproofing agents with the soil. This paper is concerned with laboratory investigations made at the Road Research Laboratory into the properties of some of these soil waterproofing materials.

## WATERPROOFING AGENTS

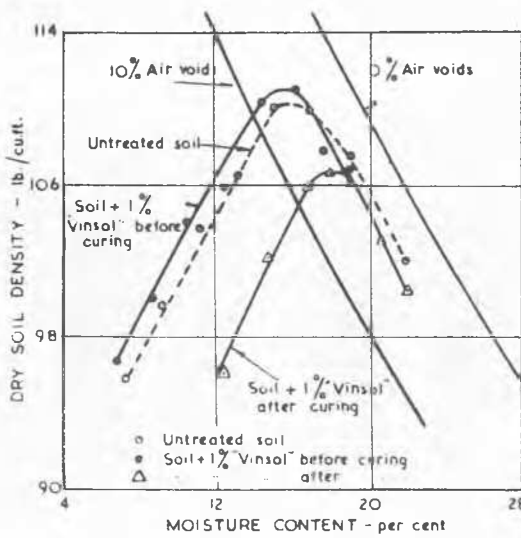
Among the more important waterproofing agents studied are resinous materials, of which "Vinsol"-resin is the most well-known, and bituminous materials, of which waxed fuel oil is a typical example.

"Vinsol" is a brown resin obtained by the solvent extraction of the residue left after the distillation of pine-tree roots for turpentine 1), and it is available commercially in the form of a fine powder. Although its exact chemical constitution is not known, it contains, like abietic acid, the main constituent of rosin, a carboxyl group which confers polar properties on the molecule as a whole. By virtue of this property the resin is able to spread over the surface of water in the soil in a layer of molecular thickness. The waterproofing action of "Vinsol"-resin and other resinous materials which behave in a similar way, is believed to be due to the resistance to displacement offered by this layer to additional water entering the soil. The spreading action of resin on water can be demonstrated by dusting a small quantity of French chalk on the uncontaminated surface of some distilled water contained in a photographic developing dish. When a few grains of the resin are dropped lightly from a penknife on to the water surface, the chalk particles will be seen to move slowly away leaving a clear area near each grain.

A bituminous material that has been found to have a very effective waterproofing action when mixed with many types of soil is a fuel oil containing about 4 per cent of paraffin wax 2). The commercial product has a viscosity of 30 seconds B.R.T.A, at 25° C. when measured on the 4 mm cup, and has been used in conjunction with a flocculating agent such as lime 3). The mechanism of the waterproofing action has been dealt with by Jackson 4) who concluded that the oil spreads out on the air/water interfaces in the soil, in very thin films. A layer of paraffin wax micro-crystals possessing some rigidity is then thought to develop on the surface of the oil films. A rigid water-repellant layer formed in this way on the soil particles would present a hydrophobic surface to water entering the soil and would not be displaced by it.

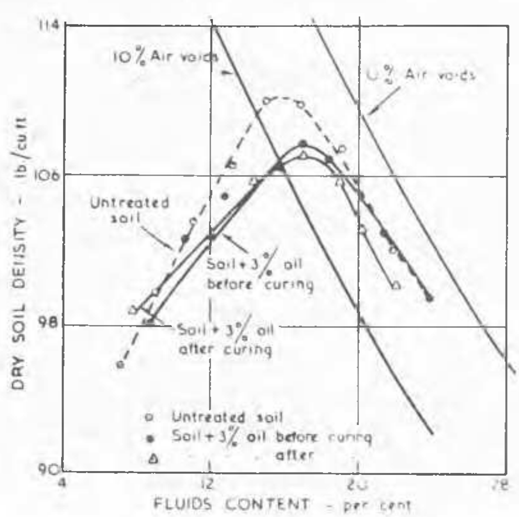
## CAPILLARY WATER ABSORPTION TEST

The method developed at the Road Research Laboratory for assessing the effectiveness of stabilizing agents for waterproofing soil is known as the Capillary Water Absorption test. In this method a standard compaction test 5) is first made on the soil having a stabilizer content in the middle of the range that it is intended to investigate; i.e., a stabilizer content of 3 per cent would be selected if absorption tests were to be made over the range 0-6 per cent. The compaction test is required for the purpose of determining the dry density and moisture content at which to prepare specimens for studying the water absorption of the treated soil; these should approximate to conditions obtainable in practice, and research at the Road Research Laboratory has shown that of the available laboratory tests, the standard compaction test most closely reproduces field conditions in Great Britain. It is not possible to use the results of a standard compaction test on the untreated soil, as waterproofing agents of the types being considered make the soil more difficult to compact, resulting in a different moisture density relation. This is illustrated in Fig. 1 and 2, in which compaction curves are shown for a sandy loam soil from Harmondsworth, with and without the addition of respectively 1 per cent "Vinsol"-resin and 3 per cent of waxed oil. Curves are shown for the treated




Moisture / density relations for Harmondsworth sandy loam containing 1% "Vinsol" resin, before and after curing.

FIG.1

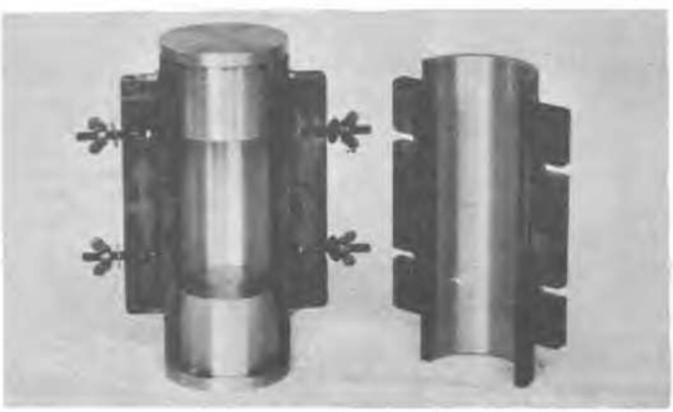



Moisture / density relations for Harmondsworth sandy loam containing 3% of waxed fuel oil, before and after curing.

FIG.2

soil when freshly mixed with the stabilizer and after having been allowed to cure for 1 week. It will be seen that the addition of the stabilizer causes a reduction in the maximum dry soil density in both cases, the reduction being obtained immediately with the waxed oil, but only after curing with the soil treated with "Vinsol"-resin.

The dry soil density and moisture content at which the water absorption specimens are prepared are those selected by drawing the 10 per cent air-voids content line on the same graph and finding the co-ordinates of the point at which this line and the relevant compaction curve intersect. The use of a 10 per cent air content ensures a condition in which the untreated soil can absorb water. If the soil in the field is to be compacted as soon as mixing has finished, the curve for the uncured mixture is used, but if the mixture is to be allowed to stand unrolled, as for example in a stock pile, the second curve for the cured material is used. Duplicate specimens are then made up in the split cylindrical mould shown in Fig. 3, which has a known internal volume (3 in. long and 2 in. diameter), when the two plungers are pressed home; it is thus possible to obtain a required dry density by compressing a calculated weight of the treated soil in the mould. The use of the split mould enables specimens to be removed rapidly without damage. The bulk density of specimens are checked by weighing and measuring after moulding.



Split Cylindrical Mould, with a constant internal volume, for preparing capillary water absorption specimens.

FIG.3

Specimens are then kept in a humid atmosphere for three days since some stabilizing agents have been found not to develop their full waterproofing effect immediately. The curved surfaces of the specimens are then given a thin coating of paraffin wax, and the cylinders are weighed and stood in about 2 mm of water in a closed tank. The amount of water absorbed is determined by measuring the increase in weight after periods of 1, 3, 7, 14 and 28 days.

Since the specimens are made up to a constant volume (154 cc.) and a fixed air-voids content (10 per cent) it follows that the volume of air-voids is 15.4 cc. This is also the volume of water required to saturate each specimen if it is assumed that water enters all the air-voids and that no swelling takes place. The volume of air-voids that are unfilled at the end of the test can thus be used as a criterion by which the efficiency of a stabilizing agent can be compared.

Typical results from two series of tests with "Vinsol"-resin and a waxed fuel oil are shown in Fig. 4 and 5. The soil used in the tests was a sandy loam from Harmondsworth having the characteristics shown in Table 1 below.

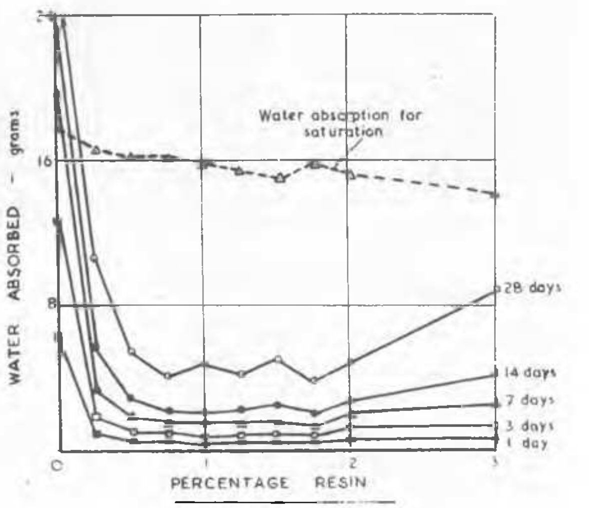
From Fig. 4 it will be seen that the water absorption is considerably reduced by the addition of about 1 per cent of "Vinsol", but that additional resin effects no further improvement, and in fact the addition of 3 per cent causes an increase in water absorption. The specimens of untreated soil are fully saturated after 7 days, whereas those contain-

TABLE 1

Particle size analysis, index 6), and compaction test 5) results for a sample of Harmondsworth sandy loam

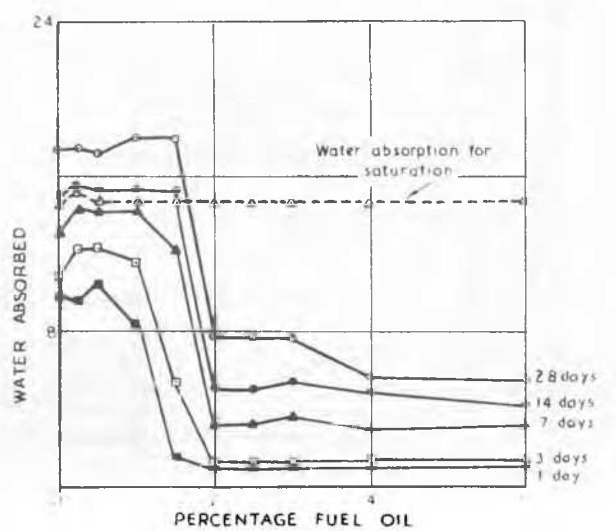
| | | |
|---|---|---|
| **Particle size analysis** | | |
| Coarse Sand (2.0 mm - 0,2 mm) | (%) | 4 |
| Fine Sand (0.2 mm - 0,02 mm) | (%) | 57 |
| Silt (0.02 mm - 0.002 mm) | (%) | 14 |
| Clay ( < 0.002 mm) | (%) | 25 |
| Total | (%) | 100 |
| **Index tests** | | |
| Liquid Limit | (%) | 32 |
| Plastic Limit | (%) | 18 |
| Plasticity Index | (%) | 14 |
| **Compaction test** | | |
| Maximum dry soil density(lb./cu.ft.) | | 110 |
| Optimum moisture content | (%) | 16 |

(Mechanical Analysis by International method)




Water absorption of specimens of Harmondsworth sandy loam containing various percentages of "Vinsol" resin.

**FIG.4**




Water absorption of specimens of Harmondsworth sandy loam containing various percentages of waxed fuel oil.

**FIG.5**

ing 1 per cent of resin are less than 10 per cent saturated after the same period.

The shape of the curve for the specimens treated with the waxed oil (Fig. 5) is different from that for the "Vinsol"-resin. The amount of water absorbed after 14 days is constant for oil contents up to 1.75 per cent, and completely saturates the soil. The water absorption is much less at 2 per cent oil content when the soil is only 20 per cent saturated.

Experience at the Road Research Laboratory with a number of such tests has indicated that a soil that can be waterproofed satisfactorily will absorb about 6 gm. of water after a period of 28 days.

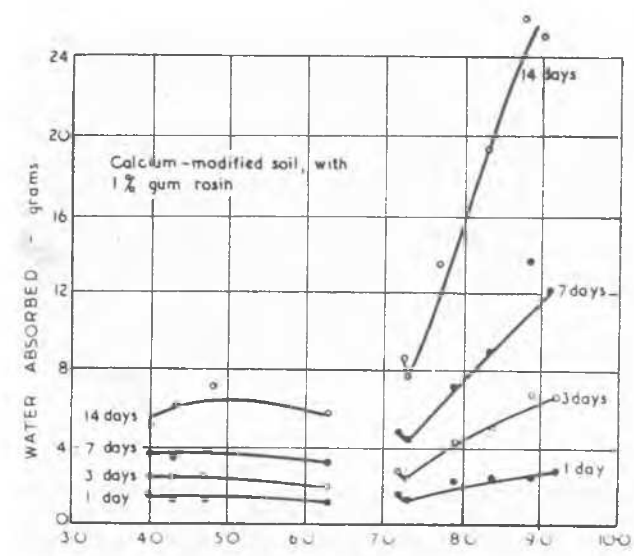
## THE INFLUENCE OF THE pH OF SOIL ON THE WATERPROOFING EFFECT OF RESINOUS MATERIALS

The reaction of the soil water, that is to say its acidity or alkalinity, is conveniently expressed on the pH scale. The pH value of a solution is defined as the logarithm to the base 10 of the reciprocal of the hydrogen ion concentration. A completely neutral solution has a pH value of 7, while acids and alkaline solutions have pH values below and above this figure respectively. The reaction of most British soils varies between about pH 4 for acid heath and fen soils and pH 8 for alkaline chalky soils.

The pH of water as it exists in the soil is difficult to measure directly, and for most engineering purposes it is sufficient to determine the reaction of a soil suspension. Since the pH of such aqueous suspensions varies with the concentration, the practice at the Road Research Laboratory is to determine the reaction of a standard suspension containing 1 part of soil by weight in 3 parts of distilled water. The determination is carried out electrometrically by measuring the potential difference between the suspension and a glass electrode, using a saturated calomel electrode as a reference level.

To investigate the effect of soil reaction on the waterproofing properties of resinous materials, capillary water absorption specimens were made up with a 1 per cent admixture of gum rosin in an acid sandy loam soil from Oaklands, Hertfordshire. The pH of this soil was adjusted to different values by the addition of calcium hydroxide. The various specimens were subjected to capillary water absorption test for periods from 1 to 28 days.

The results of these are shown in Fig. 6.




Relation between water absorption and hydrogen ion concentration (pH) for a sandy loam soil treated with 1% gum rosin.

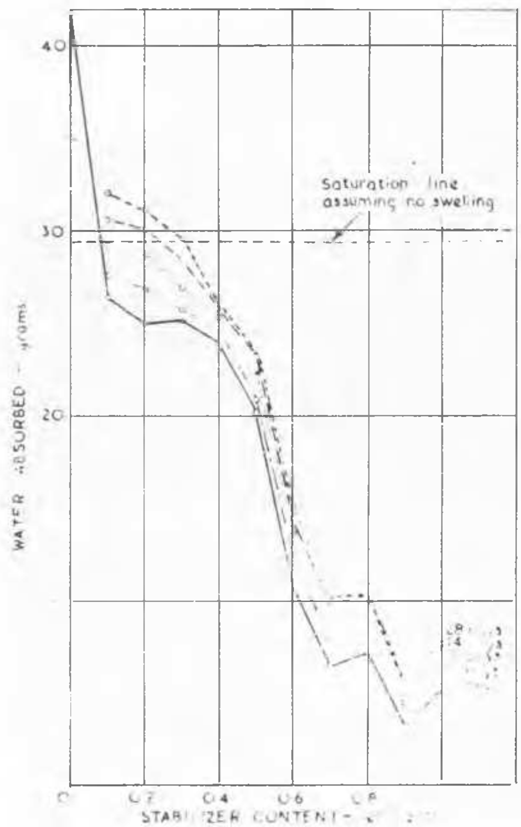
**FIG.6**

It will be seen that the rosin exerts a waterproofing effect in all cases where the soil reaction was acid, whereas when the pH value exceeded 7 there was a definite increase in water absorption, the amount absorbed increasing with a numerical rise in pH value. Similar results were obtained when "Vinsol"-resin was employed. It is therefore concluded that natural (i.e. unmodified) resins of this type can only exert a waterproofing action when used with acid soils.

THE WATERPROOFING OF ALKALINE SOILS

Recognising the limitations imposed by the pH effect described above, it was felt that a method should be found for waterproofing alkaline soils, particularly in view of the wide occurrence of such soils in Southern England. As a result of observations made during another investigation involving cation-active materials, it was decided to determine the effect of anionic soaps as waterproofing agents for alkaline soils.

Capillary water absorption tests were therefore made to determine the waterproofing effect obtained by mixing sodium stearate in powdered natural chalk. The results (Fig. 7) showed that the untreated specimens absorbed 40 gm. of water after 1 day, whereas the addition of 0.9 per cent of stearate reduced this figure to about 3 gm., or less than one-tenth of the original value. The effect was

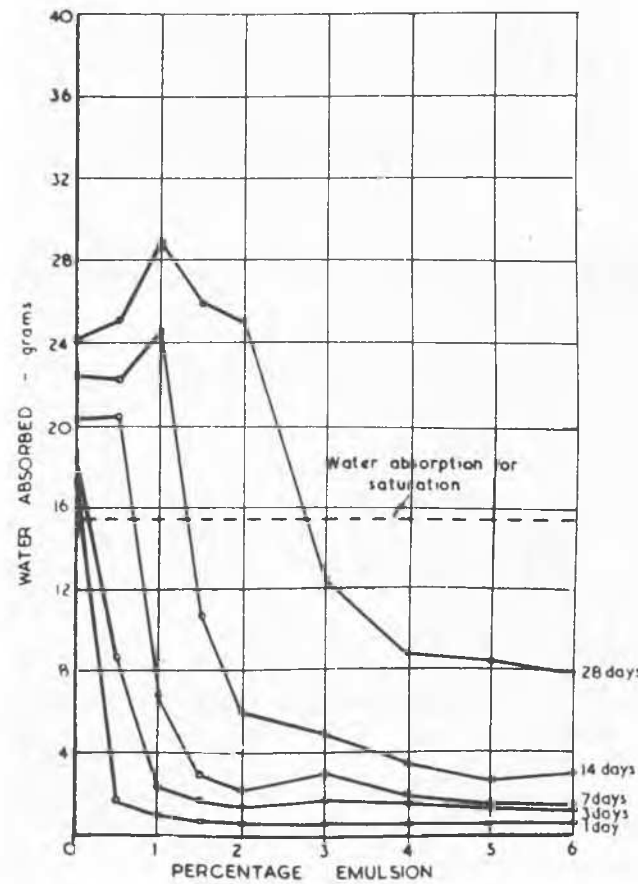



Relation between stabilizer content and water absorption for capillary water absorption specimens of chalk treated wich sodium stearate.

**FIG.7**

still operative after 28 days. Similar results were obtained when this chemical was added to laterized soils containing a proportion of free iron oxide, and it is thought that the waterproofing is due either to the adsorption of the soluble stearate ions on to the surfaces of the soil particles or to the formation of water-insoluble calcium or iron stearates at the water/air interfaces in the soil pores.

There are now a number of commercial soil stabilization processes, many of them patented 7), involving the use of water-soluble soaps of organic acids of different types. Metallic salts such as calcium hydroxide and the sulphates of aluminium and iron are often added to precipitate the required water-insoluble soaps, and these will also presumably have a flocculating action on the clay particles in the soil. One of those materials, a commercial resinous emulsion derived from the tall oil or liquid rosin obtained as a by-product in the manufacture of paper was found to have a waterproofing action when mixed with soils having chalk contents of 4 per cent or more. Fig. 8 shows the results of capillary water absorption tests on a sandy loam soil containing 4 per cent of chalk when admixed with this emulsion.



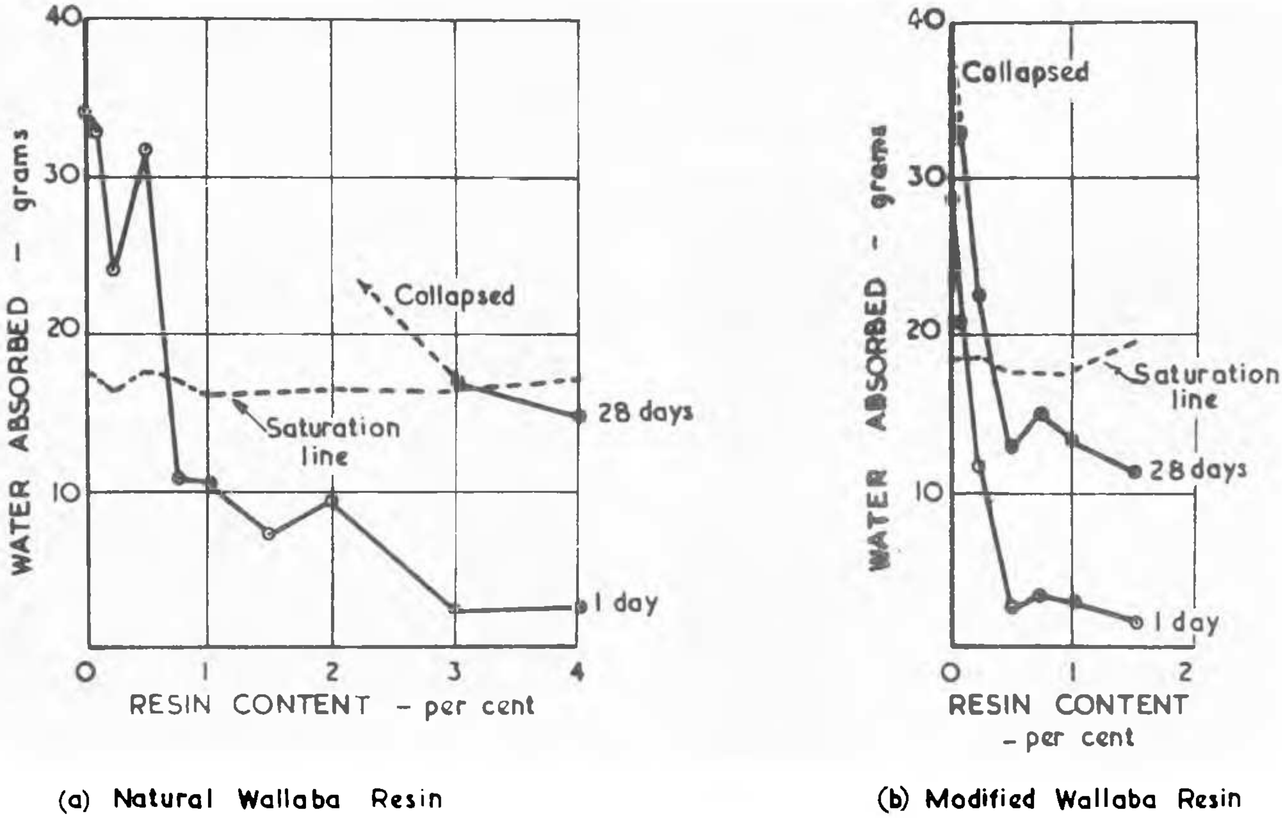

Variation of water absorption of a sandy loam soil containing 4% of chalk when treated with a resinous emulsion.

**FIG.8**

THE USE OF TROPICAL RESINS

Both "Vinsol"-resin and gum rosin are obtained from pine trees, which occur in temperate climatic conditions. The waterproofing properties of several other resinous materials from tropical regions have, however, also been studied. Among the materials investigated were Copal and Damar resins from the Dutch East Indies and the Belgian Congo, and resins from Ceylon and Nigeria. The only resin having waterproofing properties comparable with "Vinsol under the conditions of test was a Manila Copal resin.

An interesting aspect of this work was the improvement of the waterproofing characteristics of a rosin obtained by the modification of its molecular structure. Fig. 9(a) shows the results of water absorption tests on specimens of Harmondsworth sandy loam containing resin from the Wallaba tree of British Guiana. Fig. 9(b) shows the results of similar tests with a derivative of the rosin obtained by treating




Effect of modification of chemical structure on the waterproofing properties of wallaba resin from British Guiana.

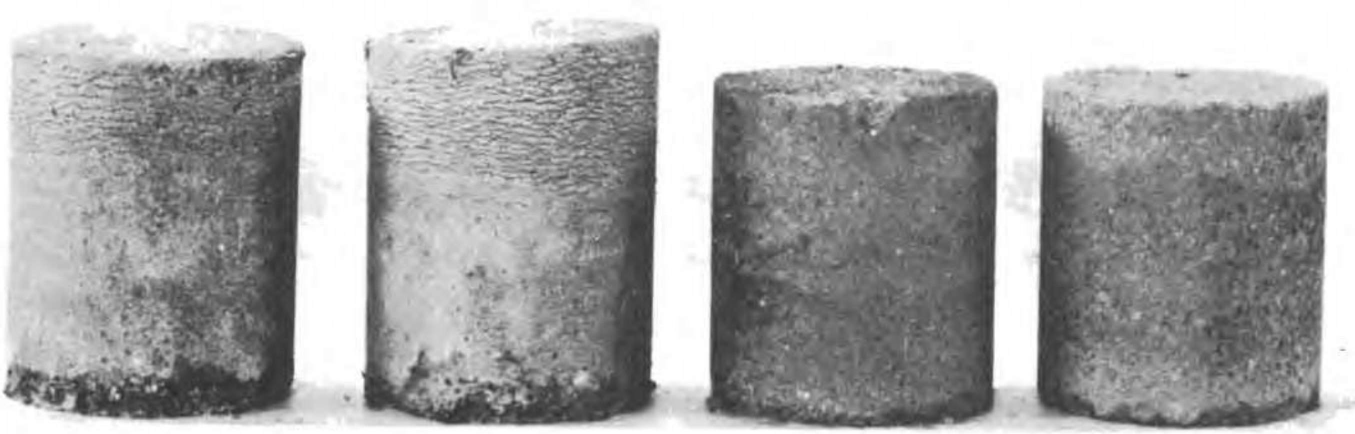
FIG.9

it with acetyl chloride. An improvement in both the minimum resin content required and in the permanency of waterproofing was obtained, presumably because the film formed by the modified resin has greater stability than that of the natural material.

EFFECT OF "VINSOL"-RESIN ON FROST RESISTANCE OF CHALK

A particular characteristic of chalk is its susceptibility to damage by frost, and several cases have been observed in Southern England in which roads on chalk subgrades have been disrupted during severe winters. Experiments were therefore carried out at an early stage to determine whether resinous treatment of chalk could reduce this susceptibility.

Fig. 10 shows four specimens of powdered natural chalk which were prepared in the standard compaction mould, and subsequently



Chalk specimens after being subjected to a temperature gradient freezing test for 16 hours. The two specimens on the left are made with the original material, while the two on the right contain 1% "Vinsol" resin.

FIG.10

subjected to a temperature gradient by allowing the top surfaces to come into contact with air at - 10° C., while the lower surfaces were immersed in water maintained at a temperature slightly above 0° C. Two of the specimens were prepared from the natural chalk, while the others were made with the same material containing 1 per cent of "Vinsol"-resin. It will be seen that under the conditions of the test the resin-treated specimens remained unchanged, whereas ice-lenses were formed in the untreated specimens as a result of which they increased in height about half an inch. It was concluded therefore, that the addition of resin may inhibit the damage of chalk by frost to some extent, but the mechanism by which this is accomplished is not yet known.

## EFFECT OF "VINSOL"-RESIN ON THE STABILITY OF SOIL

It was originally thought that the addition of resinous material might increase the stability of a soil by raising the inter-particle friction, by analogy with the use of rosin on pulleys and belts. A series of box shear tests were therefore made with untreated and treated samples of Harmondsworth sandy loam to investigate this possibility. The results are given in Table 2 below:

TABLE 2

Results of box shear tests on specimens of Harmondsworth sandy loam soil, with and without the addition of "Vinsol"-resin

| | | | | |
|---|---|---|---|---|
| Resin content | (%) | 0 | 0.5 | 1.0 |
| Moisture content | (%) | 10.3 | 9.6 | 10.1 |
| Dry soil density (lb./cu.ft.) | | 103 | 104 | 105 |
| Cohesion (c) (lb./sq.in.) | | 16 | 16.5 | 18 |
| Angle of Internal (Ø) Friction | (°) | 40 | 40 | 41 |

It will be seen that, within the limits of experimental error, neither the angle of internal friction nor the cohesion are changed by the addition of the resin.

## ACKNOWLEDGEMENT

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