The Effect of Pulverization on the Quality of Clay-cement

Influence du Degré de Pulvérisation de l'Argile sur la Qualité du Sol-ciment

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Summary

This paper describes a laboratory investigation to determine the effect of the degree of pulverization (size of aggregation) on the quality of a heavy clay soil stabilized with Portland cement.

Aggregations ranging in size from about 0·1 to 5 mm were simulated artificially. The clay aggregations were mixed, by hand, with from 15 to 30 per cent of cement and with water, and the mixed material was moulded into cylindrical specimens. After 7 days' curing in wax at constant moisture content, and 7 days' curing in wax followed by 7 and 28 days' immersion in water, the cylinders were tested in unconfined compression.

The results showed that: (a) the strength of clay-cement increased linearly with increase in cement content; (b) the strength of clay-cement decreased with increase in aggregation size; (c) the clay-cement specimens remained intact in the presence of water except for those made with $\frac{3}{16}$ in. (≏ 5 mm) aggregations.

Sommaire

Les auteurs décrivent une recherche de laboratoire entreprise pour déterminer l'effet du degré de finesse de pulvérisation du sol, sur la qualité d'une argile lourde stabilisée au ciment Portland.

On a reconstitué artificiellement en laboratoire des finesses de pulvérisation variées s'étendant entre 0·1 et 5 mm. L'argile était alors mélangée à la main, après addition de 15 à 30 pour cent de ciment et d'eau; puis le matériau était moulé en éprouvettes cylindriques. Après 7 jours de conservation sous paraffine, à teneur en eau constante (méthode du Road Research Laboratory pour les essais de ciment), ou après 7 jours de la même conservation suivie d'une immersion dans l'eau pendant 7 ou 28 jours, les éprouvettes cylindriques ont été soumises à l'essai de compression simple.

Les résultats ont montré que: (a) La résistance de l'argile-ciment varie linéairement avec la teneur en ciment; (b) La résistance de l'argile-ciment décroît lorsque la dimension de l'agrégat croît; (c) Les éprouvettes d'argile-ciment sont insensibles à l'eau, sauf celles qui étaient confectionnées avec l'agrégat de 5 mm.

Although granular soils and light clays have been successfully stabilized with Portland cement to build road foundations, attempts to stabilize heavy clays have usually been unsuccessful owing to the inability of existing plant to pulverize the clay into sufficiently small aggregations.

This paper describes a laboratory investigation made to determine how the strength of cement-stabilized clay and its loss in strength due to immersion in water are affected by the size of the clay aggregations. The investigation is the first stage in the development of a field criterion for the degree of pulverization required to give a satisfactory clay-cement for road foundations.

Experimental Method

Constituents of mix—A sample of London clay from Heathrow, Middlesex, with a liquid limit of 75 per cent and a plastic limit of 28 per cent (BRITISH STANDARD, 1948) was chosen as the clay constituent, and ordinary Portland cement was employed as the stabilizing agent.

Degree of pulverization—After several possible methods of assessing the degree of pulverization, including that of counting and measuring the number and size of aggregations in a plane cross-section, had been considered it was decided to simulate different degrees of pulverization in the following two ways:

(1) By preparing specimens containing single-sized aggregations. Four such sizes of aggregation were chosen, viz:

(a) Sieved aggregations:

Passing B.S. No. 10 sieve and retained on B.S. No. 14 sieve;

Passing B.S. No. 36 sieve and retained on B.S. No. 52 sieve;

Passing B.S. No. 150 sieve and retained on B.S. No. 200 sieve.

(b) Extruded aggregations $\frac{3}{16}$ in. diameter by $\frac{3}{16}$ in. long.

(2) By preparing specimens containing aggregations having a continuous grading (Fig. 1) and various proportions of single-sized extruded aggregations.

Preparation of soil—(a) Sieved aggregations of single size. The clay was air-dried, pulverized to pass a B.S. No. 7 sieve and sieved by hand into the required fractions. It was necessary to prepare these aggregations at a moisture content of 10 per cent. Above this moisture content the aggregation size was

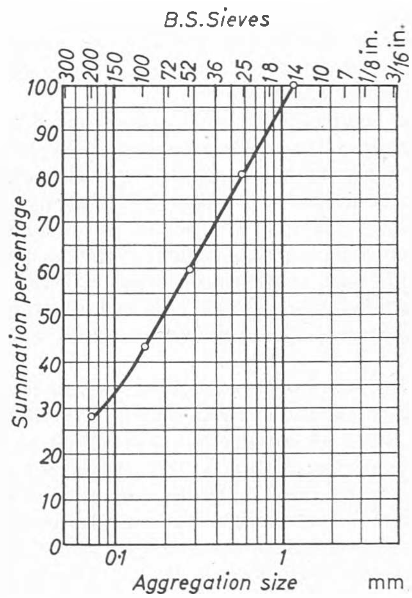

Fig. 1 Grading of aggregations of London clay passing B.S. No. 14 sieve

Composition granulométrique des aggrégations d'une argile de Londres qui passent au tamis B.S. No. 14

increased by coalescence of the individual aggregations: below this moisture content the aggregation size was reduced by the crumbling of aggregations into powder when handled even very gently.

(b) Extruded aggregations of single size. The powdered clay was first mixed with water in a double Z paddle mixer to a moisture content of 26 per cent, the extra 1 per cent of water needed to bring the soil to its natural moisture content being added during mixing. It was then extruded through a steel plate perforated with $\frac{3}{16}$ in. diameter holes and the long clay cylinders produced were cut into $\frac{3}{16}$ in. lengths by a grid of fine wires.

(c) Graded aggregations passing B.S. No. 14 sieve. These aggregations consisted of the whole of the pulverized material (moisture content 10 per cent) obtained in (a) above, excluding the fraction retained on the B.S. No. 14 sieve.

Type of mixing employed—It was necessary to mix the clay aggregations with cement and water in such a manner that no additional pulverization, with consequent decrease in the aggregation size, or coalescing of aggregations, with consequent increase in the aggregation size, would take place. Experience indicated that with the machines available mixing would smear the aggregations against the sides of the mixer and against each other. Since smearing is equivalent to additional pulverization, machine mixing was not suitable for this experiment.

Tests were therefore made to determine whether hand mixing could be performed without excessive additional pulverization taking place; examination under a microscope, before and after hand mixing, of a trial mix containing B.S. No. 36 to 52 sized aggregations, showed that hand mixing was quite satisfactory in this respect.

Mixing aggregations, cement and water—(a) Sieved aggregations of single size. The moisture content of the aggregations was determined by oven drying and was used to calculate the quantities of cement and water to be added to give the required mix proportions. The cement and the clay aggregations were thoroughly mixed together by hand, and water was then added in the form of a fine spray. Mixing with cement before the addition of water was found to reduce coalescence of the aggregations to a minimum. The mixing of the materials was carried out in a flat-bottomed balance pan 12 in. in diameter by 2 in. deep so that the actual increase in weight of the mix during the addition of water could be measured. This obviated the problem of allowing for the evaporation of water during mixing.

(b) Extruded aggregations of single size. These aggregations were brought to a moisture content of 26 per cent, 1 per cent below the design moisture content, so that a small amount of water would be available to assist in preventing segregation of cement during mixing. The water was sprayed on the aggregations before mixing with cement so that as much cement as possible would stick to their moistened surfaces.

(c) Mixing graded aggregations with various proportions of extruded aggregations. The mixing procedure was the same as in (a) above.

Making, curing and testing unconfined compressive specimens—Sets of cylindrical specimens 4 in. long by 2 in. diameter were prepared at a state of compaction corresponding to an air content of 1 per cent according to the method set out in B.S. 1924 (British Standard, 1953) for the various degrees of pulverization and various cement contents previously specified. The specimens were cured for the following periods:

(a) 7 days coated with wax at 25° C. This is the curing period normally adopted in the testing of a soil to determine its suitability for stabilization with cement (British Standard, 1953).

(b) 7 days coated with wax plus 7 days' immersion in water at 25° C. after removal of wax.

(c) 7 days coated with wax plus 28 days' immersion in water at 25° C. after removal of wax.

The curing periods specified in (b) and (c) were used to determine the effect of duration of immersion on strength.

At the end of the appropriate curing periods the specimens were tested in unconfined compression and the stress at failure was recorded.

Results

Specimens containing aggregations of single size—The relations between unconfined compressive strength and cement content for curing conditions of 7 days in wax, 7 days in wax plus 7 days' immersion in water and 7 days in wax plus 28 days'

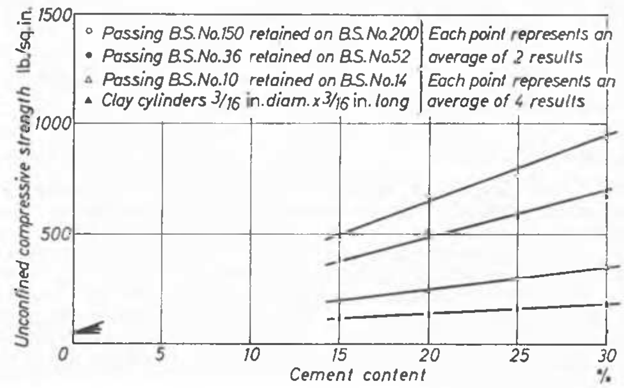

Fig. 2 Relation between unconfined compressive strength and cement content for specimens containing single-sized aggregations. Curing: 7 days in wax

Relation entre la résistance à la compression libre et la teneur en ciment d'échantillons confectionnés avec des aggrégations de dimension unique. Durcissement: 7 jours dans de la cire

immersion in water are shown respectively in Figs. 2, 3 and 4. Examination of these illustrations shows that:

(a) The relations between strength and cement content over the range considered are linear.

(b) The strength increases with decrease in aggregation size for all three curing conditions. (The relation between strength

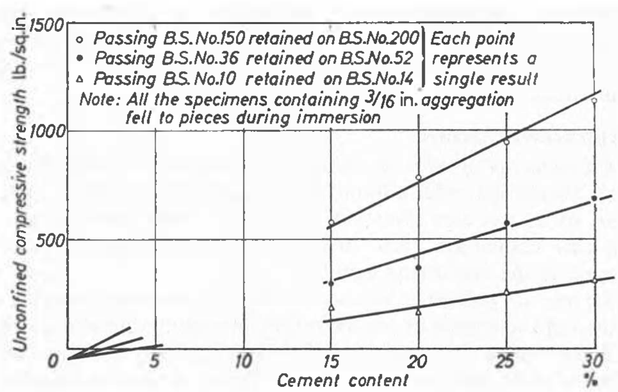

Fig. 3 Relation between unconfined compressive strength and cement content for specimens containing single-sized aggregations. Curing: 7 days in wax plus 7 days' immersion

Relation entre la résistance à la compression libre et la teneur en ciment d'échantillons confectionnés avec des aggrégations de dimension unique. Durcissement: 7 jours dans de la cire suivi de 7 jours d'immersion

and aggregation size for the particular condition of 7 days' curing in wax has been plotted in Fig. 5.)

(c) The unconfined compressive strength after 28 days' immersion was greater in all cases, except those in which the specimens fell to pieces during immersion, than that after 7 days' immersion.

It may be inferred from Figs. 2, 3 and 4 that:

(d) The ratio of strength after immersion to strength after curing in wax decreases with increase in aggregation size. Specimens containing the smallest aggregations (B.S. No. 150–200) gave increases in strength after 7 and 28 days' immersion of the same order as would be expected after curing in wax for the same period, whereas the specimens containing the largest aggregations ($\frac{3}{16}$-in.) fell to pieces after 3 or 4 days' immersion.

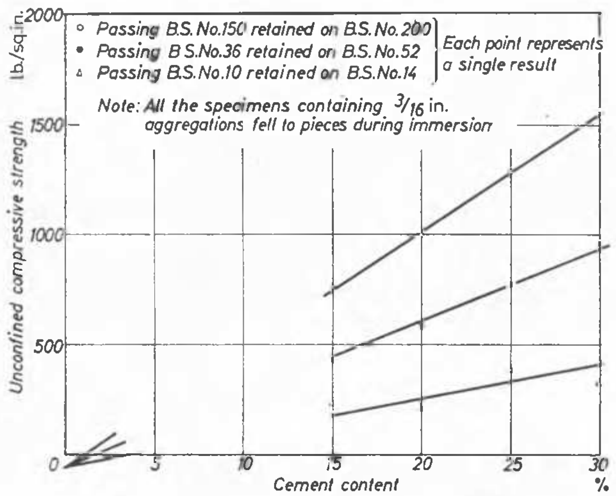

Fig. 4 Relation between unconfined compressive strength and cement content for specimens containing single-sized aggregations. Curing: 7 days in wax plus 28 days' immersion

Relation entre la résistance à la compression libre et la teneur en ciment d'échantillons confectionnés avec des aggrégations de dimension unique. Durcissement: 7 jours dans de la cire suivi de 28 jours d'immersion

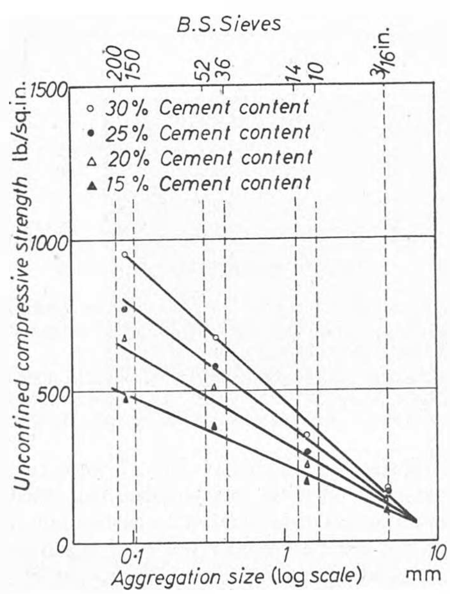

Fig. 5 Relation between unconfined compressive strength and aggregation size for various cement contents. Curing: 7 days in wax

Relation entre la résistance à la compression libre et la grandeur d'aggrégation à diverses teneurs en ciment. Durcissement: 7 jours dans de la cire

Specimens containing graded aggregations and various proportions of $\frac{3}{16}$ in. aggregations—The relations between unconfined compressive strength and cement content for the three curing conditions are shown in Figs. 6, 7 and 8. Examination of these illustrations shows that:

(a) The relations between strength and cement content over the range considered are linear.

(b) The strength increases with decrease in the percentage of $\frac{3}{16}$ in. aggregations. (The relation between strength and percentage of $\frac{3}{16}$ in. aggregations for the particular condition of 7 days' curing in wax has been plotted in Fig. 9.)

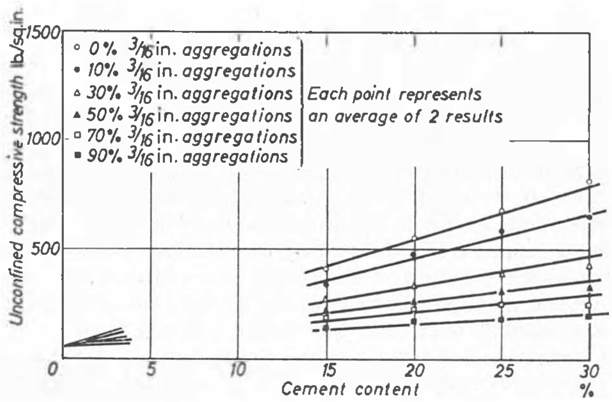

Fig. 6 Relation between unconfined compressive strength and cement content for various percentages of $\frac{3}{16}$ in. aggregations. Curing: 7 days in wax

Relation entre la résistance à la compression libre et la teneur en ciment à divers pourcentages d'aggrégations de $\frac{3}{16}$ de pouce. Durcissement: 7 jours dans de la cire

(c) The unconfined compressive strength after 28 days' immersion was greater in all cases than that after 7 days' immersion.

It may be inferred from Figs. 6, 7 and 8 that:

(d) The ratio of strength after immersion to strength after curing in wax decreases with increase in the percentage of $\frac{3}{16}$ in. aggregations.

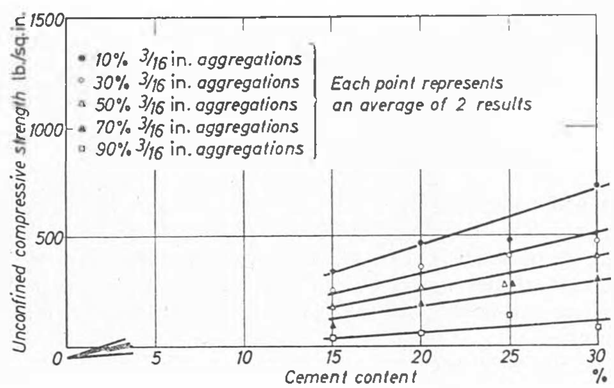

Fig. 7 Relation between unconfined compressive strength and cement content for various percentages of $\frac{3}{16}$ in. aggregations. Curing: 7 days in wax plus 7 days' immersion

Relation entre la résistance à la compression libre et la teneur en ciment à divers pourcentages d'aggrégations de $\frac{3}{16}$ de pouce. Durcissement: 7 jours dans de la cire suivi de 7 jours d'immersion

Discussion of Results

It is believed that clay-cement consists of aggregations of soil particles in a cement matrix. This matrix forms a honeycomb type of structure on which the strength of the clay-cement largely depends, since the clay aggregations within the matrix have little intrinsic strength and probably contribute little to the strength of the clay-cement as a whole. The structure is thus very different both from that of granular soil stabilized with cement, and from that of concrete, where the cement coats particles which are intrinsically stronger than the final product.

CLARE (1955) has discussed the uniformity of mixing and arbitrarily divides the cement distribution into two categories viz. a macrodistribution, which is defined as the distribution of cement over intervals of 1 in. or more, and a microdistribution, which is defined as the distribution over less than 1 in. The present investigation has shown that for aggregation sizes between 0·1 mm (B.S. No. 150–200 sieves approx.) and 5 mm ($\frac{3}{16}$ in. approx.) the strength of clay-cement containing single-sized aggregations varied from 500 lb./sq. in. to one-fifth of this value. It is evident that, even where the macrodistribution is good, the microdistribution can be such as to result in any strength varying from the maximum obtainable to a strength little more than that of the unstabilized clay; it is just as important to obtain a good microdistribution of cement in cohesive soils as it is to obtain a good macrodistribution.

In the proposed British Standard test entitled 'Determination of the degree of pulverization of a soil or stabilized soil mixture' the degree of pulverization is defined as the ratio of the weight of aggregations finer than $\frac{3}{16}$ in. to the total weight of the soil, and is expressed as a percentage. In the light of this research this size seems quite appropriate since aggregations larger than

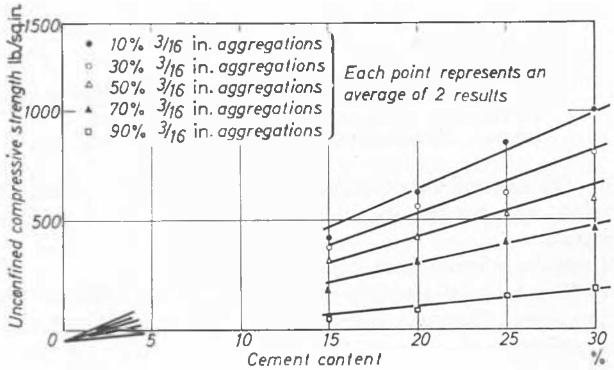

Fig. 8 Relation between unconfined compressive strength and cement content for various percentages of $\frac{3}{16}$ in. aggregations. Curing: 7 days in wax plus 28 days' immersion

Relation entre la résistance à la compression libre et la teneur en ciment à divers pourcentages d'aggrégations de $\frac{3}{16}$ de pouce. Durcissement: 7 jours dans de la cire suivi de 28 jours d'immersion

this will contribute very little to the strength of the clay-cement. The 'degree of pulverization' as defined could, however, be misleading since the strength of the clay-cement is a function of the whole of the aggregation grading and not just one particular point on that grading. To take an extreme example:

(a) The specimens made with 15 per cent of cement and containing B.S. No. 10–14 size aggregations ('degree of pulverization' = 100 per cent) had a strength of 200 lb./sq. in.

(b) The specimens made with 15 per cent of cement and containing graded aggregations with 30 per cent of $\frac{3}{16}$ in. aggregations ('degree of pulverization' = 70 per cent) had a strength of 270 lb./sq. in.

Taking a strength of 250 lb./sq. in. (ROAD RESEARCH LABORATORY, 1952) as the criterion of successful stabilization, the anomalous position arises where specimens with 100 per cent 'pulverization' are not satisfactory, whereas those with 70 per cent are. Under field conditions, however, the gradings of aggregations produced may have grading curves which are similar in shape but occupy different positions on the size axis; in these circumstances the 'degree of pulverization' may well be a useful parameter for the whole curve.

The considerable increase in strength with increase in pulverization suggests that the 'mixing efficiency' (MACLEAN, ROBINSON and WEBB, 1952) of a machine as measured on clay soils is really a measure of the efficiency with which the machine pulverizes the soil, pulverization and not mixing being the main factor governing the strength of clay-cement. Evidence in support of this view is given by the results of a field mixing machinery trial carried out by the Military Engineering Experimental Establishment. The main results obtained are reproduced below in the Table.

Table

Results of field mixing trials on a heavy clay

Résultats d'essais de mélange sur chantier sur une argile lourde

Soil		Heavy clay	
Liquid limit		55%	
Plasticity index		31%	
Moisture content before mixing		23%	
Number of passes of mixer	1	2	3
Mixing efficiency (%)	20	40	60
Figure number	10	11	12

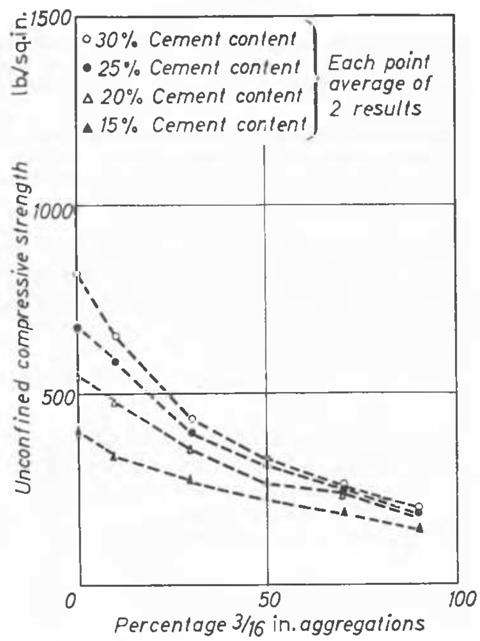

Fig. 9 Relation between unconfined compressive strength and percentage of $\frac{3}{16}$ in. aggregations for various cement contents. Curing: 7 days in wax

Relation entre la résistance à la compression libre et le pourcentage d'aggrégations de $\frac{3}{16}$ de pouce à diverses teneurs en ciment. Durcissement: 7 jours dans de la cire

The slabs shown in Figs. 10, 11 and 12 were cut from the stabilized pavement after the clay-cement had hardened. A smooth face was cut on each slab with a carborundum saw and scrubbed with hot water to remove pieces of unpulverized clay. The cavities formed were then filled with plaster of Paris and photographed. These photographs show in a qualitative manner that the strength of soil-cement increased as the percentage of large lumps in the soil-cement decreased, i.e. as the pulverization increased.

It is suggested that two main factors affect the strength of specimens immersed in water: (a) a reduction in strength which increases with aggregation size and which is caused by the clay aggregations absorbing water, swelling and slightly rupturing the cement matrix, and (b) an increase in strength due to the normal age hardening of the cement matrix. The results

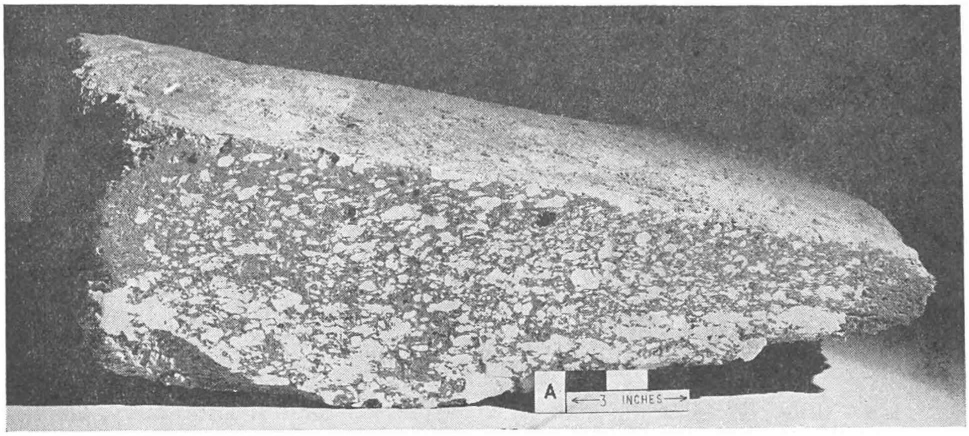

Fig. 10 Cross-section of clay-cement pavement after one pass of mixing machine. Mixing efficiency, 20 per cent

Profil d'une chaussée en argile-ciment après le passage d'un malaxeur. Efficacité de malaxage 20 pour cent

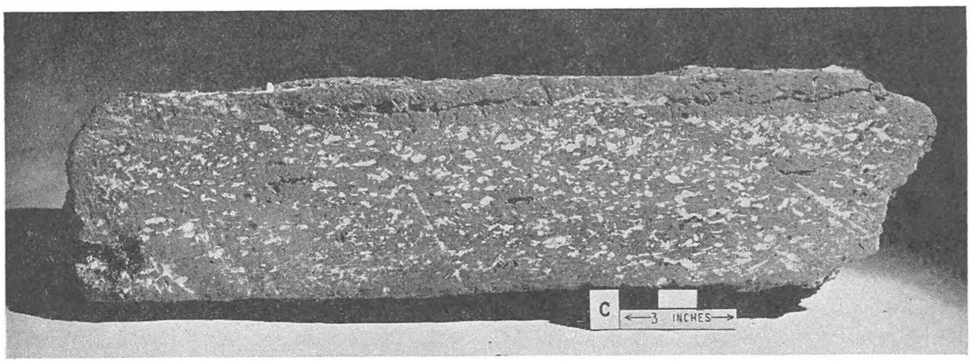

Fig. 11 Cross-section of clay-cement pavement after two passes of mixing machine. Mixing efficiency, 40 per cent

Profil d'une chaussée en argile-ciment après deux passages d'un malaxeur. Efficacité de malaxage 40 pour cent

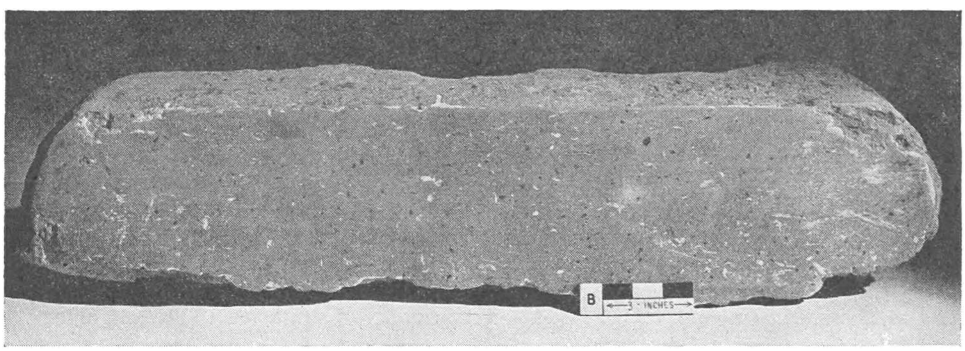

Fig. 12 Cross-section of clay-cement pavement after three passes of mixing machine. Mixing efficiency, 60 per cent.

Profil d'une chaussée en argile-ciment après trois passages d'un malaxeur. Efficacité de malaxage 60 pour cent

obtained for immersed specimens are consistent with the reduction in strength occurring in the first 7 days or so, due to the absorption of water; after 7 days the clay-cement gained strength in the normal way. It therefore seems reasonable to suppose that any lack of durability of clay-cement in the presence of water would be observed within the first month or two in British climatic conditions.

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