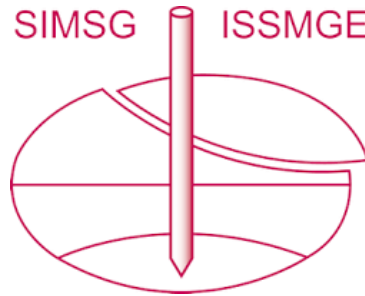


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# Keuper Marl Research

## Recherche sur la marne Keuper

J. KOLBUSZEWSKI, PH.D., D.I.C., DIPL.ING., A.M.I.C.E., *Professor, Department of Transportation, University of Birmingham, Birmingham, Great Britain*

N. BIRCH, M.SC., D.G.S., A.M.I.STRUCT.E., *Department of Transportation, University of Birmingham, Birmingham, Great Britain*

J. O. SHOJOBI, B.SC., M.SC., PH.D., A.M.I.H.E., *Department of Transportation, University of Birmingham, Birmingham, Great Britain*

### SUMMARY

This paper summarizes some aspects of an investigation into the properties of Keuper marl. A general description of the deposit is given in Section I and is followed in Section II by a study of moisture affinity. This includes investigations into moisture adsorption, swelling, cation exchange capacity, and the modifying influence of cemented clay particles. Section III describes the effectiveness of cationic chemicals as waterproofing agents.

### SOMMAIRE

Cette communication résume quelques aspects d'une enquête sur les propriétés de la marne Keuper. La première section offre une description générale de ce dépôt; la seconde une étude de son affinité pour l'eau. Celle-ci comporte les résultats de recherches sur l'absorption, le gonflement, le potentiel d'échange de cations et l'influence modificatrice d'agrégation de particules d'argile. La troisième section discute de l'efficacité des réactifs cationiques comme agents hydrofuges.

ON MANY OCCASIONS our contact with Keuper marl has been established through engineers who have encountered unexpected problems with this material during and after construction in spite of extensive testing during the site investigation period. Surprisingly little has been written about Keuper marl in spite of its extensive outcrop and so in 1963 a large research programme was initiated to investigate its variability and engineering behaviour. This paper summarizes a few aspects of this investigation.

### I. GENERAL DESCRIPTION

#### Geology

Keuper marl is the name given to a particular series of rocks laid down in the British Isles during the late Triassic period in an environment believed to be that of a great semi-arid plain bounded by a lateritic hinterland. They were terrestrial deposits, sometimes water-borne, sometimes wind-borne, sometimes building up on the dry land surface, sometimes accumulating in lakes in playa basins. The period, which persisted for some 20 to 30 million years, ended with the invasion of the Rhaetic sea and the deposit was succeeded by the Jurassic and Cretaceous formations. Subsequent erosion exposed large areas of Keuper marl, which in central England may have been subject to pressure from some 4,000 to 6,000 feet of overburden, at one time in its history (Lees, 1964).

Fig. 1 shows the present area of solid outcrop in Great Britain. The thickness of the deposit may be as much as 3,000 feet, but is commonly between 600 and 1,200 feet. It comprises a variety of rock types, but in the main, consists of red-brown to green mudstones and shales generally referred to as "marl." It is with these materials that our investigations have been concerned. Unweathered marls are usually found in a hard fissured state. In the weathered zone they are in a softer condition with higher moisture content.



FIG. 1. Map indicating the solid outcrop of Keuper marl (shown hatched) in Great Britain.

#### Classification

Some grain size distribution curves (Fig. 2) and a plasticity chart plot (Fig. 3) of marls from various locations illustrate their variable nature. Variations may occur both "vertically" and "horizontally" at any one site. However, from a large scale survey (Maclean, 1964) the majority of marls would be classified as inorganic clays of low to medium plasticity.

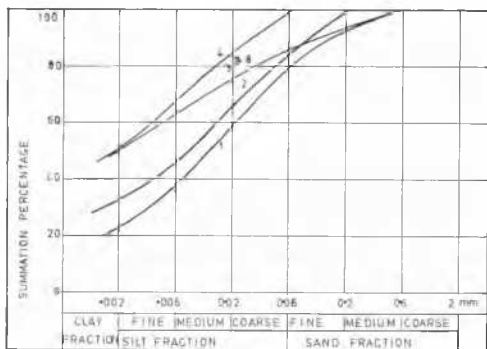


FIG. 2. Grain size curves.

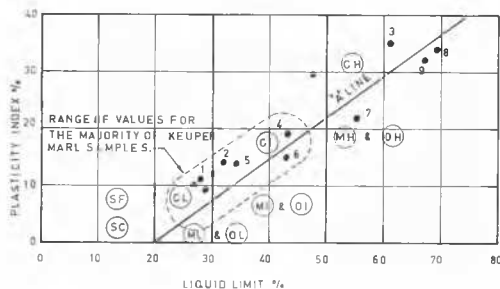


FIG. 3. Plasticity chart.

### Mineralogy

X-ray examinations by Davis (1964) of three of the samples shown on the plasticity chart (samples 2, 5, and 8) indicate a variable mineralogy. For sample 2 the minerals observed were an equal quantity of illite and chlorite with a small amount of muscovite. Non-clay minerals were quartz, the carbonate dolomite, and haematite. In sample 5 illite was present as the only clay mineral. The carbonate was calcite as opposed to dolomite and there was a significant lack of crystalline iron oxides in spite of the red colouration. The fibrous nature of sample 8 could be attributed to sepiolite which constituted most of the clay mineral content and is one of the rarer chain-silicate clay minerals. While sepiolite was the dominant clay mineral, both illite and chlorite were present in traceable quantities and the non-clay minerals were quartz, gypsum, and dolomite.

### II. MOISTURE AFFINITY

As certain marls exhibit rapid "softening" when exposed to wet conditions, particular attention has been paid to assessing, in some way, their affinity for moisture. This may be done by considering (a) index properties, (b) moisture adsorption or specific surface, (c) swelling in contact with a free water surface, and (d) cation exchange capacity at a known pH.

The suitability of any of these methods in assessing moisture affinity may depend on the structure of the marl and the modifying influences of weathering and cementation.

### Moisture Adsorption

Moisture adsorption measurements have been used by various workers to calculate the specific surface of a clay soil.

Keeling (1961) presented a simple technique to determine moisture adsorption capacity. It consists in measuring the increase in weight of an oven-dry sample of powdered soil in an atmosphere of 75 per cent relative humidity and at a temperature of 25 C. The ratio of the increase in weight to the oven-dry weight, expressed as a percentage, is called the MA value. Unless significant quantities of iron oxides or carbonaceous material are present, MA, a reflection of specific surface, depends mainly on the type and proportion of clay particles in the sample.

This procedure was carried out on both complete samples of marl (samples 2 to 9 previously shown on the plasticity chart) and on samples containing only clay size particles. The latter were obtained by sedimentation and, although these may not be exactly representative of the clay fractions of a complete sample, their MA values provide a comparative indication of the specific surface of the clay particles present. An approximation to the proportion of clay mineral present in a sample may be obtained from the ratio of the MA of the complete sample to the MA of the clay size fraction.

TABLE 1. MA LIQUID LIMIT AND CLAY CONTENT

Sample no.	MA %		$w_L$ %	Clay size content %	Clay mineral content %
	Complete sample	Clay size only			
2	3.5	9.9	32	33	36
3	8.1	13.9	61	50	58
4	6.2	10.6	43	50	58
5	4.1	11.0	34	35	37
6	6.3	10.9	43	45	58
7	8.3	14.2	55	42	58
8	8.3	15.0	69	50	56
9	8.1	14.3	67	53	58

Table I shows that samples with similar types and proportions of clay particles may have different proportions of clay size material and different liquid limit values. It suggests that varying proportions of clay particles may be cemented together to form granular particles through which, at 75 per cent relative humidity, water vapour may diffuse and cover individual clay particles with a few monomolecular layers of water. At higher humidities the cemented clay particles are unable to separate to develop their diffuse double layers and so do not contribute significantly to liquid limit values.

As a basis for comparison, the proportion of the MA of a complete sample which may be ascribed to the non-cemented clay fraction may be approximately assessed from the product of the percentage clay size and the MA of the clay size fraction. Fig. 4 shows the MA/liquid limit plot indicating a reasonably linear relationship between the MA of the non-cemented clay fraction and liquid limit.

It suggests that the specific surface of a complete sample may not always provide a reliable indication of soil behaviour at high moisture content and also that a possible increase in liquid limit may occur if cementation is in some way destroyed.

### Swelling of Compacted Marl

Compacted soils when soaked may expand and lose their original undrained strength. In order to recognize marls

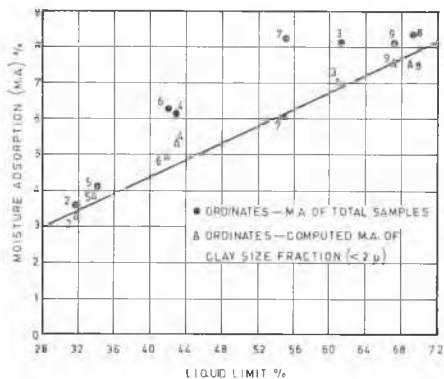


FIG. 4. Moisture adsorption versus liquid limit.

possessing undesirable expansive properties, tests were carried out to determine values of swell potential, previously defined by Seed, Woodward, and Lundgren (1962) as the percentage swell on soaking in distilled water under a surcharge of one pound per square inch of a sample compacted at optimum moisture content to maximum dry density in the standard A. A. S. H. O. compaction test.

Fig. 5 shows that the swell potential of a compacted marl depends to a certain extent on the moisture deficiency at optimum moisture content (omc). This deficiency has been related to liquid limit and is called the "optimum liquid limit deficiency" ( $w_L - omc$ ). Fig. 6 shows that it increases in a general way with increase in liquid limit.

While liquid limit is a guide to swell potential (percentage swell at optimum), it does not assess swelling at other moulding moisture contents. Samples show similar rates of reduction in swell with increase in moulding moisture content and, when zero swell is attained, a further increase in moulding moisture content presumably induces net positive pore pressures during compaction. A guide to percentage swell (under a surcharge of one pound per square inch) at a moisture content,  $w$ , may be approximately obtained from a modified liquid limit deficiency:  $c(w_L - w)$ , where  $c$  may vary between 0.5 and 0.6. Modified deficiencies of 0 per cent and 10 per cent would indicate percentage swells of about 0 per

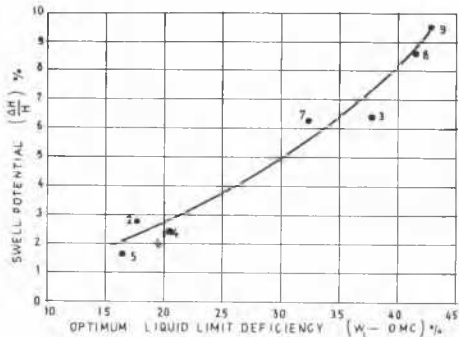


FIG. 5. Swell potential versus optimum liquid limit deficiency.

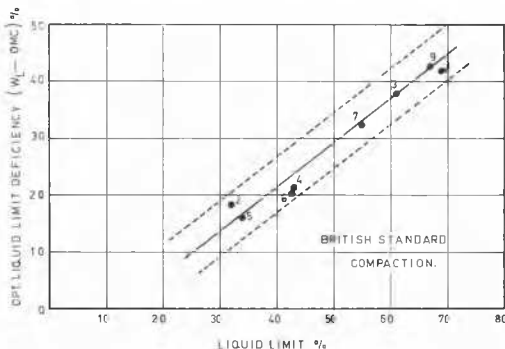


FIG. 6. Optimum liquid limit deficiency versus liquid limit.

cent and 10 per cent respectively. Values outside these limits have not been assessed.

These conclusions, although only applying to samples compacted under standard laboratory conditions, provide a basis for comparison. For example, marls of low liquid limit compacted at optimum do not constitute a problem with respect to swell but are sensitive to moisture content in that an increase of moulding moisture content of only a few percentage points above optimum is sufficient to induce positive pore pressure during compaction.

#### Cation Exchange

There are several reasons why cation exchange has a diagnostic value in the engineering study of a soil. Firstly, all silicates in the soil which have moisture affinity will take part in cation exchange reaction. This moisture affinity, therefore, can be measured by the exchange capacity of the soil. Secondly, depending on the type of silicates taking part in cation exchange reactions, the types and amounts of cations exchangeable play different but important roles in the plasticity characteristics of the soil water system. The different properties of Na-montmorillonite and Ca-montmorillonite are well known.

In the determination of the cation exchange capacity of Keuper marl, normal ammonium acetate has been used as the leaching salt. The ammonia adsorbed by the soil is distilled off having been replaced by magnesium and measured by titration. Half portions of the leachates were evaporated and the exchangeable cations in them determined by titration. The types and amounts of individual cations were determined in the remaining half portions using the EE-L flame photometer and the Unicam Sp 900 flame spectrophotometer. The results of some cation exchange properties of Keuper marl are given in Table II. The exchange capacity values obtained for <200 B.S. sieve size fractions are plotted in Fig. 7 against clay size fractions (<2 $\mu$ ) and in Fig. 8 against plasticity indices. In these figures corresponding values obtained by Davidson and Sheeler (1953) for Iowa loess are plotted for comparison.

Cation exchange capacity values obtained for Keuper marl samples investigated vary between 20 and 47 milliequivalents per 100 grams of <200 B.S. sieve size fractions. An examination of Table II reveals interesting relations between the carbonate content, cation exchange capacity, and cation saturation. High values of exchange capacity are associated with low carbonate contents, whereas high values of cation

TABLE II. SOME RESULTS OF CATION EXCHANGE STUDIES

Sample no.	Carbonate content %	Exchange capacity m.e./100 grams	Total exchangeable cations m.e./100 grams	Cation saturation tec/cec %	Cations exchanged %			
					Ca <sup>++</sup>	Mg <sup>++</sup>	Na <sup>+</sup>	K <sup>+</sup>
2	6.97	30	34	113	40	16	34	9
10	2.13	47	50	106	42	12	30	12
11	12.00	22	25	114	56	14	29	4
12	7.40	28	32	114	51	15	27	4
13	10.25	37	41	108	58	16	21	4
14	21.57	20	32	160	80	8	9	2

saturation are associated with correspondingly high values of carbonate content and *vice versa*. The trend is also supported by other results not shown in the table. These relations suggest that the reduction in carbonate content results in the development of active silicates and that because of very slow reaction between ammonium acetate and the carbonates in the marl, their effects on the cation exchange capacity (cec) values obtained are negligible.

The cation activity (cec/% clay size) chart presented in Fig. 7 shows that Keuper marl may contain more active silicates than its Atterberg limit values and its grain size distribution may lead one to expect. On the basis of this chart, Keuper marl is more active than Iowa loess which is known to be predominantly illitic but slightly less active

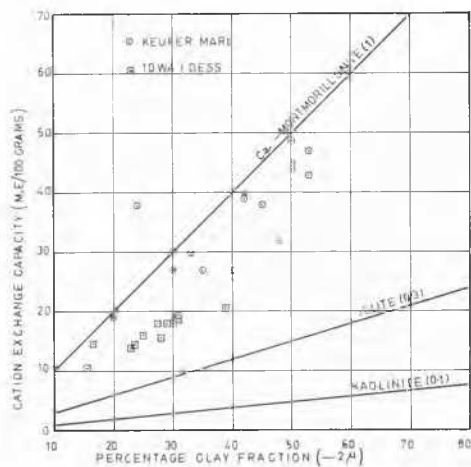


FIG. 7. Cation activity chart.

than Ca-montmorillonite. If the cation activity of Ca-montmorillonite be taken as 1, most of the marls investigated have their activities in the range between 0.68 and 0.98. Fig. 8 demonstrates the relationship between plasticity index and exchange capacity of Keuper marl compared with Iowa loess. Because of cementation effects in some of the marls, high exchange capacity values do not necessarily result in corresponding high plasticity indices.

In summarizing this section, it may be said that Keuper marl samples may have higher clay mineral contents and higher cation exchange capacities than would be inferred by their Atterberg limits or grain size distributions. This is due to the cementation of some clay particles into larger granular

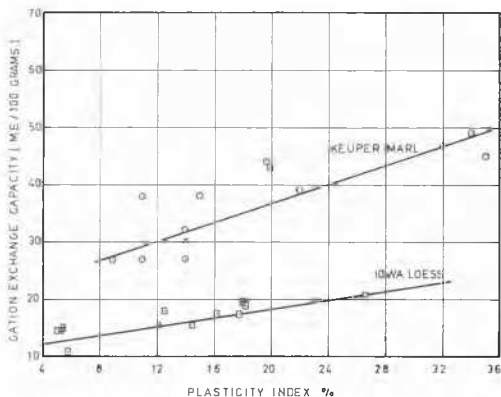


FIG. 8. Cation exchange capacity versus plasticity index.

particles. Clearly, a breakdown of cementation would lead to a change in properties and, although standard tests provide essential information, a satisfactory picture of the material requires the use of additional parameters such as moisture adsorption and cation exchange capacity. Although sufficient experimental evidence is not yet available, it seems likely

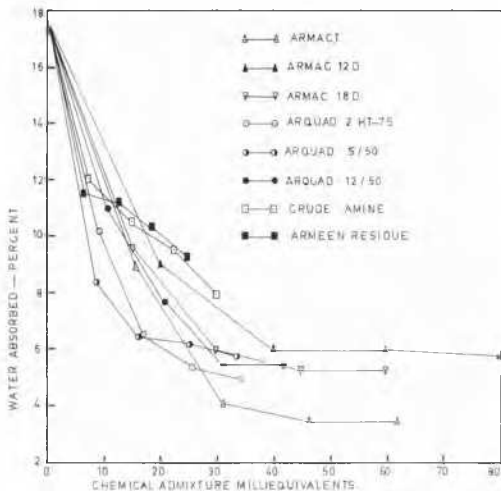


FIG. 9. Water absorption of samples treated with organic cations.

that the presence of iron oxides is the main cause of cementation.

### III. STABILIZATION

Compacted Keuper marl usually has a satisfactory shear strength and the main aim in this work is to render it hydrophobic so as this strength may be maintained. Giesecking (1955) has shown that it is possible to render clays hydrophobic by exchanging their attached cations for organic cations.

In the stabilization study, a preliminary evaluation of eight organic cationic chemicals has been made. The main criterion for this evaluation is the reduction in the amount of water absorbed. Fig. 9 shows the reduction in water absorption of organically treated Keuper marl. The results show on one hand the potentialities of these agents in waterproofing Keuper marl and on the other the importance of comparing the agents in terms of milliequivalents used rather than by weights as traditionally done. All the agents were used in 0.25, 0.5, 0.75, and 1 per cent of dry weight of soil but as shown in this graph the milliequivalents furnished by different chemicals differ in accordance with their valencies and molecular weights. As a result of this evaluation, Armac T and Arquad 2HT-75 were found to be most promising and are now being further evaluated.

### ACKNOWLEDGMENTS

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