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Some Physical and Engineering Properties of Chalk

Quelques Propriétés Physiques et Mécaniques de la Craie

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Summary

The geology and nature of the chalk of south-east England is briefly described and its engineering significance pointed out. Satisfactory samples of chalk cannot be obtained by open-drive sampling, and diamond-drill coring of intact chalk is recommended.

Tests on intact chalk show dry densities of 92 to 101 lb. per cu. ft., moisture contents of 23 to 26 per cent, and specific gravity 2·71 to 2·72.

Triaxial tests were carried out with cell pressures up to 1000 lb. per sq. in. Shear strength parameters are quoted. Young's modulus varied between 6500 and 13,000 ton per sq. ft. At high pressures disaggregation of the chalk was noted.

High pressure consolidation tests showed apparent pre-consolidation loads of about 100 ton per sq. ft., and a coefficient of compressibility of 0·00038 sq. ft. per ton.

Typical results for triaxial tests on frost-shattered chalk are given.

Sommaire

Cet exposé décrit brièvement la géologie et la nature de la craie, et en signale l'importance pour les ouvrages du génie civil. Le prélèvement des échantillons de la craie par battage ne donne pas des échantillons intacts; il faut employer le forage au diamant.

Des essais sur la craie intacte ont montré des densités sèches de 1·55 à 1·62, des teneurs en eau de 23 à 26 pour cent, et un poids spécifique de 2·71 à 2·72.

A la suite d'essais triaxiaux à haute pression, on donne les paramètres de résistance au cisaillement. Le module d'Young varie de E = 6500 à 13,000 kg/cm². A haute pression une désagrégation de la craie se produit.

Des essais de consolidation à haute pression ont montré une pression apparente de préconsolidation d'environ 100 kg/cm², et un coefficient de compressibilité de 0·00037 kg/cm².

On donne aussi les résultats des essais triaxiaux sur la craie brisée par l'action du gel.

Introduction

Chalk is a relatively strong material, beneath softer Tertiary sediments and even softer recent alluvium, in the industrial areas of Portsmouth, in Norfolk, and in the London Basin. It is, therefore, of considerable engineering importance. There are, however, almost no published data concerning its properties as a foundation stratum. The tests described in this paper were made, as a first step towards an evaluation of its properties, using such samples as were readily obtainable. Before describing the tests an outline of the geology and nature of chalk is given.

Geology and Nature of Chalk

The term 'chalk' is generally understood to mean a soft, very fine-grained, friable, white limestone. The English chalk, of Upper Cretaceous age, is a highly porous, fine-grained, calcitic mudstone, chiefly coccoliths, with foraminiferal shells and occasional macrofossils. The high porosity lies in the hollow microfossil shells and in intergranular spaces. Lithification of the original calcitic mud may have taken place well before the burial of the chalk beneath many hundreds of feet of Eocene sediments, as suggested by a marked unconformity. The intergranular cohesion of chalk is assumed to be caused by the formation of secondary calcite.

Practically all chalk is bedded and notably jointed. Bedding units range from an inch or two to several feet, but are most commonly about one foot thick. Solution enlargement of joints and bedding is widespread, but not as noticeable as in some crystalline limestones. The solution enlargement is irregular; the solid chalk is, therefore, in contact over most of the bedding and joint plane surfaces.

In south-east England the chalk is sub-divided as follows:

Upper Chalk	350–450 ft. thickness
Chalk Rock	A few feet
Middle Chalk	150–190 ft. thickness
Melbourne Rock	10–20 ft. thickness
Lower Chalk	170–200 ft. thickness

The upper and middle divisions vary little from the average, but the lower division is often more argillaceous and in places harder and more dense. The Melbourne Rock and the Chalk Rock are harder horizons which are, comparatively speaking, dense limestones with more interstitial secondary calcite.

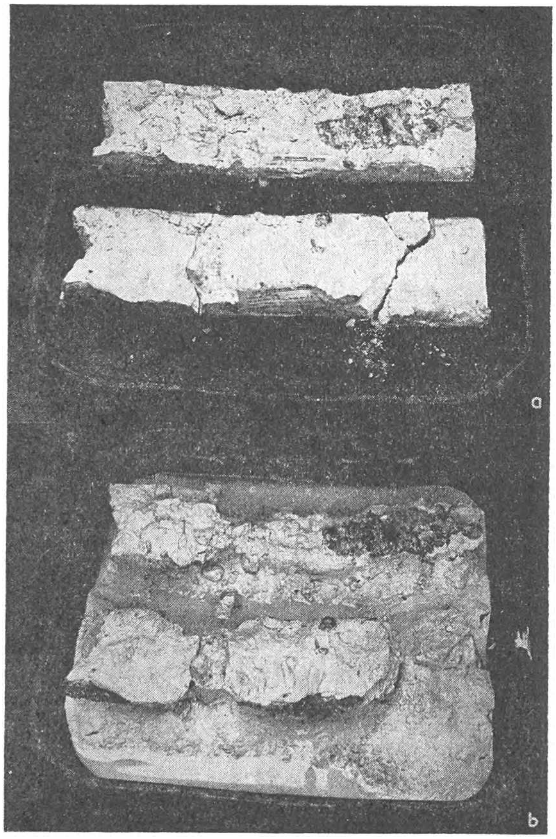

Fig. 1 Result of open-drive sampling in intact chalk. (a) Split 4 in. diameter samples. (b) After drying and subsequent wetting

Résultat de prélèvement d'échantillons de craie par battage. (a) Échantillons fendus. (b) Après séchage et humidification consécutive

Disaggregation of chalk—Significant softening of the chalk by colloidal and chemical changes which affect, sub-aerially, rocks such as shale, does not seem to occur, probably because of the constant calcium bicarbonate saturation of the pore water, and of the 'inactivity' of the calcium carbonate in the clay sense. The application of stress, above a certain value, can, however, lead to rapid breakdown of the intergranular cement, resulting in disaggregation into a cohesionless calcitic silt, sometimes known as 'putty chalk'. As will be seen later this condition can be produced in the laboratory. It exists in nature, to a slight extent in shear zones, and to a marked extent as the result of alternate freezing and thawing. As the initial frost action works chiefly from existing planes of weakness, incomplete breakdown results in fragmentary intact chalk in a putty chalk matrix. The effect of present day frosts, although clearly seen, is superficial compared with the deep freezing which occurred under periglacial conditions during the Pleistocene period.

On valley slopes, solifluction accompanied this breakdown of chalk. Frost-shattered chalk has been found beneath later glacial deposits, notably near Norwich where it is at least 30 ft. thick.

Sampling of Chalk

Open-drive sampling of chalk does not produce undisturbed samples. The intense compressive stresses from the cutting shoe invariably create putty chalk to a greater or lesser degree, and this can be seen in Fig. 1 which shows split 4 in. diameter tube samples from Tilbury. The lower photograph was taken after drying and subsequent wetting and shows clearly the non-cohesive nature of the putty chalk. Some experimental diamond-drill coring of intact chalk below the water-table was done at the same site. Satisfactory NX size cores were obtained using a bottom-discharge bit.

Samples for the laboratory tests—To gain a first idea of the physical variations of chalk, laterally and in depth, hand specimens were taken at convenient exposures along three traverses (Fig. 2).

For laboratory triaxial and consolidation tests two block samples of the upper chalk were obtained from a quarry at Coulsdon, Surrey.

Laboratory Tests on Intact Chalk

Density, moisture content and specific gravity—Density and moisture content measurements were made on samples from the traverses and also on the triaxial test specimens cut from large blocks. Densities and moisture contents of the hand specimens are listed in Table 1. Taking the Middle and Upper Chalk together, the average dry densities for traverses 1, 2 and 3 were 95, 101 and 92 lb./cu. ft. respectively (1·52, 1·62 and 1·47 g/cm^3), with little difference between middle and upper. One

Table 1

Density and moisture content measurements—Hand specimens
Densité et teneurs en eau — échantillons prélevés à la main

Traverse 1 Croydon to Merstham				*Traverse 2 Orpington to Brasted*				*Traverse 3 Dartford to Kemsing*			
Sample No.	*Locality*	*Dry density* γ_D lb./cu. ft.	*Moisture content* %	*Sample No.*	*Locality*	*Dry density* γ_D lb./cu. ft.	*Moisture content* %	*Sample No.*	*Locality*	*Dry density* γ_D lb./cu. ft.	*Moisture content* %
	Upper Chalk				Upper Chalk				Upper Chalk		
1/1	*South Croydon*	102·5	9·9	11/2	*Betsom's Hill*	102·5	20·7	21/2	*Lower Austin Lodge*	93·5	24·6
2/3	*Purley Station*	98	19·6	15/1	*Pratt's Bottom*	102	21·0	25/2	*Farningham Road*	88·5	17·0
3/2	*Kenley Station*	97	20·5	16/1	*Knockholt Stn*	100·5	22·0	26/5	*Mile End Green*	92	25·5
4/3	*Riddlesdown Quarry*	91	27·7	16/4	*Knockholt Stn*	97·5	14·5	26/6	*Mile End Green*	92·5	22·4
10/2	*Coulsdon Quarry*	86·5	25·6	17/2	*Foxburrow Wood*	113	18·0	27/3	*Little Dale*	92·5	15·3
								28/1	*Quarry nr. Stone*	92·5	3·2
								30/2	*Thrift Cottages*	89·5	8·0
								31/1	*Chemical Works, Dartford*	98·5	20·8
								32/2	*Stone Quarry*	95	16·4
								33/1	*Sutton at Hone*	92·5	27·6
	Middle Chalk				Middle Chalk				Middle Chalk		
6/5	*Greystone Quarry*	95	6·6	12/1	*Brasted Quarry*	89	18·8	18/1	*Shore Hill*	86·5	12·3
				12/3	*Brasted Quarry*	110	8·3	19/1	*St. Clere*	85·5	34·1
				12/5	*Brasted Quarry*	104	23·2	20/1	*Wrotham Hill*	93	11·6
				13/1	*Chevening Park*	101·5	24·4	23/1	*Timberden Bottom*	104	20·0
				14/2	*Dunton Green*	96·5	23·4				
				14/7	*Dunton Green*	99	25·8				
	Melbourne Rock										
6/1	*Greystone Quarry*	120	9·7								
	Lower Chalk										
6/2	*Greystone Quarry*	115	11·3								

sample was taken from the Lower Chalk and one from the Melbourne Rock, these having dry densities of 115 and 120 lb./cu. ft. respectively. Moisture contents of the hand specimens were variable, as might be expected, but laboratory shrinkage tests showed no measurable change of volume on drying and hence the dry densities quoted are not invalidated by the moisture content variation.

The triaxial test specimens had average densities, moisture contents and specific gravities as follows:

Block sample	*Dry density* lb./cu. ft.	g/cm³	*Moisture content %*	*Specific gravity*
A.1	101	1·62	23·4	2·71
A.2	97	1·55	25·7	2·72

The block samples were found to be approximately 95 per cent saturated and no appreciable increase in saturation could be achieved by placing the specimens under a vacuum in contact with water. The three diamond-drill core samples from Tilbury were found to be saturated, with an average dry density of 98 lb./cu. ft. and average moisture content of 26·7 per cent.

Triaxial compression tests—Compression tests were carried out in the high pressure apparatus (Golder and Akroyd, 1954)

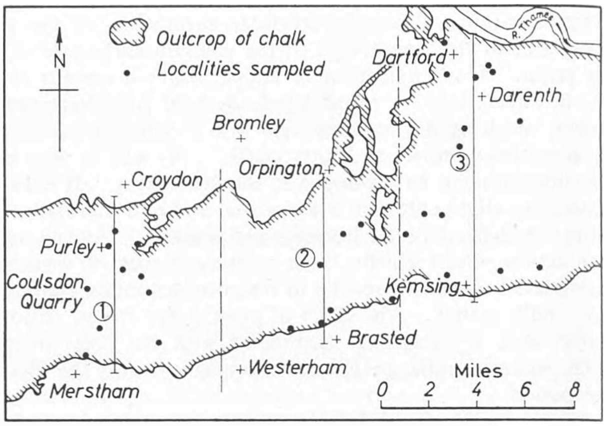

Fig. 2. Plan of traverses
Plan des zones de prélèvements

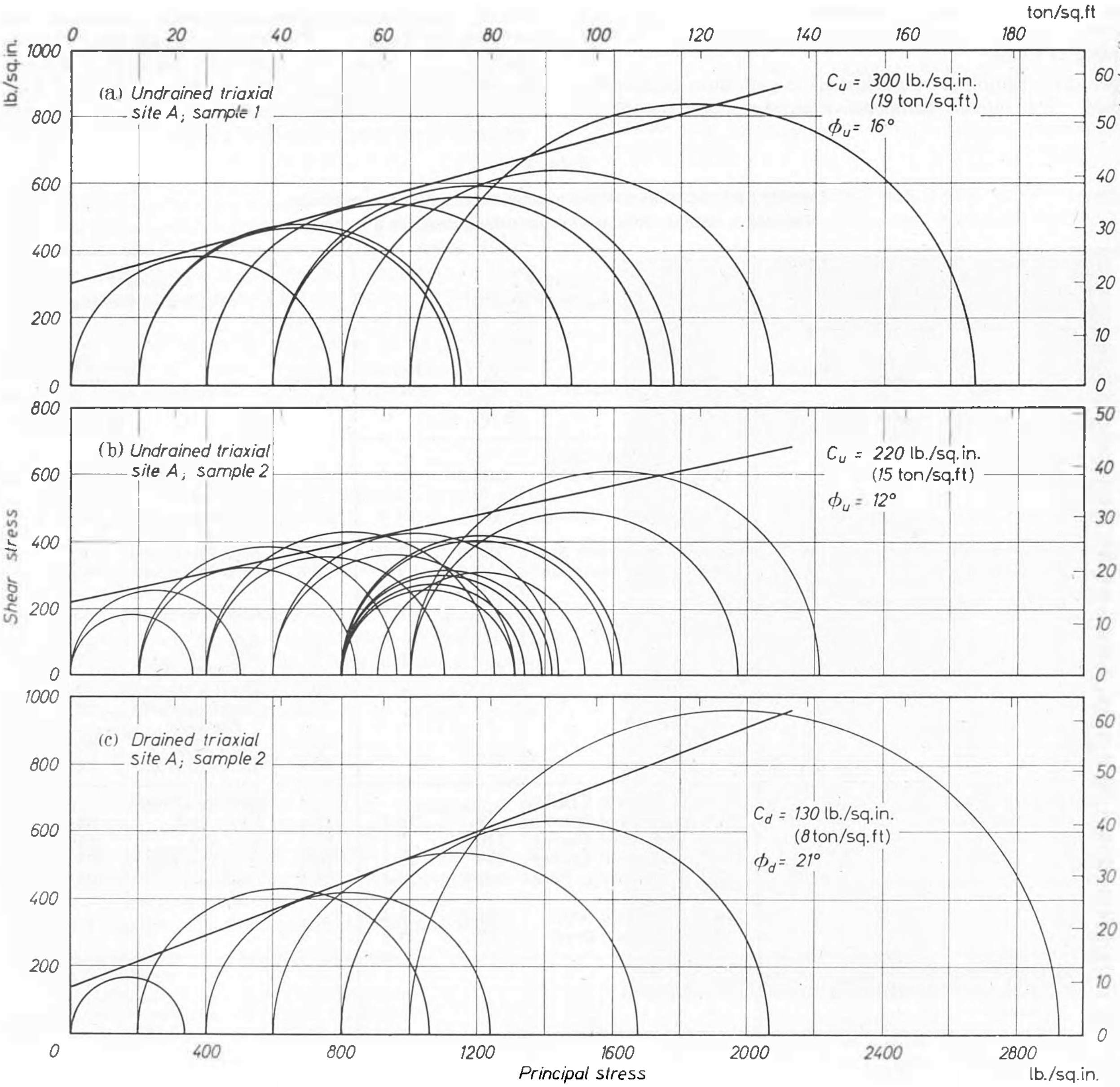

Fig. 3 High-pressure triaxial test results—Mohr circles
Résultats des essais triaxiaux, cercles de Mohr

with cell pressures up to 1000 lb./sq. in. (64 ton/sq. ft.). Specimens for these tests were cored in the laboratory, using a diamond bit, from blocks from the Coulsdon quarry.

Mohr circle diagrams for the first series of tests are shown in Fig. 3a. It can be seen that, although an average envelope can be drawn, the results for cell pressures of 600 and 800 lb./sq. in. are low, and the result for the test at 1000 lb./sq. in. is high. This latter test was in fact discontinued at 5 per cent strain, failure not being reached. With the other specimens, failure occurred at between 0·3 and 1·0 per cent strain. To investigate these differences a second series was carried out. The results (Fig. 3b) show considerable variations for tests carried out at a cell pressure of 800 lb./sq. in. and again a higher strength is measured at 1000 lb./sq. in., with a much higher percentage strain at failure. Some understanding of this can be gained from a study of the stress/strain curves which are shown in Fig. 4. For tests at low cell pressures the stress/strain curve is almost rectilinear, and failure occurs suddenly. For tests at 600 and particularly 800 lb./sq. in. the steep straight-line portion is followed by a zone in which the stress is increasing at a greatly reduced rate. In some cases an apparent failure takes place between the two zones, and in other cases the failure is complete at the end of the straight-line portion. The tests at 1000 lb./sq. in. invariably show these two zones.

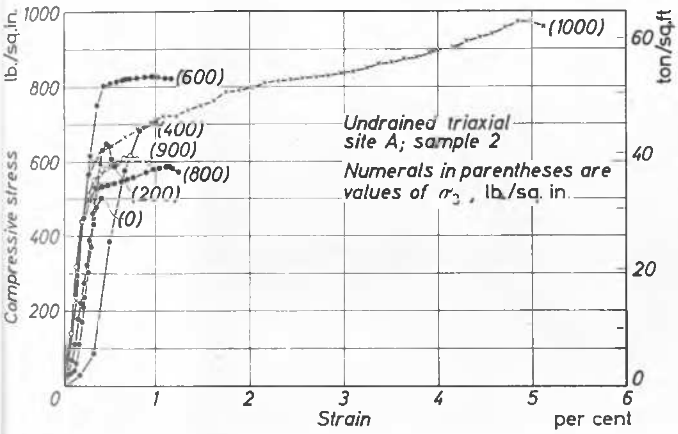

Fig. 4 High-pressure triaxial tests—stress/strain curves
Résultats des essais triaxiaux, courbes tension/deformation

The values of Young's modulus E, taken from the straight-line portions of the stress/strain curves, vary from approximately 6500 ton/sq. ft. for unconfined compression up to 13,000 ton/sq. ft. for triaxial compression at high pressures. A plot of E against cell pressure is shown in Fig. 5.

The mode of failure of the triaxial specimens can be seen in Fig. 6. For the unconfined compression test a splitting failure occurs. For higher cell pressures the failure appears to be a true shear. With increasing cell pressure it is suggested that disaggregation is occurring, leading to reduced compressive strength, but at cell pressures approaching 1000 lb./sq. in. the effect of a higher cell pressure appears to be one of compaction of the collapsed structure and strength is regained. The appearance of the failed 1000 lb./sq. in. specimens is radically different, considerable disturbance in the shear zone being evident. Disaggregation can be demonstrated by wetting the test specimens after drying. Parts (b) and (c) of Fig. 6 show this. The specimens which had been tested at low cell pressures are not affected, whereas those at higher cell pressures disintegrate, illustrating the collapsed structure. The proportion of the sample in which disaggregation occurs increases with increasing cell pressure.

The results of a set of drained high-pressure triaxial tests are shown in Fig. 3c.

Unconfined compression tests were made on the three diamond-drill core samples from Tilbury. These gave an average unconfined strength of 37 ton/sq. ft., which is of the same order as the samples from the Coulsdon quarry.

A limited number of tests was made on oven-dried specimens; these showed strengths 2 to 3 times greater than the undried specimens.

For the range of densities tested, strength appears to increase linearly with density.

Consolidation tests—Consolidation tests were also carried out to very high pressures, and for this reason the tests were made in a loading frame, as for high pressure triaxial tests, the load being kept constant by hand operation. Settlement during each load increment took place rapidly, equilibrium being reached generally within about 20 minutes, but in some cases requiring about 60 minutes. It was necessary to correct the readings for compression of the porous discs above and below the 1½ in. diameter × 2 cm thick test specimens. For one test, which was carried to 1000 ton/sq. ft., it was necessary to use steel discs since the crushing load of the porous discs was exceeded; drainage was limited to the 0·005 in. annulus between the top steel disc and the steel ring containing the specimen.

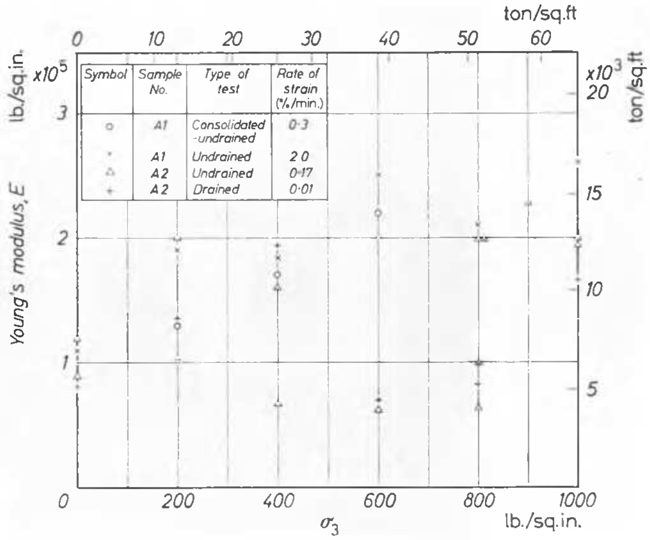

Fig. 5 Young's modulus, E, plotted against cell pressure, σ_3
Module d'Young, E—pression de la cellule triaxiale, σ_3

At loads exceeding 400 ton/sq. ft. some chalk was squeezed through this annulus.

The results of the tests are plotted in Fig. 7. A rapid change in slope of the voids ratio/pressure curve is seen to occur at loads between 70 and 170 ton/sq. ft. and this again is attributed to disaggregation of the chalk. The Casagrande construction for pre-consolidation loads gave values of 95, 95, 100 and 160 ton/sq. ft. The geological data are scanty and somewhat conflicting, so that it has not been possible to make a check on these values. At very high pressures there is a tendency for the curve to flatten again, indicating that compaction of the disaggregated chalk is almost complete.

Within the range of pressures up to about 400 ton/sq. ft. the value of the coefficient of compressibility, m_v, was found to be sensibly constant. The average calculated value for the four tests was 0·00038 sq. ft./ton (range, 0·00033 to 0·00041). Above 400 ton/sq. ft. m_v fell to about half this value.

Properties of Frost-shattered Chalk

The nature of frost-shattered chalk and the difficulties involved in obtaining undisturbed samples from it have been

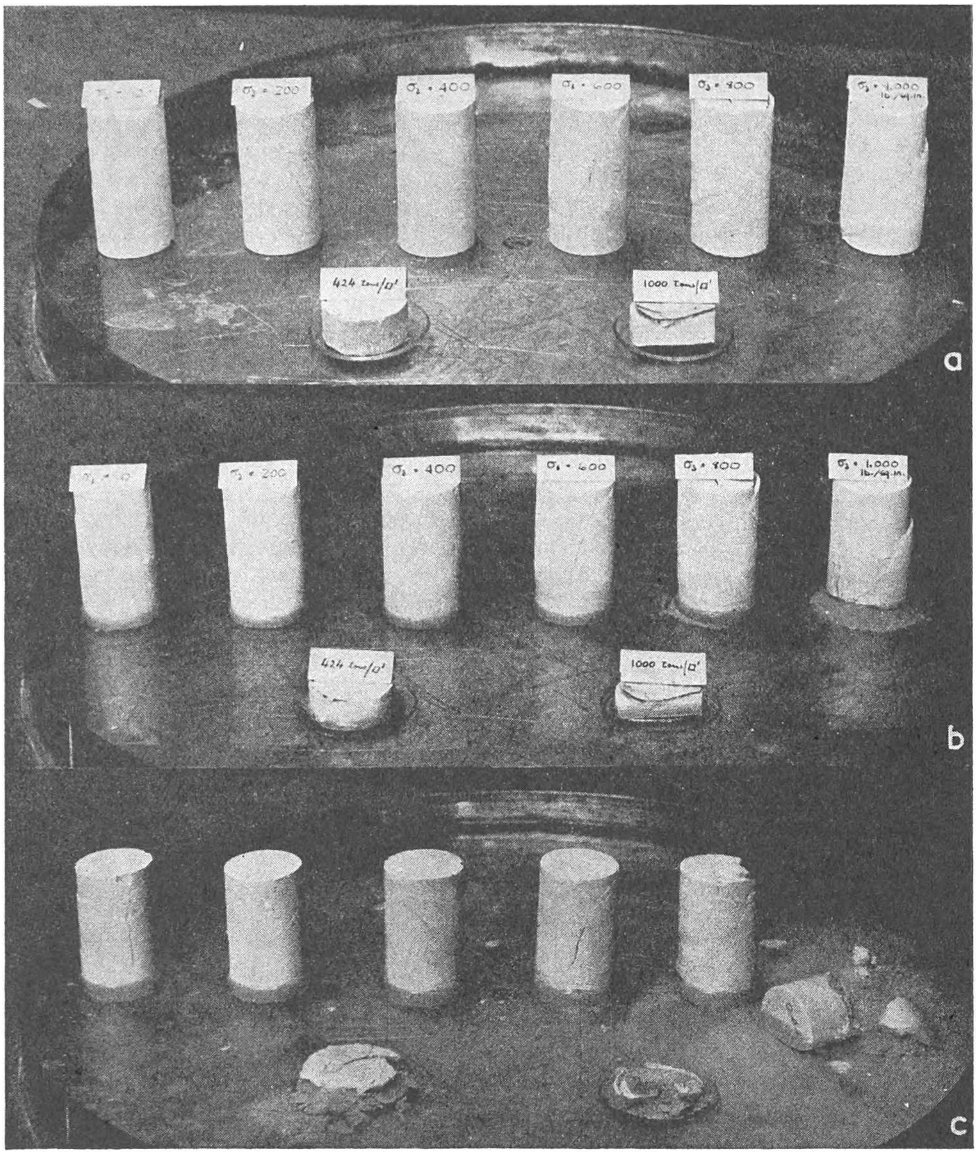

Fig. 6 High-pressure triaxial test specimens. (a) After test, and drying. (b) Five minutes after standing in water. (c) Ten minutes later, after water poured over specimens

Echantillons d'essais triaxial à haute pression. (a) Après l'essais, et séchage. (b) Cinq minutes après humidification. (c) Quinze minutes après humidification

discussed above. The results of triaxial compression tests on specimens prepared from such samples are invariably erratic in the extreme. Considerable judgment is required in selecting shear strength parameters for use in estimating bearing capacity. The range of values found at a site in Norwich can be taken as typical. They showed a variation between a $\phi = 0$ material, with an undrained shear strength of 1·1 ton/sq. ft., and a c, ϕ material, with $\phi_u = 16°$ and an apparent cohesion = 0·8 ton/sq. ft. The average moisture content was 25 per cent and the average density 125 lb./cu. ft. The strength of solifluction chalk may be even lower (the 'soft' chalk described by GUTHLAC WILSON (1948) is probably solifluction chalk).

Conclusions

(1) Chalk is met, as a foundation material, in two forms, intact chalk and frost-shattered chalk. Experience has shown that open-drive sampling in intact chalk does not provide satisfactory samples. Satisfactory diamond-drill cores can be obtained using a bottom discharge bit.

(2) Laboratory tests on intact chalk from the traverses and from the quarry show a dry density of 92 to 101 lb./cu. ft. and a moisture content of 23 to 26 per cent (95 per cent saturation). Specific gravity is 2·71 to 2·72.

(3) High pressure triaxial tests on specimens, cored in the laboratory, from blocks, showed a c, ϕ material in undrained tests with c of the order of 17 ton/sq. ft. and ϕ_u about 14°. For cell pressures of 800 lb./sq. in. and above, shear was accompanied by disaggregation of the chalk and failure at comparatively high strains. Young's modulus, E = 6500–13,000 ton/sq. ft.

(4) High pressure consolidation tests demonstrated apparent pre-consolidation loads of the order of 100 ton/sq. ft. The coefficient of compressibility was approximately constant up to pressures of 400 ton/sq. ft., averaging 0·00038 sq. ft./ton. About 400 ton/sq. ft. m_v fell to about half this value.

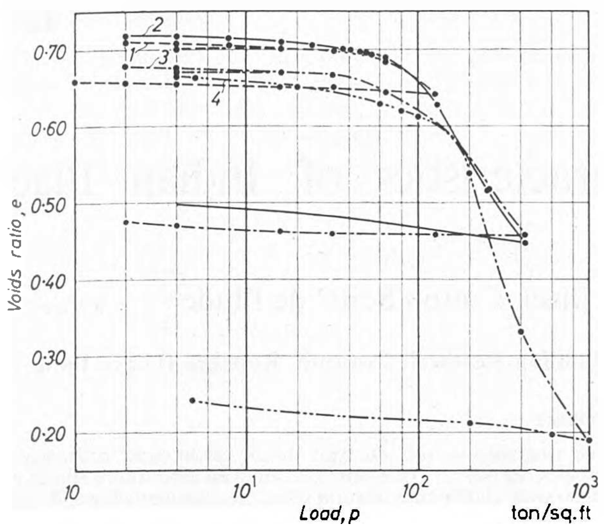

Fig. 7 Consolidation test results
Résultats des essais de consolidation

(5) Triaxial compression tests on frost-shattered chalk give erratic results, but typical values for the undrained shear strength parameters might lie within the range $\phi_u = 0$, $c = 1{\cdot}1$ ton/sq. ft. and $\phi_u = 16°$, $c = 0{\cdot}8$ ton/sq. ft.

(6) The work described in this paper has been a first step in the examination of the engineering properties of chalk, and as such it has made use of the chalk samples readily available. The next step is clearly to carry out extensive tests on truly undisturbed samples obtained from below the water table.

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