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A LABORATORY STUDY OF THE SETTLEMENT OF LOADED RECTANGULAR PLATES INTO SOFT SOIL

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H.W.W. POLLITT,

W.A. LEWIS

P.H.T. LEWIS

SUMMARY

The use of track-laying vehicles in civil engineering has led to consideration of the most suitable design of suspension and tracks in relation to soil conditions.

In this connexion experiments have been made at the Road Research Laboratory to investigate the factors affecting the sinkage of various sized plates into soft soil to determine the model law, if any, governing the sinkage. Tests were also made to investigate the effects on sinkage of spuds, plate shape and cut-away areas.

The experiments were carried out using a lever-loading machine which introduced inertia factors, and a mathematical analysis of the results was necessary for their proper interpretation.

Two soils were used in the tests; a London clay and a Harmondsworth brickearth.

The following main conclusions were reached:

1) The sinkage of a square plate in either of the soils used in the tests is not proportional to its size except over a narrow range of plate pressures described as the "scaling pressure". This scaling pressure, of the order of 8 lb./sq.in., was approximately the same for both soils but it is thought probable that it varies for any soil with the design of plate under test.
2) The estimated soil resistance decreases with increasing plate size. The surface bearing capacity component also decreases with increasing plate size as predicted by Housel's perimeter shear theory.
3) While quantitative results should be obtainable from model tests on square plate at the appropriate scaling pressure, only qualitative comparisons should be expected from plates of dissimilar design.
4) The maximum error in the sinkage of plates on the lever machine due to its inertia was estimated to be + 15% of those of similarly loaded plates sinking freely under gravity. Direct loading machines are therefore to be preferred to such lever loading machines as they avoid the inertia problem.
5) Increase in plate size and/or pressure cause increased sinkage. The sinkage-plate pressure curves are approximately linear for pressures greater than 6 lb./sq.in.
6) For a given area, plate shape has little effect on sinkage. The tendency is for square plates to sink farther than rectangular plates under the same loading.
7) The presence of spuds or of "cut-away areas" tended to reduce the sinkage of a given plate but there would appear to be a limit to the effect of the latter factor.

INTRODUCTION.

In connection with the performance on soft ground of tracklaying vehicles a laboratory investigation has been made into the factors affecting the sinkage of plates (representing idealised track-links) into soft soil under vertical loading only.

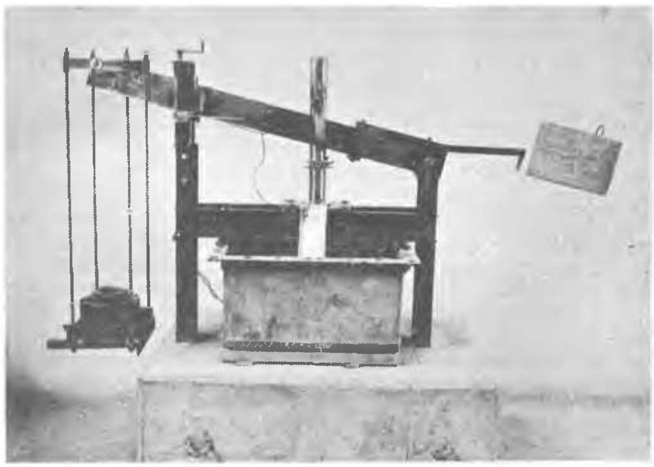
This investigation comprised;-

I. A study of the effect of plate size on the sinkage with a view to determining the scale effect. If this scale relation was found to be simple, then the work on the improvement of the soft ground performance of armoured fighting vehicles would be facilitated by making many of the experiments on the model scale.

II. An investigation of the effect of plate shape, spuds and cut away areas on the sinkage.

Two very different types of soil were chosen for the experiments; a heavy clay and a sandy clay (brickearth) as representing extremes within which cohesive soils critical to tank mobility will fall.

In this work, which was essentially exploratory, an existing lever loading machine was modified to apply the test loads to the plates through a vertical plunger. In this machine, the linear acceleration of the loaded plate was less than that of a plate under the same static load applied directly by reason of the angular momentum that had to be imparted to the lever system. The mathematical analysis of this effect, given in this report, involves lengthy computation before the results given by such a machine can be evaluated in terms of direct loading and for this reason this type of machine is not recommended for future work.



Apparatus used in sinkage tests.

FIG.1

TEST SOILS.

The heavy clay (London clay) was obtained from Staines Reservoir and the sandy clay (brickearth) was obtained from the Laboratory grounds. The characteristics of the soils as prepared for the experiments are given in Table 1.

METHOD OF TEST.

Apparatus. The apparatus used is shown in Fig. I. It consists of a hinged lever giving a 3:1

TABLE 1

Characteristics of the soils used in the tests

Test	Heavy Clay (London Clay)	Sandy Clay (Brickearth)
Liquid Limit	75%	28%
Plastic Limit	28%	18%
Plasticity Index	47%	10%
Mean moisture content during tests	49%	25%
Range of moisture content during tests	50–47%	26–25%
Mean Liquidity Index during tests	44%	71%
Mechanical Analysis:		
Coarse Sand, 2-0,2 mm.	0%	10%
Fine Sand, 0.2-0.02 mm.	11%	56%
Silt, 0.02-0.002 mm.	25%	14%
Clay, $<$ 0.002 mm.	64%	20%
International Method		
Shear box test on soil at test moisture content:		
Cohesion	0.85 lb./sq.in.	0.80 lb./sq.in.
Angle of internal friction	7.70	10.2^{o}
Prandtl's bearing capacity for strip-load (calculated)	6.3 lb./sq.in.	6.7 lb./sq.in.
Dry soil density	73 lb./cu.ft. (m/c = 48%)	99 lb./cu.ft. (m/c = 25%)

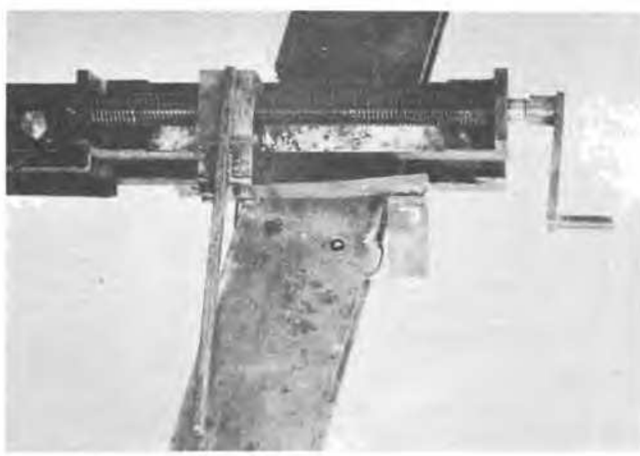
ratio, bearing through links on a vertical column at the lower end of which is fitted the test plate. Straight line, vertical motion of the column and plate is obtained by means of plain brass bearing blocks.

The system could be held in, and released from any desired position within a range of approximately 3 inches by the height adjustment and release mechanism shown in Fig. 2.

The sinkage-time records were obtained by means of a thin springsteel reed clamped to the vertical column and carrying at its lower end an inked brush (see Fig. 3). The reed vibrated at a frequency of 4 cycles per second and was released electrically the instant that the system began to sink and so provided a sinkage-time wave-trace on a record sheet mounted on a fixed vertical board. Successive values of the sinkage were obtained by measuring the distances between the zero point and the successive peaks and troughs on the wave trace, the corresponding times being calculated from a knowledge of the period of vibration of the recording brush assembly.

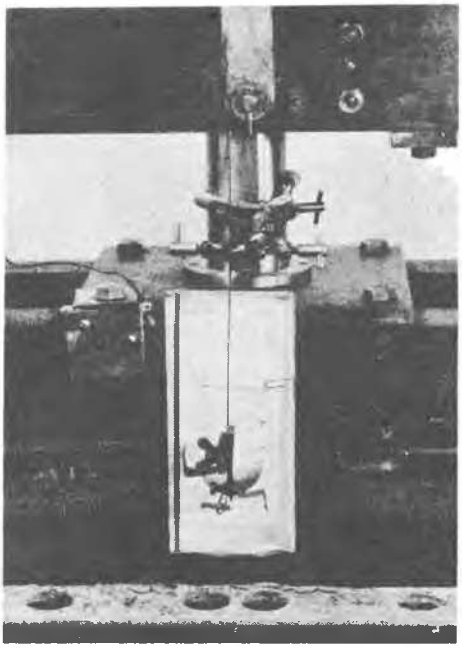
The bath containing the soil was 2-ft. square and was filled to a depth of approximately 1-ft.

Soil preparation and placing. Each batch of about 100 lb. of the soil used in the tests



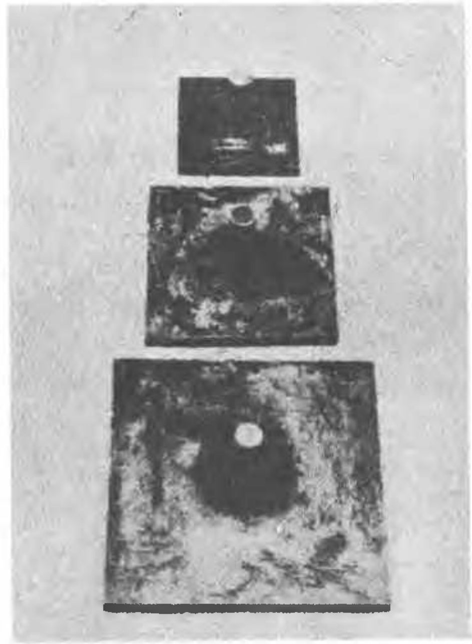
Close-up view of release and height adjustment mechanism.

FIG.2



Close-up view of sinkage recording apparatus, showing typical wave trace after a test.

FIG.3



Flat plates used in the experiments concerning the effect of scale on sinkage.

FIG.4

was oven-dried, pulverised and then mixed for 20 minutes with the required amount of water in a "Liner" concrete mixer.

The mixed soil was placed in the tank in 3 in. layers and well punned to eliminate air voids.

Routine procedure with the soil. Samples of the soil were taken at the beginning and end of each day of testing and their moisture contents determined as a check on the uniformity of the test conditions.

After each test, the disturbed soil was worked and then levelled with a large spatula, care being taken to avoid the formation of air-voids.

Test procedure. The soil having been levelled, the plate to be tested was fixed to the column of the machine and its position adjusted until it was completely in contact with the soil. The required weight was then placed upon the hanger and the recording brush held in the zero position by means of the electro-magnet. On releasing the system, the circuit of the electro-magnet was broken and the brush vibrated as the plate sank thus providing the sinkage-time trace on the record sheet.

The procedure was repeated ten times for each plate under test for each loading and in some cases further groups of ten tests were carried out as a measure of the reproducibility of the results. The majority of the tests carried out on the London clay were repeated on the brickearth. Certain tests were omitted as they were considered unlikely to add to the information already obtained.

MACHINE INERTIA.

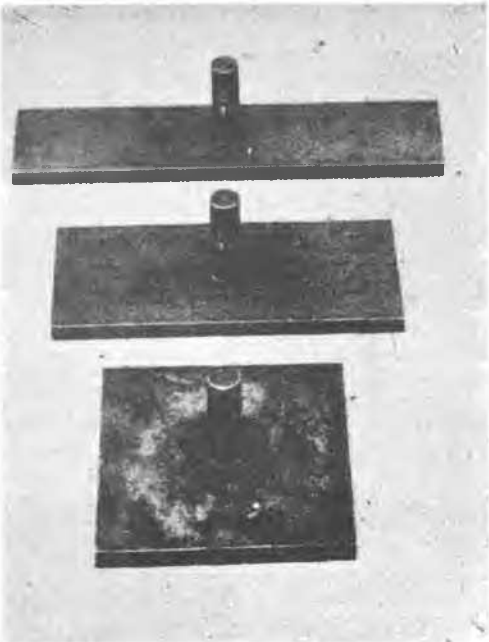
The inertia of the lever loading mechanism had to be considered and a mathematical analysis of this effect was therefore undertaken. The computations involved were very laborious and showed that the effect of the inertia would probably not exceed 15%. It was only carried out for the study of the effect of plate size on the sinkage in soft London clay owing to the necessity for winding up the investigation.

Plates with spuds used in the investigation of scale effects.

FIG.5

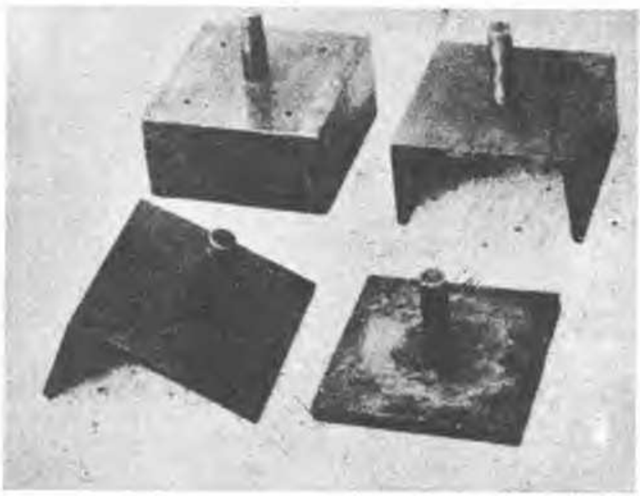
I. EFFECT OF PLATE SIZE ON THE SINKAGE.

The three plates used in this investigation were square of 4-in., 6-in. and 8-in. sides (Fig. 4). The plate pressures used were 4, 6, 8 and 10 lb./sq.in. The mean sinkage-time curves obtained with the clay are shown in Figs. 20 and 21 and those with the brick-



Links used to investigate the effects of link shape on sinkage.

FIG.6

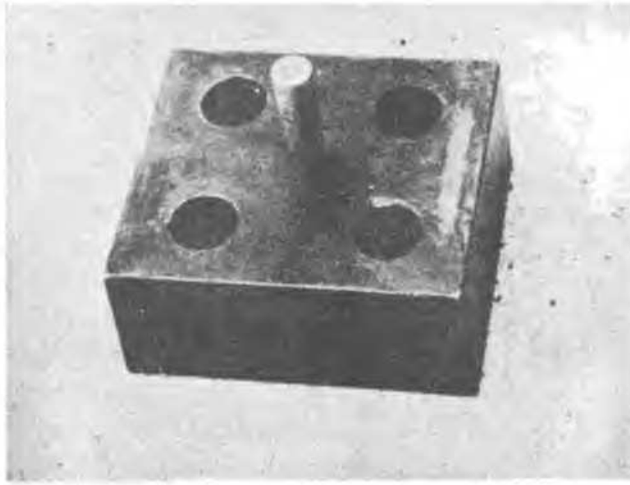


Set of links with varying number of 3-in. deep spuds.

FIG.7

earth in Figs. 9 and 10. The curves obtained with the clay were then corrected for the inertia effect in the case of the 8-in. plate under loads of 4 and 10 lb./sq.in. (see Fig. 15).

Method of analysis. The analysis was designed to express the sinkages of the various plates in terms of the freely falling acceleration (g^1) of the loading column and plate, this acceleration being a fraction of the gravitational acceleration (g), the value of the fraction depending upon the load applied to the plate. By substituting g for g^1 in the equation of motion, the free sinkage under gravity of a given plate is then deduced.



Link with 1¾-in. diameter holes used to determine the effect of cut-away areas on sinkage.

FIG.8

The following symbols are employed:-

- P = effective column load (lb.) (see Fig. 11)
- S = effective soil resistance (lb.)
- A = area of plate (sq.in.)
- p = $P/_A$ = plate pressure (lb./sq.in.)
- g = gravitational acceleration (in./sec./sec.)
- g^1 = linear acceleration of column and plate when system is freely falling about hinge (in./sec./sec.)
- I = Moment of Inertia of system about hinge (lb. sq.in.)
- 3l = length of lever from hinge to hangar load (in.)
- $\dot{\theta},\ddot{\theta}$ = angular velocity, acceleration of system about hinge (rads./sec., rads./sec./sec.)
- h = sinkage of plate (in.)
- t = time (secs.)
- q,k,λ = constants for the soil
- V = $\frac{dh}{dt}$ = velocity of plate.

The scheme of analysis is as follows:-

1) Evaluation of the equation of motion of the column and plate in terms of the load on the lever arm P and the effective soil resistance S.

Thus the equation of angular movement of the machine about the hinge is

$$\frac{I\ddot{\theta}}{g} = (P-S)\,l \qquad (1)$$

and hence for a small angular movement of the machine the linear acceleration of the column and plate is given by

$$\frac{I}{gl^2}\cdot\frac{d^2h}{dt^2} = (P-S) \qquad (2)$$

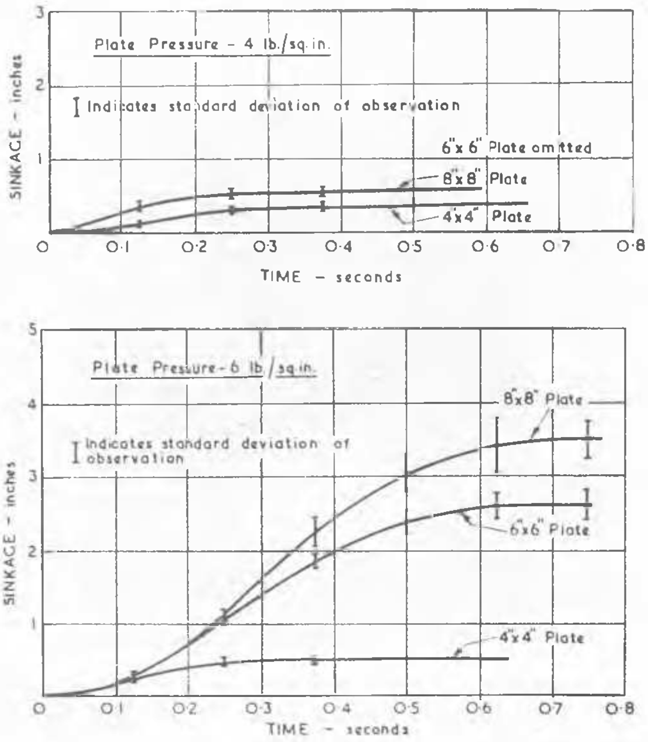
When the soil resistance S = 0, the system is freely falling i.e.

$$\frac{d^2h}{dt^2} = g^1 \qquad \text{Substituting in (2)}$$

$$\frac{I}{gl^2}\cdot g^1 = P \quad \text{or} \quad \frac{I}{gl^2} = \frac{P}{g^1} \qquad (3)$$

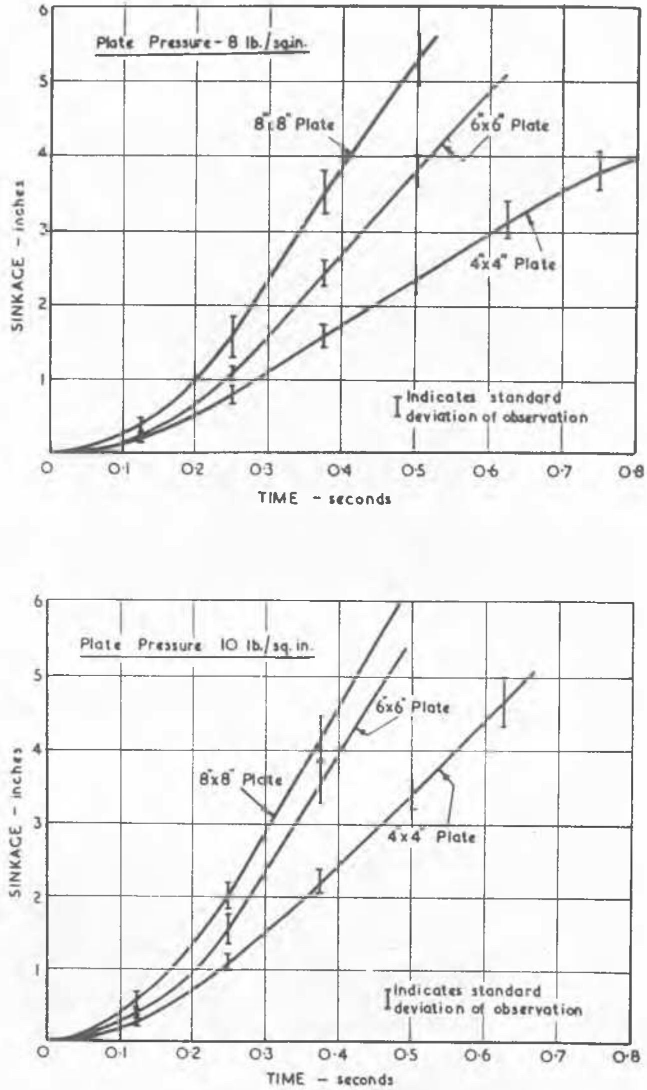
and (2) becomes

$$\frac{P}{g^1}\frac{d^2h}{dt^2} = P-S \qquad (4)$$



SINKAGE - TIME CURVES FOR SQUARE PLATES UNDER VERTICAL PRESSURE IN BRICKEARTH

FIG.9



SINKAGE - TIME CURVES FOR SQUARE PLATES UNDER VERTICAL PRESSURE IN BRICKEARTH

FIG.10

This is the equation of linear motion of a plate in a gravitational field g^1 and is of such a form that the substitution of g for g^1 gives the equation of motion of a freely sinking plate.

2) The resistance of the soil is now assumed to be of the form of a surface bearing capacity q, a depth factor λh and a dynamic factor KV^2; thus

$$S = A(g + \lambda h + KV^2) \quad (5)$$

i.e.
$$\frac{P}{g^1}\frac{d^2h}{dt^2} = P - A(q + \lambda h + KV^2) \quad (6)$$

or
$$\frac{P}{g'}\frac{VdV}{dh} + AKV^2 = P - Aq - A\lambda h \quad (7)$$

or
$$\frac{P}{2g^1}\frac{d(V^2)}{dh} + AK(V^2) = (P - Aq) - A\lambda h \quad (8)$$

or
$$\frac{d(V^2)}{dh} + 2g^1\frac{AK(V^2)}{P} = \frac{2g^1}{P}(P - Aq) - \frac{2g^1A\lambda h}{P} \quad (9)$$

3) The equation of motion is now solved to obtain an implicit expression for the sinkage of the plate in terms of the three soil factors and the acceleration of the loading column and plate.

Introducing an integrating factor exp. $\frac{2g^1KAh}{P}$ and writing $\frac{P}{A} = p$ we have

$$\frac{d}{dh}\left[V^2\exp\left(\frac{2g^1K.h}{p}\right)\right] = 2g^1\left(1-\frac{q}{p}\right)\exp\left(\frac{2g^1K.h}{p}\right) - \frac{2g^1\lambda h}{p}\exp\left(\frac{2g^1K.h}{p}\right) \quad (10)$$

Integrating

$$V^2\exp\left(\frac{2g^1K.h}{p}\right) = 2g^1\left(1-\frac{q}{p}\right)\frac{p}{2g^1K}\exp\left(\frac{2g^1K.h}{p}\right) - \frac{2g^1\lambda}{p}\int h.\exp\left(\frac{2g^1K.h}{p}\right)dh \quad (11)$$

$$= \frac{1}{K}(p-q)\exp\left(\frac{2g^1K.h}{p}\right) - \frac{p}{2g^1}\frac{\lambda}{K^2}\left[\frac{2g^1K.h}{p} - 1\right]\exp\left(\frac{2g^1K.h}{p}\right) + \mu \quad (12)$$

Where μ is a constant of integration. Dividing through

$$V^2 = \frac{1}{K}(p-q) - \frac{p\lambda}{2g^1K^2}\left(\frac{2g^1K.h}{p} - 1\right) + \mu\exp\left(-\frac{2g^1K.h}{p}\right) \quad (13)$$

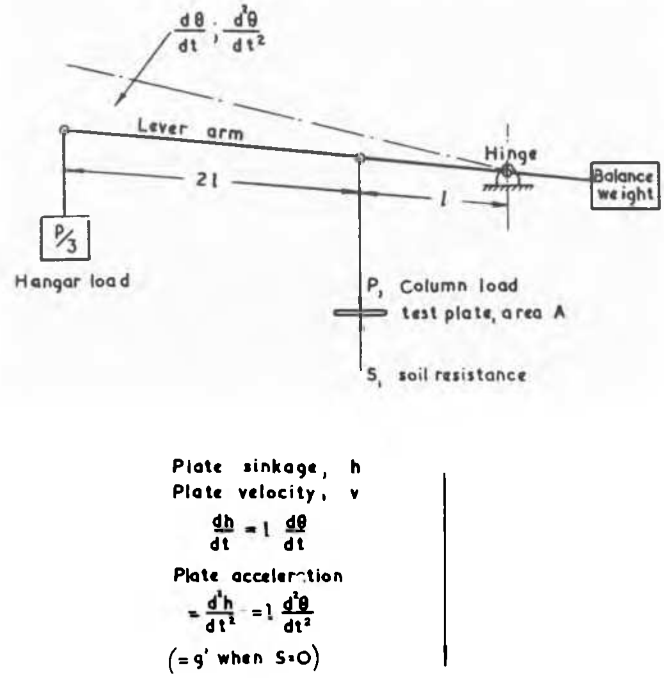
When h = 0, V = 0 thus

$$\mu = -\frac{1}{K}(p-q) - \frac{p\lambda}{2g^1K^2} \quad (14)$$

and hence

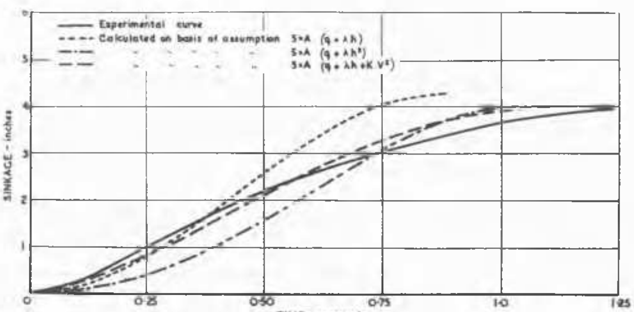
$$V^2 = \frac{1}{K}(p-q) - \frac{p\lambda}{2g^1K^2}\left(\frac{2g^1Kh}{p} - 1\right) - \left\{\frac{1}{K}(p-q) + \frac{p\lambda}{2g^1K^2}\right\}\exp\left(-\frac{2g^1K.h}{p}\right) \quad (15)$$

$$= \left[\left(\frac{p-q}{K}\right) + \frac{p\lambda}{2g^1K^2}\right]\left[1 - \exp\left(-\frac{2g^1Kh}{p}\right)\right] - \frac{\lambda}{K}h \quad (16)$$



SCHEMATIC ARRANGEMENT OF LEVER MACHINE FOR ANALYSIS

FIG.11



COMPARISON OF TYPICAL EXPERIMENTAL SINKAGE-TIME CURVE AND CALCULATED CURVES BASED ON VARIOUS ASSUMPTIONS; 6"x6" PLATE, PLATE PRESSURE 6 lb/sq.in.

FIG.12

To relate this expression to the actual sinkage-time curves the values of V^2 corresponding to different values of h were obtained from equation (16) and a curve of V against h was then plotted. The h scale was then divided into small increments Δh and the mean velocity $\Delta h/\Delta t$ was determined for each increment. The quantity Δh was then divided by the mean velocity V to give the incremental time Δt. These values of Δt were then summed progressively against the corresponding values of h to give the approximate sinkage-time curve.

4) The values of the soil resistance factors, q, λ, and K were chosen by trial and error to give reasonable agreement with the experimentally determined final sinkages.

For the value of the final sinkage in any given case it is only necessary to write V = 0 (h ≠ 0) in equation (16) giving

$$h_{max} = \left\{\left(\frac{p-q}{K}\right) + \frac{p}{2g^1K}\right\}\left\{1 - \exp\left(-\frac{2g^1K}{p}h_{max}\right)\right\} \qquad (17)$$

h_{max}, p, and g^1 being known experimentally, Equation (17) is of the form

$$h_{max} = \alpha\left[1 - \exp(-\beta h_{max})\right] \qquad (18)$$

Where βh_{max} is small, $\exp(-\beta h)$ can be taken as approximately $1 - \beta h + (\beta h)^2/2$ and hence

$$1 - \exp(-\beta h) \doteq \beta h - \frac{\beta h^2}{2}$$

$$\text{or} \quad h_{max} \doteq \frac{2(\alpha\beta - 1)}{\alpha\beta^2} \qquad (19)$$

This approximation was used in the first approach to the smaller sinkages. For the larger sinkages, since $1 - \exp -\frac{2g^1Kh}{p} \doteq 1$ the first approximation used was

$$h_{max} \doteq \frac{p-q}{K} + \frac{p}{2g^1K} \qquad (20)$$

5) The implicit equation for the plate sinkage was then integrated numerically yielding sinkage-time curves and the values of the soil resistance factors were then adjusted to give agreement in detail with both the final sinkages and the sinkage-time curves. The free sinkage under gravity was then finally estimated by substituting g for g^1 in the implicit equation, and by integrating this equation numerically giving the estimated sinkage-time curves for free sinkage under gravity.

<u>Other assumptions of soil resistance.</u> A less satisfactory fit was found making the simpler assumptions $S = A(q+\lambda h)$ and $S = A(q+\lambda h^2)$. This is shown in Fig. 12 for comparison with the final assumption chosen $S = A(q+\lambda h+KV^2)$ for the case of the 6 in. x 6 in. plate loaded to 6 lb./sq.in. An even better fit is possible if the depth factor is taken as λh^2. Then

$$V^2 = \frac{1}{K}\left[(p-q) - \frac{\lambda_1}{2}\left(\frac{p}{g^1K}\right)^2\right]\left[1 - \exp\left(-\frac{2g^1K.h}{p}\right)\right] - \frac{\lambda_1}{K}\left[h^2 - \left(\frac{p}{g^1K}\right)h\right] \qquad (21)$$

$$\left\{h^2_{max} - \left(\frac{p}{g^1K}\right)h_{max}\right\} = \frac{1}{\lambda_1}\left[(p-q) - \frac{\lambda_1}{2}\left(\frac{p}{g^1K}\right)^2\right]\left[1 - \exp\left(-\frac{2g^1K}{p}h_{max}\right)\right] \qquad (22)$$

<u>Results of the analysis.</u> The analysis showed that the model law was not simple under the conditions of the experiment.

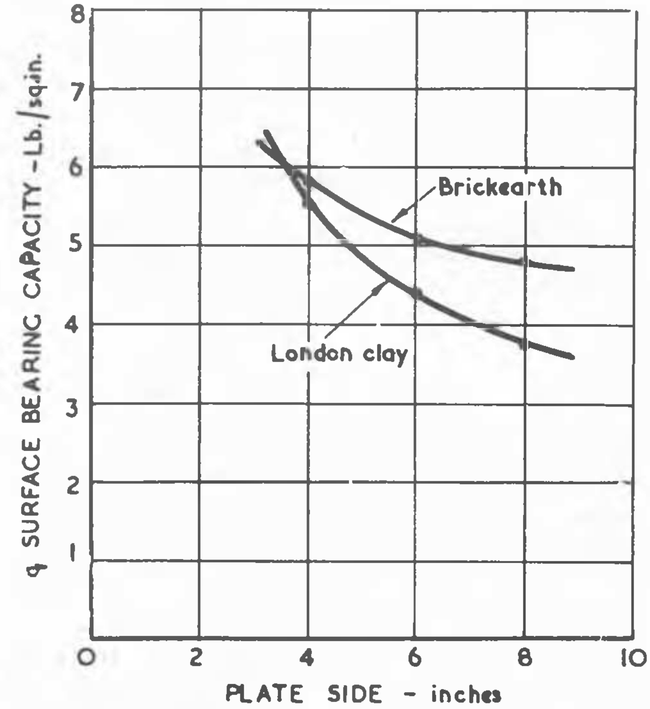
Table 2 shows the values of q, K, and λ for the three sizes of plate tested and for the London clay.

Table 2

Plate side (in)	q lb./sq.in.	λ lb./sq.in.	K lb./sq.in.
4	5.56	0.636	0.745
6	4.41	0.607	0.745
8	3.75	0.520	0.745

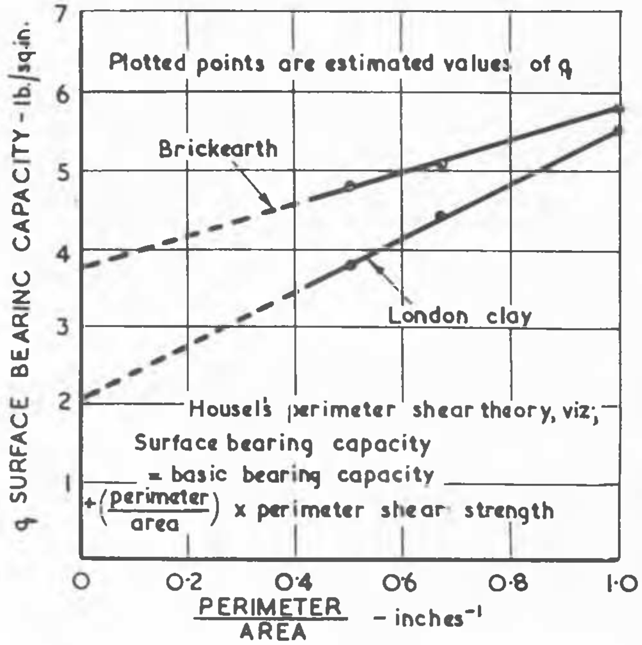
The values of q and λ decrease with increasing plate size so that the critical pressure below which theoretically no sinkage takes place is higher for small plates than for large ones. This is shown in Fig. 13 for both the brickearth and the London clay.

In fig. 14 the values of q have been plotted against the perimeter/area ratios for the



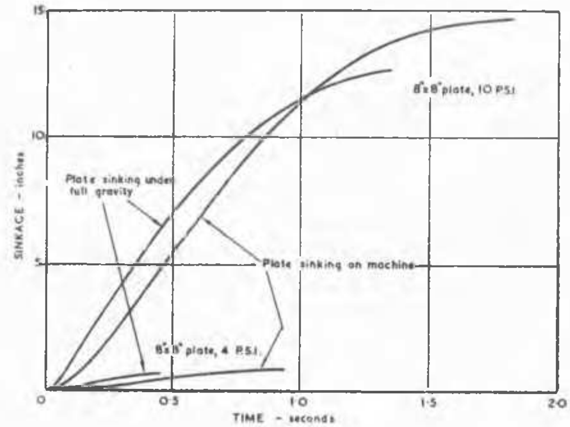
ariation of surface bearing capacity with size of square plate.

FIG.13



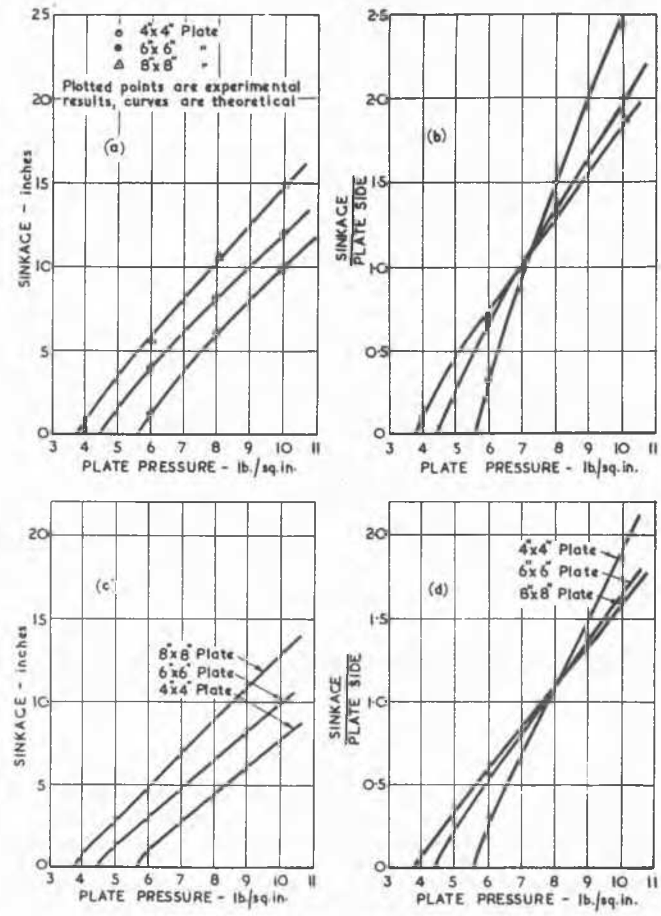
Variation of surface bearing capacity with perimeter area ratio of square plates

FIG.14



Comparison of calculated sinkage-time curves for 8" x 8" plate on machine and under full gravity.

FIG.15

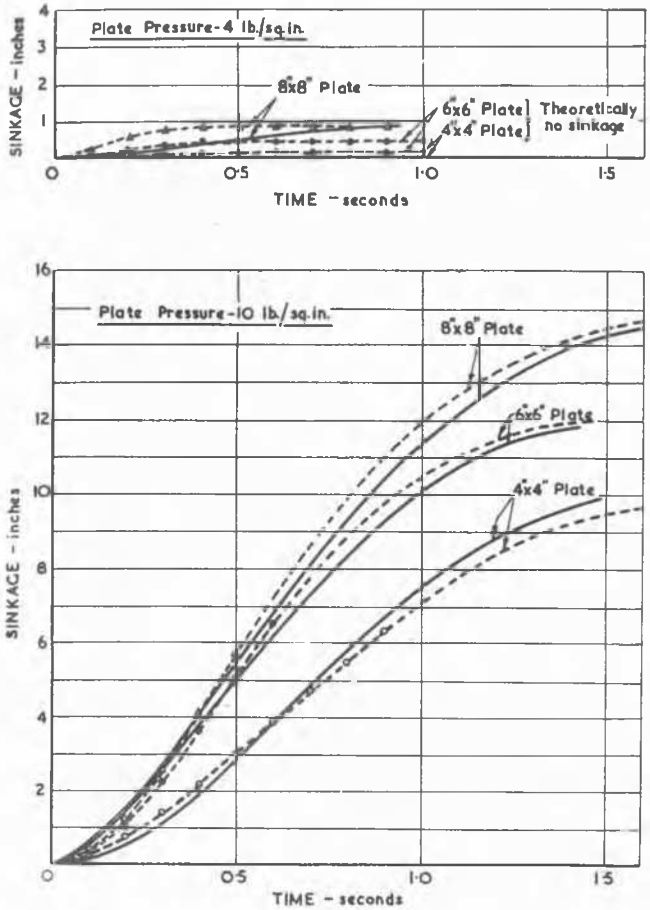


EFFECT OF PLATE PRESSURE ON SINKAGE IN CLAY OF SQUARE PLATES (a) AND (b) ON THE MACHINE, (c) AND (d) UNDER FULL GRAVITY

FIG.16

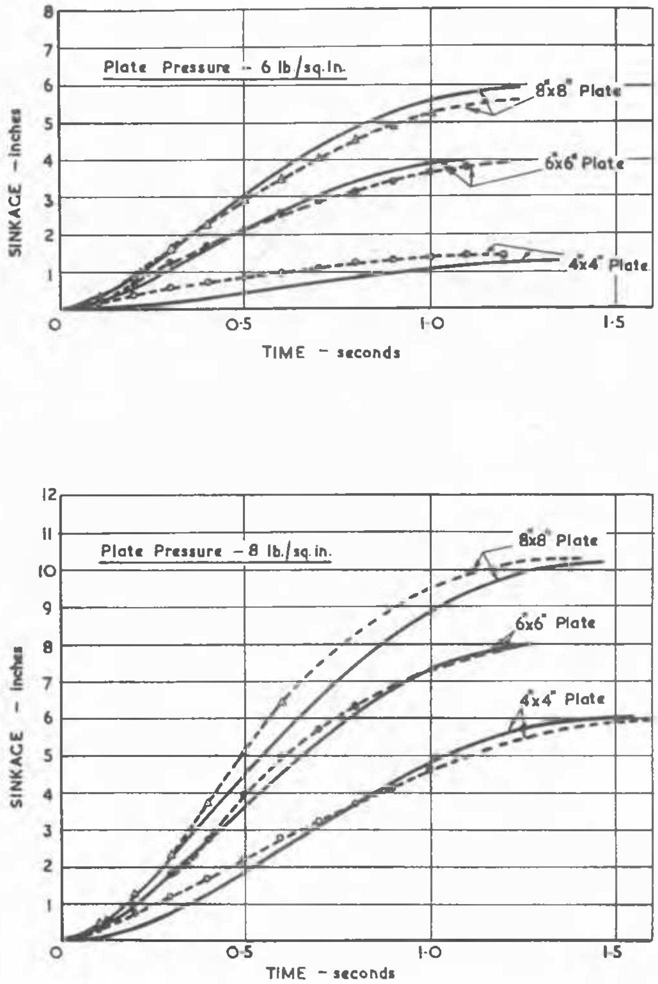
plates. The three points obtained fall quite well on a straight line. This is consistent with Housel's perimeter shear theory which postulates a basic bearing capacity together with an additional bearing capacity due to perimeter shear. For the soft London clay used in three tests the basic bearing capacity is estimated to be 2.1 lb./sq.in. and the perimeter shear addition to be 3.5 lb./in.

Fig. 15 shows the estimated sinkage-time curves for the 8 in. x 8 in. plate under pressures of 4 and 10 lb./sq.in. (a) on the machine, and (b) falling freely into the soil under gravity. It will be seen that the machine causes greater final sinkage (about 15% in the extreme case), but gives a lower average velocity of sinking. This result was confirmed by



COMPARISON OF THEORETICAL AND EXPERIMENTAL SINKAGE-TIME CURVES FOR SQUARE PLATES SINKING IN LONDON CLAY (DOTTED CURVES ARE EXPERIMENTAL, FULL CURVES ARE THEORETICAL)

FIG.17



COMPARISON OF THEORETICAL AND EXPERIMENTAL SINKAGE-TIME CURVES FOR SQUARE PLATES SINKING IN LONDON CLAY (DOTTED CURVES ARE EXPERIMENTAL, FULL CURVES ARE THEORETICAL)

FIG.18

a rough experiment in which the inertia effects were reduced by applying the load directly to the column carrying the plate producing the same pressure as that applied by the full lever mechanism of the machine.

The effect of plate pressure on the final sinkage in the clay for the three plates tested is shown in Fig. 16. It will be seen that the agreement between the theoretical and experimental plottings is good except for the small sinkages which occurred with the smaller plates under the smallest plate pressure (4 lb./sq.in.). Fig. 16 shows also curves of final sinkage/size of plate side plotted against pressure. Here the slope and the intercept on the pressure axis decrease with increasing plate size. These curves suggest that true scaling may only hold over a narrow range of pressure. For tests carried out on the machine the "scaling" pressure is about 7.3 lb./sq.in. while under gravity it is about 8 lb./sq.in.

The degree of accuracy of fit of the theoretical expressions to the experimental sinkage-time curves is shown in Figs. 17 and 18 for the square plates sinking in London clay for the values finally chosen of q, K and .

Results for sandy brickearth. Owing to the amount of computation involved the results for brickearth were not treated in the same detail. The form of the curves suggests that the type of result obtained would be essentially the same but with different values for q, K and λ.

The approximate surface bearing capacities for the different plate sizes can be obtained from Fig. 19. These bearing capacities have been plotted against plate size and perimeter/area ratio in Figs. 13 and 14. Fig. 14 shows that the basic bearing capacity for the brickearth is 3.76 lb./sq.in. and the perimeter shear addition is 2.04 lb./in.

II. EFFECT OF PLATE SHAPE, SPUDS AND CUT-AWAY AREAS ON SINKAGE.

The variables studied comprised :-

a) The effect of spuds on plate sinkage. For this a set of square plates was used of 4-in., 6-in. and 8-in. side with a 2-in., 3-in. and 4-in. spud respectively as shown in Fig. 5. In addition a further set of the 6-in. side plates was used having 1, 2 and 4 3-in. deep spuds around the perimeter of the plate as shown in Fig. 7.

b) The effect of plate shape. Three plates were used as shown in Fig. 6 all with an area of 36 sq.in., viz. 6-in. x 6-in.; 9-in. x 4-in.; and 12-in. x 3-in.

c) The effect of cut-away areas. This was studied by cutting four 1/8-in. dia. holes

TABLE 3

EXPERIMENTAL VALUES OF PLATE SINKAGE (INS.) IN LONDON CLAY

(NOTE: Each value is an average of 10 observations)

Mean Plate Pressure lb./sq.in.	Time Secs.	Plate Shape (ins.)			Number of 3-in. spuds on 6-in.sq. plate			Cut Away Areas Diameter of Holes in 7" x 6" Link. (ins.)			
		6x6	9x4	12x3	1	2	4	¼	½	1	1.11/32
4	1/8	0.12	0.14	0.16	0.21	0.18	x	x	x	x	x
	1/4	0.26	0.21	0.21	0.41	0.26	x	x	x	x	x
	3/8	0.30	0.23	0.24	0.57	0.36	x	x	x	x	x
	1/2	-	-	-	-	-	x	x	x	x	x
6	1/8	OMITTED			0.28	0.27	0.19	0.29	0.12	0.14	0.08
	1/4				0.81	0.63	0.38	0.56	0.14	0.19	0.11
	3/8				1.20	0.79	0.47	0.73	0.19	0.23	-
	1/2				1.44	0.85	0.52	-	-	-	-
	5/8				1.47	-	-	-	-	-	-
	3/4				1.50	-	-	-	-	-	-
8	1/8	0.36	0.35	0.34	0.43	0.41	0.26	0.49	0.36	0.32	0.29
	1/4	1.24	1.13	1.11	1.25	1.44	0.90	1.23	0.94	0.83	0.78
	3/8	2.40	2.12	2.25	2.22	2.36	1.45	2.07	1.63	1.39	1.25
	1/2	3.69	3.23	3.41	3.04	3.40	2.04	2.72	2.19	1.91	1.69
	5/8	4.91	4.40	4.74	3.88	3.91	2.39	3.23	2.60	2.19	1.94
	3/4	-	-	-	-	-	2.68	3.43	2.81	2.36	2.13
10	1/8	0.32	0.25	0.37	0.58	0.39	0.33	0.49	0.38	0.31	0.36
	1/4	1.18	1.10	1.23	1.72	1.53	1.33	1.46	1.16	1.05	1.04
	3/8	2.60	2.38	2.71	3.45	2.79	2.29	2.64	2.20	1.88	1.78
	1/2	4.33	4.02	4.34	4.80	4.00	3.49	3.76	3.21	2.78	2.79

x Sinkage too small to be recorded.
- No further sinkage was, or could be, recorded.

which were successively enlarged for subsequent tests to ½-in., 1-in. and 1.11/32-in. dia., in a 7-in. x 6-in. plate with 3-in. perimeter spuds. Fig. 8 shows the plate with 1.11/32-in. dia. holes.

RESULTS.

The results obtained are given in Tables 3 and 4. These are uncorrected for the inertia effect of the lever loading machine but are useful for comparative purposes. In any one case the error due to inertia is probably not more than 15%.

Typical sinkage-time curves for square plates with and without one spud are shown in Figs. 20 and 21. It will be seen from the curves and from Tables 3 and 4 that the presence of a single spud in general decreases the sinkage of a plate and that the sinkage is further reduced by the addition of more spuds to a total of four.

Tables 3 and 4 show that within the limits studied the shape of the plate has little effect on the results obtained. Cut away areas caused a reduction in sinkage (Tables 3 and 4), the greater the proportion of cut away area the greater the reduction in sinkage. There is almost certainly a limit however to the amount of area that can be cut away and still produce a reduction in sinkage.

The sinkages in the brickearth are in general less than those in the London clay.

III. DISCUSSION OF RESULTS.

Reproducibility. The standard deviations of typical observations are shown in figures 9, 10, 20 and 21. The main cause of the scatter of individual observations is thought to be variations in the soil. When left undisturbed for weeks or even days the soil was found to

TABLE 4

EXPERIMENTAL VALUES OF PLATE SINKAGE (INS.) IN BRICKEARTH

(NOTE: Each value is an average of 10 observations.)

Mean Plate Pressure lb./sq.in.	Time Secs.	Plate Shape (ins.)			Number of 3-in. Spuds on edge of 6-in.sq. Plate			Cut-Away Areas Diameter of Holes in 7" x 6" Link (ins.)			
		6x6	9x4	12x3	1	2	4	¼	½	1	1.11/32
6	1/8	0.26	0.24	0.31	0.21	0.11	x	OMITTED x			
	1/4	1.05	0.89	1.02	0.70	0.34	x				
	3/8	1.86	1.64	1.65	1.10	0.46	x				
	1/2	2.39	2.22	2.07	1.21	0.47	x				
	5/8	2.61	2.57	2.21	1.26	-	x				
	3/4	2.63	2.71	2.25	1.26	-	x				
8	1/8	0.32	0.20	0.27	OMITTED			OMITTED x			
	1/4	1.21	1.00	1.09							
	3/8	2.37	2.20	2.19							
	1/2	3.41	3.38	3.21							
	5/8	4.23	4.48	4.09							
10	1/8	0.42	0.18	0.26	0.28	0.18	0.15	0.13	0.16	0.15	0.18
	1/4	1.52	1.09	1.18	1.11	0.74	0.47	0.40	0.45	0.36	0.61
	3/8	3.06	2.62	2.60	2.28	1.57	0.80	0.56	0.62	0.48	0.90
	1/2	4.55	4.26	4.07	3.26	2.38	0.98	0.61	0.67	0.51	1.00
	5/8	-	-	-	4.02	3.04	1.04	0.63	0.68	-	1.03
14	1/8							0.25	0.27	0.25	0.27
	1/4							0.73	0.89	0.91	1.01
	3/8							1.07	1.49	1.48	1.73
	1/2							1.23	1.90	1.95	2.30
	5/8							1.26	2.00	2.09	2.58
	3/4							-	2.06	2.14	2.70

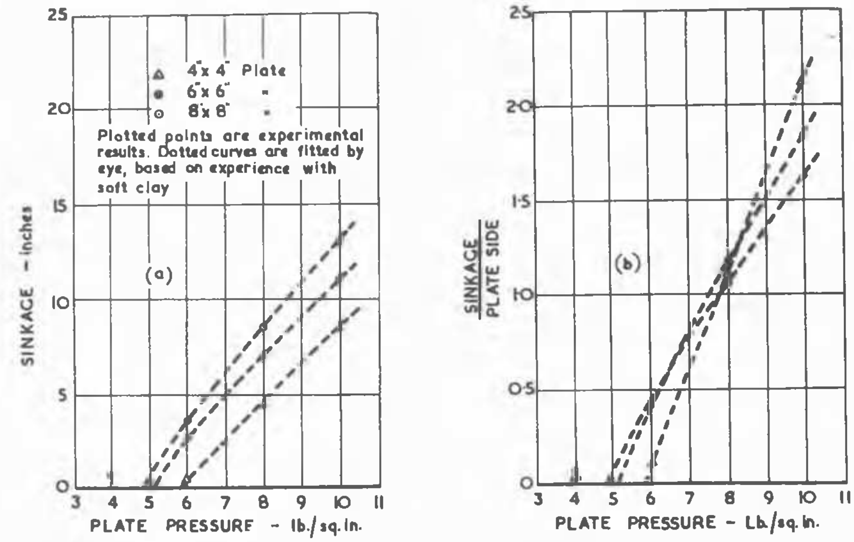
x Sinkage too small to be recorded.
\- No further sinkage was, or could be, recorded.

develop a greater bearing capacity, and thus repeat tests carried out as controls from time to time, gave markedly different results unless the soil was adequately worked beforehand. With such working the overall reproducibility of the results was in general within about 10%.

Other causes of scatter of the results may be imperfect seating of the plates on the soil before test, the existence of cavities in the soil, variable friction in the moving parts of the machine and irregularities of operation of the recording system, though these were minimised as far as possible.

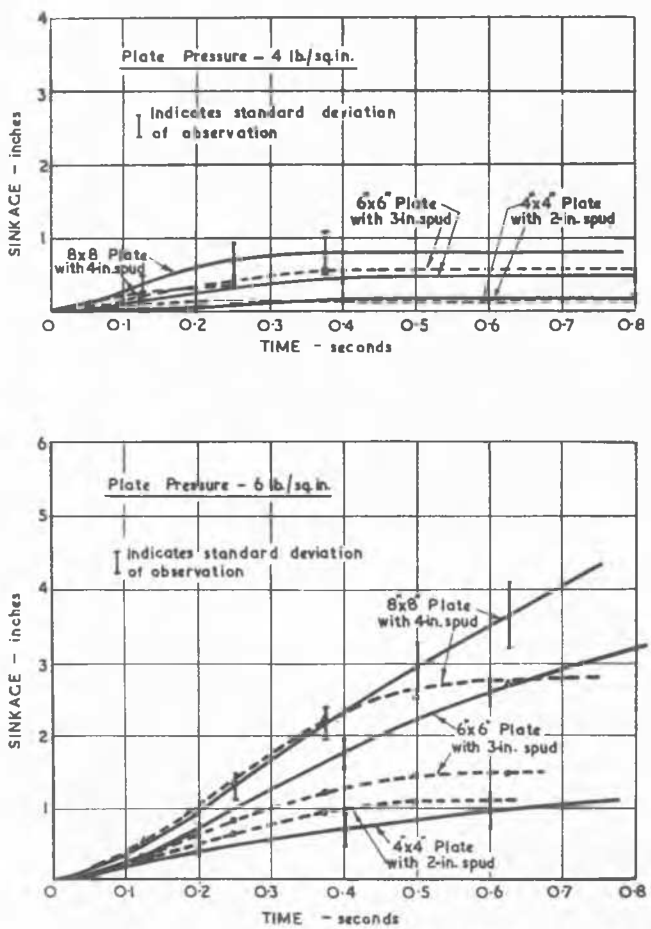
Validity of assumptions. The fit of the theory to the experimental data is good except for the sinkages of the smallest plates under the smallest pressures. This arises because the theory takes no account of the small initial semi-static plastic deformations in the soil which are appreciable for the small slow sinkages. This trouble would be minimised in tests on the model scale by making the scale as large as was practicable.

Perimeter shear. All the experimental results show that perimeter shear is an important factor in the resistance of a soil to plate sinkage, particularly where spuds and cut away areas are involved. This vitally concerns tests on models since the perimeter/area ratio and its effect are larger the smaller is the model. In "openwork" tracks, i.e. tracks with substantial cut away areas the contribution of perimeter shear forces in giving greater bearing power may compensate for the drawback of the increased pos-



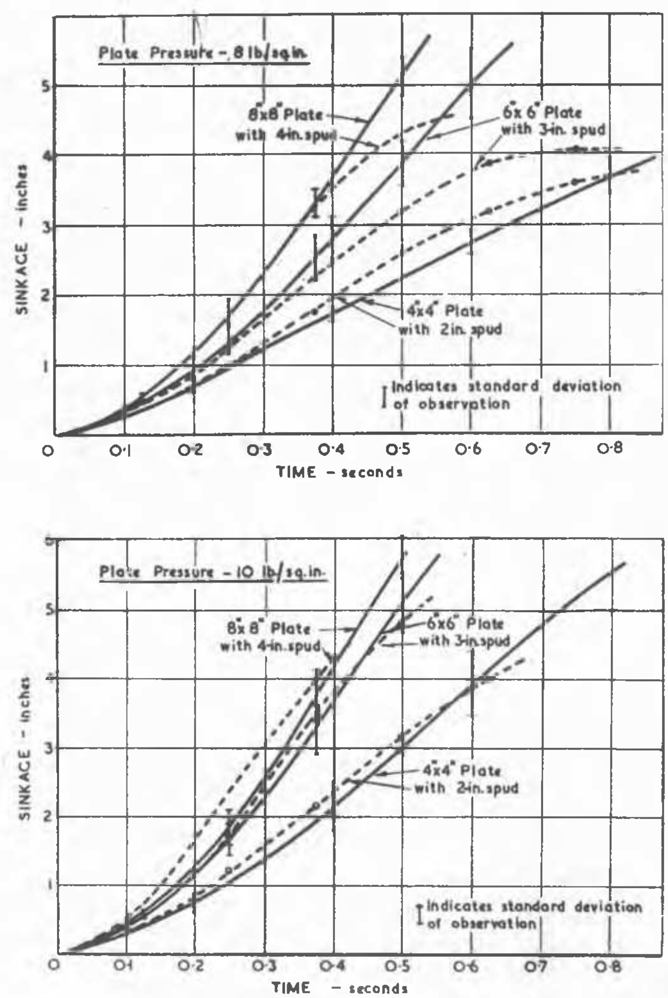
Effect of plate pressure on sinkage in brickearth of square plates on the machine.

FIG.19



SINKAGE - TIME CURVES FOR SQUARE PLATES WITHOUT SPUDS (FULL LINES) AND WITH ONE SPUD (DOTTED LINES) UNDER VERTICAL PRESSURE IN LONDON CLAY

FIG.20



SINKAGE - TIME CURVES FOR SQUARE PLATES WITHOUT SPUDS (FULL LINES) AND WITH ONE SPUD (DOTTED LINES) UNDER VERTICAL PRESSURE IN LONDON CLAY

FIG.21

sibility of mud flow through the tracks into the suspension.

Scaling pressure. For the square plates on both soils Figs. 16 (b), (d) and 19 (b) show that there is a narrow pressure range for the three plates where scaling holds. This is the region where the three curves intersect and is about 7.3 lb./sq.in. (about 8 lb./sq.in. if the results are corrected for machine inertia) for the clay and about 7.7 lb./sq.in. for the brickearth. The curves of sinkage against plate pressure (see Figs. 16 (a), (c) and 19 (a)) are roughly parallel so that within the range of pressures and plate sizes studied, model tests could be used to reveal qualitative differences in plate performance.

The scaling pressure appears to be less well defined for the plates carrying a spud as the presence of spuds adversely affects the consistency of the results. Figs. 20 and 21 show that although in general the sinkage is less with the plate carrying a spud than with a plain plate, in some cases it is greater. A further inconsistency appears in the curves for 4 lb./sq.in. loading (Fig. 20) where the curve for the 8-in. plate with a 4-in. spud crosses that for the 6-in. plate with a 3-in. spud.

Estimated bearing capacity. A comparison of the estimated basic bearing capacity and perimeter shear values for the two soils with their measured cohesions and angles of internal friction shows that the basic bearing capacity is predominantly influenced by the angle of internal friction while the perimeter shear is predominantly influenced by the cohesion. This suggests that the effectiveness of open-work tracks and spuds would be expected to be greater in cohesive than in non-cohesive soils. However, there is an unknown factor - "arching", to be considered. This factor would be expected to offset the perimeter shear deficiencies of an openwork track in non-cohesive soils by giving a pressure distribution almost as uniform as that for a plain plate.

Conclusions. See Summary.

ACKNOWLEDGEMENTS.

The work described in this paper was carried out at the Road Research Laboratory of the Department of Scientific and Industrial Research on behalf of the Ministry of Supply. The paper is presented by permission of the Director of Road Research and the Chief Scientist of the Ministry of Supply.

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SOME LABORATORY TESTS ON CHALK

GUTHLAC WILSON, S.M., B.Sc.

A site exploration was undertaken in 1946 at Messrs. Reckitt & Colman, Ltd., 's Carrow Works at Norwich. As a result of this exploration, it was found possible to divide the site into five areas, which differed from one another from the point of view of the construction of foundations. These five areas are outlined in figure 1. The sequence of strata in the respective areas is given below:

Area A, along the river Wensum

	Stratum	Average thickness
Sub-Area (i)	Fill	10 ft.
	Peat	6 ft.
	Gravel	8 ft.
	Medium Chalk	- at least 100 ft.

Sub-Area (ii)

As sub-area A (i), but the chalk is very soft to a considerable depth.

Area B

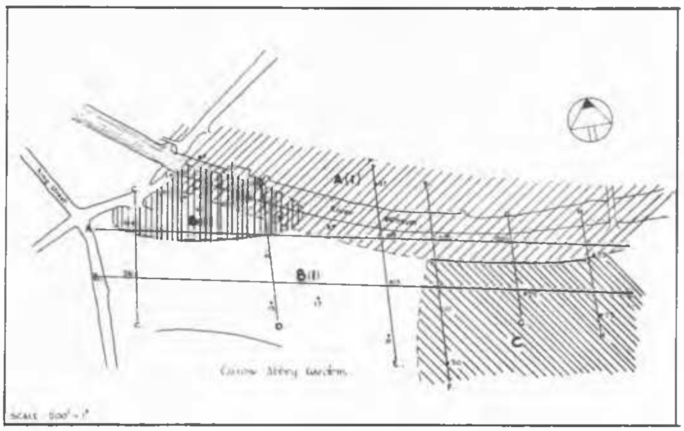
Sub-Area B (i)	Fill	av. 6 ft.
	Thin layer of gravel in some places.	
	Medium chalk	- at least 100 ft.

Sub-Area B (ii)

As sub-area B (i) but the chalk is very soft to a considerable depth.

Area C	Fill	av. 6 ft.
	Gravel	20 + ft. to 50 + ft.

Presumably medium chalk below gravel, but not confirmed by boreholes.



Foundation conditions at Carrow works, Norwich

FIG.1

The chalk varied in colour from pure white to orange yellow and was lumpy, the interstices between the lumps being completely filled with a smooth, plastic, chalk paste. The size of the "lumps" varied from quite large pieces down to grains of the size of coarse sand.

In this area the chalk is overlain by a deposit which varies considerably, containing beds of sand, laminated clays and pebbly gravels. This deposit is known locally as Norwich crag. Its full extent is about 40 miles in a north-south direction and 20 miles east-west.