have commenced investigations for the use of electro-chemical hardening for a cutting).

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# VIII f 3 THE INFLUENCE OF LIGHT SURFACENGS ON THE TRAFFIC CARRYING CAPACITY OF SOIL

H.W.W. POLLITT


## SUMMARY

A recent development in civil engineering has been the use of light metal tracks (L.M.Y.) and Prefabricated Bitumenised Surfacing (P.B.S.) as means of increasing or preserving the ability of soil to carry traffic. This paper gives a brief account of studies of some of the problems associated with the use of these light surfacings. Laboratory work included small-scale loading tests on model tracks, full-sclae tests on experimental and production tracks and accessories, and mathematical studies.

Among the conclusions reached were the following:-

1) On the sand and sandy-clay used in the tests, the efficiency of a light metal track surfacing of a given weight per square foot was increased by decreasing the size and spacing of the wires of which it was composed.
2) The influence of light metal track on the bearing capacity was much greater for granular than for non-frictional soils. An extension of Prandtl's analysis of the bearing capacity of a strip-loaded plastic medium suggests that this influence is a function of the angle of internal friction of the soil.
3) Under the climatic and test conditions obtaining, no upward migration of soil moisture took place in the subgrade beneath Prefabricated Bitumenised Surfacing. All cases of subgrade softening occurred directly beneath porous areas of P.B.S.


## INTRODUCTION.

In connexion with the recent development of light metal tracks and prefabricated bitumenised surfacings as means of increasing or preserving the traffic-carrying capacity of soils, studies have been made at the Road Research Laboratory of the problems associated with the use of these light surfacings. The work included full-scale and small-scale tests and mathematical analyses.

## FULL-SCALE LABORATORY TESTS.

In order to compare the performances of different experimental and production surfacings full-scale traffic tests were necessary. For this purpose a portion of the grounds of the Road Research Laboratory was converted to a test area (Fig. 1). The soil was ploughed, harrowed and then sprayed by an oscillating spray-pipe to bring it to a uniform consistency. The test sections were then laid and were trafficked by a four-wheel lorry loaded to a gross weight of c. 6.6 tons with a maximum wheel load of c. 2.6 tons, and running 20 times over the same wheeltracks. The performance of a section was measured by the average rut-depth after a number of passes of the lorry.

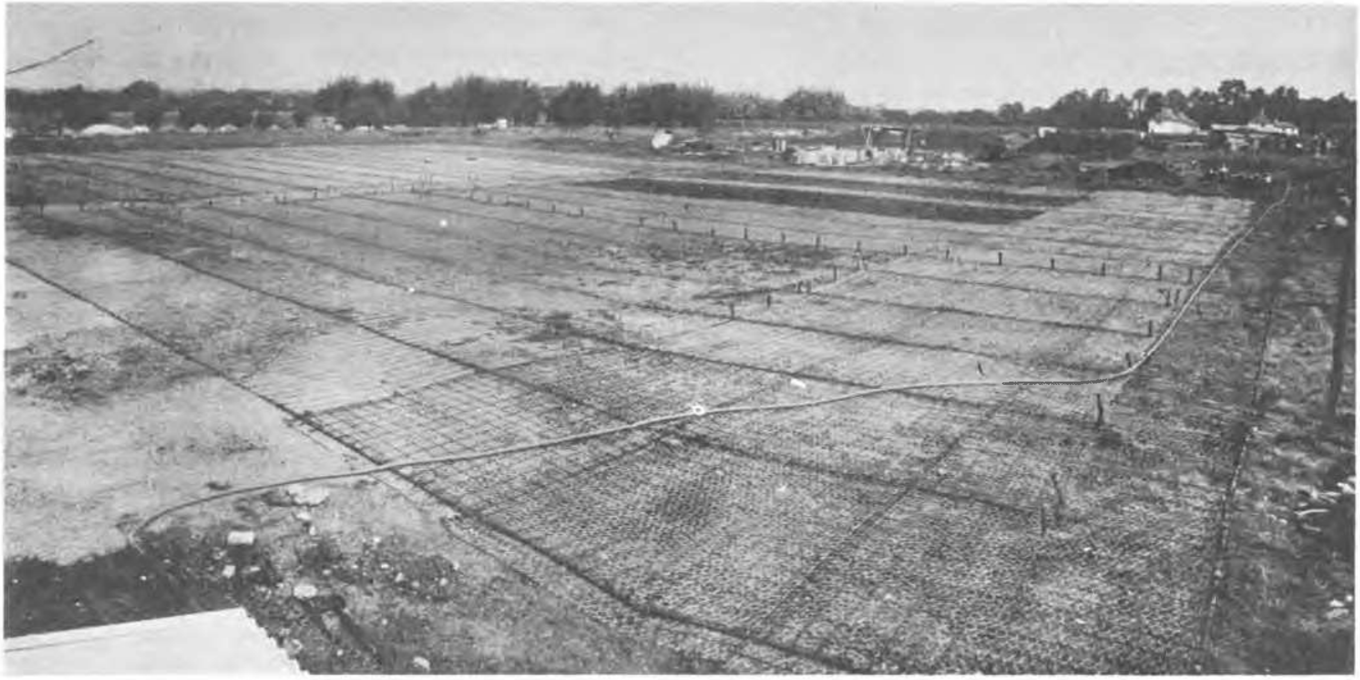
In the first series of tests a number of rather similar designs of L.M.T. were tested and it was generally found that heavier tracks were more effective than lighter tracks (Table 1 and Fig. 2). It became clear that this testing technique could not be expected to differentiate between types of L.M.T. unless the differences between their properties were sufficiently marked. In the course of these tests it was also observed that the depth of rut formed was approximately related to the logarithm of the number of passes of the lorry.

Another series of tests was devoted to the effect of varying the distribution of steel in L.M.T. as between longitudinal bars, transverse bars, and in some cases, steel-sheet underlay. This series was closely related to the more comprehensive small-scale tests described later. The experimental sections were of square-mesh; and had the same total weight, 1.8 lb./sq.ft., but different arrangements of longitudinal and transverse bars and different underlays. The soil conditions are given in Table 2, details of the test sections are given in Table 3 and the results are given in Table 4.

It was concluded that

(I) more steel should be places transversely than longitudinally.
(II) small diameter bars closely spaced are more effective than large diameter bars widely spaced.
(III) there is a limit to the proportion of steel that should be used as an underlay.

Further observation of the increase of rut depth with number of passes of the lorry confirmed the generally logarithmic nature of the relationship between them. (Fig. 3.).



General layout of test site for full-scale steel-distribution tests on square-mesh surfacings

FIG. 1

TABLE 1

Measurements of Ruts caused by Loaded Lorry in First Series of Full-scale Tests

| Type of track | | Soil | | After 1 passage | | | | After 10 passages | | | | After 20 passages | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Section | Approximate effective weight. (lb./sq.ft.) | Moisture content (%) (average of 6) | Density (lb./cu.ft.) (average of 2) | Rut depth (in.) (average of 5) | Order | Relative curvature x) (in.) | Order of merit | Rut depth (in.) (average of 5) | Order of merit | Relative curvature x) (in.) | Order of merit | Rut depth (in.) (average of 5) | Order of merit | Relative curvature x) (in.) | Order of merit |
| A xa) | 1.4 | 21.7 | 87.5 | 2.9 | 6 | 0.55 | 3 | 5.4 | 6 | 1.30 | 5 | 6.9 | 7 | 1.02 | 4 |
| B | 1.7 xa) | 20.5 | 87.5 | 2.1 | 2 | 0.37 | 1 | 3.6 | 2 | 1.05 | 3 | 4.3 | 2 | 0.63 | 2 |
| C | 1.7 xa) | 22.6 | 88.5 | 2.0 | 1 | 0.42 | 2 | 3.2 | 1 | 0.47 | 1 | 3.8 | 1 | 0.62 | 1 |
| D | 1.0 | 24.2 | 87.5 | 3.2 | 7 | 0.92 | 6 | 4.7 | 7 | 1.45 | 7 | 5.7 | 6 | 1.45 | 6 |
| E | 0.6 | 22.5 | 91.0 | 2.4 | 4 | 0.72 | 5 | 4.2 | 4 | 1.05 | 3 | 4.8 | 4 | 1.10 | 5 |
| F | 0.7 | 23.2 | 93.0 | 2.6 | 5 | 1.00 | 7 | 4.3 | 5 | 1.32 | 6 | 5.3 | 5 | 1.58 | 7 |
| G | 1.4 | 24.2 | 88.5 | 2.1 | 2 | 0.65 | 4 | 3.9 | 3 | 0.70 | 2 | 4.2 | 3 | 0.75 | 3 |

x) Curvature is measured as the mean difference in depth of rut between the depths at the centre and those taken at points 4 in. each side of the centre.

xa) For description of type of track see Fig. 2.

SMALL-SCALE LABORATORY TESTS.

To study the factors influencing the performance of light metal track surfacings, loading tests were made with the apparatus shown in Fig. 4.

The first series of tests was conducted with a rubber sheet (representing a flexible bituminous surfacing), a steel sheet (representing a heavy elastic surfacing), and a sheet of wire-netting (representing a light metal surfacing). Each surfacing was tested in turn on a dry sand, on a plastic soil and on a liquid soil. The latter two were Harmondsworth brickearth at the Liquidity Indices of 0 and 185% respectively. The load-deflection relations for the various soil-surfacing systems were obtained and these are shown in Fig. 5.

As indicated by an extension of Prandtl's analysis of the bearing capacity of a strip-loaded plastic medium it was found that the influence of the surfacings was much greater on granular than on plastic or liquid soils.

An interesting result was that on plastic soil the wire-netting was more effective in proportion to its weight than the steel sheet. This was thought to be due to the "keying" action of the netting, inducing surface shear stresses in the soil.

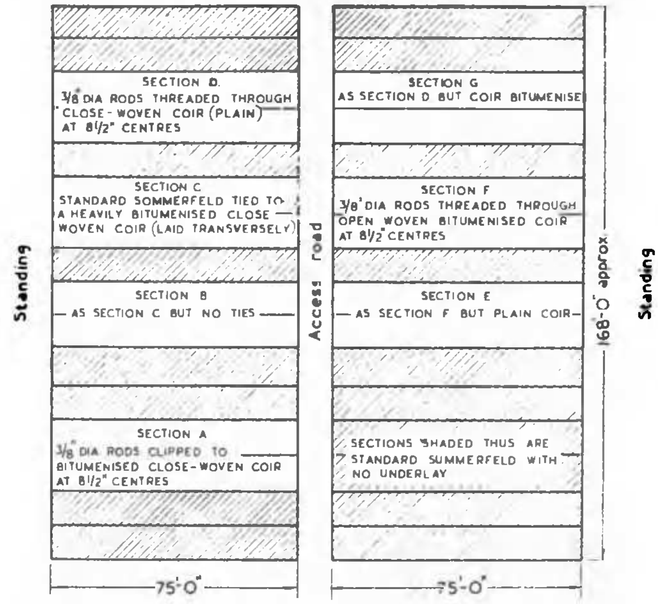
A more comprehensive series of tests was made to determine the effect of different wire diameters and spacings of square-mesh track while maintaining constant weight per square foot. By suitably arranging these dimensions

### TABLE 2

**Characteristics of Harmondsworth Brickearth in Full-scale Steel Distribution Tests.**

| | |
|---|---|
| Liquid Limit | 28% |
| Plastic Limit | 18% |
| Plasticity Index | 10% |
| **Mechanical Analysis:** | |
| 2 mm. - 0.2 mm. | 10% |
| 0.2 mm. - 0.02 mm. | 56% |
| 0.02 mm. - 0.002 mm. | 14% |
| < 0.002 mm | 20% |

For details of moisture content and density during the tests, see Table 4.




General arrangement of test sections in first series of full-scale tests (c.f. Fig. 1.)

**FIG. 2**

### TABLE 3

**Details of Materials Tested in Full-scale Steel Distribution Tests**

**Total Weight of all Materials, 1.76 lb./sq.ft.**

| Group No. | Section No. | Dimensions of section | Longitudinal bars | | Transverse bars | | Thickness of steel sheet |
|---|---|---|---|---|---|---|---|
| | | | Diameter | Centres (in.) | Diameter | Centres (in.) | (B.G.) xa) |
| 1 | 1 | 37'6" x 21'0" | $\frac{3}{8}$ in. | 9.0 | $\frac{3}{8}$ in. | 9.0 | (Hessian underlay) |
| | 2 | do. | 2 SWG. x) | 8.1 | 5/0 SWG. | 8.5 | do. |
| | 3 | do. | 7 SWG. | 9.9 | 7/0 SWG. | 8.9 | do. |
| | 5 | do. | 1 SWG. | 5.8 | 1 SWG. | 5.8 | do. |
| | 6 | do. | 3 SWG. | 6.8 | 3/0 SWG. | 6.3 | do. |
| | 7 | do. | 9 SWG. | 6.7 | 4/0 SWG. | 5.7 | do. |
| | 9 | do. | 5 SWG. | 2.9 | 5 SWG. | 2.9 | do. |
| | 10 | do. | 7 SWG. | 3.3 | 3 SWG. | 2.9 | do. |
| | 11 | do. | 10 SWG. | 5.2 | 1 SWG. | 3.2 | do. |
| 2 | 4 | do. | Usual | 12 SWG. | 6/0 SWG. | 8.8 | do. |
| | 8 | do. | chicken | at 3'6" | $\frac{3}{8}$ in. | 5.8 | do. |
| | 12 | do. | netting | mesh | 2 SWG. | 3.1 | do. |
| 3 | 13 | 6'0" x 9'7½" | - | - | - | - | 20 |
| | 14 | do. | 1 SWG. | 15 | 1 SWG. | 10.0 | 22 |
| | 15 | do. | 6/0 SWG. | 18 | 6/0 SWG. | 12.0 | 26 |
| | 16 | do. | 4/0 SWG. | 17 | 4/0 SWG. | 11.5 | 24 |
| | 17 | do. | - | - | 4/0 SWG. | 10.75 | 22 |
| | 18 | do. | 5 SWG. | 15 | 3/0 SWG. | 11.5 | 22 |
| | 19 | do. | - | - | 6/0 SWG. | 9.25 | 24 |
| | 20 | do. | 2 SWG. | 16 | 6/0 SWG. | 11.5 | 24 |
| | 21 | do. | - | - | 6/0 SWG. | 7.25 | 26 |
| | 22 | do. | 1 SWG. | 15 | 6/0 SWG. | 9.0 | 26 |

x) SWG. = Standard Wire Gauge

xa) B.G. = Birmingham Gauge.

TABLE 4

Results of Full-scale Steel Distribution Tests

(a) Groups 1 and 2 (Hessian underlay)

| Spacing of Wires (in) | | Proportion of Transverse Steel (%) | | | |
|---|---|---|---|---|---|
| | | 50 | 70 | 90 | 80 |
| 9 | S | 1 | 2 | 3 | 4 |
| | M | 20 | 19 | 20 | 20 |
| | D | 105 | 94 | 99 | 94 |
| | R | 2.3 | 2.7 | 2.4 | 2.6 |
| 6 | S | 5 | 6 | 7 | 8 |
| | M | 20 | 20 | 18 | 18 |
| | D | 96 | 99 | 93 | 98 |
| | R | 1.4 | 2.1 | 0.8 | 1.5 |
| 3 | S | 9 | 10 | 11 | 12 |
| | M | 20 | 19 | 19 | 18 |
| | D | 95 | 101 | 101 | 101 |
| | R | 1.2 | 1.7 | 0,4 | 1.1 |

(b) Group 3 (Steel Sheet Underlay)

| | | | | | |
|---|---|---|---|---|---|
| S | 13 | 14 | 15 | 16 | 17 |
| M | 22 | 24 | 22 | 24 | 22 |
| D | 86 | 89 | 86 | 89 | 86 |
| T | - | 16 | 33 | 25 | 27 |
| U | 100 | 73 | 46 | 57 | 73 |
| R | 0.9 | 2.4 | 1.0 | 2.5 | 0.9 |
| S | 18 | 19 | 20 | 21 | 22 |
| M | 24 | 22 | 24 | 22 | 24 |
| D | 89 | 86 | 89 | 86 | 89 |
| T | 23 | 43 | 34 | 54 | 44 |
| U | 73 | 57 | 57 | 46 | 46 |
| R | 2.0 | 1.0 | 1.5 | 1.1 | 1.4 |

S = Section Number (of. Table 3)
M = Moisture content of soil (%)
D = Dry density of soil (lb./cu.ft.)
T = Proportion of Transverse Steel (%)
U = Proportion of Underlay Steel (%)
R = Rut Depth (in.)

it was possible to obtain meshes of different weights and tensile strengths but of the same flexural rigidity, and vice-versa. These meshes were tested on a dry sand and, incompletely, on a sandy clay. Details of these soils are given in Table 5.

The results are shown in Fig. 6. and indicate that, on sand, the contact area between track and soil is the predominating factor, i.e., that small wires, closely spaced are more effective than large wires, widely spaced. It was verified that, on sand, for a given weight of track, the best results were obtained with a steel sheet.

These conclusions are the same as those reached in the full-scale tests already referred to.

TABLE 5

Soil Conditions for Small-scale Steel Distribution Tests

DRY SAND

Grading on B.S. Sieves

| | | |
|---|---|---|
| | ret. 7 | 0.2% |
| Pass 7 - | " 14 | 4.0% |
| " 14 - | " 25 | 16.8% |
| " 25 - | " 52 | 60.1% |
| " 52 - | " 100 | 17.2% |
| " 100 - | " 200 | 1.5% |
| " 200 | | 0.2 |
| | | 100.0% |

Dry density during test 111 lb./cu.ft.

CULHAM SANDY CLAY

Mechanical Analysis

| | | |
|---|---|---|
| | > 2.0 mm. | 1% |
| 2.0 mm. | - 0.2 mm. | 23% |
| 0.2 mm. | - 0.02 mm. | 27% |
| 0.02 mm. | - 0.002 mm. | 11% |
| | < 0.002 mm. | 38% |

| | |
|---|---|
| Liquid Limit | 51% |
| Plastic Limit | 23% |
| Plasticity Index | 28% |
| Moisture Content during test | 36% |
| Dry soil density during test | 113 lb./cu.ft. |

Unfortunately it was not possible to repeat these tests on a heavy clay soil in view of more pressing work.

MATHEMATICAL STUDIES.

In connection with the practice of tensioning certain types of L.M.T., an analysis was made of the problem of an elastic, tensioned surfacing, resting on a "Westergaard" medium and subjected to strip loading. This analysis suggested that tensioning the surfacing had little effect on bearing capacity except where very flexible track was laid on very soft soil.

An estimate of the effectiveness of surfacing was made by calculating the proportion of the total load removed by the surfacing from the soil directly beneath the loaded area. This proportion, termed the "Fractional Relief", is shown in Table 6. for various tracks, soils and loads.

Assuming that tensioning is to be applied, however, another problem is that of the most suitable form of picket to hold the track down.

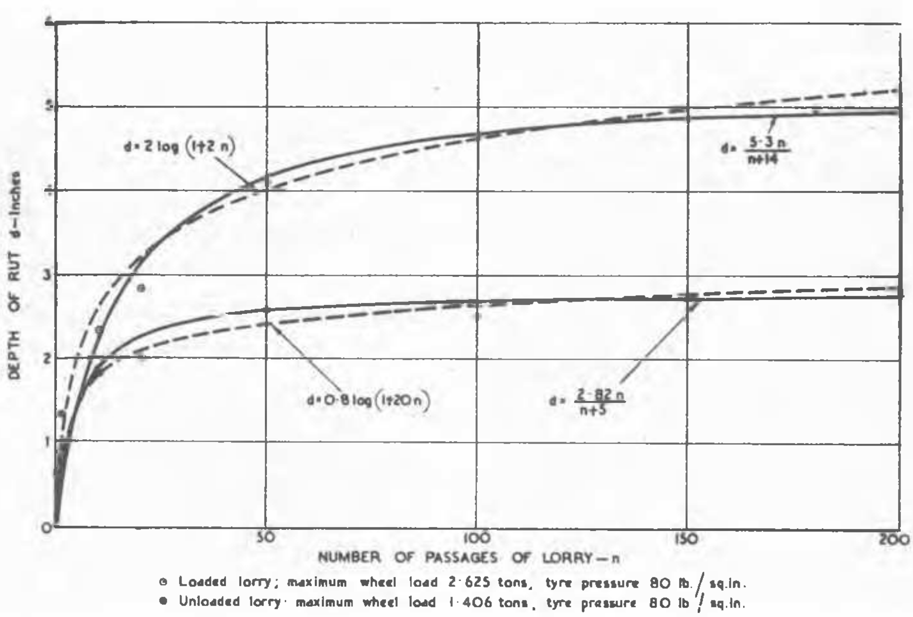
An analysis was made of the load-deflection relationships of elastic pickets embedded in a "Westergaard" medium. This led to a suggested improved design of pickets and it was concluded that two lengths of picket would be sufficient to cover a wide range of soil conditions. It was also concluded that a number

**TABLE 6**

**Fractional Reliefs for Various Track, Soil and Load Conditions.**

| Flexural Rigidity of Light Metal Track; (lb./sq.in/in. width) | Tension Applied to Light Metal Track; | Fractional Relief xa)<br>Width of Strip Load = 5.18 in.<br>Pressure = 68.1 lb./sq.in. | | | Width of Strip Loading 19.0 in<br>Pressure = 46.2 lb./sq.in. | | |
|---|---|---|---|---|---|---|---|
| | | λ = 50 x) | λ = 200 | λ = 500 | λ = 50 | λ = 200 | λ = 500 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100 | 0 | 0.17 | 0.11 | 0.09 | 0.04 | 0.03 | 0.02 |
| | 200 | 0.37 | 0.21 | 0.14 | 0.11 | 0.06 | 0.04 |
| 1,000 | 0 | 0.34 | 0.23 | 0.17 | 0.08 | 0.06 | 0.05 |
| 3,700 | 0 | 0.47 | 0.34 | 0.29 | 0.11 | 0.08 | 0.06 |
| | 200 | 0.52 | 0.37 | 0.30 | 0.14 | 0.09 | 0.06 |
| 10,000 | 0 | 0.57 | 0.43 | 0.34 | 0.14 | 0.10 | 0.08 |
| 100,000 | 0 | 0,74 | 0.64 | 0.57 | 0.29 | 0.19 | 0.14 |
| 300,000 | 0 | 0.80 | 0.72 | 0.66 | 0.39 | 0.27 | 0.20 |
| | 400 | 0.80 | 0.72 | 0.66 | 0.39 | 0.27 | 0.20 |

x) λ is Westergaard's Modulus of subgrade Reaction (lb./sq.in/in.)
xa) The Fractional Relief is the proportion of the total load removed by the track from the soil directly beneath the loaded area.




Variation of depth of rut with number of passages of lorry using summerfeld track on Harmondsworth brickearth.

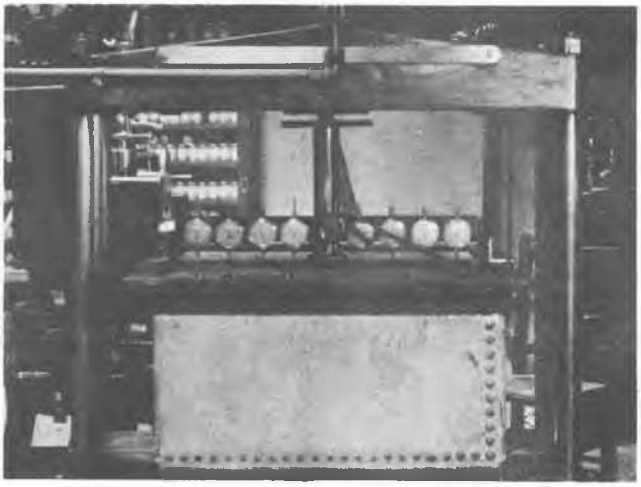
**FIG. 3**

of small pickets would be more effective than one large picket of equal total volume and geometrically similar shape.

PREFABRICATED BITUMENISED SURFACING.(P.B.S.).

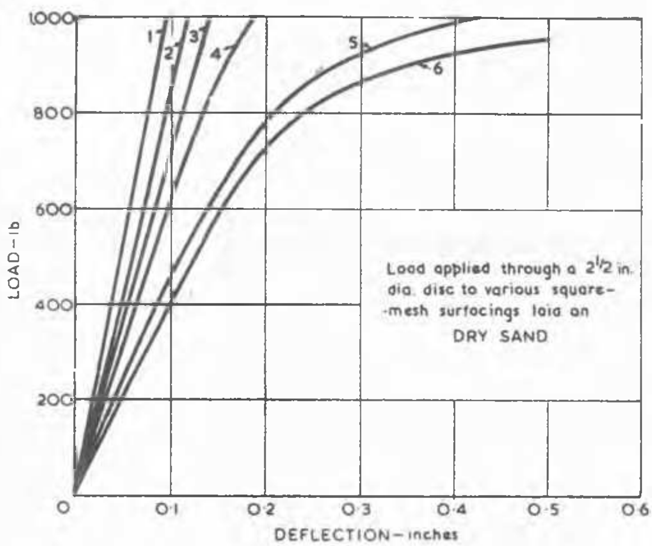
It was realised that the usefulness of L.M.T. was dependent on soil conditions and that unless these could be prevented from deteriorating in bad weather it would become unserviceable. A prefabricated bitumenised surfacing (P.B.S.), similar to a roofing felt, was therefore developed to protect the ground from rain, and this was found to obviate the need for L.M.T. except for special purposes.

The main problem that then arose was to determine whether the ground under the P.B.S. was likely to soften considerably due either to downward percolation through the P.B.S. or to upward migration of soil moisture. Samples of P.B.S. were taken from affected areas on two airfields and tested for porosity by measuring the rate of flow of water through them and tested for porosity by measuring the rate of flow of water through them and by making photographic contact prints by interposing the samples between a light source and a light-sensitive surface. It was found that softening of the soil occurred only under porous areas of P.B.S. and that no significant upward



Apparatus for small-scale tests on various surfacings.

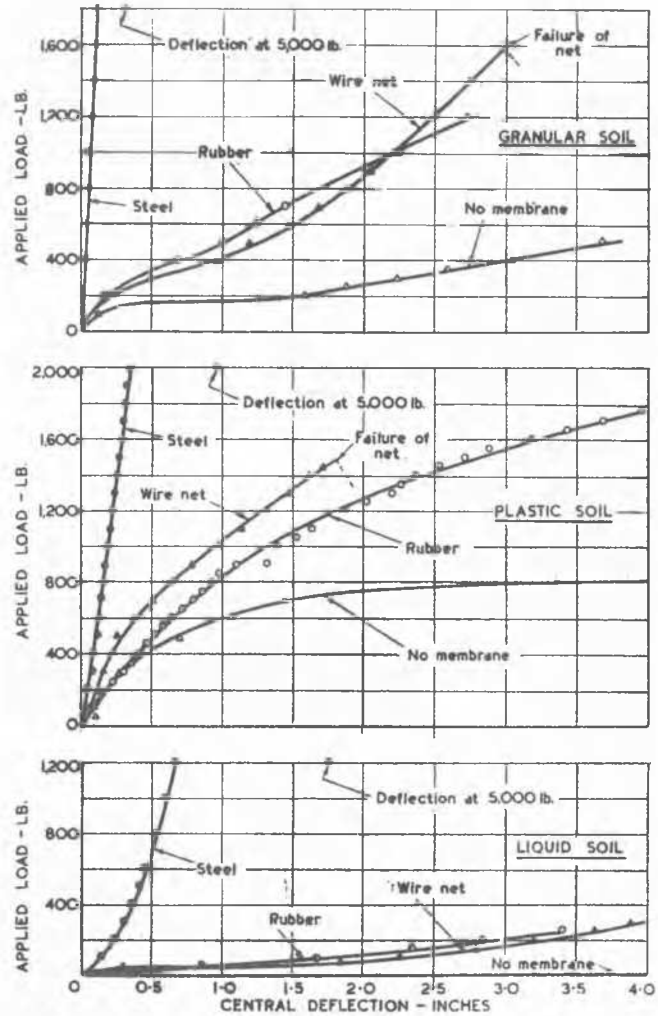
FIG. 4




| DETAILS OF SQUARE-MESH SURFACINGS TESTED | | | | | | |
|---|---|---|---|---|---|---|
| No. | Weight lb/sq.ft. | Wire dia. in. | Wire Spacing in. | Tensile Yield Strength ton/in²/in.width | Flexural Rigidity ton/in/in.width | % Area in Contact |
| 1 | 2 | 0·064 | 0·13 | 0·446 | 0·086 | 74·3 |
| 2 | 2 | 0·092 | 0·27 | 0·443 | 0·176 | 56·6 |
| 3 | 2 | 0·116 | 0·43 | 0·442 | 0·279 | 46·7 |
| 4 | 1 | 0·092 | 0·54 | 0·222 | 0·088 | 31·3 |
| 5 | 1 | 0·128 | 1·05 | 0·221 | 0·170 | 22·9 |
| 6 | 1 | 0·160 | 1·64 | 0·221 | 0·265 | 18·7 |

Load deflection curves for various soil-membrane systems. Small-scale loading tests.

FIG. 6




Small-scale steel-distribution tests on dry sand

FIG. 5

movement of soil moisture took place.

To study further the possibility of the upward migration of soil moisture under P.B.S., an experimental surfacing was laid on Harmondsworth brickearth in the Laboratory grounds. No significant change in moisture content distribution was recorded after 2 years.

It must be emphasised that this result must have depended on the climatic conditions obtaining at Harmondsworth during the tests and it is possible that upward migration of soil moisture may occur beneath an impervious surfacing under certain conditions.

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