load it, the soil will rise elastically. After a repeated loading by the same pressure, the soil settles elastically and behaves like an elastic material. When building embankments and consolidating the subgrade under the pavements, we consolidate then to the so called equilibrium unit weight according to the maxim pressure, which is likely to act at that place, in order that the soil should behave like an elastic matter. The equilibrium unit weight can be determined in the oedometer, where we load the soil sample by the pressure p, let it consolidate and then unload again. The unit weight of the unloaded soil sample is called the equilibrium unit dry weight for the pressure p. We then apply various pressures p to the soil and as for each loading and unloading in the oedometer the volume V of the soil and its total weight Q are known, the equilibrium unit weight G_o can be calculated for each pressure p.

The control of the compacting is carried out by determining the unit dry weight of the compacted soil G and by comparing it with the equilibrium unit weight G_o. Should G be smaller than G_o, the soil is not compacted satisfactorily and tamping must be continued, otherwise the soil would settle by an amount

$$\Delta h = h \frac{G_o - G}{G_o} \;;$$

h being the height of the not completely compacted soil-stratum. We determine the max. pressure p in the embankment or subgrade in order to find the corresponding equilibrium unit weight G_o.

To compact the soil to its equilibrium unit weight, the tamping roller must exert pressure bigger by c = 3-5 kg/cm^2 than the max. pressure p_{max}., which will act in the compacted stratum. The necessary weight of the roller per 1 m length is

$$Q = F\,(p_{max} + c),$$

where F is the area of contact of the roller,
c = 3-5 kg/cm^2,
p = max. pressure, which will act in the compacted stratum.

To compact the soil to its equilibrium unit weight, it must have a certain humidity given by the equation:

$w = 0{,}85\; n_o S_v / G_o$, where
n_o = the porosity of the soil compacted to the equilibrium unit weight G_o,
S_v = the specific gravity of water,
G_o = the equilibrium unit weight.

The required equilibrium unit weight can be achieved, if a roller of the necessary weight is used. The number of roller runs and the height of the layers can be determined experimentally by making 1,2,3 ...n runs and after each run taking a sample from the lower portion of the compacted layer and by finding its unit dry weight, which increases with the number of runs. Then we plot the relationship between the number of roller runs and the unit weight achieved. From this graph we can determine the number of roller runs necessary to get the required unit dry weight.

The soil compacted by tamping to its equilibrium unit weight behaves like an elastic material and settles only elastically under the influence of a load.

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VIII f 2

THE PRESENT SCOPE AND POSSIBLE FUTURE DEVELOPMENT OF SOIL MECHANICS IN BRITISH RAILWAY CIVIL ENGINEERING CONSTRUCTION AND MAINTENANCE.

A.H. TOMS, B.Sc., A.M.I.C.E.,
Southern Rly. Company

PRECIS

This paper deals with the application of Soil Mechanics technique by British Railways, to problems of settlement and bank, cutting, and formation instability, in which boring, sampling and laboratory tests are combined with full scale trials of experimental remedial methods.

Details are given of bank and cutting slips, some involving wall failures, and stabilisation by drainage, toe walls, sheet piling, toe loading, trimming, and cement grouting.

Reference is made to fundamental research on track instability on clay formations, and methods of treatment by blanketing, load distribution by concrete slabs, waterproofing, and also cement grouting.

Projected work is mentioned.

INTRODUCTION.

Earthworks problems have had to be dealt with by railway engineers ever since railways came into being, but it was not until about ten years ago that Soil Mechanics sampling and testing technique began to be applied seriously on British Railways. The following is a brief description of present British Railway practice.

SITE EXPLORATION.

Extensive use is made of trial holes for shallow explorations, but for depths to 30 feet, post hole hand augers are commonly used, hand operated percussion boring rigs of diameters from 4" to 6" being adopted in more difficult sites and for depths up to about 60ft.maximum. For greater depths and extensive investigations, specialist firms are often employed for the boring.

Penetration resistance type site investigation methods are used in suitable cases such as the determination of the depth of ash pockets in embankments.

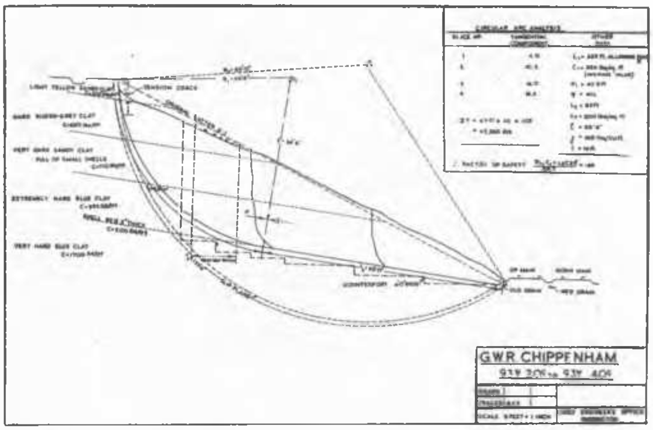


FIG. 1

FIG. 2

The position of the slip surface in a bank or cutting on the move is conveniently located by driving down into the bank a mandrel rod surrounded by a continuous run of short lengths of close fitting tubes which are slightly cone ended. The mandrel is then withdrawn. Any slipping will result in a break in vertical alignment of the tubes, the depth of which can be ascertained by probing with the mandrel or a light rod. An experimental apparatus of this type has been made by the Southern Railway Company, which incorporates a pyramidal point welded to the first length of tube. The mandrel rod fits into a square sinking in the point whereby the point can be turned independently on the tubes and an indication of the type of ground passed through can be obtained by the "feel".

Undisturbed samples of cohesive soil are obtained from trial holes by cutting out, or the use of coring tools, while cores of 4", 1½" or 1" diameter are obtained from the borings with normal type samplers. Disturbed samples from augers are kept in hermetically sealed jars and are used for moisture and classification tests.

Where possible, simple compressive strength tests are carried out in the field, whereas the 4" diameter cores are sealed for laboratory tests.

STAFF AND TESTING FACILITIES.

All the Railway Companies have one or more Assistants trained in Soil Mechanics and most possess a small amount of equipment for simple compression and classification tests.

The importance of the new science is fully appreciated and there would have been more development if war had not intervened.

The following is a resume of the principal fields in which soil mechanics has been used by the Railway Companies.

CONSOLIDATION AND SETTLEMENT.

Consolidation and settlement investigations have been made use of and records are kept of the movements of bridges and structures. The Railway Companies do not, however, possess their own consolidation test apparatus, but Building Research Station facilities have been used for such work. Space limitations preclude inclusion of details.

CUTTING SLIPS.

With relatively few exceptions, the cuttings which give most trouble are in clay.

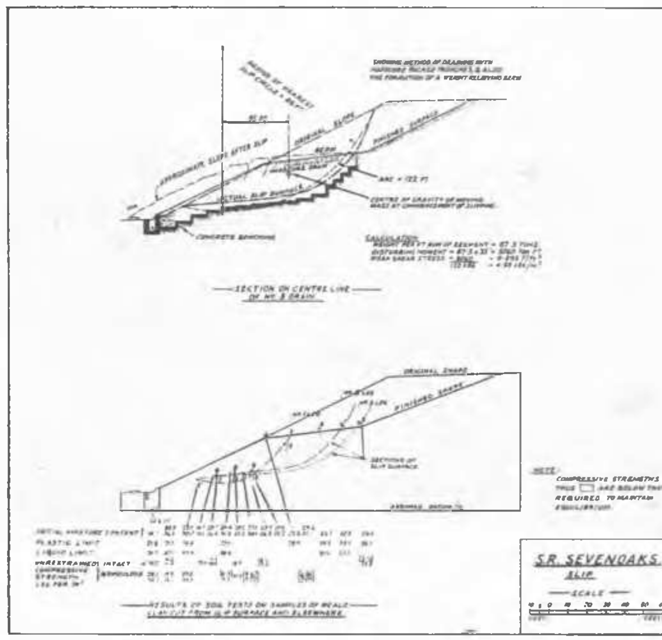


FIG. 3

Clays which have been well consolidated during their geological history have a high strength when newly exposed and there are many cuttings which were excavated to side slopes of 1 in 2 and steeper. Some have remained stable for many years, gradually absorbing water and weakening by opening up along fissures, which appear to exist in all the stiff clays. Then, as a result of some abnormal weather, slips have occurred.

Fig. 1. is an example from the Great Western Company's practice of investigation and treatment of a large slip in a 50-ft. deep clay cutting at Chippenham. Measured soil strength confirmed the general weakness of the slope and deep 4-ft. wide rubble counterforts at 25-ft. centres were decided upon to drain and strengthen the cutting. It is assumend that the strengthening effect of the counterforts will mean that any further slip would have to go deeper, where the theoretical factor of safety is higher, due to increase of clay strength with depth.

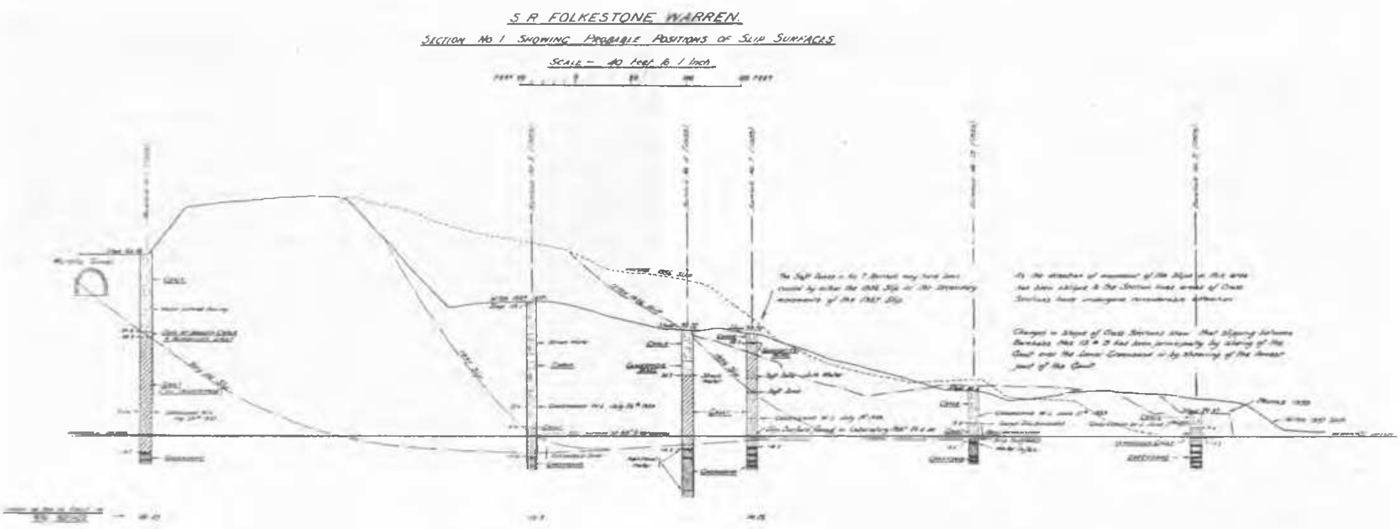


FIG. 5

FIG. 4

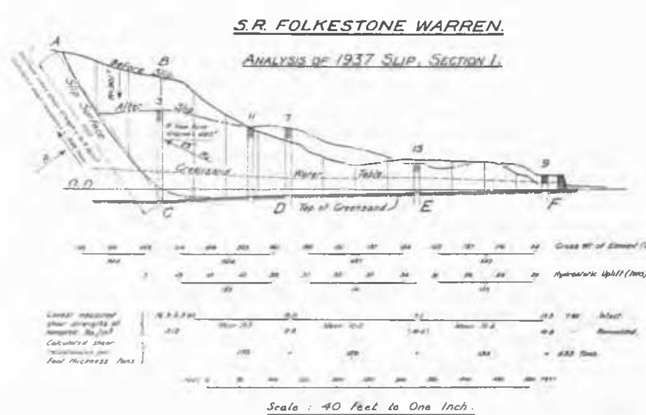


FIG. 6

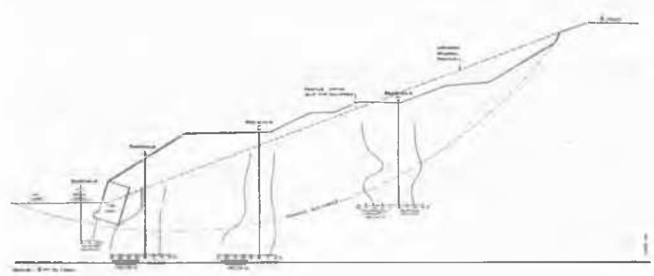


FIG. 7

Photo Fig. 2. shows a big slip which took place in 1939 in Weald clay cutting at Sevenoaks, Kent, and Fig. 3. indicates the slip surface as found during excavation for the drainage trenches, which were benched in concrete and backfilled with tightly packed brick rubble. The results of tests on the clay from the slip zone and other points are shown, together with a calculation based on the nearest arc, from which it will be seen that the measured shear strengths (taken as half the unconfined compressive strengths) were in many cases less than the calculated shear stress along the arc.
The slope was re-shaped with a "berm" to reduce the weight on the back of the slip.

The extremely large coastal landslides in the Gault clay in the "Warren", east of Folkestone, Kent, are of major concern to the Southern Railway, since for over two miles it passes over ground which at various times in the past has slipped bodily, or in part, towards the sea; See Photo Fig. 4.

Fig. 5. indicates deep boreholes sunk in 1938 and 1939 to study the slips which took place at the Folkestone end. Large numbers of samples of the Gault clay were tested, and Fig. 6. shows a rough correlation between a stability analysis and the resistance to movement based on shear strengths obtained. The natural moisture contents, liquid limits and plastic limits of the Gault have wide ranges here.

A 25° angle of friction was assumed between the driving wedge at the back of the slip and the mass it is pushing forward. The stratigraphical and strength results obtained related well to the known surface disturbances in 1936 and 1937.

A large slip in a cutting in blue Lias clay between Northampton and Rugby (L.M.S.) is illustrated by Fig. 7.

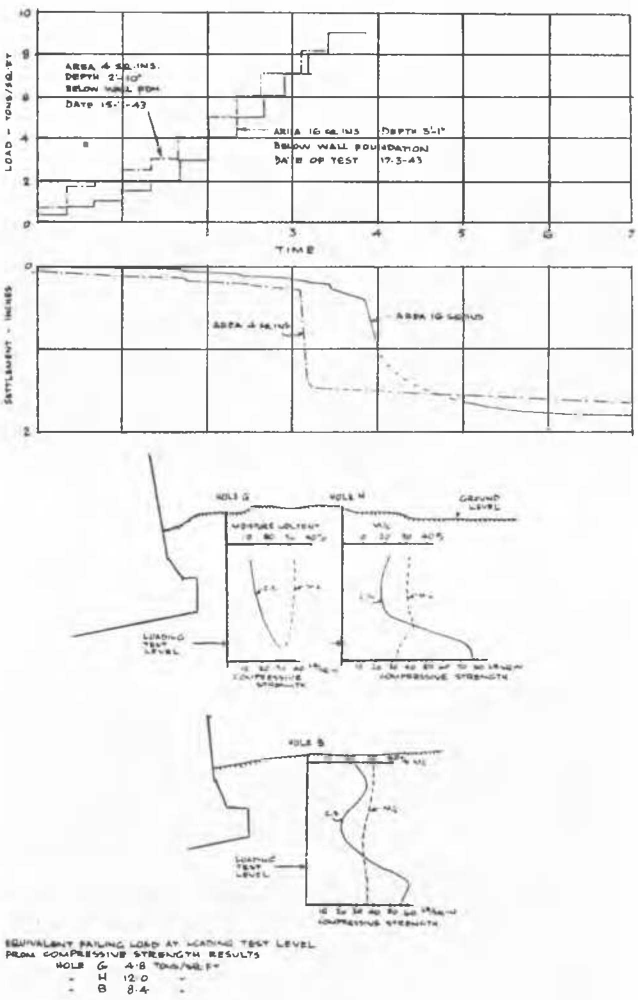


FIG. 8

The slip, 180-ft. long, involved a wall which was pushed forward 3-feet with corresponding 6-inch upward and lateral movements of the Down line only. Test results are shown, the average clay density being 125-lbs.per ft^3 and the liquid limit about 35%.

The thoretical worst slip circle is close to the soft zones and therefore it was decided to flatten the slope and construct drainage counterforts. No sheet piling has been driven.

An interesting wall failure on the L.M.S. at Mill Lane, West Hampstead, London, (which was investigated by the L.M.S.Company and the Building Research Station) is shown in Figs. 8 , 9 , 10 , 11 and 12 . This wall, built in 1902, of height from 28-ft, to 45-ft, had a 1 in 6 front batter. It is founded in blue London clay and supported some 20-ft. of brown clay above 18-ft. of blue. Failure occurred in 1943 with forward movement of 3-feet, the siding in front being lifted 2'6".

Clay was immediately excavated from behind the wall to a depth of 12-ft. and borings sunk.

Gypsum, silt seams, and fissures were prominent in the upper clay. The solid clay proved stronger than the 5.5-lbs/in^2 calculated for stability and fissuration must, therefore, have lowered the effective strength below that of small test specimens. Heavy rains just prior to failure may have caused hydrostatic pressure.

Stability was restored by sheet piling the toe.

Photos Figs. 13 and 14 and Fig. 15 show a slip in the cutting in mottled clay of Woolwich and Reading beds at Arundel, Sussex. After a period of stability, the wall commenced to move forward slowly. In the winter of 1946-7 the movement developed rapidly and a slip of the cutting became evident with heaving and pushing out of line of the adjacent track. Reference points were immediately established and 150-tons of rails were deposited on the track to resist the heave and to act as a mass against which to strut the wall; and this stopped movement.

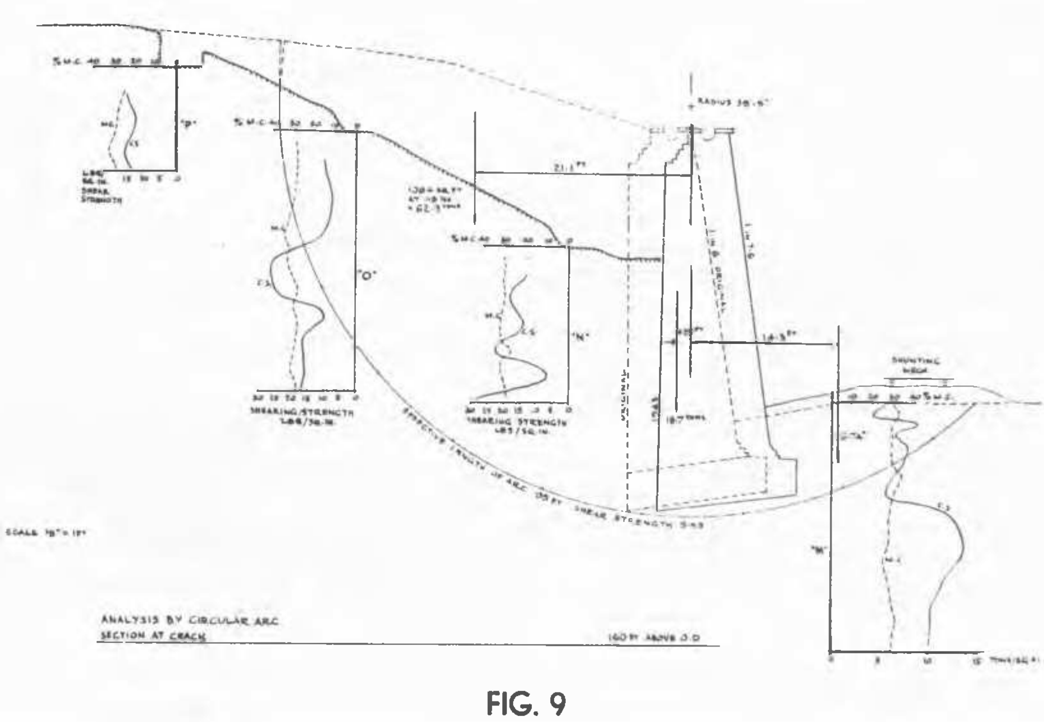


FIG. 9

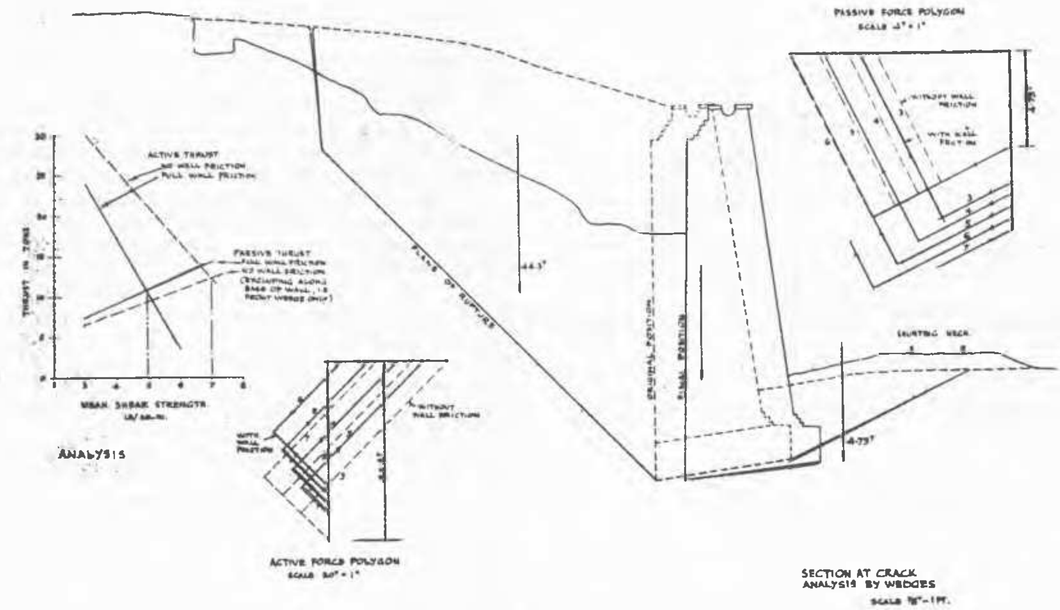
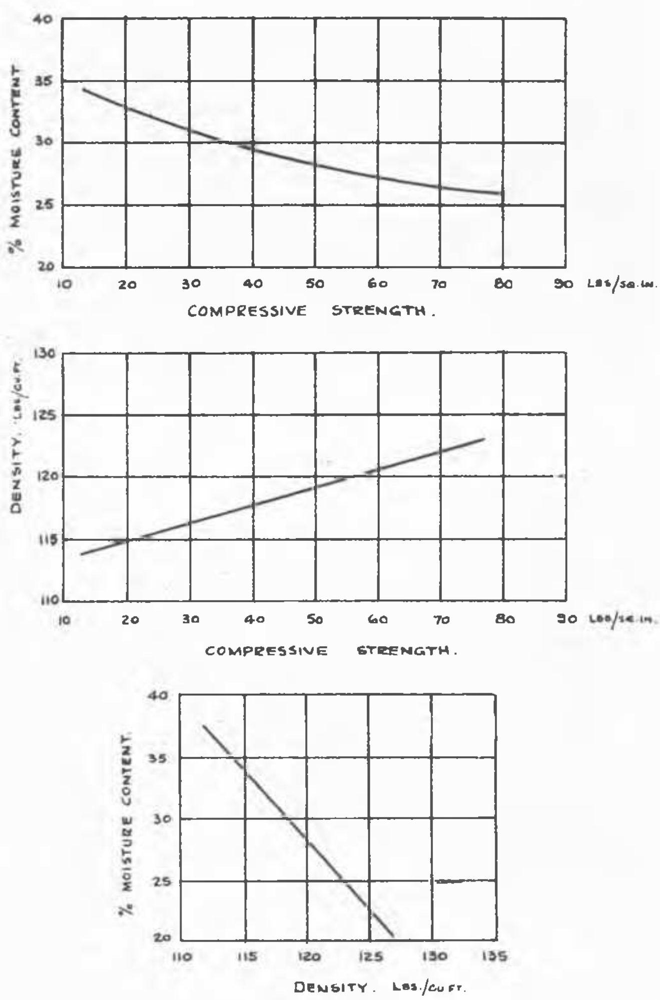


FIG. 10



Laboratory test results.

FIG. 11

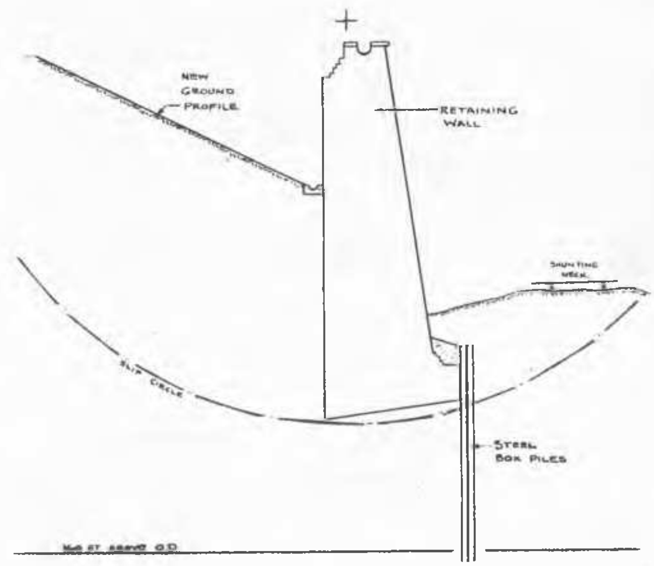


FIG. 12

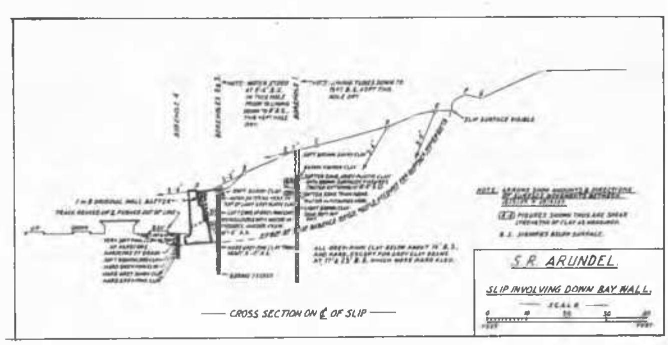


FIG. 15

FIG.13

FIG. 16

FIG.14

The movements recorded indicate a deep slip, but in the boreholes, no recognisable slip surfaces were found, all measured strengths being well above the calculated limits for stability.

Large quantities of surface water were, however, found in the upper loamy strata and, prior to diversion, this was probably causing hydrostatic pressures.

The wall will be cut down to 3-ft above rail level after sheet piles have been driven along the back, and the bank will be re-shaped to take weight off the back of the slip.

A large 80-ft. deep cutting slip in Lias Clay, near Grantham on the L.N.E.Railway, which has been moving for 30 years, is shown in Photo Fig. 16 and Fig. 17. It was investigated by the Building Research Station in collaboration with the Railway Company.

The slip exposed 4-ft. of iron stone overlying the clay. Trial pits, borings and probes established the positions of the slip surfaces and the characteristics of the clay, which was stiff, but contained numerous fissures. A mechanical analysis of a sample from the slip plane gave the following;-

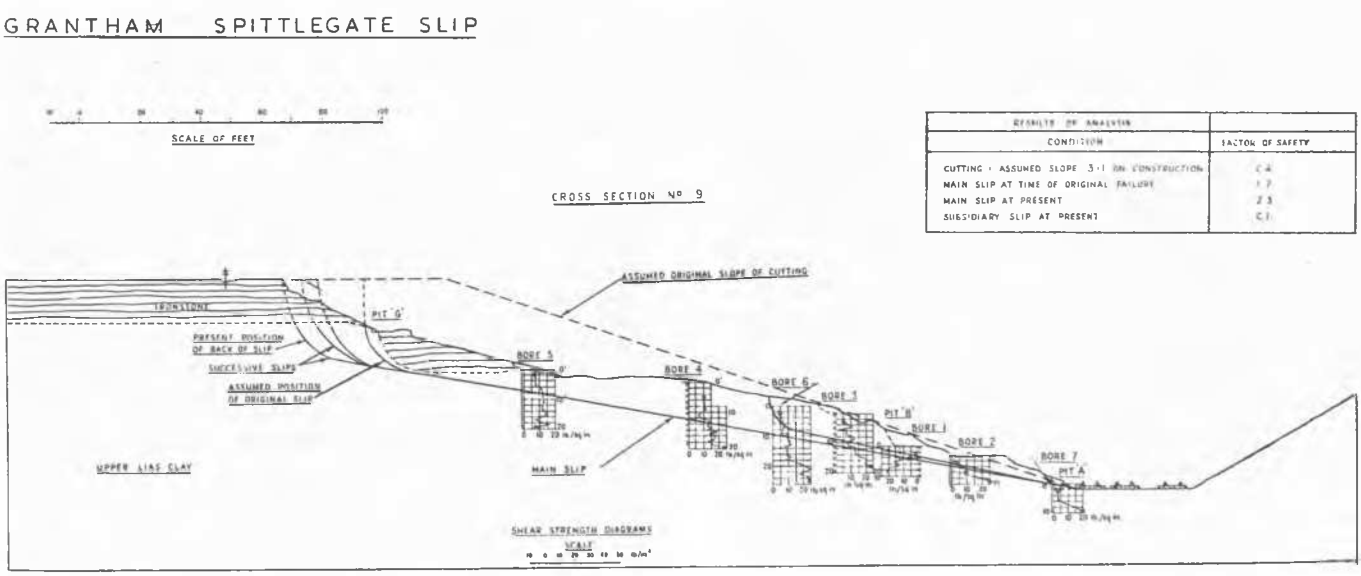


FIG. 17

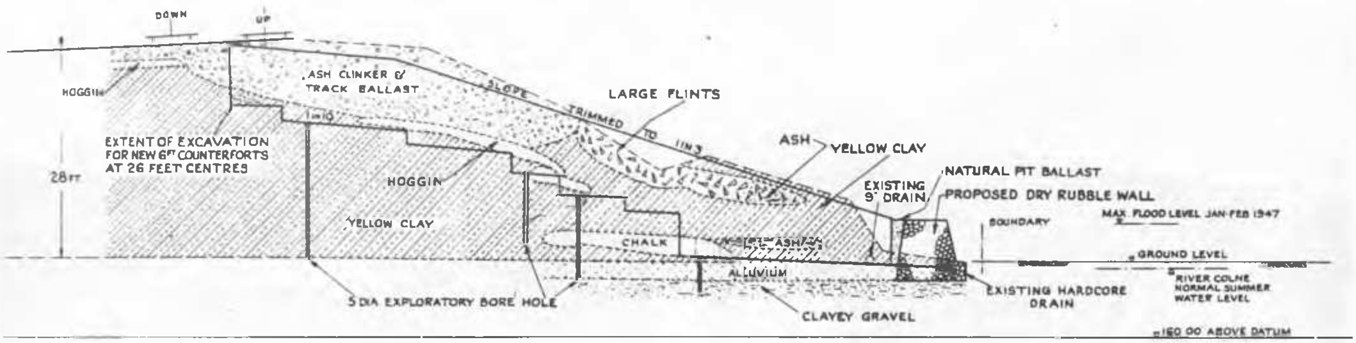


FIG. 18

Clay	< 0.002	m m dia.	51.5%
Fine Silt	< 0.006	" "	46.2%
Coasre Silt	< 0.03	" "	2.3%

Loss on treatment with HCl = 20%, which indicates carbonate content. Gypsum was also present.

An undisturbed and unsoftened sample gave:-

Natural moisture content	- 19 - 20%
Liquid Limit	- 55.6%
Plastic Limit	- 26.6%
Density	- 128 lb/cub.ft.
Shear Strength	- 14 lb/sq.inch (up to over 25 lb/sq.inch in others).

Average shear strength of samples from the main slip is 7.0 lb/sq. inch, with 2.1 lb/sq. inch from the subsidiary slip.

The corresponding calculated stability figures are 3.0 lb/sq. inch and 2.1 lb/sq.inch from the subsidiary slip.

This slip has been stabilised by removal of all the slipped material and trimming back the cutting to a slope varying from 1 in 7 at the bottom to 1 in 3 at the top, and also the construction of a very deep ground and surface water cut-off drain and trench along the top, and 150-ft. behind the old fence line.

BANK SLIPS.

Railway embankments were generally constructed with the materials obtained from the cuttings. Often, however, other materials were imported. Compaction was poor in comparison with modern ideals and considerable voids probably remained. Also concentration of track load on the centre of the formation caused uneven consolidation and dishing of the formation, resulting in rain accumulating in the centre of the banks. Softening of the clay of such banks has continued since their construction and many have become unstable, slips sometimes occurring slowly over a period of years and at other times suddenly.

To re-establish a train service, the resulting cavity at the top of the bank has been filled with ashes, as these are light and always to hand. As a result, a pocket of porous ashes is formed in which rain water collects, aggravating the slip. The formation of such waterlogged pockets seems an inevitable consequence of this method of slip treatment which is necessary for maintenance of train services.

Fig. 18 shows an embankment at Moor Park on the London Transport System where such as ash pocket exists. This drawing illustrates the manner in which the bank was explored by excavation and boring, and how rubble-filled

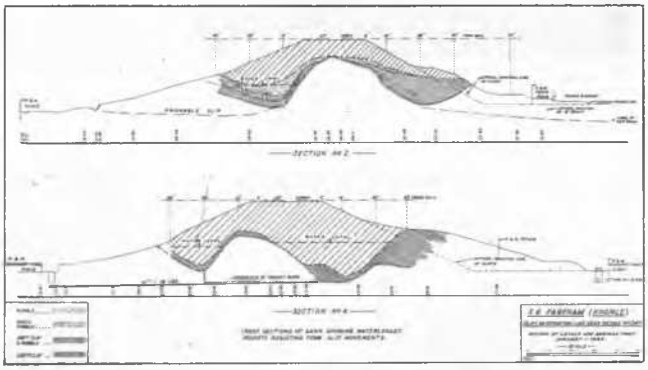


FIG. 19

counterforts are being constructed to drain it.

Extra stability will be provided by a dry stone wall and trimming the slope.

A remarkable example near Fareham in Hampshire is shown in Fig. 19 where, as a result of slips, waterlogged pockets now exist to below the level of the adjoining virgin ground, and brick rubble which presumably was originally on top of the bank is now at the bottom.

In the past, the normal methods of stabilising the banks have been:

1) Drainage of contained water by means of hardcore filled trenches or "counterforts"
2) Construction of toe retaining walls or stop blocks sunk into the undisturbed soil.
3) Driving sheet piling along the toe.

More recently the tipping of additional heavy material on the toe of the slip has found favour where adjoining land has been available at reasonable cost and the importance of the line has warranted such expenditure.

Photo Fig. 20 and Fig. 21 show a very long and important embankment at Witley in Surrey, which was dealt with in this manner after soil tests had given an indication of the best distribution of the extra toe load. In this analysis, the theoretically worst slip circle was determined by trial for an assumed hard basement 4-ft. below original ground level, and the shear stress on this surface calculated. Various profiles of tipped material were then investigated similarly on the basis of this shear strength for the clay and a profile adopted at each of several sections of the bank, giving a factor of safety of 1.25. As the filling progressed, a most marked and immediate dim-inution in the amount of packing of the track above was brought about. As an additional precaution, one drainage "leg" was constructed in each of the main bulges in the bank.

Most British Railway Companies have made experiments on draining water pockets in em-

FIG. 20

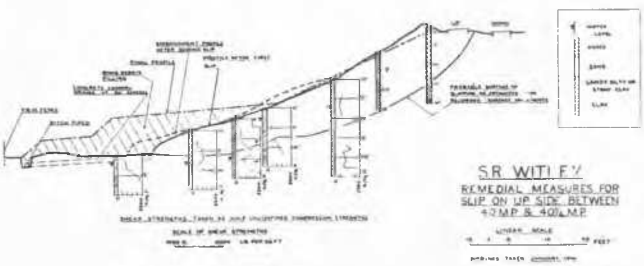


FIG. 21

FIG. 22

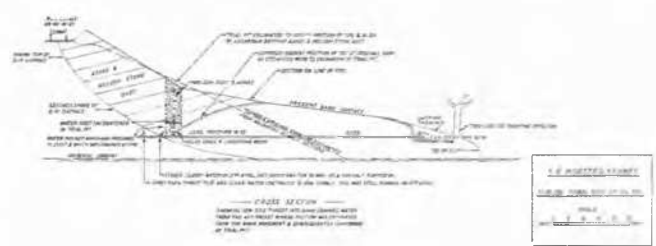


FIG. 23

bankments by thrusting into them small diameter perforated pipes with a pointed spear head.

Photo Fig. 22 illustrates a jack used for this purpose by the Great Western Company. 2" internal diameter tube in 5-ft. lengths with screwed couplings is used, and the method has given very encouraging results.

A troublesome embankment slip at Horsted Keynes in Sussex which was tapped in this manner is shown in Fig. 23, the position of the water pocket having been estimated from the toe movement which has occurred. The pit shown was sunk to confirm the position of the pipe and the water pocked and also to act as a drainage sump when filled with hardcore.

INVESTIGATION AND TREATMENT OF UNSTABLE TRACK FORMATIONS.

Most tracks laid on shallow depths of ballast on clay formations have given a great deal of trouble with the clay working up through the ballast, fouling the drains and causing waterlogging and general instability of the track in winter. With few special exceptions, the customary treatment of such sites was the removal of all the dirty ballast and an arbitrary amount of the underlying softened clay, and backfilling with sand, ashes or some equivalent non-cohesive fine material.
The track drainage system was also overhauled in the conventional manner, which, from recent investigations appears to have left weaknesses due to the coarse graded drain filling used which has permitted the clay to soften and flow into the large voids it contains.

Since 1939, the Southern Railway Company have sunk trial holes and borings at such sites to obtain clay strengths and other data from which to estimate the depths to which such "blanketing" with fine granular materials should extend.

Fig. 24 shows a typical set of simple compressive strength results in such borings in London Clay at Clapham Junction, London, together with the theoretical curve of maximum shear stress vertically under the sleeper with chair loads of 15-tons (a load based on recent work on Concrete Sleeper design). The clay was excavated to a depth of 3'6" below top of sleeper and precast concrete load spreading slabs, shown in Fig. 25 and Photos. Figs. 26 and 27, were bedded on a 1-ft. thickness of Meldon stone dust over the clay, 1'5" of track ballast being deposited on the slabs to receive the track. This is now the most common method of track stabilisation used on the Southern Railway. Other methods, some of which have severe limitations, have been tried, such as the casting of a continuos "in-situ" reinforced "Colgrout" concrete slab, see Photo. Fig. 28, or the laying of a 3" consolidated layer of mixed bitumen emulsion

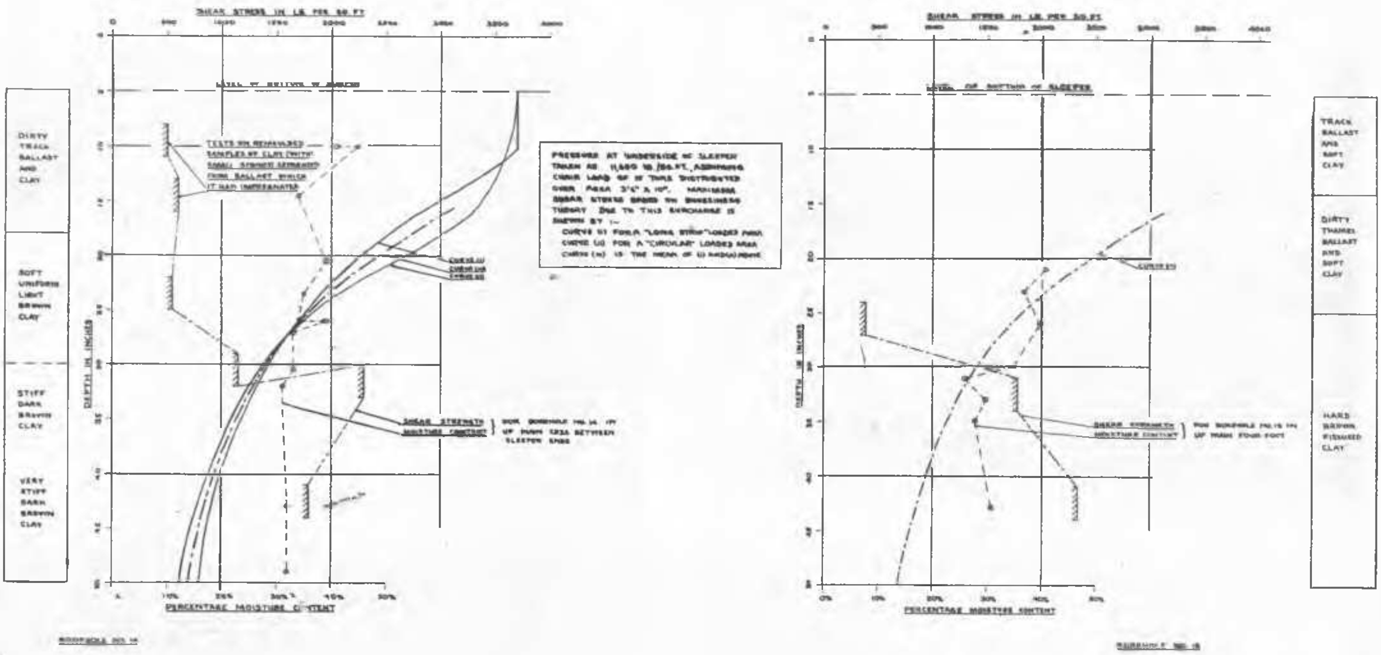

PERCENTAGE MOISTURE CONTENT
DEPTH IN INCHES

FIG. 24

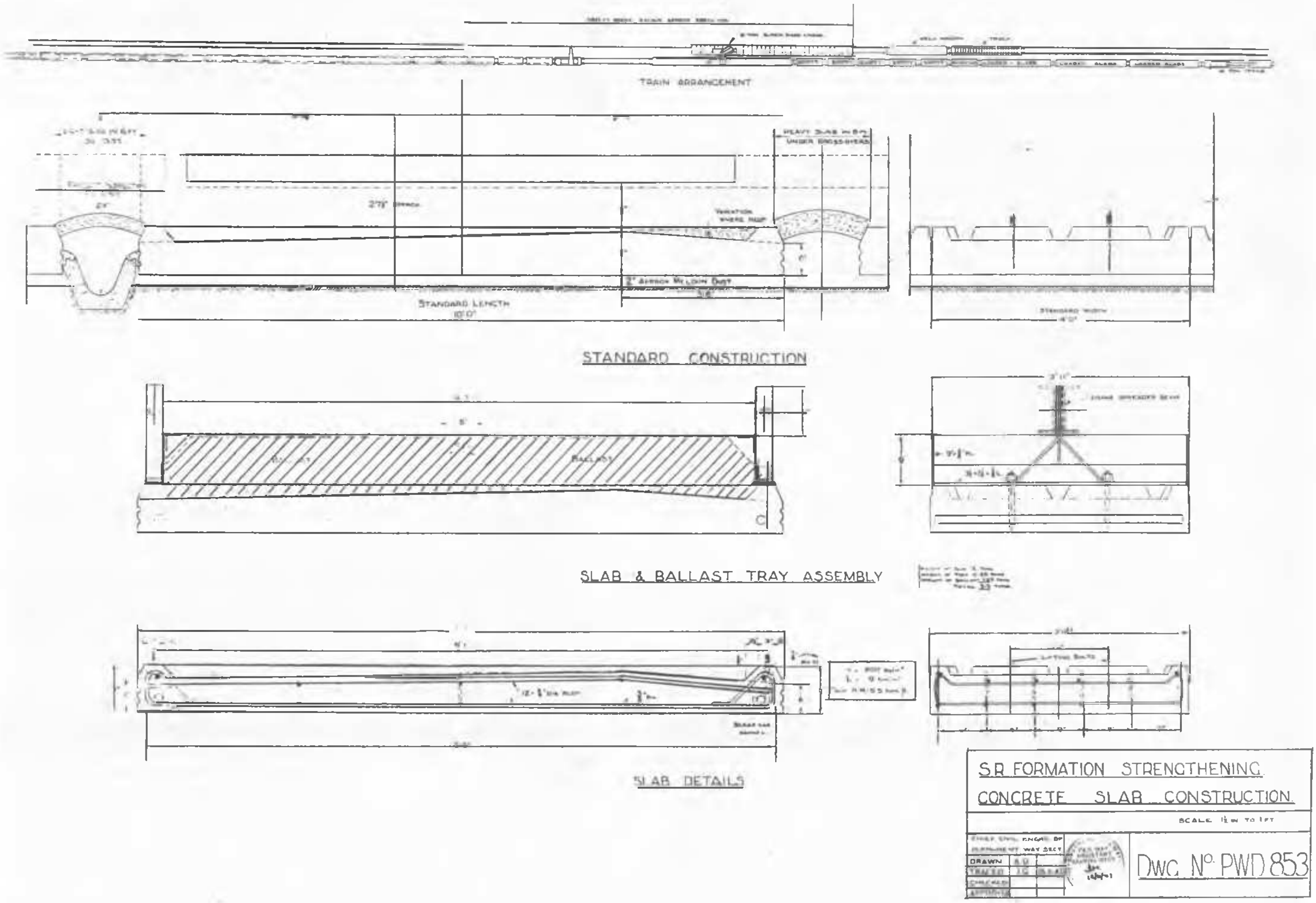

TRAIN ARRANGEMENT
STANDARD CONSTRUCTION
SLAB & BALLAST TRAY ASSEMBLY
SLAB DETAILS
S.R. FORMATION STRENGTHENING
CONCRETE SLAB CONSTRUCTION
DRAWN
TRACED
CHECKED
APPROVED
DWG. No. PWD 853

FIG. 25

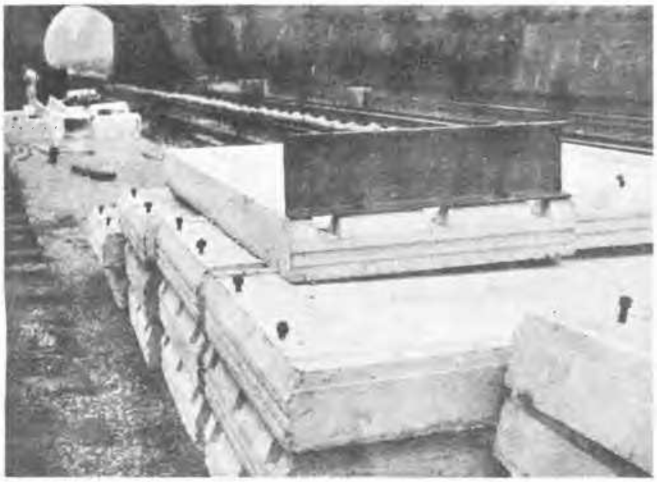


FIG. 26

FIG. 28

FIG. 27

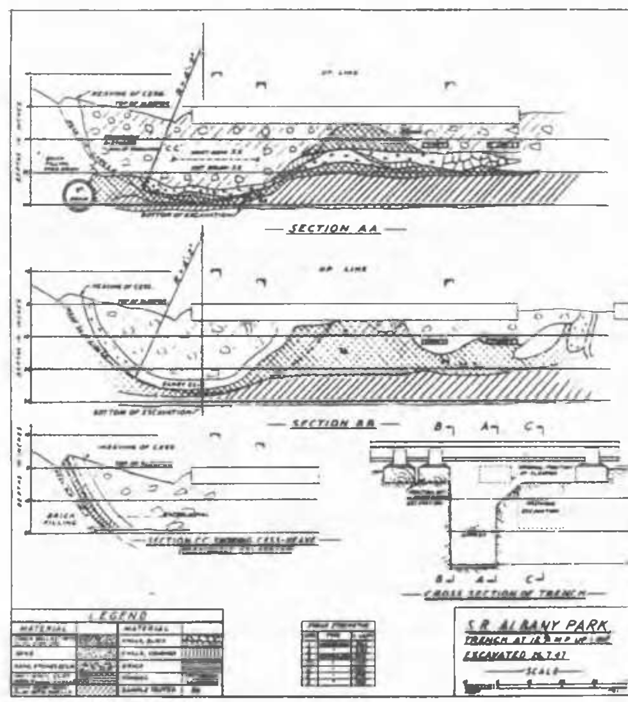


FIG. 29

spray. This latter process was intended to act as a waterproofing and blanketing layer.

Fig.29 shows an excavation made at Albany Park in Kent, in a clay cutting where heaving occurred in both the cess and the 6-ft.space, and where the track needed constant packing.

Progressive rotary movement of the ballast under the sleeper ends was occurring in the manner of a circular slip, the clay in contact with the ballast becoming softened to a point at which it was unable to support the sleeper load, when it was forced into the zones of lowest pressure. Drains were clogged and upheaved.

The mean measured shear strength of the clay in the failure zones was 360 lb./ft^2.which corresponds with an equilibrium chair load of 10-tons spread 2'6" longitudinally. Loads well in excess of this occur on a well packed sleeper.

All Companies have their individual methods of treating clay formations to minimise subsequent maintenance work, and Fig. 30. shows the standards adopted by London Transport for embankments and cuttings. The good crossfall of the formation and the use of fine grained materials in contact with the clay will be noted.

TRACK GROUTING.

The Great Western Railway Company is making tests of cement grouting, for track stabilisation by the elimination of water pockets produced by the punching action of the ballast into the formation. The results so far are inconclusive.

That Company is now attempting the stabilisation of an embankment at Fenny Compton on the main line to Birmingham, by similar methods, slips having occurred frequently in the past. Fig. 31 shows a typical section and borings into this bank. The formation consists of a layer of broken bricks and sand and shows no deform-

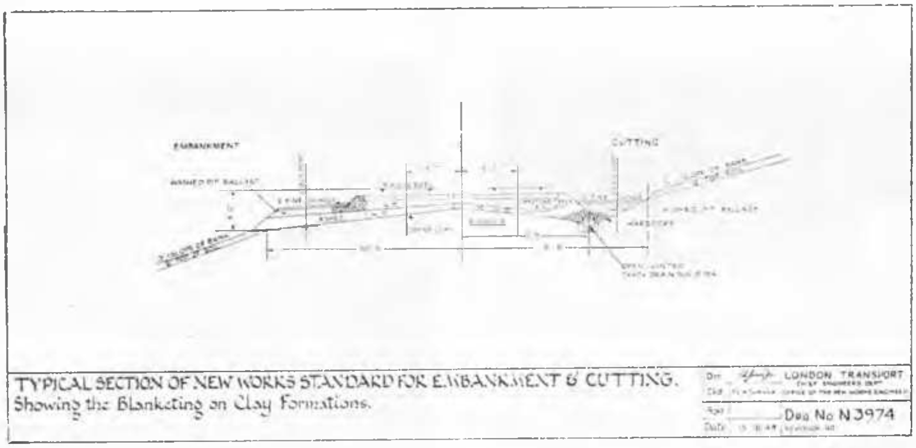
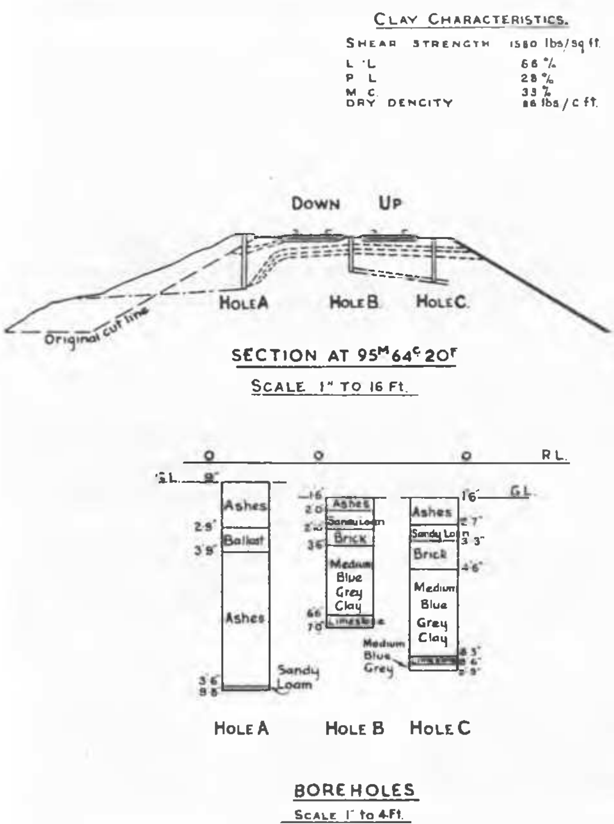


FIG. 30



Fenny compton embankment

FIG. 31

ation under the tracks, while the body of the bank is fissured clay having the following average characteristics:-

Shear strength	-	1580 lbs./ft²
Liquid limit	-	66%
Plastic limit	-	28%
Average moisture content	-	33%

Slips in the bank have been made up with ashes. Cement grout is being injected by means of "points" driven to 8-ft.depth at the cesses and the "6-ft" at intervals of about 5ft.

Trenches will be excavated to enable the result to be studied and vibrograph record on the bank are being taken before and after grouting for comparison.

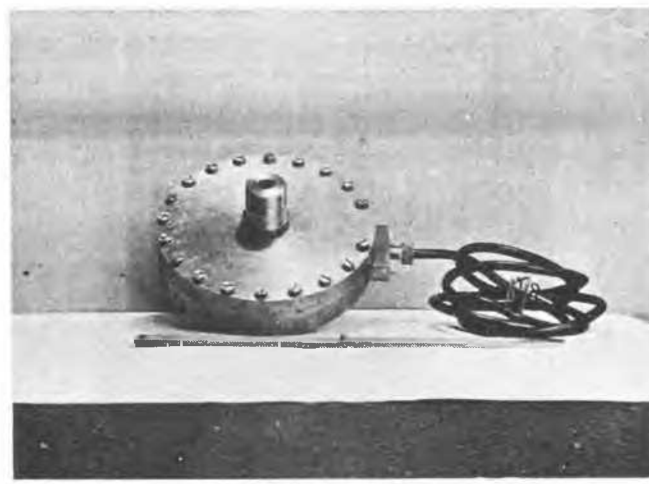


FIG. 32

CONCLUSION.

The future scope and development of soil mechanics on British Railways may be principally in the following:-

1) Kit for boring and sampling non-cohesive soils.
2) Tests on bulk strength of fissured clays relative to that of small test specimens.
3) Continued tests on banks and cuttings with a view to a better understanding of the breakdown and swelling of fissured clays and the pressures developed thereby, together with exploration of all likely methods of treatment, such as surface waterproofing etc.
4) Continued investigation of track formation failures and treatments.
5) Apparatus for measuring pressures in track formations. (The Southern Railway Company has already constructed an experimental cell shown in Fig. 32. with a hydraulic calibration cell on top).
6) Laboratory and site investigation of track ballast and fill gradings and treatment such as vibration, to establish conditions for maximum density and stability under traffic.
7) Development of graded filters for clay drainage.
8) The use of electro-osmosis or electro-chemical hardening for bank,cutting,and track stabilisation.(The London Passenger Transport Board

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

ACKNOWLEDGMENT.

Acknowledgement is gratefully made to the Chief Engineers of the British Railway Companies for permission to present this information, and also to their undermentioned representatives for their valued collaboration in the preparation of the paper:

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" P.Protopapadakis, A.M.I.C.E., Dipl.Ing.Civ./Mech. Eng (Athens)	- G.W. " "
" F.S.P. Turner	- L.P.T.B.

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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.).