Recent Research into the Coastal Landslides at Folkestone Warren, Kent, England

Recherches sur les glissements de terre de Folkestone Warren, sur la côte de la Manche, Grande-Bretagne

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Summary

The research by the author in 1938–39, for the Southern Railway Company, showed that the subsidiary landslips on the sea side of the railway on the Kent Coast between Folkestone and Dover were due to deep shear failure in the Gault clay resting on the Lower Greensand. It was not, however, until the continuation of this research by deeper borings, in 1948–50, now described, that proof was obtained of the author's predictions, from the earlier research, that the mechanism of the main slips is the same as that of the subsidiary slips.

This recent research revealed high ground-water levels in the back of the slip area, and calculations have been made to assess the relative factors of safety against further movements which would be provided by ground-water lowering or toe-loading of the slips.

In 1948, as a result of the research, a programme of major slip prevention works was commenced.

Sommaire

Les recherches entreprises par l'auteur en 1938–39 pour la «Southern Railway Company» avaient montré que les glissements subsidiaires entre la mer et la voie ferrée observés sur la côte de la Manche, entre Folkestone et Douvres, provenaient d'un cisaillement très profond dans l'argile du Gault qui repose sur le «Lower Greensand». Néanmoins il a fallu attendre jusqu'à 1948–50 pour poursuivre ces recherches et vérifier les hypothèses émises antérieurement par l'auteur, à savoir que le mécanisme des glissements principaux est le même que celui des glissements subsidiaires.

Les recherches de 1948–50 ont montré que le niveau de l'eau dans le sol au revers des glissements est très élevé. Des calculs ont été faits pour déterminer les facteurs relatifs de sécurité contre tous glissements ultérieurs provoqués par l'abaissement du niveau de l'eau ou par une surcharge au pied des glissements.

Un vaste programme de travaux de stabilisation a été entrepris en 1948 sur la base de ces recherches afin de prévenir tous nouveaux glissements.

Introduction and General Geology of the Area

Fig. 1 is a plan of the western half of the Warren (the two mile long slip area between the high cliffs and the sea) showing the 1938–39 borings for investigation of the subsidiary slips, and those sunk in 1948–50 into the main slips also.

Descriptions of the 1938–39 research into these landslides were given by *Toms* (1939–48).

The geology of the unslipped strata in the high cliffs was described by *Osman* (1917), but his deductions as to the nature of the slips are now shown to be incorrect as are also his estimates of the total thickness of the Gault.

Fig. 2 shows typical cross-sections through the Warren. The unslipped strata of the high cliff comprise the middle and lower chalk resting on the Gault clay, overlying the Lower Greensand. The Coast runs north of east and the Gault increases in thickness in this direction by 14 ft. per mile.

The borings showed the top of the Lower Greensand to be almost a plane having a dip of about 1 in 52 with a "strike" 57° west of north, thus proving that the slips had been confined to the overlying strata. The length of Coast affected by slips is roughly from the point at the west end at which the base of the Gault rises above shore level, to the corresponding point at the east end where the top of the undisturbed Gault sinks below shore level.

Fig. 3 is a typical section through the undisturbed Gault showing the subdivision into thirteen beds identified by zonal Ammonite type fossils. It was prepared by the author's assistant Mr. *A. M. M. Wood*, M.A., A.M.I.C.E., from the 1948–50 borings and other sources, for the purpose of establishing the vertical displacements of the slipped soil masses. Alongside are shown the classification indices of samples not involved in shear zones. The author hoped originally that these indices might be of assistance in the assessment of vertical displacements, but it will be seen that slight variations only over large depths rendered zoning by them impossible.

Description of the 1948—1950 Investigations

By 1947 a triangulation survey covering the Warren area, which had been established before the war, showed that a slow movement involving the sea wall was continuing on the sea side of the railway. Shearing occurred of two drainage headings.

Boreholes Nos. 1 to 4 (see Fig. 1) were therefore sunk close to these headings to locate the slip and to help in determining the most suitable stabilising measures. These headings are some distance east of the western end of the Warren, the base of the Gault there being well below shore level. The slips were found to pass down close to the base of the Gault, but the mechanism of the toe upheaval appeared to differ from that of a normal "Circular" slip in homogeneous material. Photographs of the 1915 and 1937 slips and the appearance of the denuded Gault in 1948 suggested that the backs of many old slips exist in the shore, and that thrust causes upheaval by wedge action under them, except towards the west end of the Warren where the Gault cover to the Greensand is thin. There the Gault crushes up at random. The seaward limits of disturbance of the foreshore were estimated by levelling at different times on rail stumps driven deep into it.

The 1948–50 borings were generally lined temporarily for most of the depth to exclude water above the Gault and to permit determination of the head of water in the Lower Greensand. Liner tubes having square-threaded joints proved insufficiently leak-tight and were replaced by tubes with V threads caulked with white lead compound. Swelling of the Gault in one or two of the deep holes made extraction of liners exceptionally difficult.

To minimise disturbance of the stiff Gault by the Sampling tool experiments were made with thinner Coring tools. It was found that one having a ratio of displacement to Core area of 25% was the thinnest which would withstand the driving stresses.

The Gault

"Undisturbed" cores of the stiff Gault were often found to contain fissures, some having the characteristic "slickenside" polish and striation. It is thought that many of these fissures may, however, have been caused by the driving of the Sampler.

Owing to the high strength of some samples of Gault they could not be overstressed in a standard shear box apparatus. One was therefore adapted to take samples 1″ square only. Similarly it was found necessary to adapt an Adie Cement-testing machine to determine the simple compressive strength of this Gault. The mean compressive yield point so found was about 600 lbs./in².

The natural moisture content of the Gault in its undisturbed state was found to be generally 5 to 10% below the Plastic Limit. Therefore, since in the Warren it is under much less than its preconsolidation overburden, zones where movement had occurred were generally indicated by much higher moisture contents, sometimes exceeding the Plastic Limit, and much reduced strengths. A comparison of moisture contents of corresponding beds of the "undisturbed" Gault in the shallower and deeper borings revealed no significant differences, indicating that it has no appreciable tendency to swell and soften due to the progressive reduction of the overburden by the repeated slipping. On the evidence available the repeated incidence of slips could not therefore be attributed to gradual softening of the Gault in the Warren due to swelling alone.

Tests on samples in special oedometers at the Building Research Station, Watford, confirmed the view that there was still sufficient overburden pressure at the positions from which the samples were taken to restrain the Gault there from further swelling and weakening unless involved in a zone of shearing

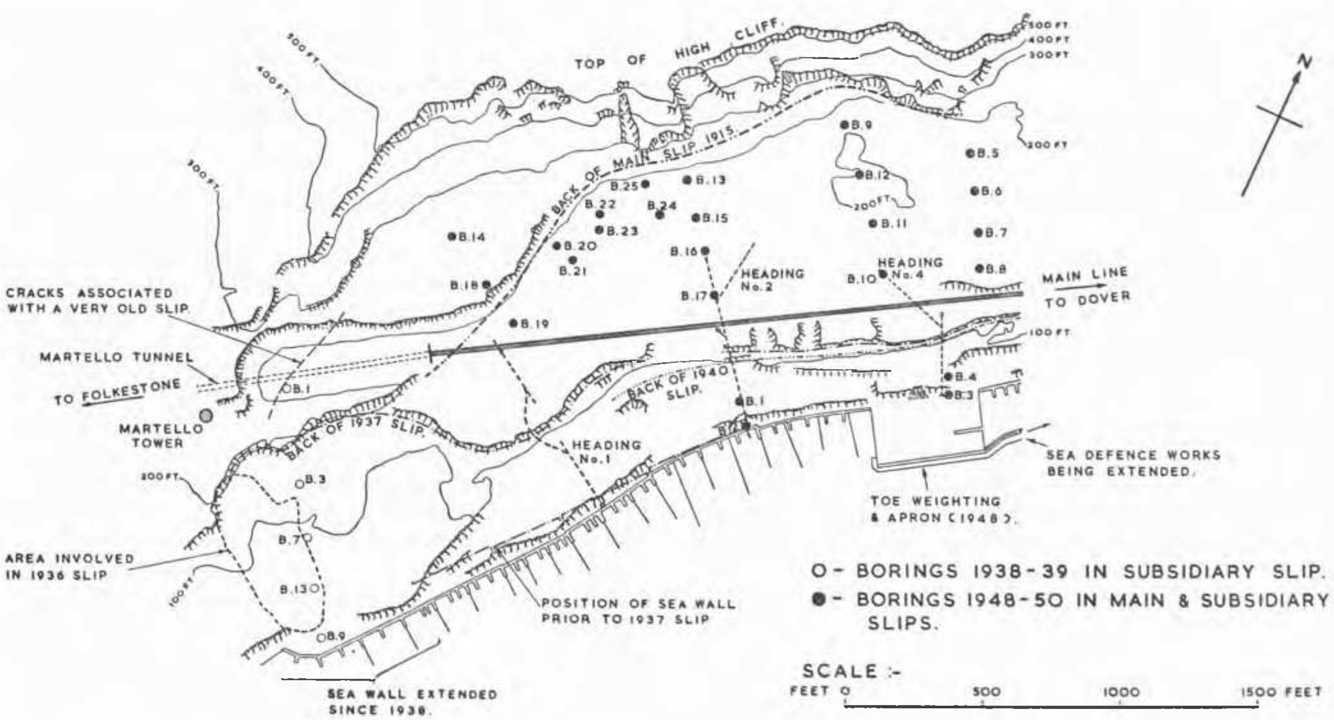


Fig. 1 Plan of the Western Half of Folkestone Warren Showing the Areas Investigated by Borings in 1938–39 and 1948–50
Plan de la partie ouest de Folkestone Warren indiquant l'emplacement des recherches et sondages entrepris en 1938–39 et 1948–50

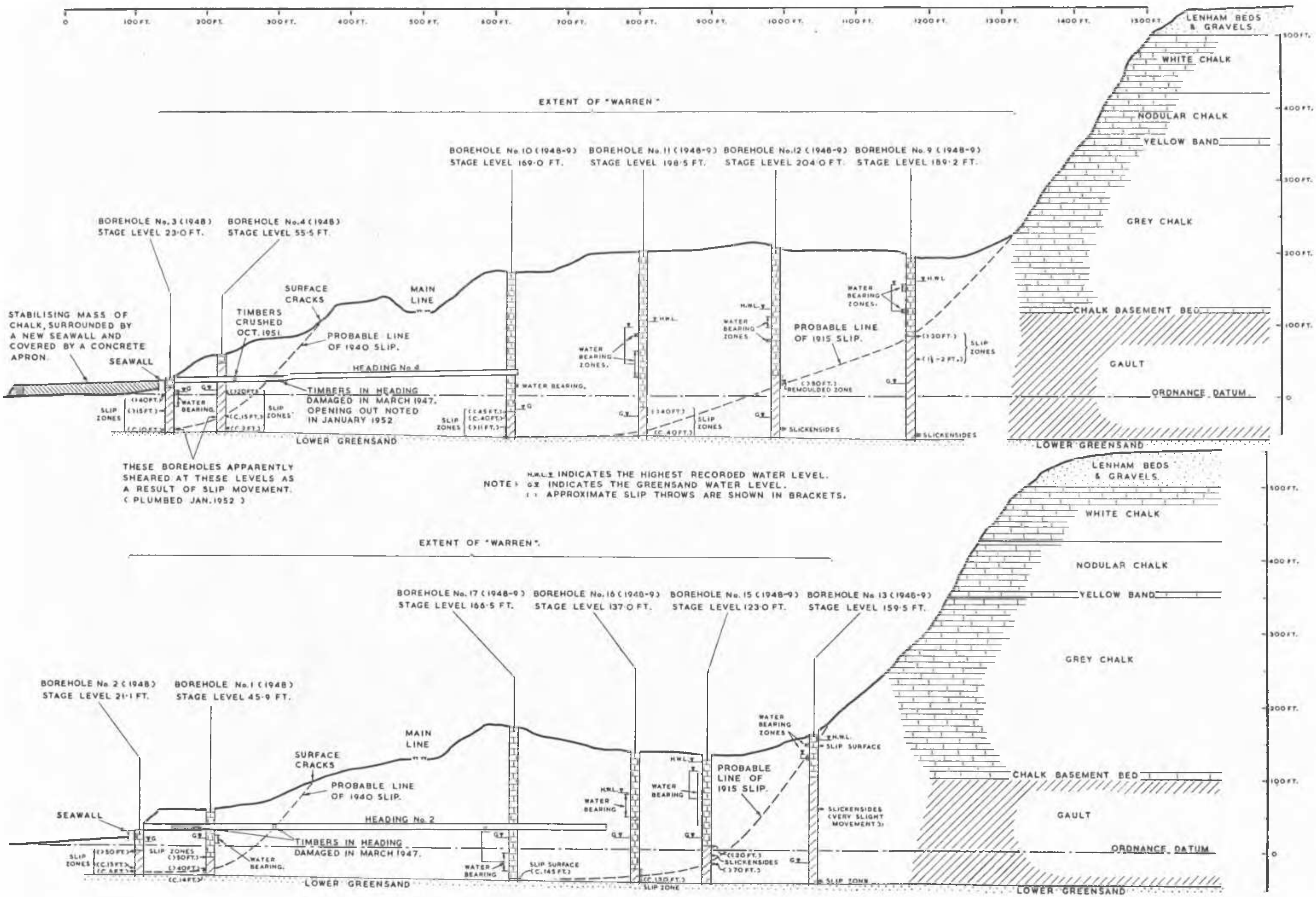


Fig. 2 Typical Cross-Sections Showing Boreholes and Headings
Profils montrant les sondages et galeries

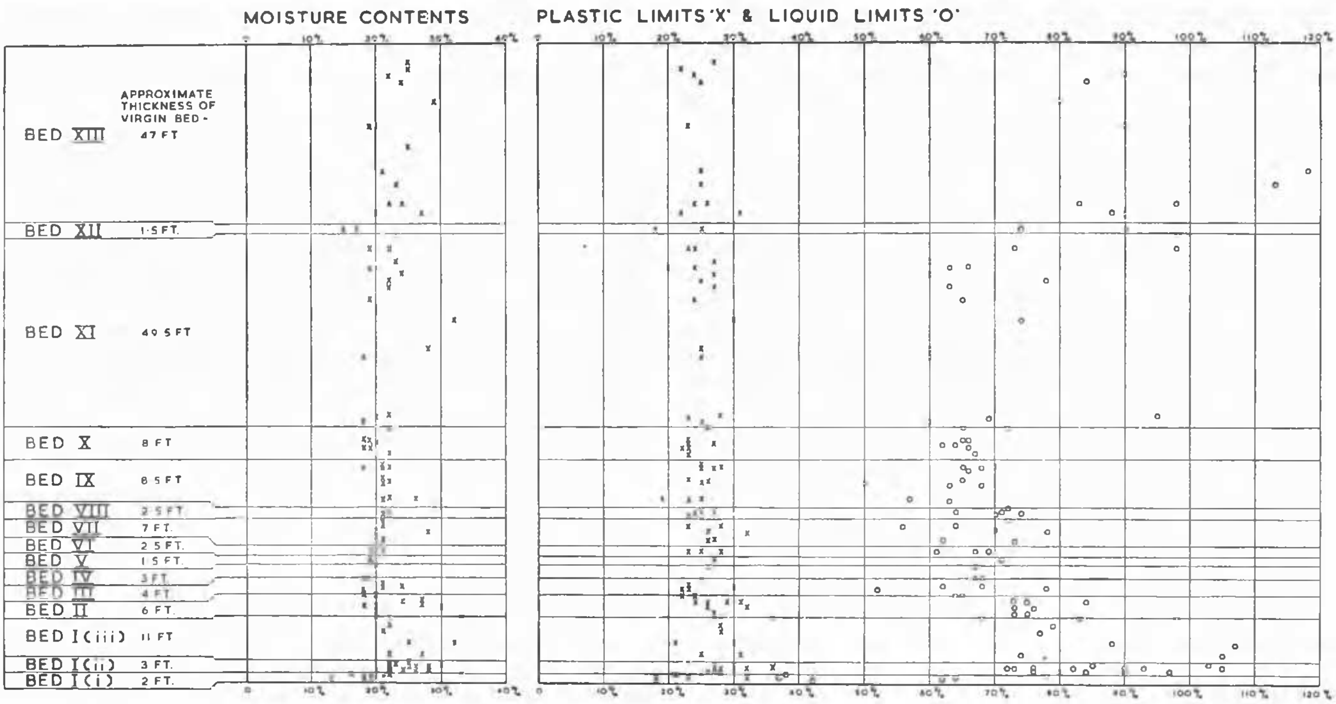


Fig. 3 Atterberg Limits and Moisture Contents of the Gault Beds
Limites d'Atterberg et teneur en eau des différentes couches du Gault

due to some other cause. It was not possible, during these tests, to apply shear stress at the same time as normal stress, and the effect of such combined stress is, therefore, not known.

At various times cliff top settlements of a few feet have occurred followed, at varying intervals, by cliff collapses sometimes but not always associated with a major slip. In boring No. 5, in what was believed to be completely undisturbed Gault below the rearmost main slip, slickensides were found associated with small reductions of bed thicknesses of the order of a few feet. This suggests that the small settlements of the cliff are related to these strains in the Gault, further displacement being held up until sufficient yielding occurs in the Warren to render the whole system unstable.

Mechanism of the Landslips

Fig. 2 shows the positions and shapes of the slip surfaces as determined from:—

(*a*) Features and known changes in the ground surface.
(*b*) The positions of shearing of headings Nos. 2 and 4.
(*c*) Weak zones and other significant discontinuities in the borings.
(*d*) Disturbances and discontinuities of the foreshore.
(*e*) The levels at which shearing has already occurred in boreholes Nos. 2 to 4 in which earthenware standpipes were installed specially for the detection of such movements.

All the deep boreholes showed ample evidence of previous slip movements on a large scale and that the subsidiary and major slips always tend to follow the softened zones resulting from the earlier slips.

The 1938–39 investigations, described by *Toms* (1939), were confined to the subsidiary, slips, on the sea side of the railway, at the western end of the Warren. They showed that these slips pass down steeply to the basement bed of the Gault and then horizontally along it, which resulted in upheaval and the formation of temporary islands on the foreshore during both the 1915 and 1937 slips.

Semi-artesian water was found, in all boreholes, in the Greensand below the Gault. These recorded water levels may not, however, have been entirely in equilibrium since it was not possible to leave the borings open to this depth indefinitely, as they had to be plugged off for measurement of the standing water levels above the Gault. These were all found to be much higher than the corresponding Greensand water levels. From the water table gradient it was suspected that water was entering the Warren from the high cliff behind. This emphasized the need for subsoil and water exploration in the back of the Warren and a study of the practicability of minimising its adverse effects by drainage.

Fig. 2 shows how the slips have resulted from shear failure of the Gault principally along its basement bed, involving large displacements of the earth masses and correspondingly large reductions in thickness of the Gault in the "Warren" compared with its "unslipped" thickness.

Slips in the past were due to progressive sea erosion of the foreshore (now proved to have been assisted by large hydrostatic pressures from the high ground water in the broken chalk overlying the gault). Construction of the seawall and groynes over a period of years modified the conditions but has not arrested shore erosion entirely.

The 1948–50 boreholes proved, for the first time, that the major slips are due to shear failure of the Gault on slip surfaces which pass down deeply into it: in fact right down to its basement bed in the western half of the Warren at least. They also revealed very high ground water levels in the back of the Warren, indicating the existence of large hydrostatic pressures tending to drive it into the sea.

Distribution of Underground Water

The boreholes permitted the determination of the water distribution in the broken chalk overlying the gault. After driving the liners into the gault to seal off the water from the chalk, further boring, into the Lower Greensand, enabled the head of water in this stratum to be recorded. Finally each boring was sealed above the Lower Greensand and earthenware pipes, or steel standpipes with bronze gauze and gravel filters at the water-bearing zones were inserted for the subsequent recording of the levels of the water over the Gault. These standpipes are shown in Fig. 4.

The discharge from several of the existing drainage headings was measured and was found to exceed the quantity which could be accounted for by the rainfall on the appropriate catchment area in the Warren alone. This fact and also the very high ground water levels in the back of the Warren point to the conclusion that water must be flowing into the Warren from the undisturbed strata of the high cliffs at levels below the Warren surface. At one point only is there a visible spring in the high cliff face.

For many years attempts have been made to lower the ground water in the Warren by means of timbered headings running back from the seawall but, owing to their wide spacing and inadequate length, and also the difficulty of maintaining them due to slips, the water table remains very high at the back of the Warren. It is however markedly lower near headings, showing that, if the system could be improved and extended it should be effective.

Stability Calculations

Calculations have been made to analyse the equilibrium conditions of the Warren and the probable benefit thereto of the alternatives of toe loading or lowering by drainage of the high ground water level in it. Space limitations however preclude the inclusion of these calculations.

For borderline equilibrium of the subsidiary (or "toe") slip, the average shear strength of the Gault was calculated as 7.35 lbs./in², which compared with the value of 7.85 lbs./in² obtained for the 1937 Slip (*Toms*, 1939). The mean shear strength of the samples taken from the slip zone in borings Nos. 1 to 4 was 11.1 lbs./in². As the toe is approached there is however reason to expect a reduction in shear strength.

Calculations for the main slip show that, for equilibrium, the mean shear strength throughout the slip surface (excluding the part involved in the subsidiary slip) must be about 21.0 lbs./in².

The average shear strength of the few samples obtained from main slip zones was about 16.0 lbs./in². The differences between these calculated stresses and the measured strengths may be due to:—

(*a*) unknowns in respect of which assumptions had to be made in calculation;

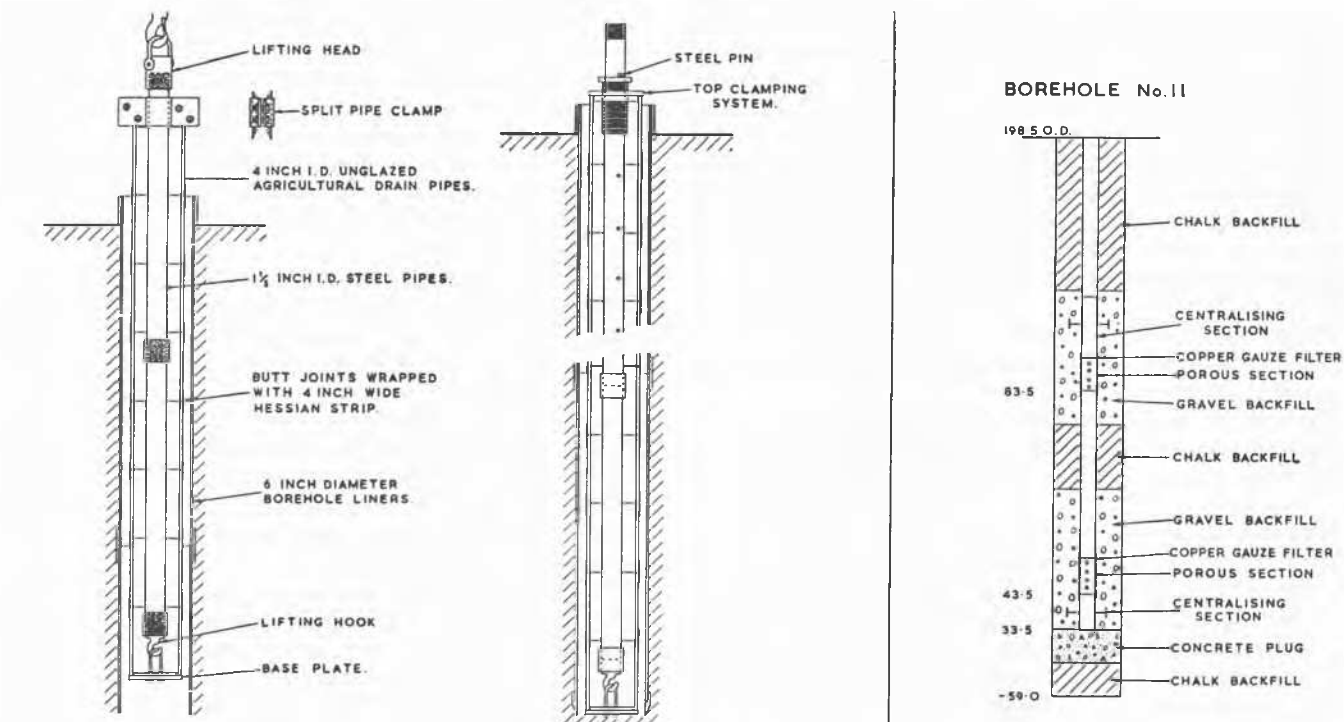
(*b*) insufficient samples from slip zones to enable a fair average strength to be obtained.

Stabilising Measures Adopted and Proposed

Since the primary cause of the slips has always been continual erosion by the sea of stabilising mass along the shore, the steps taken in the past to minimise this action have been

(i) The construction of a sea wall to protect the shore line low cliffs.

(ii) The construction of groynes to reduce the eastward drift and continual loss of shingle and sand, which forms a natural protection.



METHOD OF INSTALLING EARTHENWARE STANDPIPES
METHODE D'INSTALLATION DES TUYAUX EN POTERIE

CLAMPING OF PIPES PRIOR TO BACKFILLING WITH GRAVEL AND WITHDRAWAL OF LINERS.
SERRAGE DES TUYAUX AVANT DE REMPLIR L'ESPACE AUTOUR D'EUX AVEC DU GRAVIER ET DE RETIRER LES TUYAUX EXTERIEURS.

INSTALLATION OF A STEEL STANDPIPE.
L'INSTALLATION D'UN TUYAU EN ACIER.

Fig. 4 Installation of Standpipes for Measuring Water Levels
Installation des piezomètres indiquant les niveaux de l'eau dans le sol

(iii) The tipping onto the shore of shingle and sand obtained elsewhere.

Nevertheless, erosion of the foreshore and undermining of the sea wall occurred necessitating underpinning. Also, before completion of the sea wall at the west end of the Warren the subsidiary slip in 1937 thrust a long length of the sea wall out to sea by amounts up to 90 feet. As mentioned above, the sea wall, completed after the main movement had ceased, continued to move. More drastic stabilising measures were therefore essential and, as a result of the research, it was decided to impose a heavy weight of filling on the foreshore in front of the existing sea wall. Therefore, in 1948–49 a new sea wall 400 ft. long with return end walls was constructed 200 ft. seawards of the old one where movement was greatest, and the "box" so formed was filled with chalk excavated from the top of the slip, this being protected with a concrete slab. Owing to serious erosion and some sea wall movement further east the work is being extended.

Calculations indicate that the factor of safety provided against a further major slip by a general lowering of the ground water at the back of the Warren of say 20 ft. would be of the order of 5.5% (1.055). By comparison the toe weighting and sea wall constructed in 1948–49 (as described above) is estimated to provide a factor of safety of about 3.6% (1.036). Theoretically therefore general dewatering of this amount should be more effective than such a costly toe weighting scheme (apart of course from pure erosion protection which is necessary in either case).

The practicability and economics of such extensive dewatering are at the moment completely unknown and much research will be necessary to obtain data on these matters. As a first step an existing drainage heading is to be extended to study its effect on the surrounding water table, and also the cost and difficulties of such an enterprise.

Owing, however, to the time which this research will take and the uncertainty of its outcome, and also that coast erosion must in any event be prevented, further work on the extension of the coast protection works is unavoidable.

Means Adopted for the Detection of Slip Movements

These are:—

(1) Permanent triangulation and traverse points throughout the area.

(2) Permanent reference points for detecting changes of level.

(3) Detection of longitudinal strain in drainage headings by means of copper wires anchored at the landward ends, passing over pulleys on the side walls, and terminating at a tensioning device near the seaward end.

(4) Soundings of the boreholes to see whether they have suffered distortion due to slip movement.

(5) Visual observations of strain in headings and at the ground surface.

References

Osman, C. W. (1917): The Landslips of Folkestone Warren and the Thickness of the Lower Chalk and Gault near Dover. Proc. Geol. Ass., Vol. 28, II.

Toms, A. H. (1939): Folkestone Warren Landslips: Research Carried Out in 1939 by the Southern Railway. Inst. of Civil Engineers, Railway Division, Paper No. 19.

Toms, A. H. (1948): The Present Scope and Possible Future Development of Soil Mechanics in British Railway Civil Engineering Construction and Maintenance. Proc. II Int. Conf. Soil Mechanics and Foundation Engineering, Rotterdam, vol. IV, p. 226.