THE INSTITUTION OF
POST OFFICE ELECTRICAL ENGINEERS

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L. G. SEMPLE, B.Sc. (Eng.)

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A PAPER

Read before the Eastern Centre of the Institution on the 27th September, 1932, and before the Scotland West Centre on the 10th October, 1932.

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LAYING ARMOURED CABLES BY MEANS OF A MOLEDRAINER.

SYNOPSIS.

Introduction.

The circumstances leading to the adoption of armoured cable construction for the Cambridge-Kings Lynn route.

Experiments with agricultural implements for cable laying operations.

Choice of tractor.

Organisation of a typical work with particular reference to :—

(*a*) The survey.
(*b*) The choice of cable lengths and jointing points.
(*c*) Records.
(*d*) Tools and appliances.
(*e*) Staff requirements.
(*f*) Costs.
(*g*) Jointing and loading.

Prospective developments.

Conclusion.

INTRODUCTION.

During the spring and summer of 1932 some twenty-five miles of protected and armoured cable were drawn into the ground between Cambridge and Kings Lynn without any previous excavation, the supervising officers and workmen employed being regular members of the Post Office engineering staff. An agricultural moledrainer was used for the work, during the progress of which many experiments were conducted and many ideas subjected to practical tests. This moledrainer method has now been officially approved for use in the Post Office Engineering Department and the future will probably see its application wherever conditions permit.

The authors of this paper were closely concerned with this experimental work and acquired a not inconsiderable experience of the difficulties and troubles encountered and of the best means of overcoming them. They offer this detailed description of the work in the hope that it will be of assistance to others who may be engaged in the control of future works of a similar nature. They have arranged the paper with this end in view and not as a statement of events in the order in which they occurred. In actual fact, most of the surveying and estimating work involved in the provision of the Cambridge-Kings Lynn cable had been completed before the moledrainer method was conceived.

The earlier part of the paper outlines the historical and experimental aspect of the subject; the later part describes in detail, by special reference to the Cambridge-Kings Lynn work, the methods and organisation considered most suitable.

PRELIMINARY CONSIDERATIONS.

The adaptation of agricultural implements to engineering works is by no means new and research into literature on the subject would no doubt reveal many instances of the principles involved. So far as the authors are aware, however, the laying of the Cambridge-Kings Lynn cable was the first occasion on which the principle was applied to a work of any considerable magnitude in this country. The circumstances leading to the adoption of the moledrainer for this work are worthy of some consideration if only as a matter of historical interest.

In a paper on " Trunk Telephone Reorganisation " read before the Institution of Post Office Electrical Engineers in 1931, Mr. J. S. Elston gave details of the traffic problems and technical development which led to the design of star-quad cable for four-wire repeater working over 10-lb. conductors. The cable provided for the Cambridge-Kings Lynn service is of that type, but as the present paper is primarily concerned with the methods of *laying the cable* further particulars of the cable itself must be confined to Fig. 1 which shows the cable lay-out, and the size of the cables provided.

Type of Cable	122/10	104/10	74/10	60/10
Diameter over Lead Sheath (ins)	1·07	1·00	0·86	0·79
Diameter over Armouring (ins)	1·75	1·68	1·53	1·46

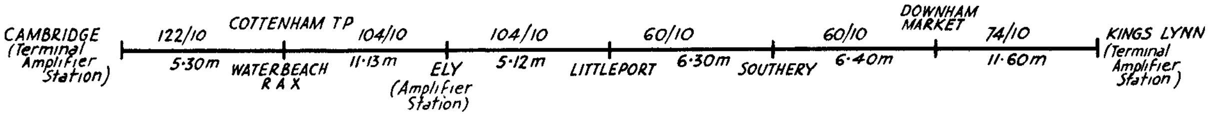


FIG. 1.

A choice of three methods of providing the cable was presented:—

(*a*) The use of a duct and cable in the normal manner.
(*b*) The erection of aerial cable on an existing or new pole route, the former method having been employed for the recent London-Brighton cable (*P.O.E.E. Journal,* Vol. 24, October, 1931).
(*c*) An armoured cable laid direct in the ground—a method not hitherto employed for trunk cables.

Description of route.

The route between Cambridge and Kings Lynn is bounded for considerable distances by wide grass margins, more especially in the twenty miles between Cambridge and Littleport. With the exception of seven miles between Littleport and Southery, the remaining twenty-six miles is fairly typical of English roads, the grass margin varying in width from only a few inches to several feet, with many ditches and banks. Between Littleport and Southery the route follows the course of the River Ouse, the level of which is generally above that of the surrounding country. The roadway is cut in the side of a high river-retaining bank and the consequences of a break in this bank would have been so serious that it was considered undesirable to disturb in any way the soil on the river side of the road. The roadside remote from the river slopes fairly steeply to the level of the surrounding country, which is, on an average, about 10 feet below the road surface. The methods used in this particularly difficult section are described below.

During the preliminary survey it was decided to lay the cable in the bank on the field side, but before cabling work could be commenced the road authorities decided to widen the road in this section. The river was dredged and the resultant sludge deposited on the bank to raise it to the level of the road, thereby covering the proposed cable track to a depth of three feet. It would have been dangerous to the cable to lay it in the sludge, which takes a matter of eighteen months to settle in position, because of the liability to strain during the settling period. On the other hand, the depth of the virgin soil below the sludge placed it out of the reach of the moledrainer. The cable was therefore laid in a shallow trench, excavated by a plough, in the narrow strip of land between the foot of the bank and the boundary of the adjacent field. At a few points along this section of the route buildings extend to the line of the existing public road and at these points the cable had to be diverted round the buildings and laid in the virgin soil beneath the sludge.

The sub-soil varies in quality and texture between gault, clay, sand, gravel, and peaty loam. The route leaves Cambridge by two miles of made-up footpath, skirts the village of Waterbeach, and passes through Stretham, Ely, Littleport, Southery, Hilgay and Downham Market, entering Kings Lynn by 1½ miles of made-up footpath. Ordinary lead-covered cables were drawn into spare duct space through these towns and villages with the exception of Stretham and Hilgay. Local line development was not sufficient to justify the provision of ducts through the latter two villages.

A pole route exists along the whole distance of forty-six miles and the positions made spare as the result of diversions to the trunk cable will be utilised for local junctions and subscribers' line requirements. This open line carries an average of forty-two wires and fairly extensive rebuilding operations would have been necessary to make it suitable for the erection of an aerial cable. Moreover, the London-Brighton aerial trunk cable had already supplied data regarding trunk line aerial cable construction and it was desired to obtain comparative data of the armoured cable method.

The conditions thus far described were considered favourable to the initiation of an experiment which would provide the required data, and arrangements were made accordingly. With the exception of the lengths required to be drawn into ducts, the cable was armoured to the following specification :—

"The continuously lead-sheathed cable to be passed through a bath of bituminous compound and immediately lapped with compounded paper. The cable again to be compounded and served with sufficient compounded jute to form a bedding at least 0.060 inches thick. A compounded mild steel tape 0.030 inches thick to be applied with an open lay, the gaps being not greater than 25% of the width of the tape, and a similar tape applied evenly over the gaps left by the first. A coating of compound to be applied immediately after armouring and the cable served with sufficient compounded jute yarn to form a covering at least 0.060 inches thick and again compounded. The completed cable to be whitewashed to prevent adhesion between the coils of cable on the drum."

The extra cost of armouring and protection per mile may be determined approximately as follows:—

	Cost per mile.
	£
With 0.02″ tapes	(D × 40) + 30
,, 0.03″ ,, ...	(D × 44) + 30
,, 0.04″ ,, ...	(D × 48) + 30

where D is the diameter of the cable in inches measured on the lead sheathing.

0.02″ tapes are used on cables up to and including 0.75″ diameter.
0.03″ tapes are used on cables up to and including 1.5″ diameter.
0.04″ tapes are used on cables above 1.5″ diameter.

EARLY EXPERIMENTS.

It is convenient at this stage to refer to previous efforts directed to the laying of cables by machine methods, although they were not brought to the authors' notice until the successful completion of the experiments hereinafter described.

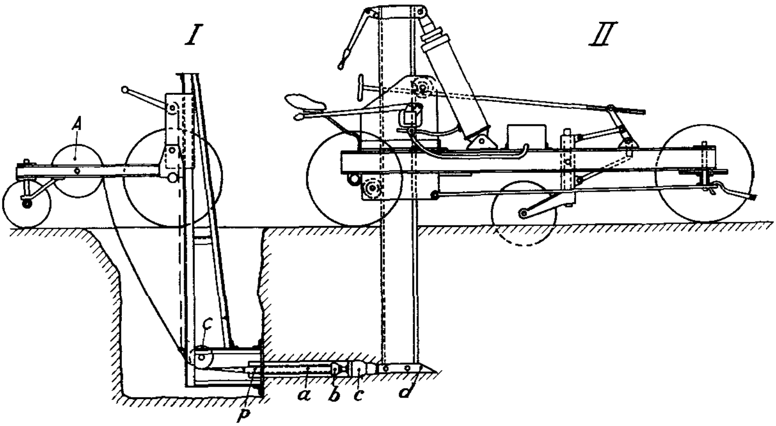
The use of agricultural implements for cabling works can apparently be traced as far back as the time of the Crimean War, for in Vol. XXIV, of *The Post Office Electrical Engineers' Journal,* there appears a drawing showing a plough being used for the purpose.

In Vol. XIV, July, 1921, of the same Journal, reference is made, on page 89, to the use of a modified drainage plough for laying the earth network at Leafield Wireless Station and we are indebted to Mr. R. E. Hughes, who was engaged on that work, for the following additional information. The implement used comprised a plough from which the plough shares were removed and a knife edge coulter and torpedo-shaped mole substituted, thus forming in effect a mole-drainer. This was hauled backwards and forwards across the fields by two traction engines hauling on steel ropes attached to the moledrainer and the wires forming the earth network were drawn in behind the mole. It was estimated that a saving of £500 was effected on that work.

Of more recent date is the experiment carried out in the North Eastern District whereby about a mile of trench for a protected cable was excavated in a wide level grass margin by means of a plough and tractor to a depth of 12″ below ground level. (*P.O.E.E. Journal,* Vol. XXIV, April, 1931).

An article by Mr. R. Borlase Matthews, M.I.E.E., in the *Electrical Review* of July 17th, 1931, refers to a tube-forming machine, which, when used in conjunction with a moledrainer, forms a strip-steel tube around the cable as it is drawn into the ground.

Fig. 2 illustrates the construction of the machine. *cd* is



I. TUBE FORMER II. MOLEDRAINER.

FIG. 2.

the mole itself, the grip for the tube being at *b* and the tube itself at *a*. The supply of strip sheet steel is held at the drum at A, and this passes over the forming roller C, and is finally shaped into the complete tubing at the point *p*. The portion of the apparatus marked I in the diagram remains stationary, while the portion II, which is the moledrainer proper, is drawn forward.

Early in January, 1932, the first experiments were commenced on the Cambridge-Kings Lynn route using a small plough drawn by three horses, the maximum net depth attained being about 12 inches. To secure this depth with a horse-drawn plough it was necessary to traverse the ground three times in the same direction, two adjacent parallel furrows being ploughed so that the earth thrown up from the second furrow was accommodated in the first, leaving a clean furrow which was deepened at the third cut. Manual labour was employed to deepen this further to 18″ and the method showed a saving of approximately 50% direct labour over manual labour throughout, the manhour costs, inclusive of filling in, amounting to 15 minutes and 30 minutes per yard respectively.

The savings foreshadowed by the adoption of such an elementary labour-saving device stimulated further investigation which brought to the authors' notice the implement known as a moledrainer. This type of implement—a simple and modified form of which is shown in Fig. 3—has been in

FIG. 3.

use for upwards of one hundred years for the drainage of land. It consists essentially of a framework or chassis to the lower side of which is attached a steel blade—or coulter—of anything up to 24″ working length and 1″ thickness. At the bottom of the coulter is a solid steel cylinder—or " mole "—3″ in diameter having a wedge-shaped nose.

The implement is held vertically as shown and is hauled either by horses or by a tractor *via* the hawser shown in the bottom right hand corner of the illustration. As it moves forward the weight of the implement combined with the burrowing action of the wedge-shaped nose causes the mole to force its way into the earth to a depth limited by the chassis sliding along the ground and leaves a natural drain of up to 3″ in diameter according to the size of the mole. Conical enlargers may be fitted to the rear of the mole if a larger drain is required. So far as agricultural experience takes us the drain is very durable especially where hard soil or clay is concerned. Drains formed in this manner have functioned satisfactorily for as long as forty years and a life of ten years may be taken as a fair average. The slot made by the coulter closes naturally within a week or so of the work being done. Clay soil is considered the best for moledraining although the tractive effort required is comparatively large. Loose friable soils such as the Fen peat have insufficient binding properties to maintain a "drain," but do not prevent a cable from being drawn-in behind the mole. Whether the "drain" is formed by compression or by displacement of the earth vertically upwards or by both is not clear, but the indications are that displacement plays the larger part.

Experiments with a thrust borer have shown that where displacement is *not possible,* the drain collapses after withdrawal of the boring-rod and it is, in fact, claimed as an advantage of the thrust borer that where displacement is not possible the highly compressed local earth expands and grips the pipe or cable with a close and even contact. Where, however, vertical displacement *is possible,* that is, at comparatively shallow depths, then the drain remains open and it is on this fact that the successful operation of a moledrainer for drainage purposes depends. The earth can in fact be seen to heave into a shallow ridge about the coulter as the mole passes through the ground.

The point is of some importance in considering the economics of armoured cable laying, in that, if the drain is formed by displacement, it will remain open and permit of the withdrawal of the cables for their scrap value at the end of their useful life. On the other hand, if the drain is formed by compression, the cable may be held so firmly that the recovery of the cable may prove uneconomical. In order to test this point arrangements have been made for several lengths of scrap cable to be laid by the moledrainer in various soils and at a later date an attempt will be made to withdraw them.

APPLICATION OF THE MOLEDRAINER TO ENGINEERING REQUIREMENTS.

The implement has an obvious potential use for cabling works in that it provides a single-way natural conduit. The problem at the time was to devise a means of introducing the cable into the conduit. It was by no means certain that the drain would remain open to permit of the drawing-in of cables in the normal way, as the use of a draw-rope might conceivably damage the drain and cause a blockage, especially in loose soil. The fact that the slot closes in naturally as soon as the implement has passed ruled out any idea of introducing the cable into the drain *via* the slot, and the last remaining method, other than lining the drain, was to draw the cable behind the mole.

At first sight this appeared to entail considerable risk and in the absence of any data or previous experience on the subject recourse had to be made to experiment. Accordingly, a well-known firm of agricultural engineers, Messrs. Ransomes, Sims & Jefferies, Ltd., were consulted in the matter and, thanks to their enthusiastic co-operation a series of trials was arranged to take place on their testing ground at Ipswich. Messrs. Ransomes, Sims & Jefferies provided the moledrainer and a caterpillar tractor, and the first experiment was made with a 160-yard length of lead-covered Cable P.C.T. 50 pair/10 lb., preceded by a 3-yard sample of 122 pair/10 lb. protected and armoured cable.

The results of the trials, which were carried out in ground of a moist sandy nature, were entirely satisfactory. They showed that the cables mentioned could be drawn through the ground behind the moledrainer at an average depth of 20″ for a distance of about 500 yards, including bends of 30 feet radius, without visible signs of damage either to the lead sheath of the unarmoured cable or to the protective covering of the armoured cable.

Dynamometer readings of the tension varied between 23 cwt. and 30 cwt. when measured between the tractor and the moledrainer (*i.e.*, the total draw-bar pull required of the tractor), and only 3.5 cwt. when measured on the cable itself. The latter measurement was obtained after the cable had been drawn in, by coupling the dynamometer between the cable end and the tractor and measuring the maximum pull required to withdraw the cable. Calculations based on these values, the tensile strength of copper, the weight of the cables, a deduced coefficient of friction and a Factor of Safety of 2, indicated that at least a standard length of the largest size cable required on the Cambridge-Kings Lynn route, namely, 122 pair/10 lb. armoured cable, could be drawn in without exceeding the elastic limit of the copper.

It should be emphasised at this point that the strain on tape-armoured cables, when drawing them into a duct (natural or earthenware), is greater than when drawing in ordinary lead-covered cables, as the strength-to-weight ratio for the former is relatively less, the strength of the cables being mainly dependent on the cross-section of the copper.

Encouraging as these results were, the evidence was scarcely sufficient to justify the application of the method to an extensive work without further details as to the tensile strength of the cable and the effect of the strain upon its electrical characteristics. The experiments had been conducted in one class of soil only, and under the best possible conditions in an open field. Samples of the cable were therefore subjected to tensile tests by the Post Office Engineering Testing Branch at Birmingham and in the meantime authority was given for a test on a 512-yard length of 122 pair/10 lb. armoured and protected cable along a section of the proposed route—the test to be carried through to destruction if considered necessary.

Fig. 4 is a general view of the trial in progress and illustrates the caterpillar type tractor and the Ransome moledrainer which is equipped with a self-lift and depth-adjustment mechanism. Fig. 5 is a view of the cable in the drain as seen from a pilot hole. The slot and the drain are clearly visible and it will be noticed that the whitewash is still adhering to the cable despite the fact that it had been hauled through the ground for a considerable distance.

The tensile tests on a sample of the cable indicated the maximum safe pull to be 25 cwts. and, to ensure that this tension was not even momentarily exceeded, a "mechanical fuse" of 7/14 G.I. wire, having a breaking load of 21 cwt., was inserted between the cable end and the mole.

Pilot holes were dug at 50 yard intervals to reveal the presence of obstacles and to permit observation of the cable during its passage through the drain. The cable was then pulled in at an average depth of 24 inches in a subsoil of sand and stones until the mechanical fuse broke. The length thus drawn in was 312 yards. The total draw-bar pull varied between 2.5 and 3.5 tons, the maximum pull on the cable, as determined by the 7/14 G.I. fuse, being 21 cwt.

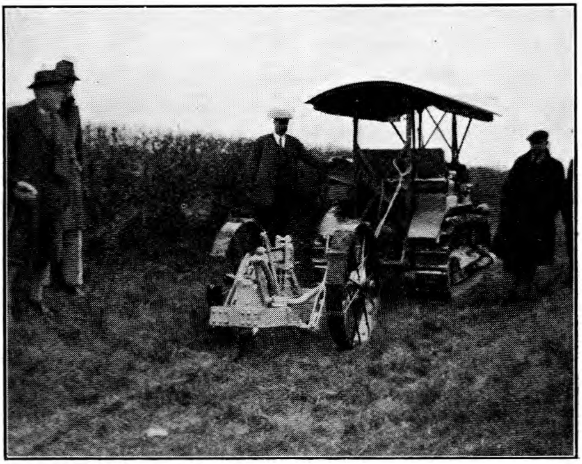


FIG. 4.

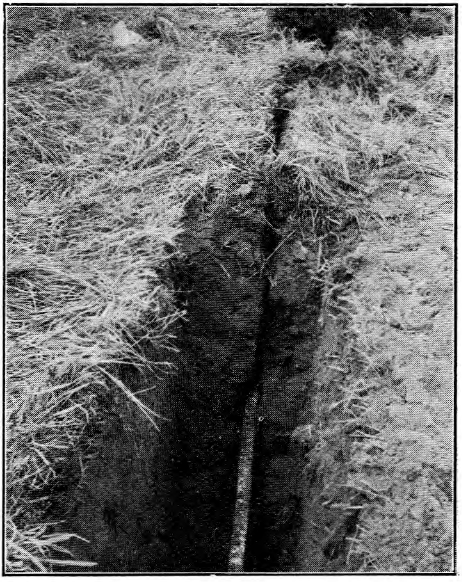


FIG. 5.

Tests for insulation resistance, loop and unbalance conductor resistance and capacity unbalance were taken both before and after the experiment, and a comparison of the results showed that the electrical characteristics had not altered sufficiently to give rise to any feeling of disquiet. It may be of interest to note in passing that the out-of-balance and mutual capacities of cables are modified quite appreciably by drawing them into ducts.

Prior to the foregoing trials some doubt had been expressed as to the safe utilisation of the moledrainer, and this paper would be incomplete without some reference to the efforts which were made to design a cable-laying machine which would enable the cable to be laid directly into the ground at a depth of 24″ without being subjected to tensile strain.

During the course of the experiments with the horse-drawn plough it had been noticed that there was a tendency for the earth to fall back into the furrow, indicating the need for two side plates behind the cutting blade, which would support the earth whilst the cable was fed or dropped into the ground between the plates. The cutting blade was formed from two $\frac{1}{2}$″ mild steel plates suitably bent and welded and fixed to a skid chassis. It was intended that the shape of the cutting edge, together with the weight, some 7 cwt., should secure the necessary digging action, but this was more than counterbalanced by the reverse moment of the earth resistance about the front skid plate. The machine would only cut its way through the ground at a depth of a few inches and, moreover, the tractive force required exceeded 5 tons, the maximum available capacity of the tractor. The minimum overall width required for the accommodation of the cable was $2\frac{1}{4}$″ and this proved too great for an effective cutting action, the effect being to raise the earth into a ridge rather than to compress it.

It was then evident that the coulter described above formed a very inefficient form of excavator and the next machine, illustrated in Fig. 6, was designed specifically to excavate a narrow trench, about 3″ in width, into which the cable could be dropped. This implement comprised a pair of disc coulters, spaced $3\frac{1}{2}$″ apart, followed by a pair of knife coulters, also spaced $3\frac{1}{2}$″ apart, thus enabling (in theory) a strip of ground to be cut and isolated. The coulters were followed by an inclined plane with deflectors at the top and

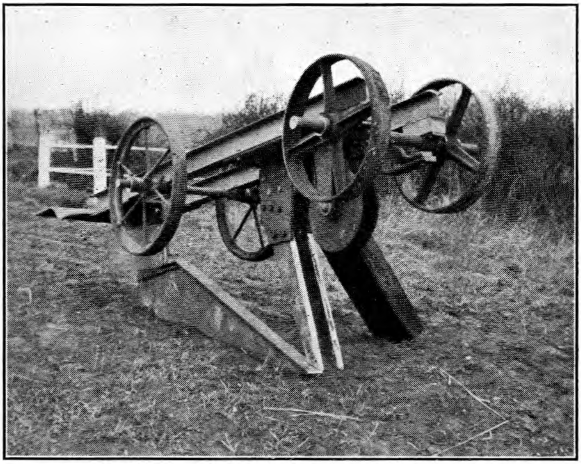


FIG. 6.

it was intended that as the machine proceeded the isolated earth would slide up the inclined plane and be deflected to form a ridge on either side of the trench. In practice, however, it was found that the ground was " chewed up " rather than cut and that, again, the moment of earth resistance exceeded the digging action. Moreover, the earth wedged the coulters apart.

Various modifications were made to overcome the difficulties and in its ultimate form a chassis of twice the length was used, the disc coulters being discarded, and the knife coulters staggered longitudinally and welded by means of spring steel to the lower edge of the inclined plane. This design fulfilled its purpose, but required a tractive effort of not less than 5 tons.

An example of the successful application of the " threading through the plough " principle appears in the Bell Telephone System's Monograph No. B.645, wherein is described an outfit which, in one operation, cuts a slot through the ground, throwing out earth on either side; lays the cable *via* a pipe extending from the cable drum into the ground; and, by means of a " back-filler " or reversed ridging plough, draws the disturbed earth back into the excavation. It appears that two, and sometimes three, tractors of the heavy caterpillar type are required to haul the outfit and the amount of room which the outfit must necessarily occupy limits its use to cross-country work and perhaps the widest of grass margins. It is also difficult to imagine any other uses to which these tractors could be put by this Department when not required for cable-laying; and the cost of the idle capital would be considerable. As will be seen later in the paper due consideration has been given to this aspect of the mole-draining method.

CHOICE OF TRACTOR.

Reference has just been made to one disadvantage of the caterpillar type tractor, viz., the necessity for finding other suitable employment when it is not engaged in cable-laying work. In addition to this it has a comparatively high prime cost and it is not always possible to run such a large vehicle along grass margins, or along sloping banks and other places which are accessible to the moledrainer. In consequence, attention was directed to a tractor-winch combination comprising a Fordson tractor equipped with a winch and self-anchoring device. Suitable controls permit of the engagement of the power unit with either the road wheels or the winch. The tractor-winch is driven forward a distance of about 80 yards to a suitable anchorage, and meanwhile the steel hawser, which is attached to the moledrainer, is paid off the winch. The power unit is then coupled to the winch and haulage commences. As the hawser is taken up on the winch the tractor is pulled backwards, but in so doing digs its anchors into the ground. The tractor now being anchored, further winding of the winch hauls along the moledrainer.

Fig. 7 illustrates the first of this type of tractor-winch employed on the Cambridge-Kings Lynn work. It will be observed that the tractor is of the agricultural type and that the winch is fitted at the rear. The heart-shaped anchors are not visible in the illustration as they are buried in the ground beneath the horizontal plate which can be seen at the bottom left of the picture. This plate and the anchors form one unit which is hinged to the framework of the winch.

Although this type of tractor-winch was very successful and was, in fact, used for the greater part of the work, yet it possessed certain disadvantages for cabling works. It was found necessary to have a workman in continuous attendance to guide the hawser on to the winch and overcome its tendency to ride up coil upon coil. Unless corrected this riding of the hawser resulted in severe strain on the whole outfit when the hawser slipped.

The anchors being fitted at the rear of the machine had a tendency to jack up the rear wheels during the anchoring operations. Thus, when it was desired to drive the tractor forward again, the rear wheels, which are the driving wheels, required to be fed with material before they could obtain a grip—the anchors only being withdrawn as the tractor moves forward.

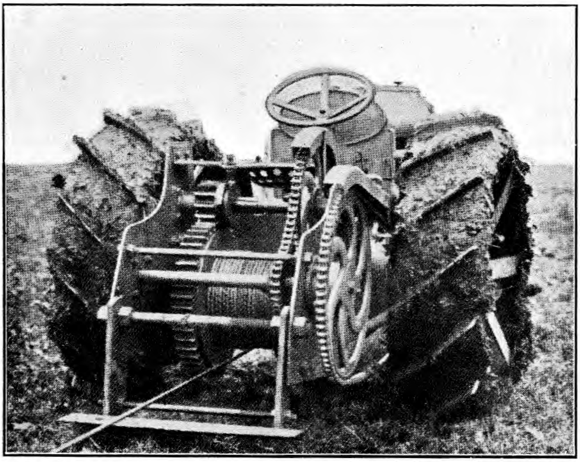


Fig. 7.

It is most important to make sure that the hawser is taut before the pull commences, otherwise there is danger of it becoming entangled in the gear wheels. This, in fact, happened on two occasions, the first being due to the inexperience of the driver, who commenced winding with a slack hawser, and the second to the hawser jumping after breakage of the mechanical fuse which was inserted between the moledrainer and steel hawser. Added to these disadvantages was the fact that the winch would not fit an industrial type tractor, a matter of considerable importance.

The industrial type tractor is fitted with pneumatic tyres and is capable of hauling heavy loads at a road speed of 15 miles per hour, and therefore can be usefully employed for general haulage when not required for cable laying works. In addition, it has potential uses for drawing cables into ducts, whereas it would not be advisable to bring an agricultural type tractor into towns. Attention was therefore directed to a type of winch suitable for attachment to an industrial tractor, and Fig. 8 illustrates the Fordson Industrial Type Tractor, fitted with a self-anchoring chassis and winch, which is manufactured by the Auto-Mower Company, of Bath. The anchors consist of two I-sections, one of which can be seen in the figure. These are controlled by the long lever to the right of the driving seat. In soft ground these

FIG. 8.

anchors do not, however, give sufficient bearing surface, a difficulty which has been overcome by fitting steel plates to them.

Fig. 9 is a rear view of the outfit showing the rollers which serve to guide the cable to the winch and assist even winding of the hawser on to the winch. The rearward movement of the tractor when anchoring is liable to cause clogging of these rollers with earth, with the result that the rollers and the hawser are subjected to heavy wear and their effective lives are shortened. Hardened steel rollers have now been fitted in an effort to minimise the wear. A set of wheel cleats has been supplied with the outfit for use in soft ground, but

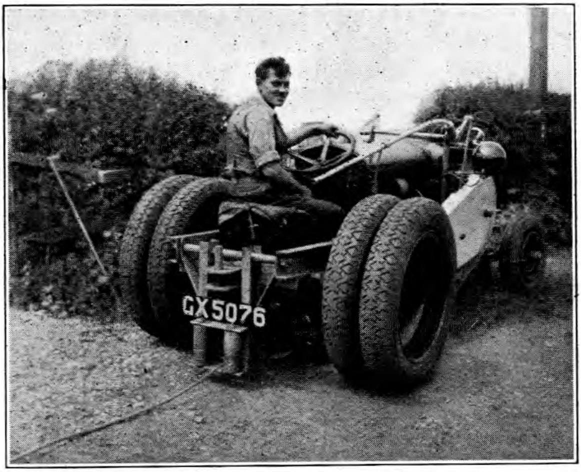


FIG. 9.

so far it has not been necessary to bring them into use. One or two minor adjustments and improvements were found to be necessary, including the addition of a driving mirror which enables the driver to see that the hawser is winding on the winch satisfactorily and gives him warning when the total length of hawser has been paid out. A jockey pulley has also been fitted to permit adjustment of the main winch driving chain. Even with this type of winch it is still absolutely necessary to ensure that the hawser is taut before the winding commences.

ORGANISATION OF A TYPICAL WORK.

The survey.

In making the survey for laying an armoured cable by the moledrainer method the usual requirements of an underground survey have to be met and, in addition, a few others which are worthy of special mention. The foremost of these is the determination as far as possible, of the sections in which the moledrainer is to be used. This is largely a matter of experience and of the design of special appliances to facilitate the negotiation of difficult conditions. The following remarks will, it is hoped, indicate the general principles and serve as a guide. It is not possible to lay down hard and fast rules and it follows that only by the accumulation of further experience will all the potentialities of the method be realised.

The experience gained on the Cambridge-Kings Lynn cable showed that the large Ransome moledrainer, which is 4 ft. 4 inches wide, is the more effective type, but in narrow margins a smaller moledrainer about 12″ wide is necessary and a model known as the "Little Wonder," slightly modified, has been successfully employed. The larger implement can be worked at a depth of 24″ or less, but if full depth is required in a narrow margin and the "Little Wonder" is to be used, a furrow 10″ deep must first be ploughed by means of a deep-digging plough. The smaller implement, having an effective coulter length of 15″, is then drawn along the furrow. Further modifications are, however, being made to this small moledrainer which will enable it to work at 2 ft. depth without the aid of the plough.*

Suitability of soil.

At the present stage of development it is not possible to quote experience of every class of subsoil likely to be met, but with the safeguards provided it is reasonably safe to try the method in any but very stony or very loose soils. The soil on the Cambridge-Kings Lynn route was mostly sand and loam mixed with small stones and occasional patches of gault and peat. Clay is an admirable medium in which to make the drain and, in general, the closer the texture of the soil the better the drain and the absence of jamming by falling earth. Most trouble was experienced with the loose black Fen soil which had insufficient binding properties to maintain a clear drain. Collapse of the drain was so frequent in this soil that the resultant jamming caused the mechanical fuse to break repeatedly when only 150 yards of cable had been drawn in. One cause has been appreciated and the subsequent provision of a torpedo-shaped protecting sleeve for the mechanical fuse has to some extent remedied this drawback. Its precise application and use are discussed later.

Hidden obstacles.

It is surprising how readily the coulter of the moledrainer will cut its way through or thrust aside small roots and

* Since the foregoing was written it has been found that to work at 2 ft. depth with the "Little Wonder" type a stronger framework is required.

buried stones. On one occasion a buried stay-block in sound condition was split in two by the coulter without damage to the implement. On another occasion a lead service water pipe was not only severed, but the ends were automatically sealed by the coulter and the fact was not revealed until the householder concerned was perturbed to find his usual water supply had been cut off. This illustrates, of course, the need for very careful enquiry into the presence of other Undertakers' plant. It is not pleasant to imagine what the results might have been had a high tension power main occupied the position of the water service in the case quoted.

The moledrainer has successfully cut its way through and laid cable beneath gravel and tar-sprayed paths even when these have had a foundation of 2″ stones. In such circumstances a certain amount of reinstatement is, of course, necessary, but certainly not more than would have been incurred by the manual excavation of a trench. As a general rule, however, no reinstatement is necessary to grass and other unmade surfaces.

Depths and road-widening considerations.

For sections in which it is clearly possible to use one or other of the moledrainers, consideration of depth will not normally enter into the calculations, because in the majority of soils the moledrainer will function just as smoothly and efficiently at the greater depths, say 2 ft., as at the shallow depths.

Occasionally, soils will be encountered which are so hard as to require a pull beyond the capacity of the tractor. In such cases, and providing other conditions permit, a reduced depth may solve the difficulty. When, however, it is clear that manual methods must be employed then the question of depth has an important bearing on the costs.

At roadway crossings and under footpaths in villages and small towns in which other Undertakers are liable to carry out works involving road-opening, it is desirable to provide standard cover as it might be difficult to prove negligence on the part of an Undertaker's employees if they damaged a cable laid at less than standard depths. On the other hand, at places where there is little likelihood of frequent road openings—as, for example, along the margins in rural districts, the question of depth is not so important. Probable future road-widening is the factor which will influence the decision and, in this connection, it should not be overlooked that an armoured cable is not as liable to damage by crushing as a duct and that shallow depths may therefore be accepted where there is no reasonable probability that road-widening will be carried out during the anticipated life of the cable. If, however, at some future date, unforeseen road-widening operations should extend to a line of cable laid at shallow depth, it would be a relatively simple and inexpensive matter to slew or lower the armoured cable as compared with a line of ducts. The Present Value of the cost which would then be involved would, in many cases, prove less than the additional cost of providing extra cover at the outset.

In the open country, manual excavation can be limited to 12″ cover in grass margin and to as little as 9″ cover on banks sloping down from the road and at the foot of such banks. There can be no traffic over these banks until the road is widened, and if and when this takes place, the additional material required to level the road will provide cover of at least 2 feet.

Course and position of route.

No serious difficulty need be anticipated in keeping the cable track reasonably straight as, with careful guiding of the hawser, it is possible to keep to within six inches of a prescribed course either on the straight or around bends.

The left-hand side of the section of route illustrated in Fig. 10, is an example of a difficult position in which the moledrainer method was successfully employed.

The moledrainer itself can be used on quite steep banks, providing safe anchorage can be found for the tractor. There is no serious tendency for the moledrainer to overturn under such conditions, because the buried mole serves as an effective anchor against lateral instability. A fairly level foundation must, however, be found for the tractor, or it may overturn into the ditch when it takes up the load. There is a tendency for the front of the moledrainer to face down the bank and this must be counteracted by pulling upwards on a rope attached to the front part of the implement. Cables have been laid by this method in banks making an angle of 40 degrees with the horizontal.

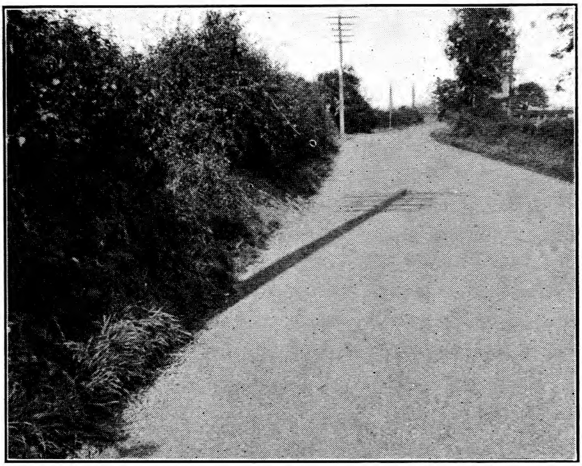


FIG. 10.

The proximity of the cable track to the edge of the made-up road is a matter which must be considered in conjunction with the methods available. If manual labour must be employed, then, unless the filling in is thoroughly consolidated, there is a risk of seriously weakening the road support. The aim will be, therefore, to keep as far away from the edge of the road as possible and, unless a clearance of not less than 2 ft. can be given, it may prove advisable to cut the trench in the road itself well away from the edge.

On the other hand, if a moledrainer can be used, there is very little disturbance of the earth, and, if a tractor is run over the track, such earth as has been displaced vertically will be rammed back into position and the original strength of the support maintained.

Methods for the more difficult sections of route.

Work at road crossings under expensive pavings and at level crossings should be carried out with the thrust borer which has very obvious advantages over other methods. It has been suggested that the thrust borer could be used to draw armoured cable under road crossings and the idea is worthy of consideration. The pilot hole would be bored in the usual way, the cable attached to the enlarging head and drawn back under the crossing in place of the usual fibre ducts or pipes. Jointing would be avoided by coiling the cable in a " figure of eight " at the edge of the road, prior to the end being attached to the thrust borer. Any other method involves opening the road at high cost, with the attendant reinstatement charges as well as obstruction of the road. The risk of hidden obstacles is negligible in rural districts.

If a thrust borer is not available, or if, for any other reason, this method cannot be adopted, the use of stout timber to protect the cable over half the width of the road may be considered. One half of the road can then be excavated whilst the remainder is kept open to traffic which will pass over the timber beneath which lies the cable.

At many places along the route of the Cambridge-Kings Lynn cable, grips had been cut across the grass margins for surface water drainage. They varied from three to ten inches in depth, increasing to fifteen inches at places where the margin was above the level of the road, but as they were quite narrow the tractor and moledrainer rode over them without sinking more than an inch or so. In order to guard against the operations of roadmen engaged in keeping the grips clear, 3″ × 1″ creosoted strips or recovered arms were used to cover the cable passing under the 15″ grips.

The presence of uneven contours need present no great difficulties. Provision should be made for levelling out very abrupt contours, as it will be realised that, since the mole and therefore the cable must of necessity follow the contour of the surface, abrupt changes will increase the friction and therefore the tension on the cable and its mechanical fuse and may cause the latter to break before the required length has been drawn in.

Bends in the route can be negotiated by guiding the moledrainer in a manner to be described later and their presence need not influence the decision as to the method to be employed.

Entrances to fields should generally be piloted to ascertain the nature of the foundations. If, as is often the case, the surface dressing is only an inch or two in thickness and the foundation does not consist of large stones or bricks, the moledrainer will cut through without difficulty.

Where a cart entrance having a hard foundation, which must be manually excavated, occurs in a section otherwise suitable for moledraining, the required trench should be excavated in advance of the moledraining operation and the moledrainer guided along the trench through which it pulls the cable before continuing on its way through the ground in the normal manner.

The presence of big trees may influence the course of the route considerably. Although the moledrainer is not stopped by small tree-roots and stones, the presence of large tree-roots is liable to impede progress; and the roots, if they spring back after the passage of the mole, may grip the cable itself. In such cases the extent of the trees and the conditions on the other side of the road will influence the decision as to whether a road crossing shall be made or manual labour employed to excavate a trench past the trees.

There appears to be no great objection to the cable being laid by means of the moledrainer at the bottom of a ditch if this is the only alternative course to excavation in the made-up roadway. Admittedly jointing work, if carried out during wet weather, may require special measures for diverting the flow of water, but nevertheless the net saving in cost would be very considerable.

No experience is as yet available of works carried out under these conditions, but it is anticipated that a work will shortly be commenced where the above conditions apply over a large section of the route, and the experience to be gained during this work will no doubt prove most interesting and valuable.

Bridges along the route require to be dealt with on their merits. In one instance the bridge concerned, although of comparatively recent construction, showed signs of rapid deterioration and it was considered inadvisable to interfere with the structure in any way. Aerial cable construction was therefore adopted, the cable being led out of the ground in a continuous length *via* stays, stiffening channels, capping and barbed wire protection, to the poles and thence through the cable rings. At other bridges, where cover was insufficient to lay the cable in the normal manner, 2″ wrought iron pipes were first laid and covered with concrete, the cable then being pushed through the pipe. This was considered preferable from a maintenance standpoint to concreting over the actual cable.

The choice of cable lengths and jointing points.

The determination of cable lengths, as measured between jointing points, and the number of such lengths is dependent on the following considerations:—

(1) Maximum lengths which can be conveniently manufactured.
(2) Maximum lengths which can be accommodated on standard drums.
(3) Maximum lengths of each size of cable which can be drawn in by the moledrainer with safety.
(4) Division of the loading coil section into a number of equal cable lengths.
(5) The minimum number of systematic joints per loading coil section necessary to the reduction of overall cross talk to the desired standard.

(6) Allowances for:—
 (*a*) Deviations of the actual route from the measured route: 1% is usually sufficient.
 (*b*) Jointing—four feet per cable length.
 (*c*) Scrapping the end which had been used to couple the cable to the moledrainer. This may be taken as two feet per pull and, if the "figure of eight" method (as described later) is to be employed, then two pulls per length are involved.
 (*d*) For lengths adjacent to the loading coil, one yard additional for testing purposes.

(7) Inequality of lengths resulting from irregular spacing of loading and jointing points. This may, of course, be necessary to secure practicable jointing positions.

It is at once apparent that considerations (1)-(5) must be settled before the detailed survey and chain measurement. Of these, (3), (4) and (5) will decide what may be termed "The unit length," that is to say, the length which will most nearly satisfy these three considerations and which, except when employing the "figure of eight" method, will be the length between jointing points. In the case of the "figure of eight" method, there will be two unit lengths in one continuous length of cable.

During the detailed survey these unit lengths should be chain measured, and the jointing and loading points numbered consecutively from end to end. At each of these points a numbered and coloured stake should be driven into the ground, different colours being used to distinguish between (*a*) loading points, (*b*) other jointing points, and (*c*) the mid-point of a " figure-of-eight " length. The precise landmark description of each of these points should be noted in the survey book for record purposes and to facilitate identification of the point should the stake become lost.

At the time of ordering the cable for the Cambridge-Kings Lynn work no decision had been reached on the use of labour-saving devices and the lengths were ordered to meet the requirements of manual methods and therefore without reference to the capacity of the moledrainer. The experiments had shown that the maximum draw-in must not exceed 312 yards of 122pr/10 cable, whereas the cable had been ordered in drum lengths of 522 yards, or four drums per loading section. It was therefore decided to lay this cable in separate lengths of 261 yards, *i.e.*, two per drum length, thus keeping the stress on the cable well within its elastic limit and at the same time equalising lengths between jointing points.

It follows that in each 522 yards of cable the moledrainer method involved one joint additional to the number which would have been required by manual methods, *i.e.*, laying the cable in an open trench. On the other hand, the additional *systematic* joint increases the degree of separation of the quads and should result in reduced overall cross-talk. Little credit can, however, be allowed for this refinement, as it is probable that systematic joints at 522-yard intervals would have given the desired standard, except for the adjacent three loading sections on either side of amplifier stations, where not less than five systematic joints per loading section were considered necessary.

The smaller size cables had been ordered in 666-yard lengths, or three drums per loading section, that is, more than double the maximum length which could be pulled in safely, and it might appear that at least two, if not three, joints would have to be introduced into each drum length. This was rendered unnecessary by the use of the " figure of eight " method, which may be described as follows:—The drum of cable is placed at the centre of a 333-yard section of route and 166½ yards pulled through the ground towards the last laid cable length. On completion of this operation another 166½ yards is paid off the drum and coiled in a figure of eight. Thus a total of 333 yards of cable, sufficient for the section of route concerned, has been paid off the drum. The cable is cut and the drum containing the remaining 333 yards moved to the centre of the adjacent 333-yard section. Meantime, the coiled length of 166½ yards is drawn through the ground by the moledrainer in a direction opposite to that in which the first 166½ yards has been drawn. In this manner the 666-yard length is laid with only one intermediate joint. The principal objection to the method is the difficulty in determining without careful measurement the exact point at which to cut the 666-yard length, and in ordering cable for another work it would be advisable under such circumstances to specify drum lengths of 333 yards. Furthermore, it is understood that the cable contractors would have preferred to manufacture the cable in the shorter continuous lengths. The drums containing the somewhat long lengths were, however, conveniently handled with the aid of the cable bogie and tractor illustrated in Figs. 3 and 11.

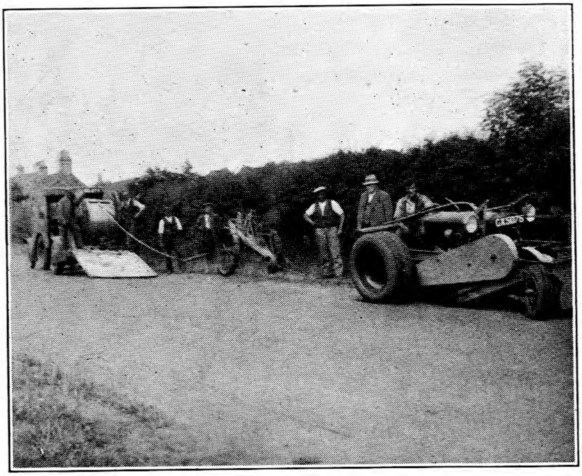


FIG. 11.

Cable deliveries.

Delivery of the cable to the site of the work was put out to contract and the fact that the jointing points had been numbered and staked simplified the delivery arrangements. Delivery instructions were accompanied by a schedule detailing the drum numbers, the relative stake numbers and landmark descriptions.

The survey record.

A loose-leaf book has proved a most convenient means of detailing survey particulars, each page being faced with a 6″ scale map of the section of route concerned. Provision should be made for the entry of the undermentioned particulars:—

(*a*) Proposed depth, course and position of track.
(*b*) Method likely to be employed.
(*c*) Notes regarding Council consents, special stipulations or other wayleave matters.
(*d*) Presence of Undertakers' plant or other obstacles.
(*e*) Reference number and landmark description of jointing and loading points.
(*f*) Length, type and size or cable.
(*g*) Relative drum lengths ordered.

In addition, a record of the following matters for each cable or loading section will be of considerable value during the progress of the work:—

(*a*) Drum numbers advised.
(*b*) Delivery instructions furnished.
(*c*) Drums delivered.
(*d*) Cable laid.
(*e*) Empty drums collected.
(*f*) Completion of each joint. Jointer's name.
(*g*) Loading sections tested.
(*h*) Loading pots installed and jointed. Jointers' names.
(*i*) Notes regarding deviations due to unforeseen circumstances.

Records.

The information contained in the survey book is intended primarily to assist in the organisation and control of the work in progress. The subsequent maintenance of the cable demands a record of the precise position in which the cable has been laid and a works diary is a convenient form for recording the details as the work progresses. It should contain information on the following points:—

(*a*) Depth and precise position of the cable, jointing and loading points relative to hedges, ditches and roadway.

(*b*) A list of centre-to-centre lengths and a running summary of mileage from each joint to the main terminal station which will facilitate fault localisation at a later date.

Tools and Appliances.

The various tools and appliances required for the work are as follow :—

(*a*) The Department's cabling bogie and Rushton tractor as illustrated in Figs. 3 and 11.
(*b*) A "Ransome C.1" moledrainer (modified). Fig. 12.
(c) The "Little Wonder" moledrainer (modified). Fig. 3.
(*d*) A "Ransome Deep-Digging" plough. Fig. 14.
(*e*) An "Auto-Mower" winch and Fordson industrial tractor. Figs. 8 and 9.
(*f*) The Department's crane-lorry — only required during loading pot installations.
(*g*) Various accessories associated with the foregoing items, *e.g.*, mechanical fuses, portable anchor, etc.
(*h*) A number of draining tools or "skippets." These may be described as grafters having blades, only about 5″ wide, which can with advantage be used in cutting narrow trenches when resort has to be made to manual labour.
(*j*) The usual gang equipment for cabling works, with the exception of the hand winch.

All the foregoing items are now owned by the Department and are obtainable on loan.

In addition, a portable hut is required for records and for the use of the Inspector stationed on the work.

Fig. 12 shows the Ransome Moledrainer in the raised position. The essential part, common to all moledrainers, is a framework which carries a coulter or blade supporting a solid steel cylindrical "mole." The leading end of the mole is wedge-shaped, to produce a digging-in action, the mole being drawn down to the required depth as the implement is pulled forward. This is an important feature, inasmuch as, during cabling operations, the pull of the cable combines with the earth resistance to give rise to a moment about the front wheels which tends to lift the moledrainer

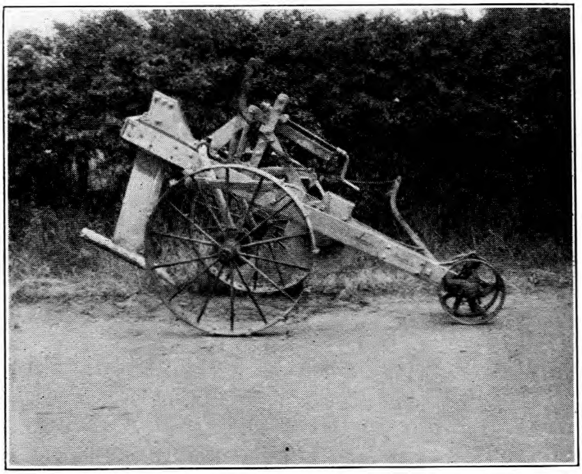


FIG. 12.

out of the ground. This lifting moment must be counterbalanced by the total weight of the implement combined with the digging-in action of the downward inclined wedge-shaped nose, and it has been found that a mole of not less than $2\frac{3}{4}''$ diameter is required to present a sufficiently large inclined area. Within narrow limits the digging-in action can be finely adjusted by altering the tilt of the mole relative to the chassis.

The remaining features of the implement illustrated are peculiar to the Ransome design, and comprise a self-lift mechanism combined with a simple means of depth-adjustment. The main framework is mounted on wheels *via* a cranked axle and the hubs of the wheels are provided with slots into which levers forming part of the self-lift mechanism can engage. At the front end is an adjustable bar for direct coupling to a tractor which takes the weight of the front end of the implement. When using a tractor winch, however, there is no such direct support and it became necessary to fit additional wheels, as illustrated.

The depth-adjustment is carried on a fixed and braced vertical, made up of two steel bars separated by distance pieces. At the junction of this vertical with its brace is pivoted a bell crank lever, the longer arm of which is connected by a rod to the forward control lever whilst the shorter arm bears on the under side of the depth-adjustment. A crank handle operating through a screwed rod and stop causes relative motion between the chassis and the wheels and so permits adjustment of the depth of the mole. Once this adjustment has been set, a release mechanism permits of the repeated lowering and lifting of the mole within the desired range, without further movement of the crank handle. The mechanism is locked in position relative to the wheels, and therefore the depth below ground level remains constant for a particular adjustment.

When it is desired to withdraw the mole, the rear control is pulled forward whilst the implement is still moving. Operation of this rear control engages its associated levers with the slots in the wheel hubs. The main frame is now pivoted about the wheels *via* these levers. As the wheels rotate with the forward movement of the implement the mole is dragged out of the ground until it regains the position shown in Fig. 12. The tension of a spring is then sufficient to bring about the release of the lever from the wheel hubs.

Fig. 3 illustrates "The Little Wonder," a narrow skid type moledrainer manufactured by Messrs. Darby & Co., of Wickford. The carbon steel coulter is reversible and can be adjusted to drain down to about 16 inches, but experiments are now being conducted with a lengthened coulter which it is hoped will permit of draining down to 2 ft. The wheels at the front end were fitted in place of a skid plate to reduce friction and overall width. The original mole was substituted by a larger one of $2\frac{3}{4}''$ diameter, having a wedge-shaped cutting edge in preference to the pointed nose of the original model in order to provide the required degree of digging-in action. To secure lateral stability it is generally necessary for the operator to keep the implement vertical by means of the long operating handle. To turn the mole out of the ground the operating handle is forced over sideways whilst the implement is moving whereupon the mole forces its way upwards. This method, however, is only practicable in fairly soft soil. Depth-adjustment is obtained by loosening the clamps and sliding the coulter up or down as required. The reduced width of this type of moledrainer makes it very useful in narrow grass margins, close to pole routes, and in other places inaccessible to the larger type, and despite its somewhat fragile appearance, it has stood up very well to a considerable amount of hard work.

Fig. 13 illustrates the implement in action and gives a good impression of the conditions under which it can be

FIG. 13.

successfully operated. The cable entering the joint hole can be seen on the extreme right of the photograph.

Fig. 14 is a view of the deep-digging plough which is

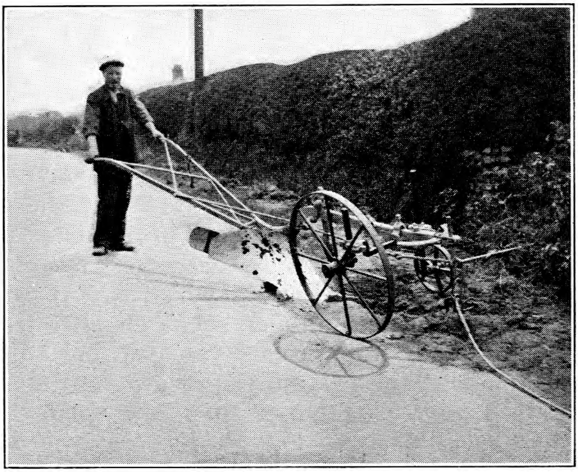


FIG. 14.

used for excavating trenches to a depth of about ten inches either for subsequent deepening by manual methods or to form a level track for the small moledrainer. This plough requires a draw-bar pull of between 20 and 30 cwt., which is within the tractive capacity of a 30-cwt. Albion Lorry. A mechanical fuse of two 7/14 G.I. wires should be used to safeguard the plough against hidden obstructions.

Fig. 15 illustrates the method of attaching the cable to the mole. The cable end is stripped of its armouring for a distance of about two feet, dressed and bent round and back through a swivel and bound with tape. The mechanical fuse links the swivel to a length of 7/8 G.I. wire connected to the mole, and over this coupling slides a fuse protection tube having a torpedo head. The drag on the tube is taken by means of a conical washer which bears against the make-off

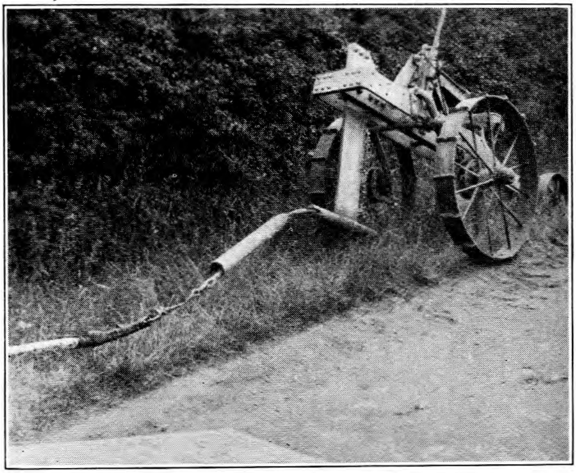


FIG. 15.

of the 7/8 wire. The provision of this tube was suggested as a means of minimising premature breakage of the fuse due to stones and loose earth falling in behind the mole. The torpedo tube transfers any resulting additional stress to a point in front of the fuse, which is therefore unaffected by partial collapse of the drain. It is, in effect, a second mole, which has the advantage of being practically continuous with the cable.

The method of attaching the fuse by means of thimbles involved some waste of time whenever renewal was necessary, and a small clamp was designed on lines similar to a stay clamp, to which the fuse wire could be quickly fitted. This method of make-off was found to be unreliable for fuses smaller than 7/14 wire due to difficulty in designing a clamp which would satisfactorily grip unevenly stranded wires. The original method of making off the wires around a thimble undoubtedly proved the most reliable, and it has now been suggested that a supply of such fuses should be made up in advance and held ready for fixing in position by means of keystone links.

The actual size of the fuse to be employed must be carefully determined for each type of cable and in this connection it is important to bear in mind that the tensile strength of the cable depends mainly on the cross-section of the copper. The lead sheath will contribute slightly towards the strength, but it is unsafe to place any reliance on the armouring. Under no circumstances, of course, should the fuse be omitted. The elastic limits of the four sizes of cable employed for the Cambridge-Kings Lynn work were 25, 22, 18 and 17 cwt. respectively, and the respective fuses were made of 7/14, 7/14, 5/14 and 4/14 G.I. wire. As already stated, 7/14 G.I. wire has a breaking load of about 21 cwt. and it is clear that the fuses employed provided ample margin of safety.

In the early stages of the work some difficulty was experienced in locating exactly the buried end of the cable after the fuse had broken and some effort was wasted in digging for it. A 7/14 G.I. pilot wire was therefore connected to the end of the cable, threaded through the slot made by the coulter and connected above ground level to a No. 8 gauge wire strand which in its turn was connected to the framework of the moledrainer. During the drawing in operation this pilot wire moved along the slot cut by the coulter. If and when the cable fuse broke the stress was immediately thrown on to the pilot wire which in turn broke at its weakest point, that is, the No. 8 gauge wire, leaving the remainder of the pilot wire projecting out of the slot exactly above the cable end. Unfortunately, however, the drag of the earth on this wire increased the pull on the cable fuse and caused it to break prematurely. Furthermore, after some experience, the driver of the tractor-winch was able to determine, by the sudden drop in the load, almost exactly when the cable fuse broke, and stopped hauling at once, so that the need for a pilot wire disappeared.

The hawser from the tractor-winch is connected to the moledrainer *via* a 7/8 G.I. mechanical fuse having a breaking load of $4\frac{1}{2}$ tons, thereby safeguarding the moledrainer against excessive strain should it encounter a buried obstacle. Connected in parallel with this fuse is a comparatively slack subsidiary fuse of 7/14 G.I. wire, the object of which is to absorb the inertia of the hawser should the main fuse break. This is essential in the interests of safety, for without it, the end of the hawser may jump as much as 20 yards, to the serious danger of any persons in the vicinity. It has been suggested that the subsidiary fuse should include a powerful spring and the suggestion appears worthy of adoption.

Occasionally it happens that the cable fuse breaks repeatedly when only a few yards of a cable length remain to be drawn in. This may be due to any of a variety of causes such as the inclusion in the track of a fairly sharp bend which increases the friction of the cable in the drain. The fuse must not be strengthened for obvious reasons, and if at all possible cutting the cable and drawing in the remainder as a separate length must be avoided. The difficulty may sometimes be overcome by digging at equal spacings a number of small holes over the cable track and placing one or two men at each hole. It is then a comparatively easy matter for them working in synchronism to man-handle the cable along the drain until it is all in position. Another but less successful method was to dig a short trench at the middle of the cable track and lash a rope to the cable. A number of men hauled at this point whilst the winch continued the hauling at the leading end. The difficulty of synchronising the pulls, however, led to the abandonment of this method.

It is often impossible to secure anchorage for the tractor such that the hawser will be in line with the proposed cable track, and this necessitates guiding the hawser. Bars or road pins may be held vertically in the ground and the hawser allowed to slide around the bars if the angle of deviation is only slight. For sharper angles, however, it is advisable to use a portable anchor, as illustrated in Fig. 16, to minimise wear of the hawser.

FIG. 16.

Staff requirements.

Fig. 11 shows the general arrangement of the plant and the crew ready for drawing in a length of cable. To the right can be seen the Auto-Mower tractor-winch, in the centre the Ransome moledrainer, and on the left the drum of cable mounted on the cable-bogie which is coupled to the " Rushton " tractor.

The crew comprises a working foreman in charge who operates the moledrainer, the driver of the tractor-winch, the driver of the " Rushton " tractor, one skilled workman for sealing, dressing, and attaching the cable end to the mole, and one, or sometimes two men for guiding the steel hawser around bends.

According to conditions encountered as much as 1,300 yards of cable can be drawn into the ground in a day by such a crew. This includes all operations such as manœuvring cable drums and cable bogie into position, cutting, sealing and attaching the cable end to the mole, opening and closing necessary joint and pilot holes, and repairing occasional breakages of fuses. In addition to the moledrainer crew, the work may require three or four auxiliary gangs of about five men each, for excavating trenches or boring in advance across roads, across cart entrances to fields, or past heavy trees and for such other manual work as may be necessary.

Costs.

Fig. 17 illustrates graphically the effect of the moledrainer method on the labour costs of the Cambridge-Kings Lynn cable. It would be unwise at this early stage in the development of the method to quote data which could not be considered conclusive and the curves are therefore comparative only.

Curve 1 represents the estimated average direct labour cost of the work by manual excavation. It is based on observations of the time required for similar work and without regard to the possible use of labour saving devices.

Curve 2 shows by comparison the actual direct labour expenditure, mile by mile, on the Cambridge-Kings Lynn work, in which out of a total of 38.4 miles of armoured cable laid, no less than 25.4 miles or practically two-thirds were laid by moledrainers. A graph of progress kept in this way is a useful guide and on the assumption that the work is started from one end and continued through to the other end it is possible to deduce readily the costs over each section of the route. It must be borne in mind that Curve 2 includes the cost of laying thirteen miles of cable by *manual* methods and therefore does not present a comparison of costs as between manual methods and moledrainer methods when employed alone. Until further experience has been gained, it must suffice to say that the present experiments indicate that where the moledrainer method can be used it will show a saving of approximately 66% on the labour cost of manual methods. Against this saving must be set the cost of additional joints and extra cable amounting to say 6%, leaving a nett saving of 60%. This considerable saving takes account of all labour charges incidental to the use of the moledrainer, including :—

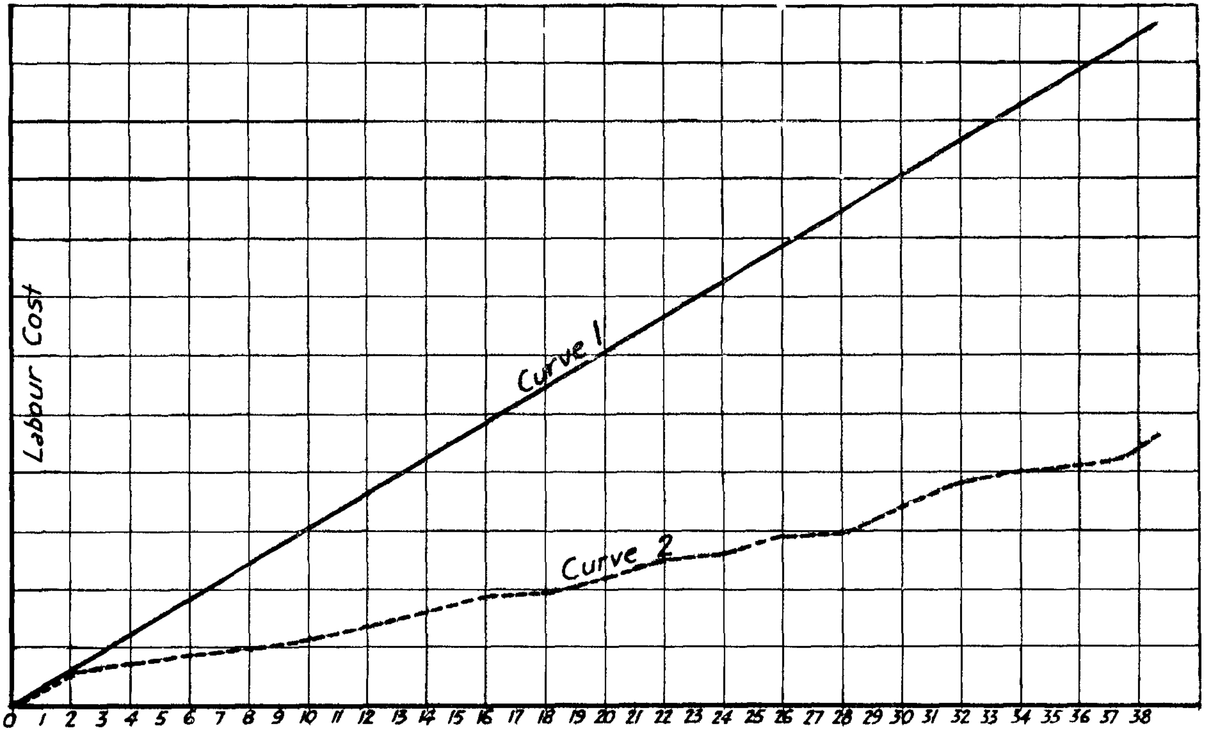
(*a*) The manhours of the moledrainer crew including the drivers, all handling of cables from the dump until finally laid, preparing and sealing cable ends, opening and closing holes and, of course, the actual drawing in operation.

(*b*) The manhours expended on pilot holes, levelling abrupt contours, trenching around very steep bends and the excavation of roadway crossings or cart tracks to permit the passage of the moledrainer as described in pages 25 and 26.

CAMBRIDGE-KINGS LYNN. LABOUR COST—CABLE PROGRESS.

Curve 1 :—Manhours. Estimated for Manual Methods alone.

Curve 2 :—Manhours. Actually taken by Moledrainer (25.4 miles) and Manual (13 miles) Methods jointly.



Date (1932) ...... April .... May .... June .... July .... August .... September

FIG. 17.

(*c*) The time expended on trenching with ploughs preparatory to the use of the small moledrainer.
(*d*) The labour costs of the preliminary trials.

Jointing and Loading.

The use of armoured cable for trunk circuits is a departure from previous practice and this paper presents a convenient opportunity for describing the extent to which jointing and loading procedure is affected by this change in practice. With the exception of joints at loading points, and at points required to connect short lengths together to form a "unit length," all joints were made in accordance with the standard systematic jointing schedule for star-quad cables. Tests were made on the first few loading sections for mutual capacity, capacity unbalance and cross-talk and the results were so satisfactory that it was decided to restrict further tests to those required to prove the accuracy and quality of the jointing work. This of itself resulted in very considerable saving on expenditure. Each joint is protected by a split coupling designed to grip the armouring of the cable and to clamp a lead strip between a ridge and groove in the upper and lower halves respectively, thus securing a reasonably watertight joint. Provision is also made for the steel armouring tapes, the cable sheath and the coupling to be bonded by a lead strip carried inside the coupling.

As the work involved was of considerable magnitude opportunity was taken to examine the jointing operations in detail with a view to the creation of an efficient organisation. Several days were spent in timing the operations to secure data for the compilation of a timed programme and a note was taken of the tools required for the execution of the work. Each jointer was supplied with a tool chest in place of the tool cart, a light motor van being held ready for the transport of jointers, tool chests and tents. During the timing of operations each man was allowed to work at his own rate and the following times are a mean of many observations on four jointers of average ability:—

Operation No. 1. Strip back armouring, clean lead sheath, saw off cable end. Wrap paper around armouring to protect inside of lead sleeve, which is now slipped over. Measure off cable, strip lead sheath, and tie up layers ready for numbering out.

Time of jointer assisted by mate—20 minutes.

Operation No. 2. Number each quad with paper sleeves already numbered.

Total time for two cable ends of 51 quads each, *i.e.*, 104 quads—30 minutes (jointer alone).

Operation No. 3. Select one quad, slip paper sleeve on each of four wires, select corresponding quad in accordance with systematic jointing schedule, joint four wires by the seven movement method, solder joints, and insulate with paper sleeves.

Total time—$2\frac{3}{4}$ minutes per quad.

Total time for 51 quads jointed, allowing 15 minutes rest period during which blow lamp is recharged—$2\frac{3}{4}$ hours (jointer alone).

Operation No. 4. Drying out.

Average time allowed—1 hour (mate or jointer alone).

Operation No. 5. Tie and wrap joint, slip over sleeve, and plumb—45 minutes (jointer alone).

Operation No. 6. Local pressure test—30 minutes (jointer alone).

With the exception of operation No. 1 the whole of the work was performed by the jointer. The lead sleeve had been prepared and the paper sleeves numbered in advance. It was apparent that the greater part of the mate's time could not be usefully employed and except where safety demanded their presence, some of the mates were withdrawn.

Following on these observations a time-table was prepared embodying the organisation illustrated diagrammatically in Fig. 18.

Joint No. 1 2 3 4 5 6 7
Jointer A B F A^1 B^1
Group I II

Light van and three mates, one of whom is the driver of the van.

FIG. 18.

It was clear that one jointer could complete more than one, but not as many as two joints per day and the figure illustrates an organisation designed to eliminate either waste of time on the one hand or overtime on the other. Seven consecutive joints are taken as the day's work for a foreman jointer and the two groups of jointers. Each group comprises two jointers A and B, general assistance being afforded by three mates under the direct control of the foreman.

Jointer A carries joint No. 1 through to completion.

Jointer B commences work at joint 2 and carries the work to the completion of the actual jointing of the wires—leaving the drying out, plumbing and testing to jointer A when the latter has completed joint 1. Jointer B then proceeds to joint 3 which he carries through to completion.

Group II follows a similar programme. The foreman-jointer (F) carries through joint 4 to completion, and in addition supervises the work of the groups.

The following time-table was actually used on part of the work and very close agreement was obtained in practice:—

Typical time schedule for jointing and plumbing a 104-pair armoured cable. Based on actual observed times and checked on two separate occasions with three pairs of jointers and found to be satisfactory.

Preliminary Note:—The hole is opened and cleaned, the tent erected and the armouring stripped off the lead sheathing by two or three men as may be necessary, according to conditions, either on the previous day, or early in the morning before jointers come on duty.

Jointers A and B at joints 1 and 2.

Item		
1	7.30-7.45	Travel to work, Department's time.
2	7.45	Unlock tool box.
3	7.50	Set up cables ready for numbering out.
4	8.10	Number out 104 quads—52 each cable end.
5	8.50	Prepare blow lamp.
6	9.0	Joint 26 quads.
7	10.15	Re-light blow lamp and rest.
8	10.30	Joint remaining quads.
9	11.45	Jointing completed.

Jointer A at joints 1 and 2.

10	11.45	Set blow lamp under joint and dry out.
11	12.0	Lunch whilst cable drying out.
12	12.30	Continue drying out.
13	12.45	Plumbing commenced.
14	1.30	Pressure test.
15	2.0	Move to joint 2 (already jointed by jointer B).
16	2.15	Plumb up joint 2.
17	3.0	Pressure test.
18	3.30	Close down.
19	4.0	Pack up. 8-hour day.

Jointer B at joints 2 and 3.

10	11.45	Set blow lamp under joint and leave a mate to dry out. Move to joint 3 which has already been numbered out by a jointer's mate under the supervision of the foreman jointer.
11	12.0	Lunch.
12	12.30	Light blow lamp and prepare tools, etc.
13	12.40	Commence jointing 26 quads.
14	1.55	Re-light blow lamp.
15	2.0	Joint remaining quads.
16	3.15	Commence drying out.
17	4.15	Commence plumbing.
18	5.0	Completed work. Leave pressure test to be carried out by foreman jointer next day. Leave hole to be filled in and marker fitted by mates next day. 9-hour day.

The duties of jointers A and B alternate so that in each two days each man works 17 hours.

Jointers' mates. One mate per pair of jointers plus one driver of van. General assistance in opening and closing holes, stripping armouring, numbering out joints 3 and 7 under supervision of foreman jointer, drying out joints 2 and 6, shifting gear.

Hours of duty as may be required according to conditions.

Duties of foreman jointers.

In charge of the groups of jointers.

Check up progress of work with time table.

Pressure test and seal joints 3 and 7 left over from the previous day.

Instruct and supervise in numbering out joints 3 and 7.

Complete one joint himself.

The effect on Performance Ratings is illustrated by the following figures based on abstracts from Progress Reports:

Performance Rating before observations were taken	... ...	81%
Performance Rating whilst under observation.	First day	60%
	Second day	57·5%
Performance Rating whilst working to time table.	First day	40%
	Second day	41·5%

It is not claimed that this method can be applied to all works. Each work must be examined on its merits and, if necessary, every detailed operation carefully timed at the commencement of the work. Then, provided reasonable continuity of conditions can be foreseen, it is felt that very considerable reductions in costs can be obtained by the adoption of the principle outlined above, which ensures that every man's time is efficiently employed throughout the day.

The loading pots were manufactured by the Salford Electrical Instrument Company and are of the stubless type designed for burying direct in the ground. Fig. 19 shows the pot in position with the outer cast iron cover removed and the cable ends prepared for jointing. The cable conductors are jointed to the beeswaxed leads from the coils, the two joints, on the "up" and the "down" side respectively, being accommodated in a brass container mounted over the loading pot proper. The container and its brass cover can be seen in Fig. 19. Fig. 20 shows the manner in which the completed joints are folded into the container.

Drying out the joints presented some difficulty until use was made of a sheet-iron drying oven designed by Mr. Werren, of the Pirelli-General Cable Company. This oven consists of a piece of sheet iron shaped to form a lining to the brass container and when in position projects about four inches above the top of the container. A slot is provided in each end to provide space for the cable entering the container. Fixed parallel to the sides of this sheet iron lining, but

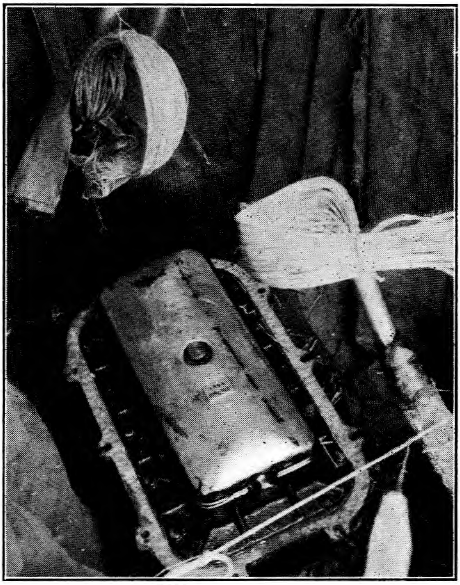


FIG. 19.

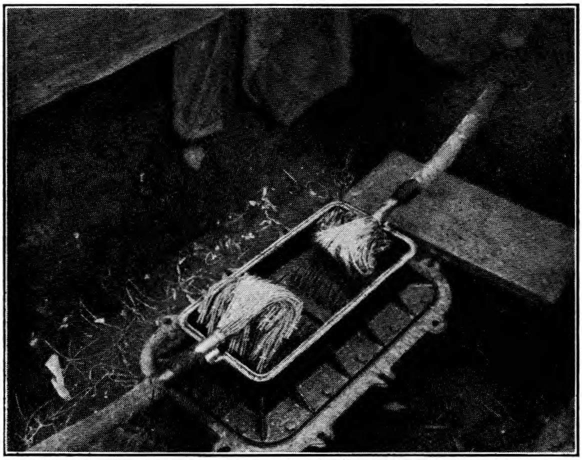


FIG. 20.

separated by an air gap of $\frac{1}{2}''$, are two perforated lining plates, and between these plates rest the joints. A removable cover is fitted over the oven and three or four blow lamps applied to that part of the oven projecting above the brass container. The outer part of the oven becomes heated and in turn heats the air contained in the cavity which then percolates through the perforated lining and so to the joints. Without the lining plates there is a real risk of the joints becoming scorched through coming into contact with metal which is directly heated by the blow lamps. The time required to dry out with four blow lamps is about half-an-hour.

Details of the construction of the Loading Pots are given in an article by Mr. W. H. Brent, B.Sc., in Vol. 25 of *The Post Office Electrical Engineers' Journal,* July, 1932.

Concrete rafts measuring 3′ 6″ by 2′ 6″ by 6″ thick were provided as foundations for the loading pots and the majority were cast *in situ*. It was felt, however, that some economy would be effected if the rafts were made at a central point and lowered into position by means of the Department's crane lorry which had been borrowed for the conveyance and lowering of the pots themselves. The method was given a trial and resulted in a saving of 25% on the combined cost of construction and installation.

PROSPECTIVE DEVELOPMENTS.

There is little or no doubt that the success which has attended the methods described will prove instrumental in focussing attention on mechanical aids to cabling, and the experiment would have been justified for that reason alone. The future must be a matter of conjecture, but there are clearly several matters which require further investigation before the moledrainer method can be exploited to the full.

The tractor-winch is equipped with one hundred yards of steel hawser and since it can be manœuvred over very uneven ground there should generally be a fairly extensive range of sites available for anchorage. In the sections of route illustrated in Figs. 10 and 13, it was possible to secure anchorage at the entrances to fields. Cases will arise, however, where a natural anchorage cannot be found either because the grass margin is too narrow or because the road is bordered by steep banks. In such cases the problem of a safe and secure anchorage becomes more difficult. An obvious method would be to break up the road surface to provide a grip for the anchors and, undesirable as this may be, it would, of course, prove far cheaper than laying the cable by manual methods. If a caterpillar type tractor can be hired locally there is the possibility that it will grip the road surface sufficiently to enable the moledrainer to be towed, but much will depend on the state of the road and the hardness of the soil in which the moledrainer is to be used. Assuming that the method is practicable, the moledrainer would be coupled to the tractor by means of a hawser which could be guided over the proposed cable track, as previously described. Experience has shown, however, that caterpillar type tractors are by no means easy to obtain on hire when and where they are required and it appears that other methods should be devised.

Consideration has been given to two other likely means of overcoming the difficulty. The one which shows the greater promise is the use of an independent and portable anchor which can be coupled to the front of the tractor. Such an anchor must be easily handled, quickly buried and withdrawn with minimum disturbance of the ground, and yet able to secure, in a confined space, a hold, sufficient to withstand the load created by the earth resistance on the moledrainer and the cable.

Experiments have so far shown that an anchor in the form of a moledrainer most nearly meets these requirements. As the anchor must withstand both the reaction of the "cabling" moledrainer and the cable it follows that the dimensions of its mole, and perhaps of its coulter, must be appreciably greater than those of the "cabling" moledrainer. An anchor on these lines is now being constructed.

A second possible solution depends upon the division of the load between two or more heavy lorries or tractors so that the load on each of the vehicles is within its tractive effort. A three-ton lorry is capable of exerting a tractive effort of between $1\frac{1}{2}$ and 2 tons without wheel slip on dry tarred macadam road and hence two such vehicles would be capable of exerting a pull of 3 to 4 tons. The method suggested is indicated in Fig. 21, in which A and B are two

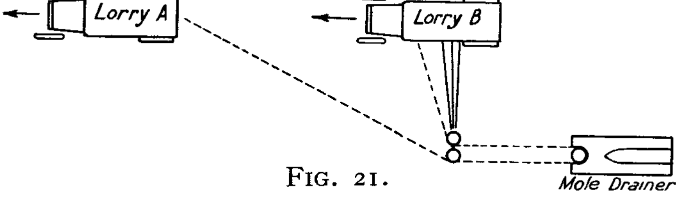


FIG. 21.

lorries, to one of which is fitted a side-arm attachment which can be adjusted for position laterally and vertically. The side-arm serves as a guide for the hawser which passes through a snatch block attached to the front end of the implement, the ends of the hawser being attached to lorries A and B respectively. Relative movement between the lorries is permissible as the hawser runs freely in the guide. The lorries must have low gears to avoid undue clutch slip when taking the load. Such a side-arm attachment has been made, but the need for its practical application has not yet arisen.

Consideration is being given to the design of an implement specifically intended for cable-laying purposes. Up to the present we have been content to adapt agricultural implements and although it is probable that the moledrainer must form the basis of any future designs there are other features which might with advantage be incorporated. The large moledrainer of the Ransome type has undoubted advantags for agricultual work and its stability enables it to score over the narrow type in wide grass margins. On the other hand, it is useless in very narrow grass margins. The solution appears to be in a model which will combine the lateral stability of the Ransome type with the adaptability of the narrow type. It would thus appear that a chassis in which the wheel track is adjustable over a range of from 1′ to 5′ should be incorporated in the new design.

Other desirable features include:—

(*a*) A readily detachable coulter so that in the event of the mole or coulter becoming caught in a tree root or other obstacle the main chassis can be wheeled away from the coulter to facilitate digging down to the obstruction;

(*b*) A coulter which can be adjusted fairly readily to depths of between 1′ and 3′ 6″. A maximum of 3′ 6″ is suggested to enable a net depth of 24″ beneath road level to be obtained when it is desired to lay the cable in a grass margin, the surface of which may be as much as 18″ above the level of the carriageway. It is not certain that the digging action of a normal size mole would be sufficient to permit of the moledrainer being worked at such a depth or that the pull required would come within the capacity of the winch. To minimise the drag on the coulter it may be possible to reduce its width to about ½″. The thickness of the "Ransome" coulter is 1″ whilst that of the "Darby" moledrainer is only ½″, yet the latter has shewn no signs of weakness, although admittedly, it has an effective length of only 16″.

(*c*) A mole-coulter assembly which can be tilted relative to the chassis in order to vary as required the degree of digging action. This could be conveniently combined with a self-lift mechanism which, although desirable, is not essential. The simplest form of self-lift action would appear to be obtained by pivoting the coulter in the chassis and providing a locking device. When released, whilst the pull on the chassis continues, the coulter would turn about its pivot until the mole emerged from the ground. The above principle is already included in one or two proprietary makes of moledrainer.

(*d*) An adjustable spring-loaded release, incorporated in the chassis, to be used in place of the 7/8 G.I. wire mechanical fuse. A powerful spring in series with a mechanical fuse should be bridged across this release in order to absorb the inertia of the hawser when the spring release operates.

Another point to be borne in mind in the re-design of a cable-laying machine is the possibility of using the machine for pipe-laying. It is unnecessary to stress the advantages of pipes if the cost of providing them can be reduced to figures comparable with those for armoured cable laid by the moledrainer method. By means of an adaptor at the rear of the mole it should be possible to draw in lengths of pipe or ducts similar to those used with the thrust borer.

A suggestion has been made that in place of the pilot wire already described a permanent magnet should be fixed at the leading end of the cable which could then be located by means of a compass when the cable fuse breaks. This is certainly worthy of trial and no difficulty would be experienced in fixing the magnet beneath the tape used in making off the cable.

Of the tractor design there is at present little improvement to be sought unless its anchors can be designed to give the same firm hold, but in a confined space to one side of the tractor. All-weather equipment in the form of a cabin for the driver and mudguards is now, however, being fitted.

Apart from the re-design of the implements, however, there are other aspects which call for attention.

The re-design of cables with the new methods in mind is a matter which appears to warrant some consideration. It is unsafe to rely upon the tensile strength of tape armouring, but wire armouring would undoubtedly permit of much greater lengths being drawn in without fear of damage to the cable. The actual drawing-in operation occupies only a small proportion of the total time per length laid and hence the greater the length laid at one operation the greater the saving in cost, quite apart from the resultant jointing economies. Again, the adoption of wire armouring as a general practice would so far strengthen the cable as to permit of its use for aerial cable construction without the provision of a suspension wire, and much labour would thus be saved in the erection of aerial cables. Wire armouring is, however, more expensive than tape armouring and the savings in labour cost might be more than counterbalanced by the increased cost of materials. It appears probable that a form of tape armouring with two or three strands of wire laid spirally over the tape, but under the protective covering, would go some way towards a solution of the problem. For aerial cable work the steel armouring would be omitted and only the wire strands provided. Yet another possibility is the inclusion of a steel core to the cable which would take the strain, but there are risks attached to this method owing to the possibility of relative sliding between the steel core and the conductors, and the likelihood, when bends are encountered, of the steel core cutting through the conductors and insulation.

The considerable savings in cost foreshadowed by the moledrainer experiment might conceivably result in a change of attitude towards private wayleaves. We may consider a case where there is no grass margin in which to lay the cable and the only alternative to private property is to disturb a made up carriageway. The negotiation of long-term wayleaves with the owners of adjacent fields would almost certainly prove economical. Mole draining methods could then be employed on the field side of the hedge as close as possible to the hedge—and if laid at a depth of 2 ft. 6 ins. to 3 ft. the risk of damage would be negligible. The wayleave agreement would probably require a clause to cover compensation for any damage done to crops, etc., during the maintenance of the cable, but the savings in first cost will leave a goodly margin for such contingencies. Developing the same idea we may visualise a time when cables will be laid by the shortest and most direct route across open country.

Conclusion.

In conclusion, the authors wish to make it clear that the success of the methods which have been described was not due to the activities of a few officers alone, but to the whole-hearted enthusiasm and co-operation afforded by all whose duties brought them into contact with the work. They desire to acknowledge the most helpful advice and practical suggestions received from many officers of all ranks, from the Engineer-in-Chief himself to the men employed on the actual work. A special word of thanks is due to Capt. N. F. Cave-Browne-Cave, B.Sc., for his very helpful advice during the preparation of this paper.

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