JOURNAL AND PROCEEDINGS OF THE

INSTITUTION OF BRITISH AGRICULTURAL ENGINEERS

VOL. 14 NO. 1 - JANUARY 1958

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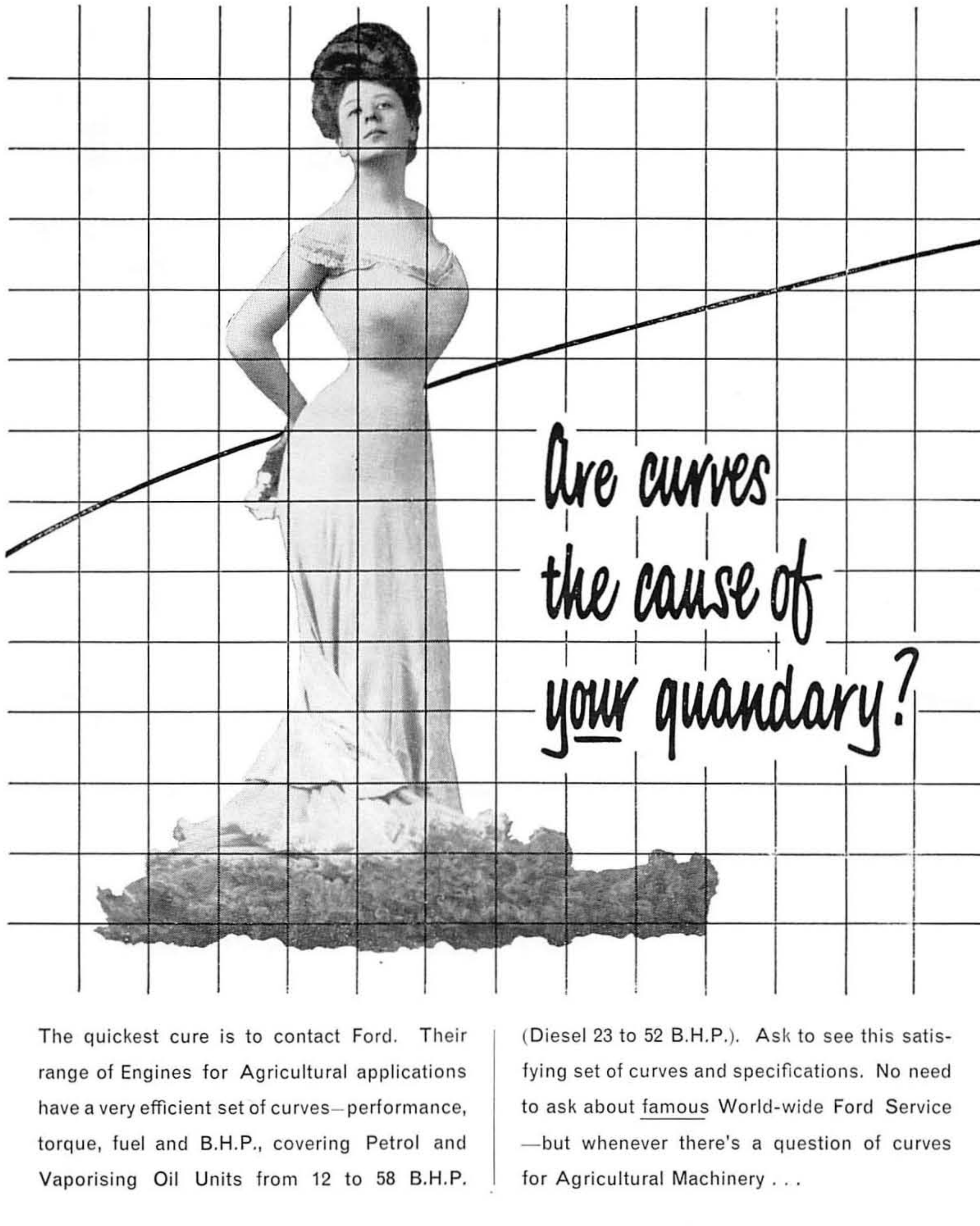
Are curves
the cause of
your quandary?

JOURNAL AND PROCEEDINGS OF THE INSTITUTION OF BRITISH AGRICULTURAL ENGINEERS

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Published by the Institution of British Agricultural Engineers, 6 Buckingham Gate, London, S.W.1
Telephone: Tate Gallery 8589

Price: Ten Shillings and Sixpence — Published Quarterly

INSTITUTION NOTES

The New Journal

THIS being the first issue of the Journal in its new form, the Council will welcome the views of members on its presentation. It is hoped that the enlarged content will enable the various interests of members adequately to be covered, and that the larger type used will contribute to ease of reading.

Suggestions as to matter to be included in future issues will be welcomed by the Secretary. The demands on space in this issue have precluded the inclusion of abstracts and library accretions, but these will appear in the next issue.

The views of members are sought on the need to provide binders. If sufficient support is received, a supply will be ordered and made available to members.

Journal Postage Rates

Early in 1957 the Council decided that, as a service to overseas members, the Journal should be sent to them by second-class air-mail. Following the recent heavy increase in this class of postage, overseas members are asked to advise the Secretary whether they wish still to receive their Journals by this means. Those who express such a wish will continue to receive publications by air ; for all others, surface mail will be used. The necessary form of application is enclosed with each overseas member's copy of this issue.

Careers Lectures

The Council is considering the provision of lectures on Careers in agricultural engineering in various parts of the country with the co-operation of the Local Centres. In November last the first lecture of the kind was given in London, when Mr. J. E. Bywater and Mr. W. H. Cashmore were the speakers.

The interest shown on that occasion, and comments subsequently received, indicate that the proposed series is likely to meet a need and become the means of attracting young men into the profession. A number of these are likely to undertake the course of training leading to the National Diploma in Agricultural Engineering, and it is all the more important, therefore, that those members who are employers or responsible for engaging qualified staff should bear this qualification very much in mind when appointments are to be filled.

It has come to the notice of the Council that the National Diploma in Agricultural Engineering is still not known in some quarters of the industry, and those members in a position to do so are asked to remedy this wherever possible. The Secretary will, on request, send particulars about the Institution's educational work to any firm who may be interested.

Work Study Conference

Enclosed with this issue of the Journal is a copy of the programme of a Conference to be held in London on February 19th. The subject will be " Work Study in Farm, Field and Factory," and as accommodation is limited, those members interested are asked to complete and return their applications for tickets without delay.

National Sugar Beet Harvester Demonstration

At the request of the British Sugar Corporation, the Institution's Safety Panel attended the National Sugar Beet Harvester Demonstration in October last and drew up a report on the machines entered from the point of view of the safety of operators. Confidential reports on individual machines were also prepared and are available solely to the manufacturers concerned.

The Panel found that, on the whole, there had been an improvement compared with previous years, but that there was still scope to further measures for the avoidance of accidents.

A.M.T.D.A. Joint Apprenticeship Scheme

The Council has accepted an invitation from the Agricultural Machinery and Tractor Dealers' Association to appoint a representative to sit on the Council set up to inaugurate and administer a Joint Apprenticeship Scheme in the Agricultural Engineering industry.

Annual Luncheon, 1958

The President announced at a recent meeting of the Council that Lord Brookeborough, Prime Minister of Northern Ireland, had accepted an invitation to be the Guest of Honour at the Annual Luncheon in 1958. Mr. Chambers was also able to inform the Council that Mr. Harry Ferguson had agreed to respond to the toast of " The Guests " at the Luncheon.

Open Meeting—Alteration of Date

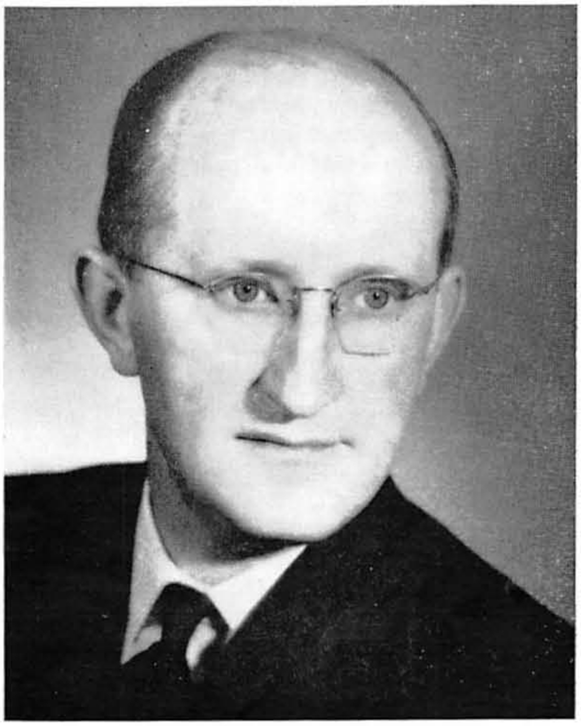
Members are asked to note that the London Open Meeting advertised to take place on February 11th will now be held on February 18th at 4.30 for 5 p.m. at 6, Buckingham Gate.

MR. JOHN CHAMBERS,

M.I. Mech. E.

PRESIDENT

1957-58



MR. CHAMBERS was born and lived on his father's farm in County Down, Northern Ireland, and served an engineering apprenticeship with Harland & Wolff, Ltd., from 1926–31.

His technical education was undertaken at the Belfast Municipal College of Technology.

After serving as a Junior Engineer on a United Molasses Co. tanker, Mr. Chambers joined Mr. Harry Ferguson in December, 1932, and worked as a Draughtsman Mechanic and Field Test Driver. Subsequently, he was on Mr. Ferguson's staff in Huddersfield from 1936 to 1939, when as a Junior Engineer he accompanied the Ferguson staff to America at the commencement of production of the Ford tractor with Ferguson System.

In 1945 he returned as Chief Engineer of Harry Ferguson, Ltd,. Coventry, and in 1953 was appointed Director and Chief Engineer (Ferguson Products) of Massey-Harris-Ferguson (Engineering), Ltd. He was appointed Technical Director for the Eastern Hemisphere Division of Massey-Harris-Ferguson in March, 1957.

Mr. Chambers served on the Council of the I.B.A.E. in 1951 and 1952, and was a Vice-President from 1952 to 1956. He is a Member of the Institution of Mechanical Engineers, the American Society of Agricultural Engineers and the Society of Automobile Engineers (U.S.A.).

Mr. Chambers' other activities include membership of the Governing Body of the National Institute of Agricultural Engineering and of its Finance Committee ; membership of the General Council of the British Standards Institution, its Engineering Divisional Council, and its Agricultural Engineering Industry Committee.

His hobbies are gardening and veteran cars.

PRESIDENTIAL ADDRESS

by J. M. CHAMBERS, M.I.Mech.E., M.I.B.A.E.

Presented at an Open Meeting of the Institution on 12th October, 1957.

IT is, perhaps, an advantage of a young and virile Institution like ours that there is no set form for what has become known as the Presidential Address. This, I believe, leaves me free to range over as much of the whole field of agricultural engineering as is conveniently possible and to include farm mechanisation both at home and abroad.

For centuries past, man has been endeavouring to apply power (other than human power and his own labour) to produce the food needed by himself and his family and for people of his own country not directly engaged in the production of food ; but only in the last one hundred years has mechanical power successfully been applied.

This is not surprising, for our ancestors in the agricultural industry did not themselves invent new means of power but successfully applied means already available to the tilling of the land, harvesting of crops and tending of flocks. I hasten to add, however, that the natural powers, wind and water, have been used for agricultural operations since time immemorial, and were rather applied than invented. Since their use, back in history, when there were few occupations other than agriculture, these natural sources of power were applied to other industries as they developed.

Our immediate past President, Mr. Bomford, addressed you in October, 1955, and drew your attention to the period of stagnation in development in our industry. Whatever the causes of this stagnation, it would seem to me that one cause might be that too much time elapsed between the final development of the steam engine and the invention and development to a power source of the petrol engine. By 1880, or thereabouts, the steam engine had reached almost the height of its development and, at the same time, agriculture in this country went into a slump, or depression, whichever term you prefer to use. Whether this was the cause of the stagnation in our industry, which lasted until years after the first World War, and whether there were other causes, I certainly do not profess to know. This stagnation period was, however, the time when we in England lost the initiative and our export markets to the American industry ; we hope now to regain them for good.

Power Units

I think it would be suitable at this point in my address if I were to speak of the power unit which is the prime mover in all our farming operations.

In the past fifty years we have had numerous power engines to stimulate our attention and to attract buyers. The petrol engine was soon followed by light, high-speed, spark ignition paraffin engines when, due to the imposition of the petrol tax, fuel became too costly and, in spite of the inconvenience to the operator of the paraffin engine, the cost saving made it an attractive and essential development.

The paraffin engine was soon followed by its sister, the V.O. engine, almost as soon as V.O. became available. This engine added some efficiency, with lower operating costs, but it did not remove any of the inconvenience of this type of engine where petrol had to be used for starting, and a vapouriser for the fuel had to be kept warm for satisfactory operation of the engine.

In recent years, the small, high-speed, multi-cylinder diesel engine has become the almost universal choice of farmers, except in countries where the petrol tax is very low or completely non-existent. It could be shown that, because of the high initial cost of a diesel engined tractor, this tractor must be worked for at least 1,000 hours per year for seven years before the saving of fuel costs could be balanced with the extra cost of the tractor and, in fact, it can be shown that if the extra capital outlay on the part of the farmer for a diesel tractor were applied to other money-making projects of his enterprise, it would require a much longer working period to be sure that the diesel was the most desirable power unit on the farm.

However, the farmer is prepared to pay a great deal for the extra reliability and convenience of a diesel engined tractor and, perhaps, for this reason alone, it is the best and most economical choice.

Gas Turbines

Recently, we have been able to watch with interest, through the medium of many technical journals, the development of the gas turbine in many places and for many purposes. One type of gas turbine, the "free piston" engine, we are told, has been fitted to an agricultural tractor in Detroit and is undergoing field trials. I will not, at this early development stage, try to evaluate the advantages and disadvantages of such a power unit for agricultural tractors, but it may be, in our lifetime, a leading development to influence tractor design and performance to the benefit of us all. It is not my intention here to discuss the relationship between the free piston gas turbine and other gas turbines not using the same principle. This might well become the subject of a Paper in about ten years' time and I am sure it would stimulate much discussion.

Whichever principle is best will eventually emerge above the other, and it might not necessarily be the first one developed in the power size suitable for installation in farm tractors. It would, however, be dangerous to assume that gas turbines will ever become suitable for agricultural-type tractors, and I should like to draw attention to the steam turbine, which, although most satisfactory and efficient for larger power requirements, never was, to my knowledge, used as a power plant where only small power requirements were necessary.

I will only touch briefly on the subject of atomic power, as its realisation as a means of direct power for a tractor is in the distant future. We know that atomic power is now being successfully applied to electrical power stations, submarines and surface sea-going vessels, and I am told that it is being seriously discussed by the senior engineering staff of the world's leading motor car manufacturers. Apparently, it is considered quite feasible to design, in the future, sufficiently small atomic installations for all types of aircraft and land vehicles, and it is thought that within fifty years some motor cars will be driven directly by atomic power. If this is so, we may look to this possibility for tractor use.

I have dealt with the subject of tractor power sources, and it will be evident to you that these have always had a great effect on trcator design. I have dealt with the past, the present and the possible future. We can see the effect the past and the present have had, and I believe that in the future the new power sources which we see on the horizon will have their stimulating affect. I cannot, however, leave you with the impression that I believe that the power source was the only stimulant in our industry, and it is not necessary to go back more than thirty years to study advancements which have been vitally important agricultural engineering developments. I will only refer to a few of these recent developments and will start with the pneumatic tyre.

Pneumatic Tyres

There is no doubt that, had pneumatic tyres for the rear driving wheels of tractors not been invented, the advancements of agricultural engineering would have been retarded and far behind where they are to-day.

Can you imagine any possibility that steel-wheeled tractors would have almost removed the work horse from the farm? and I repeat "almost removed," although there are still approximately a quarter of a million horses on the farms of England and Wales. I would suggest that many of these are now in retirement or are horses used mainly for sport or pleasure.

I, for one, rarely see, on my travels throughout the British Isles, any horses doing farm work. I very much doubt if the men who developed the pneumatic tyre for farm tractor use in the early 1930's were able to foresee how the pneumatic tyre could be made to do all the operations which were then being performed with steel-wheeled tractors and, in addition, do many jobs of haulage, etc., which, until a few years ago, were the only reasons for keeping horses on farm work. Pneumatic tyres have, therefore, been a considerable stimulant to all agricultural machinery design, and without them a new period of stagnation could have set in for our industry.

Mounted Implements

In 1936, despite adequate publicity efforts, the introduction of the three-point hydraulically-mounted and controlled implements was almost unnoticed. Fortunately for us to-day, a small but sufficient number of progressive farmers were immediately interested and the development has now spread to every country in the world.

The development of mounted implements has been basic to the spread of farm mechanisation to small farms in every type of condition of ground, climate, topography and crop throughout the world. Before 1936, without mounted implements, we came to consider ourselves in this country at almost saturation point in the use of farm machinery, but very quickly, due to the introduction of these implements, the sales possibilities expanded and we were spared another period of stagnation.

At, or about, the same time during the 1930's the self-propelled combine harvester began to make its appearance in certain parts of the world. This development stimulated much discussion and argument among agricultural engineers. Many doubted the wisdom of trying to sell to farmers what was virtually a tractor so surrounded by machinery that it could be used for one purpose only. It certainly seemed to most agricultural engineers and economists alike that no one would pay the necessary extra price for such combines, but gradually the self-propelled machine has come into its own and has expanded the possible market into areas where none other than the self-propelled machine would be of any use. It is surprising that many other machines have not been designed for self-propulsion and have not attained a similar success, but maybe no other type of operation required the same precise operation in confined spaces which has made the self-propelled combine the success that it is.

I have tried to indicate to you the main stimulants to development in agricultural engineering during the last 25–30 years. One could, however, point to many other developments which, in themselves, were not stimulants but were branches of the three main ones which I have mentioned. For example, the pick-up baler followed the combine and the tractor-mounted front end loaders were an outcome of the built-in hydraulic systems in tractors.

I am sure you will agree that it would be rash to predict the progress which will be made in the next quarter-century, but we must be aware of, and try to evaluate, what is going on to-day, not only in pure agricultural engineering, but also in the many other engineering undertakings, for a great deal of our progress in the past has been the successful application of other engineering developments to our industry.

As we, the agricultural engineers, did not invent or develop the internal combustion engine, I do not anticipate any direct developments by agricultural engineering of gas turbines for tractors or the application of atomic power for our direct purpose, but should a power plant be developed for other types of vehicles, then it will be the agricultural engineer's job to apply this to our tractors and other agricultural machines.

Hydraulic Transmission

Recent developments in hydraulic transmissions for other vehicles have made us begin to study how similar transmissions can be applied to our tractors. Such transmissions, if successfully applied, will provide many new benefits and will increase the output per tractor and the output per man-hour on the farm.

These new transmissions, when they reach the stage when they can be mass-produced, will, undoubtedly, be more expensive than the present gear-type transmission, but if they can increase the performance and the output of the tractor, then I am sure that our farmers will be prepared to pay the extra price. There are two main types of hydraulic transmissions—namely, hydrostatic and fluid flywheel torque convertor, and it is not yet certain which will eventually be the one preferred. I think that both will be produced on various types of tractors, but one must prove itself superior over the other.

It would be possible now to make out a list of the advantages and disadvantages of one as compared to the other, but, at this early stage, it would be impossible for an engineer to determine with certainty which will be the succeeding type.

Off-the-Farm Use

One of the biggest development programmes going on in almost every farm machinery Company to-day is that of designing and providing machinery for off-the-farm use, and many of our existing farm machines can be used off the farm with little or no modifications.

It is nothing new that farm tractors, with their specially designed equipment, are doing work of a non-farming nature like earth-moving, trench-digging, forestry and municipal work, but what is new to-day is the potential volume for such application. Such business is now over 20% of the total agricultural sales business of the United States and is already having its effect on tractor design. In earth-moving and trench-digging work the task is so severe and arduous that weaknesses show up early in the life of the equipment, whereas they only appear after some years of farm work.

It will be necessary for the equipment designer to improve the revealed weaknesses and this improvement will, in the long run, provide the farmer with more reliable and more efficient tractors. It will, however, be necessary for the designer to be most careful that any improvement he may apply to his machinery for off-the-farm use does not unnecessarily increase the cost of his Company's agricultural tractors and implements. It so often happens that improvements are no longer economical and, when this occurr, the improvement must only be designed for industrial, off-the-farm type tractors.

This off-the-farm use for our agricultural machinery will demand many special and additional features at extra cost—very much like the Deluxe and more expensive motor car market. These Deluxe features will be developed and, without doubt, put into production on special industrial tractors where the purchaser will be prepared to pay a considerable extra price for such features, provided they improve the output of the tractor.

Eventually, after some years of developments to improve the performance and decrease the cost, the same features will be available in agricultural tractors. In this way, I am looking to these improvements for the industrial market to provide much of the development money which will eventually improve our agricultural tractor without, in fact, the agricultural tractor carrying much of the development cost. This will follow the same pattern as in the motor car market, where expensive cars usually carry much of the development cost of their special features without adding to the cost of the cars in the low priced field. Many of the big motor car manufacturers make cars in the varying price ranges, and one can observe Deluxe features gradually coming into the least expensive cars.

I have been told—and I believe it to be true—that some of the most time-consuming jobs on the farm are in the farmyard with cattle, pigs and poultry, which need daily attention for twelve months in the year. Much has been done and I am sure that new machinery is being developed which will save labour by reducing the time taken to feed and tend stock or permit of increased head of stock being kept and looked after by the same labour force.

Barn Machinery

Just as tractor and implement designers have tackled the job of providing the farmer with machines to suit the many conditions of soil and crop, the large and small field of regular or irregular shape, some flat and some sloping, so the barn machinery designer has designed his equipment to suit the existing farm buildings as far as possible with the minimum of structural alterations. I am sorry that I cannot, because of lack of knowledge, go into any of the trends for the future on this very important section of our industry, but, as before, electricity and electric motors will continue to provide the power.

Much has been done and there is much more to do, and as I look around the country I find it more and more difficult to determine what operation on a particular crop should next be mechanised and what should be given top priority.

Some progress has been made in the past few years on the harvesting of potatoes, hops, kale and forage. Much more can be done and much more will be done ; new and more efficient machines which will lower the man-hour costs of farm work are on the way to make obsolete existing machines and widen the present market.

I have used the word obsolete as I have used it on previous occasions, when I have been challenged by some farmers who seem to think that it is our purpose and our sole purpose to plan obsolescence so as to keep our factories busy, but let me explain, for the benefit of any farmers who are present or who may read this, that we are always endeavouring to design machines which will be better than the ones now existing, so that we will make it worth their while to buy our new machines to their benefit as well as our own.

Planned obsolescence would incidate that advances in design are only made at a pace sufficient to encourage the prospective buyer to make the change and that something is always being held back for further planned obsolescence. I am sure that nothing is held back and that when a new model is introduced it is as up to date as the designer's current knowledge permits.

I have tried to sketch a little of the past history of development of some of the inventions by men of the agricultural engineering profession. During the next two years our Council and I hope that our Institution will be granted Incorporation, which, in itself, will not stimulate our rate of progress or the enthusiasm of our members, for both cannot be improved, but it will improve the status of the Institution and of its members.

For the benefit of those who could help us attain Incorporation, let me put before you my ideas of what an agricultural engineer is, for he can be one or more of the following :

(*a*) Mechanical engineer,
(*b*) Civil engineer,
(*c*) Electrical engineer,
(*d*) Chemical engineer,
(*e*) Production engineer,
(*f*) Field engineer,

depending upon which of the many classes of agricultural engineering he specialises. We include among our membership men who are already members of the Institutions of Civil, Mechanical and Electrical Engineers and, as well as these, a large number with University qualifications, research workers, lecturers and teachers, and men who lead the United Nations Food and Agricultural Organisation. Moreover, we have as associates some of the leading farmers in the country and, indeed, some of our full members are farmers and, at the same time, fully qualified engineers.

The I.B.A.E. can bring all these professions together in one body, free to discuss any subject to their mutual advantage at any time or place ; it may be in the lecture room, the milking parlour, potato storage shed, or together studying the operation of one or more of our many implements at some arduous task.

Our non-corporate membership, selectively chosen men from the farming industry and the many other professions in daily contact with farm mechanisation problems, are an essential part of this Institution, for it is they who help us define machinery requirements, and are always at hand when we have practical problems. From them the corporate members have learned how to be practical, how to get their boots muddy and their eyes full of chaff and dust so that they may be qualified to determine the performance of the many machines they design. But, on the other hand, their slide rules, their calculating machines and their strain gauges, together with other special equipment, never cease working to give many of the answers needed for the sound construction of machines for which the practical application has been found only by days, weeks and months of working with prototype machines in the field.

INNOVATIONS IN LAND DRAINAGE METHODS

by A. N. EDE,* M.Sc., M.A., A.M.I.B.A.E.

A Paper read at an Open Meeting of the Institution on Tuesday, 12th November, 1957

THE technical requirements of land drainage installation are closely linked with basic processes of soil water movement and with agricultural and economic aspects. The generalised conceptions of the water regimes by which the under-drainage systems of agricultural land operate are basically simple. They conventionally fall into two main groups, ground-water and heavy land drainage, differing in many respects only in degree, but each having certain installation features.

1. Ground-water Drainage and Heavy Land Drainage

In soil of open texture, such as sand, loam, silt or peat, the ground may become saturated with water as a result of the arrival of water in the absence of appreciable losses. Where the level of the water becomes so high as to interfere with agriculture, patterns of drains are inserted at depth in the soil with the function of drawing down the water to a lower level. If the highest desired water level is specified, it is possible from experimental and theoretical considerations to design a drainage system for a given soil to give just sufficient control. It is necessary to know the soil permeability and the influx of water, which is often the rainfall.

The design can be arranged within considerable latitude of depth, spacing and drain size ; for instance, a choice may be presented between a deep installation far apart and less deep drains of smaller capacity placed nearer. Knowledge of other factors is required in order to arrive at a decision—factors which include the economy of installation at various depths, the physical limitations of equipment and the depth limits imposed by the ditches. If the development of a new method of drainage installation is being considered, a method whose economy and limitations are unknown functions of its future design, it is necessary to reduce the number of variables by setting objectives which seem reasonable in the light of present drainage knowledge. A working depth of 2½ to 4 ft. and a drain diameter of 2 to 4 ins. have been selected as appropriate for ground-water drainage for the purpose of this research.

The removal of water from heavy land requires a technique taking advantage of the fissured structure of the soil, which may be otherwise almost impermeable. Practical measures serve to improve the get-away of water by

(*a*) The provision of very frequent conducting channels in the form of mole-drains leading to mains.

(*b*) Fissuring the soil mechanically by mole blade action, deep cultivations and busting.

(*c*) Agricultural practices favouring root penetration and the improvement of soil structure.

**Agricultural Research Council, Unit of Soil Physics, Cambridge.*

Mole-drains are commonly arranged to run at a depth of about 21 ins., a depth which is decided by experience, but which seems reasonable if the soil mechanics' aspects are understood. Unlike the conditions of the ground-water regime, no added capacity is given to the underlying tile in impermeable heavy land by deep installation, and a working depth of 30 ins. for the mains is sufficiently deep for making the connections with the moles. In contrast to the performance of ground-water systems, in which the discharge is relatively free from rapid fluctuations, the characteristic of heavy land is to follow the onset of precipitation by an almost immediate flush of water. The capacity to avoid back-pressure in the drains must therefore be higher, although it should be considered that the sites frequently have a good slope and therefore often allow a high capacity for drains of moderate size.

2. The Limitations of Conventional Installation Methods

In developing entirely new methods of drainage, a great deal can be learnt by examination of the hydraulic and economic aspects of the well-tried methods of trench cutting, tile laying and back-filling operations. Under ground-water conditions a gapped tile-drain is certain to function ideally provided that it is surrounded by a layer of highly permeable material in the trench. If the soil closes in on the drain to reform as a homogeneous medium in direct contact with it there is evidence that under the severest drainage conditions the convergence of water toward the gaps may cause the drain discharge to be reduced by 50 per cent. compared with the discharge which an ideal drain of similar size could handle. Thus the operation of trenching has the subsidiary function of conferring hydraulic advantage if the returned soil or other fill remains highly permeable. In heavy land drainage the trenching process allows the gravel or other coarse fill to be introduced as a connecting medium for the mole drains.

The economic side of tile-draining is not so favourable. This example of a contractor's rate for heavy land in Hunts. is very general.

	Per Chain. £	s.	d.
Tiles, 4 ins. standard quality, delivered	1	7	0
Trenching operations	1	0	0
Labour, distributing, feeding, laying tiles	1	5	0
Porous back-fill	0	15	0
Back-filling	0	3	0
Total cost per chain	£4	10	0

The cost per acre of an overall system with drain lines spaced at 1 chain works out to be approximately £50, in spite of the use of highly efficient machinery. Some interesting methods involve special ways of introducing conventional tile-drains. In this country giant ploughs, tile-feeding devices, or the dragging or forcing in of lines of tiles into channels make a useful contribution in some conditions by cheapening a section of the overall expenses. However, even with rockbottom material, labour and operating costs tile drainage remains prohibitively high, although most important among the capital improvements on the farm.

A useful comparison may be made with the operation of mole-draining, in which an underground channel is formed in stable clay soil without the use of tubes. The contract price for mole-draining as closely spaced as two yards varies from 35/- to 60/- per acre, not inclusive of main drains. These comparatively low figures reflect the high work capacity of the mole plough in conjunction with negligible material costs. The twentyfold cost disparity between mole-draining and tile-draining has led to the work on the use of mole ploughs for laying drains made from a cheap and readily available material —concrete. Consideration of conventional drainage methods show several features on which improvement can be made.

(*a*) Trenching is a laborious and expensive way of introducing the drain.
(*b*) Tile-drains are moderately expensive to purchase and need considerable handling.
(*c*) A large quantity of permeable back-fill material is required.
(*d*) The operation of spoil replacement requires separate equipment.
(*e*) Agricultural damage is caused by the movement of heavy equipment and by trenching operations.

There are certain obvious economies and benefits which a new method could make use of.

(*f*) The use of bulk-handled materials throughout.
(*g*) The elimination of separate soil-shifting operations.
(*h*) The combination of manufacture and placement of the drain.
(*i*) The provision of just sufficient permeable fill to conduct the water to the drain.

In respect of the drainage design data, it should be considered that

(*k*) Control of ground-water level to the same standard may be obtained by a system of drains placed shallow and close or by a system placed deep and far apart. In the shallow case the drains need be less efficient as conduits.
(*l*) For heavy land drainage there is no evidence that deep drainage as opposed to shallow confers any benefit.

3. Basic Investigations on Concrete

In 1953 a small laboratory was completed at the School of Agriculture, Cambridge, for the Agricultural Research Council, for the investigation of drain installation problems, with particular reference to the use of mole ploughs and fresh concrete for forming and stabilising channels in one operation. Initially, basic work was carried on in the laboratory only on the properties of fresh concrete[6, 7]. Information on the likely resistance to be met in forcing concrete through pipes, ducts and extrusion orifices was a basic necessity to the design of systems involving the passing of concrete through the narrow space allowed by the mole plough blade and for forming tubes *in situ*. The principal conclusion of this work is to place concrete in the freshly-mixed state into two groups, according to whether the volume of liquid in the concrete exceeds or is less than the volume of voids in the compacted mix. These two groups, saturated and unsaturated mixes, have distinct properties.

(*a*) The resistance and behaviour in pipe-lines and ducts.

In the saturated state, stresses applied to the material are born by the liquid component of the mix. The pressure p_s to shift the concrete through a pipe-line of diameter D and length x against a pressure p is :

$$p_s = p + \frac{4}{D}(A' + Kv^n)x \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where $(A' + Kv^n)$ is the frictional function taking account of the velocity of sliding v.

The type of material obeying this law can be made to move at high rates by pressures which are proportional to the length of pipe-line, and to transmit pressures over distances without incurring additional friction. By experiment it is known that, if it is well saturated, bends and changes of section can be negotiated. It has not normally enough plastic strength to stand up as a tube, nor is permeability attained when hardened, except abnormally.

In the unsaturated state the stresses are born by interparticle contact, and the moisture in the mix tends not to separate the solids but to create cohesive strength. The build-up of the pressure p_u required to force the concrete through a pipe-line is of the unfavourable exponential type.

$$p_u = pe^{4\mu k\frac{x}{D}} + \frac{A}{\mu k}\left(e^{4\mu k\frac{x}{D}} - 1\right) \quad . \quad . \quad . \quad (2)$$

In this case, μk is the friction parameter and A is the adhesion. Not only is the pressure rise with length of pipe-line very steep, but the transmission of pressure through the pipe-line leads to a cumulative build-up of resistance. On the other hand, this type of material can show useful stability and permeability properties.

It was concluded from this examination that for the mole plough project, whereas the saturated concrete handles well, it is useless as received for the formation of a drain tube, but that unsaturated concrete, whilst adequate for direct use in tube formation, is not amenable to pumping. As an alternative method to pressure pumping was available, work was first concentrated on the latter material.

(*b*) Vibratory feed.

The main direction of material movement in a mole plough has to be essentially downward, and the use of vibratory action assisted by gravity has been studied[8]. The vibration of the material itself merely serves to hasten consolidation and the development of lateral pressures within its container. The apparatus used to transmit concrete overcomes the adhesion and friction between the concrete and container by applying an intense vibration to the container, which is in the form of a long, flat, vertical duct. The concrete is unable to follow the movement of the container and is shifted downwards under gravity action.

(*c*) Permeability of concrete.

For drainage purposes, the main concern is to achieve permeability in the drain wall of the same magnitude as in free-draining soils, and not with the low permeability figures which are met with in the use of very dense concrete. By adjustment of the mix proportions, principally by using aggregate with little or no fines, unsaturated concretes can be made to have permeabilities in excess of the objective of 0·01 cms/sec. (14 ins./hour)[6] [8]. Saturated mixes of normal cement content are relatively impermeable on hardening.

To compare field results, an experimental mole plough (Fig. 2) was constructed with a dynamometer directly reading the horizontal force on the blade, which could be varied in dimensions by bolting on plates. A comparison of the theoretical and measured drawbar pulls (Fig. 3) indicates that the theory gives reasonable working estimates. By use of it a blade has been designed of section 1½ × 18 ins., a size which can work with certainty at depths of 30 ins. in heavy clay soils and up to 48 ins. in lighter alluvial soils and loams. These dimensions have been fixed in the relation to the 20,000 lb. drawbar pulls available from a number of commonly-used heavy tracklayers.

5. The Vibration Method of Drain Laying

The design data on soils and concrete enabled the initial tube laying experiments to go forward. The mole plough was adapted (Fig. 4) by fitting a hollow welded steel blade housing internally a pneumatically vibrated feed duct of section 8 × ¾ ins. The duct connects from a small hopper fitted with agitator to the mole channel (Fig. 5). Concrete emerging from the duct comes into contact with the core around which the tube is formed. The core itself is vibrated axially by a

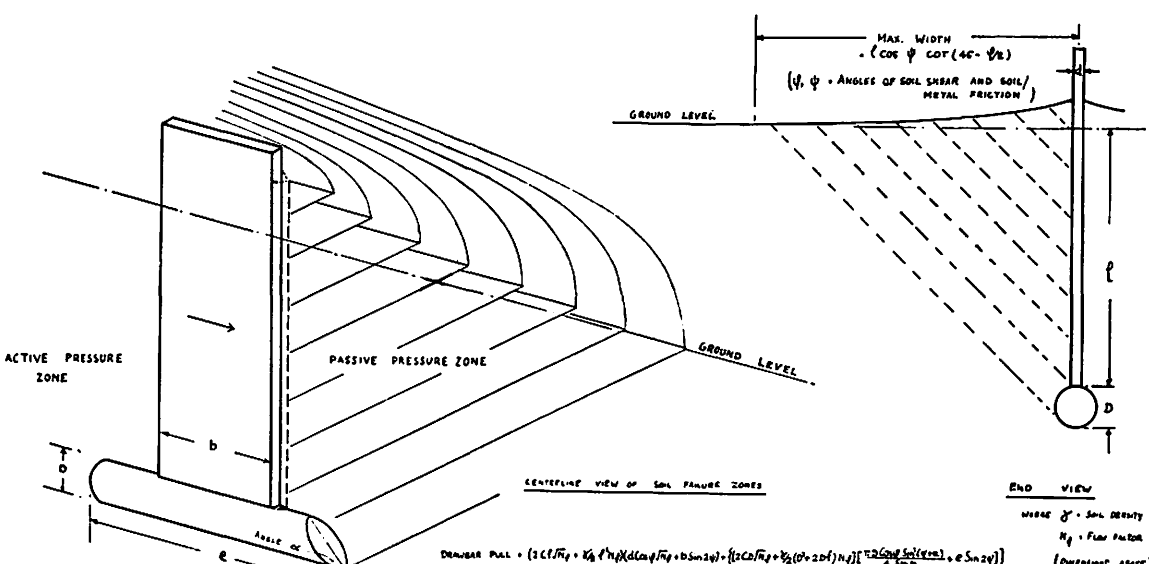


FIG. 1.—Earth Pressure Failure in Vicinity of Mole Plough.

4. Field Tests

The need to estimate the forces acting on mole plough blades varying in dimensions from the normal size and to control their action in various soils has necessitated the development of a working theory[6]. The precept of the theory is that the soil ahead of the mole plough is continuously thrown into a state of failure by reaction on the frontal surfaces of the blade and mole, and is sustained in this state until the blade and mole have passed by (Fig. 1). By measurement of soil shear strength and soil/metal friction parameters, the drawbar pull on a blade of given dimensions can be estimated.

small high-frequency pneumatic unit in the nose of the mole. The concrete is first fragmented and settles to the exposed floor of the channel. The supply proceeds to progressively build up the walls and roof of the tube in a continuous process as the machine moves forward. Finally, a roof plate presses the material down as it consolidates under the continuing vibration. The concrete then becomes a self-supporting structure, which can resist minor buffetting from loose soil as the core moves away.

With this machine 4 in. outside diameter tubes with inside diameters from 1½ to 2¾ ins. have been placed at speeds varying from 34 ft. per minute for the smaller to 4 ft. per minute for the larger. Over 100 short trial runs were made to test variations in mix and mechanism. On the evolution of a satisfactory combination the handling of the machine was improved to enable full-scale drainage tests to be undertaken. The mole plough

The functions of the gravel are :

(*a*) To prevent slit closure in heavy soils from distorting the channel.

(*b*) To form lasting connections in heavy soils for mole drains, surface run-off, etc.

FIG. 2.—Experimental Mole Plough Fitted with Dynamometer.

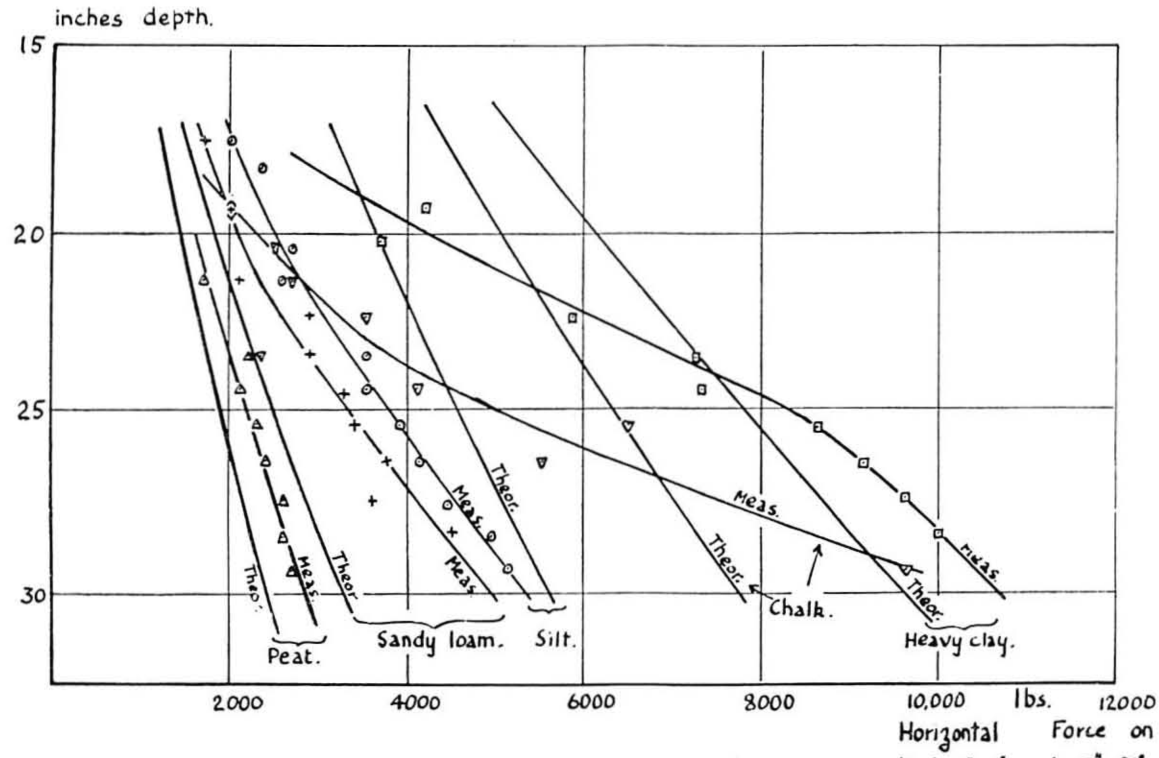


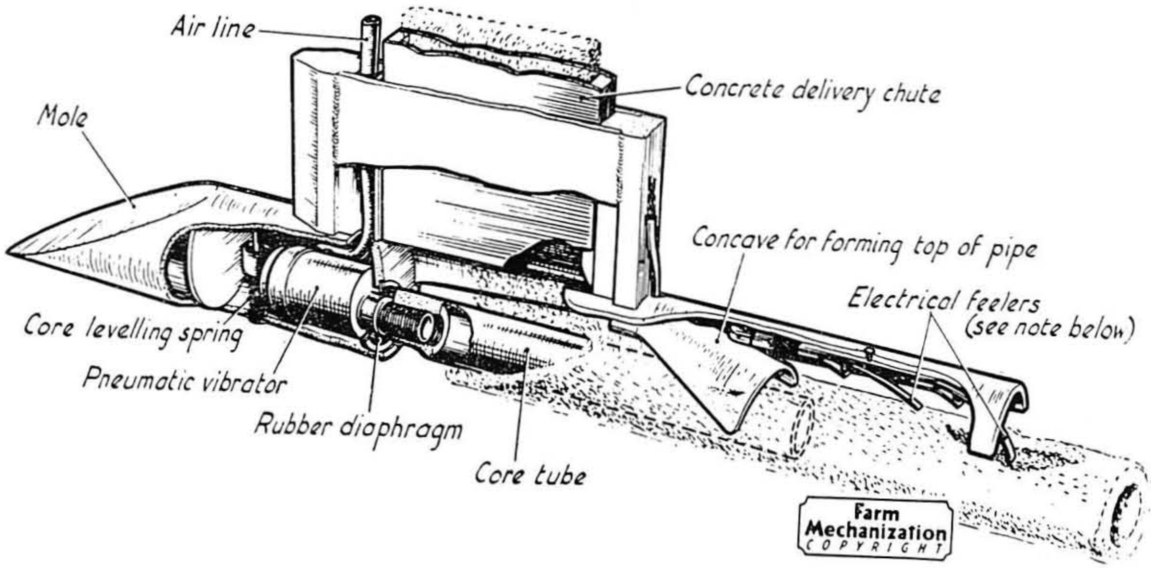
FIG. 3.—Comparison of Measured and Computed Horizontal Force on 1 by 8-in. Mole Plough Blade.

was re-mounted within a chassis (Fig. 6) with means for hydraulic lifting and depth control. A continuous feed of concrete to the blade hopper was provided by a screw elevator from a supply hopper containing material for 10 chains. An addition to the blade consisted of a slit back-filling hopper, by which $\frac{3}{8}$ in. gravel could be deposited as a continuous sheet above the concrete tube.

(*c*) To provide indirect connections between minor drains and main drains by means of the intersection of gravel sheets.

(*d*) To ensure a large effective drain size in ground-water situations.

In addition to isolated test lengths, drains were laid down in 1956/57 in soils consisting of fen peat on clay,



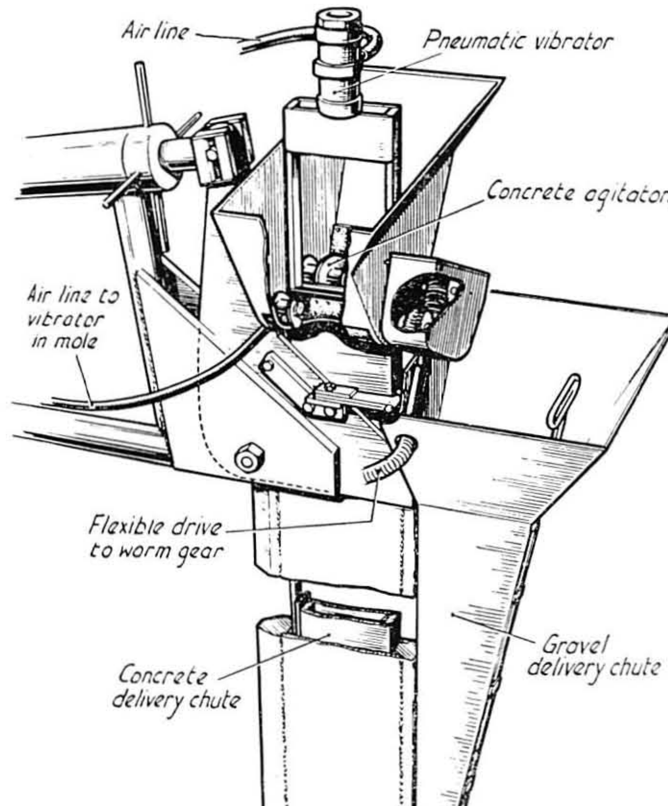


FIG. 5.—Details of the Vibration System Blade and Mole.

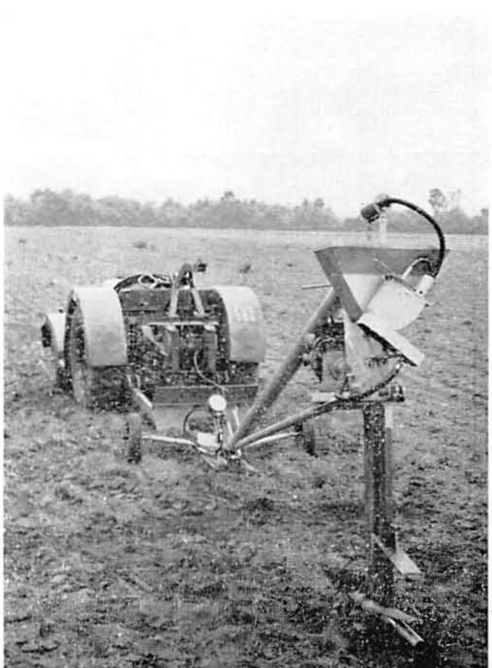


FIG. 4.—Apparatus for Preliminary Installation Tests, fitted with Mechanically-Driven Vibrators.

heavy gault clay (two schemes) and in heavy silt. Initially, haulage was arranged by use of a tractor-mounted winch and cable. Later it was possible to use a heavy track-layer for direct haulage. A reduction gearbox provided a governed speed of 8 ft. per minute. Experience gained with this tractor enabled changes to be made for more convenient field handling. The machine was shortened, the mechanical feed system and supply hopper dispensed with, and hoppers were provided at the rear astride the blade for hand-feeding of both gravel and concrete. In this semi-trailed form (Fig. 7) manoeuvring is simple, and one operator can handle the steering, depth control, and supply. Use of the machine to lay long lengths has proved satisfactory for tube sizes up to 2 ins. internally. Core sizes above 2 ins. require the blade to be withdrawn at intervals for cleaning, as the present mole and core arrangement has not been developed to give a vigorous enough scour on the core surface.

FIG. 6.—Vibration System Mole Plough as first fitted for Extensive Fieldwork.

6. Approving the Test Drains

In this work the observation of the results is inherently difficult. The most obvious check is to excavate the finished product on hardening and by this means the results on eight schemes have been checked (Fig. 8). The delay is too great for development work, and for many early tests a sand tank (Fig. 9) was used for laying short lengths of tube with the machine's speed exactly governed by an electric winch. For tests in the soil, much tedious search digging has been avoided by a recording fault detector, which tests the roof for continuity at a point to the rear of the supporting core (Fig. 5). Finally, rodding or waterflow tests may be employed to test the work.

7. Operating Equipment and Materials

Suitable units for use by a team of two or three men consist of a pan-type mixer and an elevator, front loader or skiplift for filling the raised hoppers on the drainer. The aggregate should be delivered in bulk to a mixing site in the field to be drained, and should consist of a grit evenly graded from material passing $\frac{3}{16}$ in. or $\frac{1}{8}$ in. B.S. sieve down to 25 sieve. More than 10 per cent. finer dust should be avoided. In practice, a mixture of two to three parts $\frac{1}{8}$ in. washed grit combined with one part washed sand has proved to fit the grading requirements. From some pits the material sold as coarse sand may be used directly. Variations in the aggregate can be compensated to some extent by the water content in the mix.

Portland cement is normally used, and rapid hardening cement is only required if the land is required almost immediately for cultivations. The proportion of cement by weight in relation to the aggregate may be varied from 1 : 10 to 1 : 3. For the standard mix of 1 : 5 water is required to between 30 and 40 per cent. of the cement weight. Allowance must be made for dampness of the aggregate, but fortunately the consistency can be regulated by eye at the mixing stage. A practical test is to add water until a sample of the mix squeezed in the hand is just capable of retaining its shape on release.

A mixer of 10 cubic feet nominal capacity takes 600–700 lb. of aggregate, sufficient for nearly 2 chains of drain, and four to six mixes constitutes a load. The start of the drain can be made either by pulling in the blade from the surface, requiring a distance of 6–7 yards, or by pulling in from the ditch side (Fig. 10). A pre-fabricated outfall length is slipped over the core and pushed in from the ditch and from it the concrete tube makes a direct connection.

On completion of a work period it is necessary to clean the hopper, feed duct and core parts by means of a water jet and shaped brushes.

8. Economy

The cost of the technique has been assessed on the basis of capital charges, depreciation, running costs, labour, replacements and materials charges on the yearly, hourly and footage basis given in full in reference 6. The forward velocity and the number of hours worked annually affect the overall economy materially, and to take those factors into account the costs variation has been plotted in Fig. 11. For periods of work in the region of a likely annual work period of 450 hours the cost per chain and per acre for overall drainage is as follows.

FIG. 7.—The final semi-trailed version of the Vibration Mole Plough.

Speed of Work. ft./sec.	*Linear Cost. Pence/ft.*	*£/Chain.*	*Area Cost, £/acre. Spacing (Chains),* 2	1	*1/3rd*	*1/10th*
0·1	4·30	1·18	8·5	14·4	38·0	121
1·0	1·35	0·37	2·7	4·5	11·9	38

With the present vibration equipment the speed is somewhat better than 0·1 ft./sec., and allowing the expense of 2/6 per chain for sheet gravel back-fill the overall cost can be estimated at 25–30 per cent. of the cost of conventional work. The advantages of the greatly reduced disturbance to grassland and of the beneficial heave caused by the moleblade are difficult to assess.

FIG. 8.—Excavated Section of Tube Laid in Gault Clay.

9. The Alternative Liquid Concrete Method

The potentially faster and more convenient method of pumping the concrete to the mole channel by pressure made worthwhile an investigation of the chances of converting the saturated material to the solid state by removal of excess water *in situ*. In recent years, engineers have used the process of vacuuming out excess water from freshly-cast concrete sections[9], and it was considered that if this technique could be extended to a mobile process another solution to the problem of stabilisation to tube section might be in sight. Vacuum tests were commenced on small samples in the laboratory (Fig. 12) and it was determined that :

(*a*) 1 in. thick sections of suitable liquid concrete could be vacuumed " dry " in periods from one second upwards.

(*b*) The speed of the extraction varied with the conductivity of the mix to its suspending grout and with the vacuum applied.

(*c*) The volume of liquid withdrawn could amount to 5–20 per cent. of the original volume, with contraction of the sample resulting.

(*d*) Certain highly cemented mixes formed a very favourable dense structure interspersed with channels formed from surface to surface of the sample.

The data provided sufficient basis to warrant the starting of tests on the mobile vacuum process. A mole plough of one-third scale drawn through the implement testing sand-tank was used initially. Liquid concrete passing down the hollow blade into the mole channel was brought into contact with a core, of which the tail section was perforated and acted as the vacuuming surface. The end of the core was closed and the interior was connected by a pipe-line to an evacuator. The concrete surrounding the core was solidified into a tube, which could be inspected through an aperture at the rear of the blade. The vacuum in this process not only desaturates the concrete, but exerts a dragging action on the material as it solidifies. This forward force is

FIG. 9.—Concrete Tube Formed in Testing Tank at Speeds of 6·8 to 18·2-f.p.m.

opposed by the grip of the surrounding soil and by the pumping pressure in the concrete (Fig. 13). The drag can be adjusted so that the contraction which occurs in the drying material gives rise to more or less circumferential cracks in the concrete. These cracks can be induced in concrete of a type giving little pumping difficulty and which are relatively dense, impermeable and durable on hardening. They provide a means for

FIG. 10.—Method of Starting from Ditch Side with Prefabricated Outfall.

water entry to the tube as an alternative to all-over permeability. A separate investigation on the hydraulic qualities of gapped tubes in comparison with permeable tubes has been made in order to assess this development. Provided that the gaps are spaced at intervals along the tube not greater than 1 diameter, the drain acts hydraulically with effective diameter approximately equal to the best permeable type.

10. **Vacuum Concrete Test Machine**

A machine has recently commenced full-size tests of the vacuum concrete technique, and has given very promising results. The first test showed that the machine could form a tube of $4\frac{1}{2}$ ins. outside diameter, $2\frac{3}{8}$ ins. inside diameter, with considerable variation in the operating conditions, and it remains to follow up the considerable development capabilities. The equipment (Fig. 14) is direct-mounted on a heavy tracklayer and consists basically of four items :

(*a*) Pressurised hopper A and feed hose B.

(*b*) Blade and mounting gear.

(*c*) Auxiliaries unit driven from P.T.O., with evacuator C, compressor D and hydraulic drive E.

(*d*) Cylinders for the evacuated liquid F and for water G.

The pressurised cylinder is fitted with a mechanical stirrer, which enables up to 2 tons of liquid concrete to be held for an indefinite period. Two cylinders are allowed for in the final design. The concrete flow to the hollow mole blade is through a 3 in. flexible hose, and is started by placing the cylinder under pressure and opening fully the control cock. The metering of the supply is automatically synchronised with the forward speed of the machine, provided that the main cylinder pressure is slightly in excess of the minimum required, as the end of the supply line is choked continuously by solidifying material. If the cylinder pressure rises too high the liquid concrete bursts up through the soil and

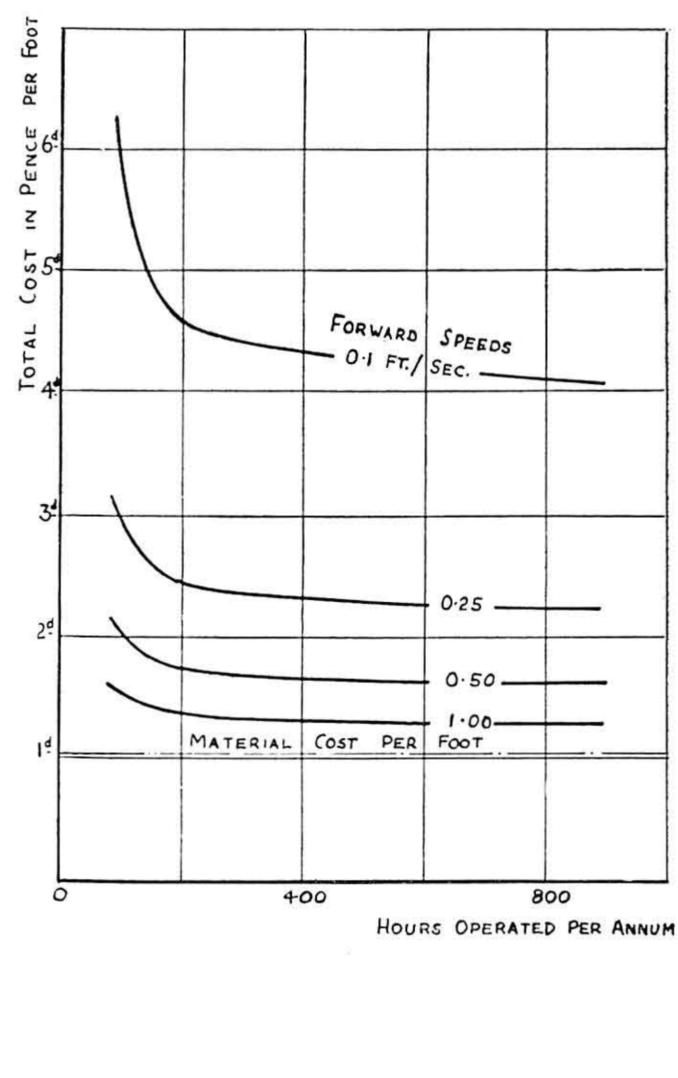


FIG. 11.—The Effect of Forward Speed and Hours Worked on Cost of 4-in. Concrete Tube.

is ejected above the ground, but the tube is still formed.

The vacuum pipe of 1 in. diameter leads from the evacuated cylinder down the front of the mole blade to the core. Thick-walled polythene tubing perforated by frequent part-circumferential slits has been found to be suitable for the tube-forming core. The slits are superior to circular holes, as they are self-cleaning with the flexing of the tube. The capacity of the evacuating pump is 10 and 30 cubic feet per minute, and in normal operation the evacuation cylinder operates at a suction of 15–18 ins. of mercury. The drawing in of air into the core as the concrete is solidified possibly gives stability against the development of excessive suction. It is not known at present what are the limits of suction and effective core area to give the required frequency of tube gapping, and no attempt has yet been made to operate at speeds in excess of the maximum ultra-low speed provided on this machine, at which speed the economy is similar to that of the vibration machine.

It has been tested that the concrete feed rate can be increased to the equivalent of $1\frac{1}{2}$ m.p.h. by increasing the operating pressure. Since the extraction rate is proportional to the vacuum and to the area of concrete exposed in unit time to the perforations, an increase in both the vacuum pump capacity and core length can be theoretically accompanied by a corresponding increase in speed. The basic conditions of the process favour the attainment of higher rates in the region of normal bottom gear speeds as a development objective. The operational cost can then be estimated to fall to 10 per cent. of that of conventional work.

11. Liquid Concrete Bulk Supply

With any increase in the present rate of work the supply train becomes an important factor. The present trial arrangement is shown in Fig. 15. The pan-type mixer is supplied with 740 lb. of coarse sand aggregate, to which is added 1 cwt. of cement and 140 lb. of water. The mix is extremely liquid and is poured from the mixer into a raising cylinder *via* a funnel and a 3 in. aperture, which is then closed. Pressure is then applied to the raising cylinder by pipe-line from the tractor, and the batch is pneumatically forced into the main cylinder through a 3 in. flexible " refuelling " hose. Five batches constitute a full load. This arrangement is not ideal, but it serves to demonstrate that pipe-line replenishment is practicable. There is considerable attraction in using a ready-mix concrete organisation for the supply, and it should be within the scope of a manufacturer to develop a pressurised truck-mixer or high discharge arrangement for dispensing the large quantities of concrete. An alternative method is for a truck-mixer to be positioned ahead of and propelled by the tractor, and for the concrete to be fed directly to the mole plough blade without the use of a major storage tank on the tractor.

12. Developments Abroad

In the U.S.A. an investigation reported by G. O. Schwab[10] about the use of plastic drains with mole-ploughs has been concerned with the method of dragging in long lengths of tubing behind the mole-plough. More recently, C. D. Busch[11] has tested a method of folding into an arched drain a slitted ribbon of plastic which can be fed down the blade off a reel. The cost is calculated to be 7 cents per foot. Water entry is by wall perforations in the first case and by the open floor in the case of the ribbon drain.

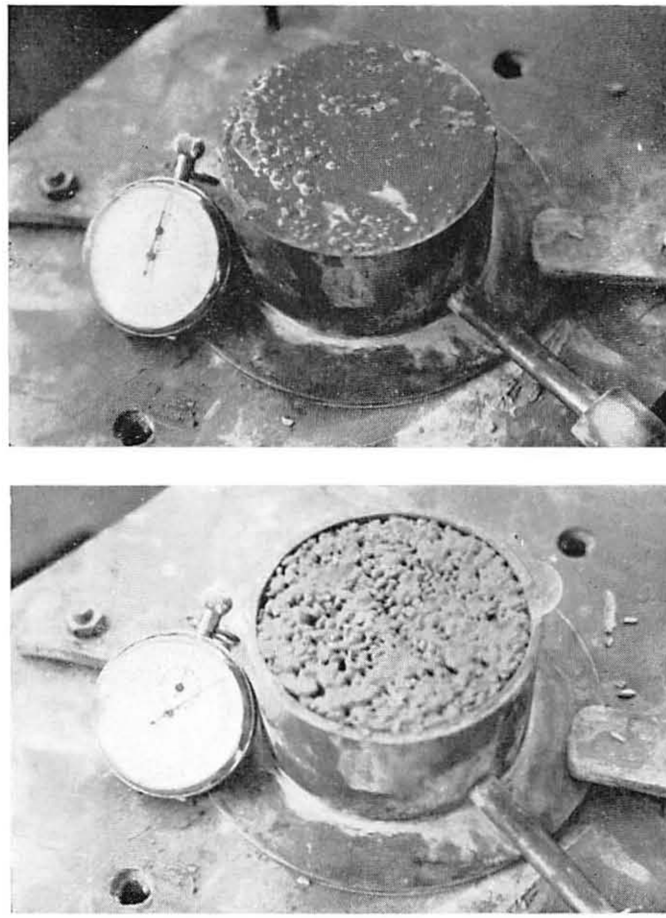


FIG. 12.—Sample of Vacuum Concrete Converted from Liquid to Solid.

In Federal Germany trials are proceeding with the use of the Poppelsdorf mole-plough technique.[12] A large double-bladed mole-plough draws in 100-metre strings of 5 cm. tile drains into a channel of depth 1 metre or more (Fig. 16). It is the workable state of development which is significant in this case. Traction is provided by a windlass side-mounted on a track-layer, which serves as an anchor. On completion of a run towards the tractor the mole-plough blade tilts backward out of the ground. The tractor moves a short distance forward to its next station while the mole-plough returns under its own auxiliary power to the far end of the field where preparations have been made for a further run. Good-quality tiles are essential, but satisfactory drainage results are regularly achieved. The cost can be brought low, provided that continuous work can be arranged to cover extensive overheads charges.

Advanced work has been carried out on the stabilisation of mole channels in the German Democratic Republic by Prof. H. Janert at Greifswald. A machine has been constructed[13] for impregnating the soil surrounding the mole channel after loosening by the

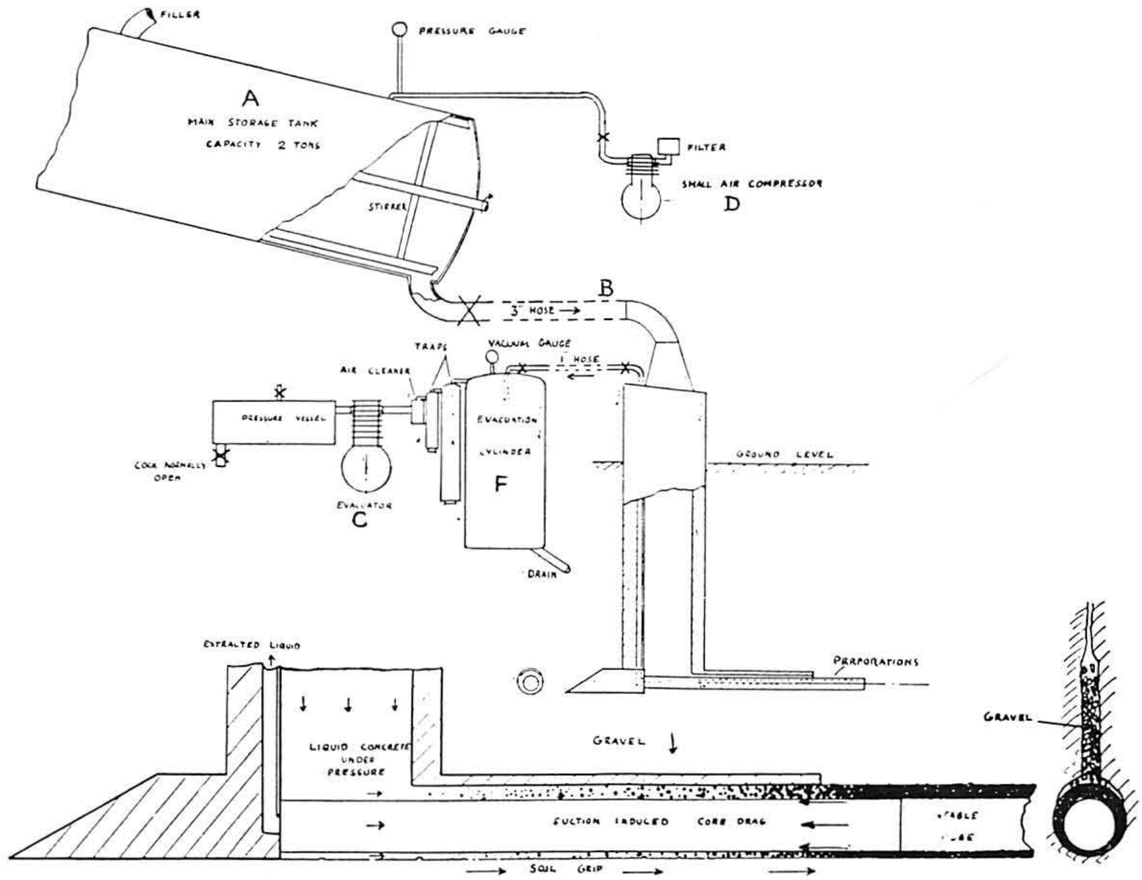


FIG. 13.—Schematic Arrangement of Vacuum Concrete Cycle.

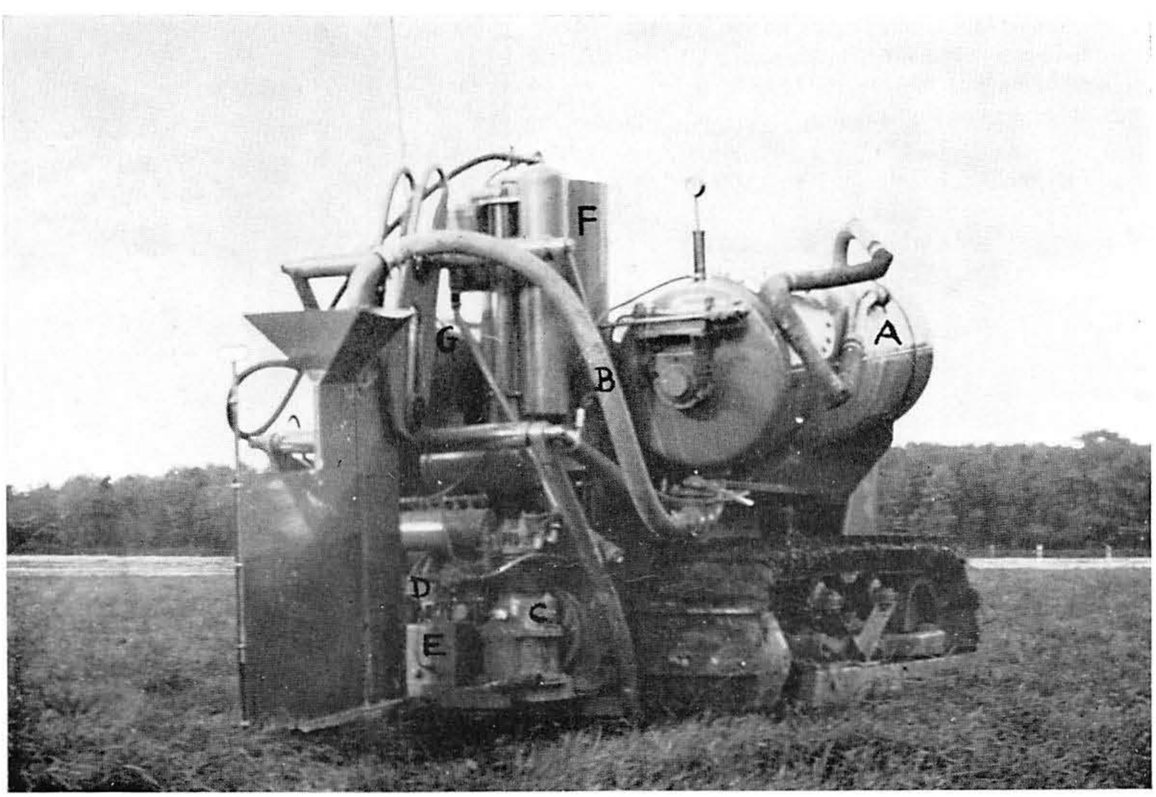


FIG. 14.—The Vacuum Concrete Drainage Machine.

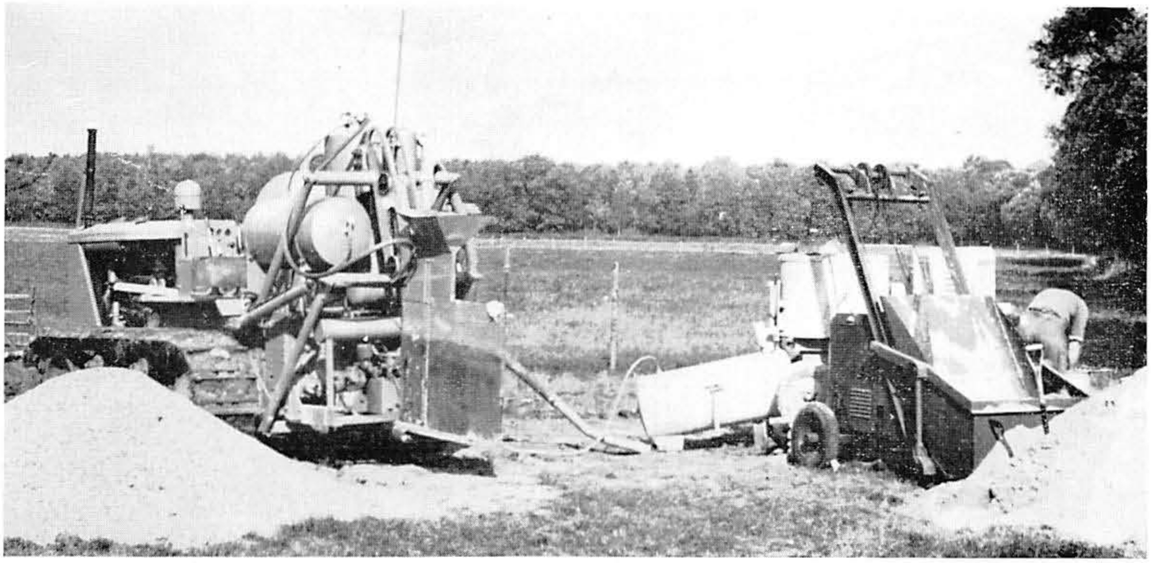


FIG. 15.—The Mixing Arrangements for Handling Liquid Concrete. The gravel on the left is for use in the Blade-Slit Hopper.

previous passage of a thickened blade. Hot bitumen or a stabilising emulsion are pumped from the nose of the mole into the soil, and a conical expander following presses the mixture to form the walls of the channel. Water entry is arranged by slitting the base of the channel with a knife. The drain is 6 cm. in diameter and can be laid at 0·75 metre depth. The work is carried out at a speed of 288 metres per hour and is calculated to be $3\frac{1}{2}$ times cheaper than tile drainage. Recently, successful experiments have been carried out on the use of a ribbon of bituminous fabric and other sheeting drawn into the channel. At a rate of 300 metres/hour, a tube is formed by rollers under heat. The tube, of diameter 1·38 ins., allows water entry by a special slit at the base.

In Poland the need for a mole drain stabilisation process has been recognised as one of considerable urgency. At Krakow University, Prof. Hendzel has followed up laboratory experiments and mole plough trials with a project for stabilising the channels with Portland cement. This is planned to be spread dry by an air jet on to the walls of the mole channel, to be pressed into the soil by an expander. Moisture taken up from the soil is to harden the cement into a crust. Experiments are engaged on a satisfactory blowing method and on a metering control to allow an eventual thickness of 1 mm. of cement on the soil wall.

In the Soviet Union two approaches towards reducing installation costs are being tried. The development of an efficient unit for manufacturing drains at the field is a first measure. Pre-fabricated tubes made from bitumen/sand mixtures, clay with sawdust, or peat and clay are being investigated. A unit operated by two persons can now produce 3,000 tubes per day, using a mixture of 95 per cent. coarse sand and 5 per cent. bitumen. In Estonia, drains made from a glassworks by-product are being produced cheaply at a factory. In mineral soils concrete drain tubes are used, but cement is expensive. These tube materials are used with conventional installation methods, except that special joiners are sometimes employed to connect the tubes.

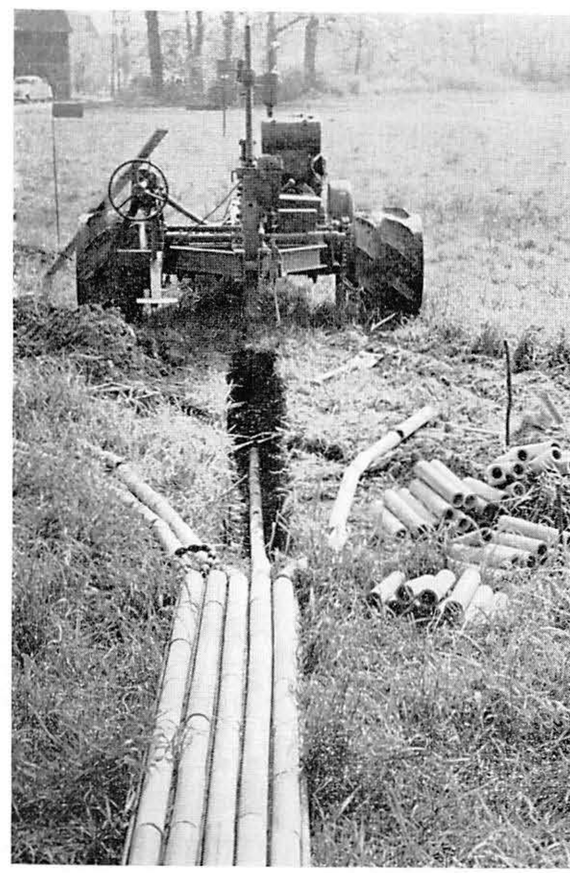


FIG. 16.—Poppelsdorf Drainage Technique Operating in Germany.

For low cost continuous drain installation the most useful material is considered to be concrete. A method is under test at the Spraying Experiment Station (Timiryazov Agricultural Academy, Moscow) by which a cement/water mixture is pumped down a mole-blade to be distributed on the walls of the mold channel *via*

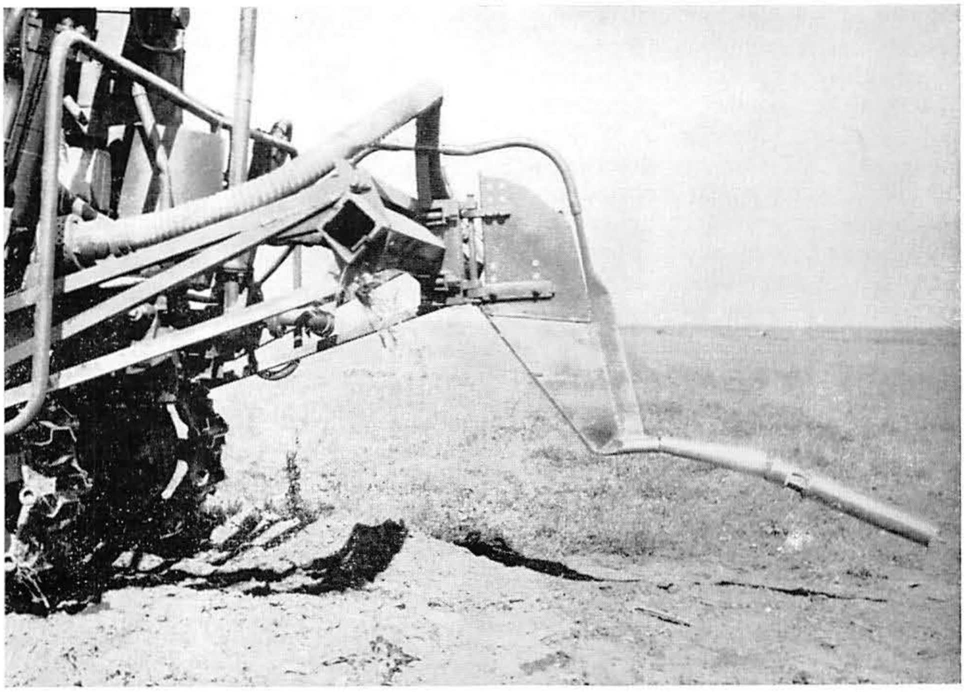


FIG. 17.—The Russian Channel-Grouting Mole Plough.

apertures in a conical expander. The rate of flow is 100 gms. per metre. The machine (Fig. 17) proceeds at normal mole plough speed, producing channels of good shape at a depth of 50–70 cms. The surface of the soil channel shows a grey deposit when exposed. The operation is considered by the users to be most instrumental in sealing soil cracks rather than in giving mechanical strength. The use of the channels as irrigators rather than as drains is the objective, and water take-up is to rely on capillary attraction. Excavated channels which have been given one four-hour immersion displayed considerable roof falls, but were still open. It is advisable to leave the channel to harden for one year before allowing water to enter.

13. Summary

Examination of the basic processes of field underdrainage enables the requirements of the installation operation to be formulated. To improve on conventional trenching methods, there is need for new techniques. Of the material available for use with the low-cost mole-plough technique, concrete has been examined for its physical properties. Two distinct systems have been evolved as alternatives, and field operations have been undertaken to test the equipment and the products. Work with similar objectives has been carried on abroad with interesting results.

ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance given by Professor Sir FRANK ENGLEDOW and by Dr. E. C. CHILDS in promoting the research.

The Fowler Challenger III tracklayer has been kindly lent by the makers.

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REFERENCES

[1] CHILDS, E. C., "The Water Table, Equipotentials and Streamlines in Drained Land." *Soil Science*, Vol. 56, No. 5, 1943.

[2] ENGELUND, F., "Mathematical Discussion of Drainage Problems." *Trans. Danish Acad. of Tech. Science*, 1951 (3).

[3] NICHOLSON, H. H., "The Drainage Properties of Heavy Soils." *Trans. 3rd Int. Con. Soil Sci.*, 1935 (1), 385.

[4] CHILDS, E. C., "Studies in Mole-Draining." *J. Ag. Science*, Vol. 33, Part 3, July, 1943.

[5] KIRKHAM, D., "Potential Flow Into Openings in Drain Tubes." *J. of Applied Physics*, Vol. 21, No. 7, July, 1950.

[6] EDE, A. N., "Concrete as a Material for Land Drains." Unpub. thesis, University of Cambridge, 1956.

[7] EDE, A. N., "The Resistance of Concrete Pumped Through Pipelines." *Magazine of Concrete Research*, Vol. 9, No. 27, November, 1957.

[8] EDE, A. N., "Land Drainage by Continuously Formed Concrete Tube." *Agricultural Engineering*, December, 1957.

[9] ORCHARD, D. F., "The Vacuum Concrete Process." *J. Inst. of Municipal Engineers*, Vol. 80, No. 6, 1953.

[10] SCHWAB, G. O., "Plastic Tubing for Subsurface Drainage." *Agr. Eng.*, 36, 36 - 39, 1955.

[11] BUSCH, C. D., "Developments in Low Cost Subsurface Drainage." A.S.A.E. Meeting Address, 27th August, 1957, University of Delaware.

[12] —, "The Poppelsdorf Mole Tile Drainage System." Private communication. Walter De Couet, K.G., Dusseldorf, September, 1954.

[13] JANERT, H., "Der Greifswalder Rohrpflug und Seine Arbeitweise." *Wasserwirtschaft-Wassertechnik*, 5 : 123 - 150, 1955.

DISCUSSION

DR. P. PAYNE : I think we must realise that Mr. Ede started off with only a brain-child, no equipment and very small funds and that he built this whole project up largely as a result of his own drive and initiative.

Mr. Ede mentioned that draught was a problem in the early days and said that he could only get a crawler that would pull 20,000 lb. I wonder whether he used the theories of soil mechanics which he has developed to reduce that draught at all. I wonder whether sloping the bottom of the stalk forwards would reduce draught and at the same time produce more bursting effect. I am not sure that this is what is wanted, but I presume it would help the entry of the water a little ; it might also increase the pressures on the concrete pipe.

Another point is whether the friction of the concrete pipe has any effect on the size to be used. I have heard it said it is possible to get away with much smaller diameter plastic pipes because the frictional coefficient is a good deal smaller.

The other point is the effect of sulphur on the cement mix. I understand that people using cement for stabilising roads have come across that trouble on certain soils. Would Mr. Ede advise against this method of those soils ?

Going back to the problem of rake on the stalk, does Mr. Ede grade by altering the angle of approach on the mole and stalk ? If he does, that will invalidate my idea of raking it forward and so reducing the draught.

One other idea occurred to me when I heard of the extraction of the water from the cement mix. If water could be supplied to the soil metal rubbing surface it would reduce the soil to metal friction. The usual argument against this is that there is no water available, but in this case could the water which is being pumped out of the cement be used to feed in again and so reduce the soil-to-metal friction on the sides of the stalk ?

I am very sorry to hear that this project has now been handed over to other authorities, because it will not be surprising if they have not the same drive as Mr. Ede himself has had on this particular problem.

MR. EDE : One of Dr. Payne's points was the slope of the stalk or blade to reduce draught. He may have noticed that Janert did slope it forward very severely—about 45 degrees. On the other hand, he may have noticed that on the Russian machine it is sloped backwards at 135 degrees, and mine is vertical. Professor Janert tells me that the reason why he sloped his forward was to increase the lifting effect of the mole blade. He does not employ a mole but a rudimentary blade. Dr. Payne will know from the soil mechanics' theory about the positive and negative effects of rake that a tine which lifts has a lower drawbar pull than one which is vertical or one which slopes backwards. In my mole plough there is a complementary lifting action from the frontal face of the mole itself. Taken in conjunction with the blade, that gives the effect of a forward sloping time. Of this we have the evidence that when we resolve the forces on the blade there is a severe downward force, which would not be the case if the blade were a mere vertical member. Nevertheless, we still get a channel.

Professor Janert seeks to break up the soil surrounding the channel by using a wide blade, which he is enabled to do because he is using a robust tube with a small diameter. Coming to Dr. Payne's point concerning depth control, we do not use the rake angle for depth control. We get the right balance of horizontal and vertical forces sustained by the blade, and depth control is advanced by moving the pivot point from which the beam is drawn, not by alteration of the rake.

It is true that plastic pipes have less friction to water than concrete pipes, but when dealing with these rather small sizes of pipe and not sewers a small increase in diameter more than makes up for increased roughness. So at the moment, having fixed my ideas on concrete, I am prepared to make a concrete pipe $\frac{1}{4}$ in. larger than any plastic pipe. The vacuum concrete drains are now being made regularly at 3 in. diameters.

On the point about sulphate-bearing soils or soil water, this is a problem which has a bearing on the way in which water entry to the drum is effected. With the fully permeable type of tube the water has access to all the voids in the concrete and therefore there is a large exposure of cement to the erosive effect of soil water, and to some extent all concretes are soluble. So if the voids can be cut down it will cut down the speed of attack. The advantage of the vacuum process is that the density of the tube material is greater, there are no voids, and water flow is confined to the wall gaps. The phenomenon which is called " end wear " in the United States in the traditional concrete " tiles " used there would probably occur in our case, but the rate of deterioration of the concrete tubes can be slowed down by using sulphate or acid-resistant cements. In some places it is necessary to take these precautions to cut down the rate of erosion. I do not know what the rate of erosion is in the case of our drains because there has not been sufficient time to find out. In most soils we would not expect the problem to be serious, but in some soils I think concrete in any form would be out of the question.

Dr. Payne also mentioned the use of the extracted water. The problem there is that a certain amount of cement is also extracted, so that what comes up is valuable and I should think it would pay to use it again in the mixing up of the next batch rather than use it to reduce drawbar pull, which itself has not been a great problem.

MR. A. C. HOWARD : I should like to ask Mr. Ede what in his opinion, in heavy Essex clay, would be about the practicable limit of depth which can be achieved to satisfy these people who are always asking for more.

I have always been interested in finding a means of getting away from tiles so that the field of sale for the trench digger shall not be tied up to where tiles are available at a commercial price. Some time ago I put up a scheme for casting the drain pipe *in situ* at the bottom of the trench. I should like to know from Mr. Ede what the position is if the ground is a little water-logged, and what the effect is of the water that percolates to the tile before it has had time to cure.

MR. EDE : I have not so much experience as some of the drainage officers here in dealing with problems such as draining heavy clay. I appreciate this call for more and more depth because I am feeling the effect of calls for more and more depth all the time. There are some very drainage-minded farmers in the Fens who want to go down six or seven feet, which is not impossible with the mole-plough, but unrealistic at present. As to what the actual depth should be, this is a point which is under current investigation in a number of countries. One cannot forecast what the results are going to be, but I think it is safe to say that in heavy Essex clay, which is probably not a soil with a recognisable water table, there is not much evidence that anything is gained by going below 30 ins. It is not a question of achieving a specified control by draining at certain depths and spacings, but of providing a get-away for surface water. Provided that the field has the slope to take a suitable drainage design, on present information there is little point in going deeper than 30 ins. If we are going to have a competition for more and more depth, I think probably the trencher will eventually win for depth-reaching powers because its complicated wheel, chain, or bucket cutting action is especially designed to cut deep—but is depth the criterion ?

The question of water-logged conditions often comes up, and I do not know the full answer to it, although we have some advance indications as to what should be done. Firstly, the concrete machine can be thought of as a duel-purpose machine both for heavy land and for lighter soils. When lighter soils have a high water table in winter heavy lands have no water table at all, because they do not sustain one, so winter is a suitable time for putting the main drains in heavy land. Conversely, in dry seasons light lands are more easily dealt with. By spacing the work out, the contractor gets the conditions most favourable winter and summer for the machine. We cannot work below the water table because the strength of the freshly-made concrete tube depends on the tension of the moisture in the concrete, and if you are down to the water table or below there is no tension, no cohesion and hence no tube. When, in our experiments, we were beset with a field in which the water table was too high we first used our machine as a mole-plough, going deeper than the final drain, along the area and a yard on each side of it. In that way the water was drawn down and we could go ahead afterwards and lay the concrete drains above the water table in conditions in which the machine would operate. Therefore, there are two approaches—one organisational and the other one to do with the physics of soil water retention.

I think that answers part of the second question raised about casting tubes in trenches. There may be some important connection here between the casting *in situ* mobile process which our machine entails and trenching for the very large size of tube for which there is at present no tractor large enough to pull a mole-plough to suit. There is nothing to prevent anyone casting tube on the move by the vacuum process or the dry-mix process in a trench, possibly combined with a trenching machine. Impervious or leaky drains up to 6 ins. diameter could be made by applying present knowledge. Restrictions due to sulphate conditions would apply to that method of manufacture also. It is possible, of course, to improve the resistant qualities of most concretes by using a measure of cement fondu instead of cement, but it has to be paid for.

MR. E. FOUNTAINE: I am very pleased to see a formally-trained mechanical engineer using soil mechanics in designing an implement, and I would point out to anyone else contemplating doing this that, at the N.I.A.E., we are building up data on the parameters of soil shear strength, and soil metal friction needed for soil mechanics' calculations.

My second point is that the work which Mr. Ede is doing might have its first practical application in the improvement of ordinary mole-ploughs, rather than in the adoption of his technique in its entirety. I believe that his method of depth control would be a great improvement on most mole-ploughs.

With regard to depth of drainage, taking the world as a whole, one of the main objects of drainage is to remove the water used in leaching salt out of irrigated land, and for that it is necessary to have drains down to 6 or 8 ft.

My last point refers to Schwab's article on plastic piping. I would emphasise that it is very detailed and complete ; for example, it specifies the wall thickness necessary to confine deformability to prescribed limits. In the N.I.A.E. Soil Department we are waiting until the price of plastic is cheap enough to apply this method at a total cost less than that of Mr. Ede's concrete method.

MR. EDE : There is a project in hand for a mole-plough mounting system, rather on the lines of the one employed on this trenching machine, using the liquid concrete method. It is rather a big topic and I have not said anything about it at all. We have had satisfactory results using this system of mounting which, briefly, involves mounting a mole-plough directly on a tractor in such a way as to reproduce the best characteristics of the floating beam mole-plough and yet to dispense with the beam itself. The Land Drainage Division of the Ministry of Agriculture will shortly begin making one of these devices for ordinary mole-plough work.

I did not want to detract from the erudite nature of Mr. Schwab's Paper. I have only been able to mention briefly one or two of the other workers in this field, so that anyone who is interested can get hold of the papers themselves.

Concerning the leaching of salt, I have not much experience of that problem, but I do know that in many cases the drainage flow required to keep the salt down to a satisfactory level is very small. That takes us back to drainage theory, whereby in taking off a very little water we are faced with the choice between deep drains extremely far apart or drains not so deep and somewhat closer.

MR. V. H. F. HOPKINS : I should not like to let this opportunity pass without paying some tribute to the extraordinary piece of development work which Mr. Ede has carried out. It must be apparent to all that in most of our technical enterprises there would have been at least five times as many men taking very much longer and costing much more to carry out the same work.

In four years, Mr. Ede has done a tremendous job, and I recommend those people in the industry who are interested in drainage to take very much notice of it. I am sure from what I have heard to-day that land drainage is a vitally important subject in agriculture, and here is a development which should continue to be guided and steered along the right lines to a successfully economic conclusion.

We have heard Mr. Ede refer to the development being taken over by other authorities. This may not be the time or the place to enquire about that, but perhaps one may ask whether the N.I.A.E. is interested. We have seen developments handled successfully by that body before ; this is something which is surely in their line, and it is to be hoped that the authorities concerned include the N.I.A.E.

There are one or two questions I should like to ask. First, it seems to me quite obvious that not only can pervious pipes be laid, but impervious ones, and pipes also for irrigation purposes. No doubt, Mr. Ede has given some thought to other possible applications ; for example, there might be a military use and perhaps a municipal application for this method of laying pipes underground.

I should like to know whether the greatly increased speed in bottom gear of the tractor of 1 to $1\frac{1}{2}$ m.p.h. is really practicable and is within the realm of possibility, because if so all costs will come down tremendously. There would then be no question about the economic success of the development.

MR. EDE : It is very kind of the last speaker to lay at my personal door the credit which really should go to the research organisation which made the work possible. All I can say is that there may be, perhaps, a lot of other work of this nature which has not been so lucky in getting support from the right authorities at the right time. What has been achieved is no less than should have been expected in view of the facilities and backing provided.

The future of the machine has been under consideration recently at a meeting at which all interested parties were present, including Mr. Cashmore from the N.I.A.E. It does not seem likely, however, that the work will be handled directly by the N.I.A.E. at the moment. What is needed now is a period of development to bridge the gap between the research stage and the manufacturing stage. That is my personal opinion. It should be handled by people who have not had their finger on it right from the beginning and who do not know what to expect to go wrong at certain times. Also, the machine must prove itself in the field over a number of years, and there is much to be still worked out, particularly on supplying the bulk of material to keep up with its capacity to lay drains.

I have just come back from the Soviet Union and I think that there they would make 20 machines straight away and give them to Government depots and tell them to get on with it and build up a glossary of information. That is how they have got on so rapidly with their irrigation work and produced a machine which is certainly much larger and certainly more complicated than mine. It might be the way to work here, but I prefer that first we should have a further period of development and then to follow with a trial on a larger scale.

There are many other applications, I think, for this process, particularly in under-soil irrigation. Also, various types of ducts and conduits can be envisaged. It is easier to make impermeable tubes than the leaky ones. It is well within the bounds of possibility to lay water piping which will stand quite a high pressure. I am not sure that municipal work is likely to be much of a field for it because most municipal work in this country is carried out in built-up areas, and I can foresee some heavy costs accruing if the effect of water pipes or telephone cables is not noticed with a 20,000 lb. draw-bar pull.

I think this machine is capable of being worked up to the bottom gear speed of a heavy tracklayer dethrottled to give a speed ujst under one mile an hour. We already know that the flow of the concrete through the 3 in. pipe-line can be speeded up twenty-fold, and the tank holding the concrete has been tested up to 180 lb. per sq. in. We are working now between $7\frac{1}{2}$ and 10 lb. per sq. in. It is possible to empty that 2-ton tank in 15 seconds if the pressure is put full on and the cock is opened, and that is equivalent to a speed well in excess of bottom gear speed.

As regards supply, there is no doubt at all that there is no practical limit to the rate at which you can provide the concrete in the mole channel. The other factor is the rate at which the water is able to be extracted, and I have given some indications in more detail in the Paper about the factors governing this extraction. It is a question of the amount of suction which is applied to a given thickness of section, and the area over which the vacuum is applied. The suction is a matter of the capacity of the pump, and the area is a question of the surface of the core, and these easily controlled factors should enable us to get the speed up appreciably. One can only guess at this stage, but my guess is that there will be no prohibitive difficulty in evacuating the water at bottom gear speeds from the kind of section one has to consider in drainage work.

CAPT. E. N. GRIFFITH: My first point has reference to the depth at which it is customary to mole in Essex clays. Against all the experience of 150 years of moling, the Government has laid down, and grants subsidies for, a depth of 24 ins. This followed the use of crawler tractors in 1940 instead of steam tackle. The experience of farming generally—and after all there was some sense behind most of the farming beliefs, was that we should go to greater depths. If facts can be found to alter that view, well and good.

As regards the time of year to mole in Essex clays, I cannot agree with Mr. Ede, because the results are much better in dry conditions than in wet. There is herring-bone cracking, and if it is done in dry conditions that cracking is improved.

The rate of water flow is rather interesting. I have been reading an excellent book by A. W. Hudson and H. G. Hopewell, Professors at the Massey College, New Zealand, and apparently tests have been carried out on the speed of water going through that can pass through the walls of a tile. The concrete ones which we have seen to-day are very much more porous than the tiles used in the test, but the flow was 24 gallons per hour over a chain in length. That is what an ordinary tile will do, whereas what is required is a flow of 1,000 gallons an hour after normal rainfall, so the porousness of the existing type of tile used is of no significance. One thousand gallons per hour per chain is what should be aimed at.

As regards the question of salt, a tremendous amount of work has been done on this subject, especially in India, and the authority on that is Dr. Mackenzie Taylor.

Looking at the siles and quickly estimating the cost of this plant, I think it would cost not less than £10,000. At 7% that is a very heavy capital charge alone of £700 a year. It is important to bear that in mind in relation to the cost of other plant for ditching.

Mr. Ede did not mention how he could make a herringbone system. The jointing of these systems is very important. Would it be necessary with his new system to dig by hand at every joint to be sure that the joint was perfect ?

MR. EDE : Capt. Griffith's first point was the depth of drainage in Essex clays. I think 24 ins. for moling is the depth of which the Ministry approves and I am happy to stand by it. The speaker has made the assertion that it is better to go deeper and he wishes me to produce evidence as to why it should not go deeper. All I can do is to ask him to produce evidence that it is better deeper. We have no evidence one way or the other, but we do know that the primary objects of mole draining are (*a*) to shatter the soil and (*b*) to produce mole channels. The two things are achieved together to assist the removal of surface water, and as much water can be conveyed away by shallow mole draining as by mole draining deeper. I think in view of that and the paucity of information on the subject we should accept present practice.

With regard to the conditions for laying mole drains, I agree it is definitely better to mole drain in rather dry conditions because then you get shattering of the soil as opposed to re-moulding of the soil. The concrete machine is not a dual-purpose one ; it is only intended to make tubes, and although the shattering near the main channels is beneficial, it only involves quite a small volume of soil in the field and is not essential by any means, because mole draining will be done at the most favourable time afterwards. That need not be done at the same time ; in fact, I would not advise doing it at the same time.

I did not understand the speaker's reference to a flow of 1,000 gallons an hour per chain rising from 24 gallons per chain per hour. I am not sure whether he was talking about the conducting capacity of the tube or the sink capacity of the tube, which are separate things.

CAPT. GRIFFITH : I meant the amount of water that would get through the walls of the tube in an hour per chain length.

MR. EDE : That is a much more complicated problem than can be answered with the factors I have spoken of so far. It involves considering the permeability of the soil, depth, spacing, depth of impermeable layer and so on. I do not think it is a sticky problem because the type of drain we are making is at least as favourable in hydraulic properties as tile drains. Therefore, if you accept the use of tile drains there is no argument on hydraulic grounds against permeable drains, although there might be some argument on other points such as deterioration.

The capital cost suggested by the speaker is something of the right order if the cost of all the items are added up which we are at present using, but it must be remembered that many are non-standard. In making my estimate of costs, I did not include the capital cost of the prime moving unit—the tractor itself. I substituted an hourly charge of £3. Furthermore, when I worked it out, interest rates were not 7%. They may not be next week, for all we know. The costing can only be known with certainty after considerable field experience, which we have not yet had.

With regard to herringbone systems, I am afraid that we have to distinguish between the herringbone system in heavy land and that system in ground water situations. I am going to avoid a detailed discussion on this point because until we know more about the operation of this machine we do not know whether we shall have to call for any changes in conventional practice.

To bring this to mind, I will tell you of some work I saw in Poland this summer, in which an apparently almost flat field had been most carefully surveyed by a local engineer. He had managed to find small undulations all over the place and he plotted a contour map. He then designed a drainage system in which all the mains and sub-mains conformed to the valleys throughout this field. They were, of course, very shallow valleys of perhaps an inch or two. He finished up with a complicated herringbone system looking like the later stages of development of a river system, but the effort was largely wasted because it was a ground water situation. In these circumstances the performance of the drains was not markedly affected at all by the contour of the ground because the passage of the water was through the body of the soil and not over the surface. That was clear because the soil was a comparatively light sand and would not sustain water on the surface. It is necessary to define the situation before the use of herringbone systems is demanded for hydraulic reasons.

It is not impossible, however, to consider the use of this machine with blind junctions made underground such as would be necessary with herringbone systems. We have made one or two experiments using the principle of passing the water from one drain to another, as was mentioned earlier this evening, by means of gravel. We intersect two drains, a lateral and main, one above the other, and both are back-filled with a sheet of gravel. These two sheets intersect each other, and provided that one knows the amount of water which is to be passed, one can design that intersection so that the water level shall not rise above a certain level above the lower drain. Within the limits of design, it is possible to achieve an adequate junction, but it is not a feature which I would put before you as an accomplished fact, but as something which we have tried and are still thinking about.

RECONDITIONING OF OLD DRAINS

by G. H. THEOBALD,* A.R.I.C.S., A.M.I.C.E., A.M.I.W.E., A.M.I.Mun.E.

A Paper read at an Open Meeting of the Institution on Tuesday, 12th November, 1957

THE draining of agricultural land has been going on for hundreds of years. Nobody knows exactly when it first started, but it was certainly practised by the Romans and has continued to some extent ever since. At times, under the impetus of government grants, loans or other stimulants, the effort was intensified whilst during periods of depression practically no new work was done and the existing works were neglected. As a result of this prolonged effort it is rare to find a field which needs draining to-day where there has been no previous attempt at drainage, and the possible existence of an old system adds yet another factor to the already complicated natural problem of draining agricultural land. As with all other factors connected with field drainage, there are no simple rules relating to the old system which are capable of universal application and each case must be dealt with on its own merits.

Reconditioning in the sense of simply cleaning the old drains is only one of many ways of dealing with them, and a discussion limited to this particular method would seem to be of little value. The title has, therefore, been interpreted in its wider sense and this paper discusses, in broad terms, the effect of the old systems on the design and installation of new drainage works.

Early Drains

By way of introduction, some notes on the various common forms of old drainage channels may be useful. The clayware field drain pipe is a relatively recent development in the history of field drainage, dating from the latter part of the 18th century. Before that, the shape and construction of the channel were largely influenced by the material available in the locality. For instance, in the upland Peat areas channels were formed by cutting the top turf to such a shape that it could be wedged a few inches above the bottom of a tapered trench to support the rest of the excavated material leaving a clear channel beneath. This is known as a " turf " drain, and examples in quite good condition are still found in these areas. Where suitable stones occurred flat slabs were often used to form channels of square or triangular cross-section, and many of these are still working effectively. In wooded areas square channels were made of timber planks nailed together to form a continuous drain, with holes drilled to allow water to enter, whilst elsewhere bundles of brushwood or faggots were used in the same way as the peat turf.

Probably the most widespread form of early drain was the trench partially or wholly filled with stone, frequently referred to as a " French " drain. It is found in most of the counties in England and Wales and retained its popularity long after the clayware drain had been introduced. This type of drain is easily overloaded, having no clear water way, and in times of heavy or prolonged rain the drains were often unable to deal with the amount of water reaching them. One attempt to remedy this defect was by using flat clayware roof tiles to support the stones and form a clear water way below. Illustrations in books published about 1800 show channels of a variety of shapes formed with these flat tiles or with specially shaped bricks. It was only a matter of time before the flat clay slab was bent before burning into a U shape and used, inverted, to form the open channel. This U or horseshoe tile was the forerunner of the modern field drain pipe, hence the term " tile " drainage, and it is possible to trace a logical sequence of development. Each individual estate brick-yard made its own improvement probably with little regard to what was being done elsewhere, and the various stages of development did not take place in the same way or at the same time all over the country. It is not possible, therefore, to link any type of pipe with a particular date.

Not only are there many different types of channels, but they are found in all stages of decay and deterioration. In some cases the channels have become silted up over part or all of the system reducing the flow to a small, but not insignificant amount. In other cases the drain may have collapsed or become blocked at isolated points causing areas of surface waterlogging. In some heavy soils, systems laid 40–60 years ago have ceased to be effective due to the impermeability of the soil, although the channels themselves are perfectly clear. There is also the possibility that several systems exist at different depths and varying stages of efficiency.

Sufficient has been said to indicate the complex nature of the old systems and the difficulty they add to the design of new drainage schemes. Their existence probably forms the main difference between drainage problems in this country and elsewhere in the world, and is one reason which makes it more difficult here than abroad to apply scientific principles to drainage.

Existing Systems

There are various ways of dealing with the existing systems—they can be repaired, reconditioned, replaced by new pipes, incorporated into a new system, or on very rare occasions just ignored. The choice of treatment will be largely dependent on the information which is available, or can be found out, about the old systems—the precise layout, the condition of the channel, the reason for the deterioration and similar matters. The pattern extent and degree of wetness on the surface of the field may give some indication, but there will still be much to be found out by careful investigation. Perhaps the greatest difficulty likely to be encountered in designing new schemes is finding out before work starts whether old systems exist in the field and, if so, their condition and the extent to which they are responsible for the state of wetness of the field.

**Field Drainage Engineer, Ministry of Agriculture, Fisheries & Food*

It is a condition of the present government grant for tile drainage work that an accurate plan of the scheme must be produced on completion. Unfortunately such conditions were not attached to previous schemes for government assistance, or, if they were, the plans have since been destroyed. Wherever the plans prepared by some of the larger estates are available, the problem of investigating the system and preparing new or reconditioning schemes is relatively simple, whilst elsewhere appreciable time and energy are usually spent in digging trial holes or trying to locate the drains in other ways. For the benefit of future generations one can only hope that those concerned with the installation of underdrainage systems at the present time will not begrudge the effort required to prepare accurate record plans and see that they are kept in a safe place.

Locating Old Systems

Where no drainage plans exist the old system will have to be located on the field. It is perhaps stating the obvious to suggest that the first move is to clear, to its original size, the ditch which would act as an outfall for any underdrainage system which may exist ; for having found the outfall the rest of the system can be traced and its condition investigated relatively easily with the aid of commonsense or a set of drain rods. It is essential that the ditch is deepened to its original bottom and that this is checked by reference to the inverts of old farm crossings or a change in colour of the excavated spoil. Several cases are known where a ditch has been carefully maintained, for a long period of years, at a depth shallower than its original depth and has formed what appears to be the bottom of the ditch. Clearing to this depth rarely reveals the old underdrainage outfalls, and it is not until this bottom is checked, found to be false, and the channel deepened to its original bottom that they are uncovered.

Sometimes, especially where no headwall has been provided, the last few pipes of the drain have been dislodged and the end of the drain remains buried even after the ditch has been cleaned and the banks trimmed. A careful watch of the bank during a drying period may reveal the presence of these buried drains by patches which remain wet longer than the rest.

Often where the underdrainage system has ceased to function because failure to maintain the ditch has allowed the outfall to become covered with silt, the defect is limited to the few pipes adjoining the ditch and the system can be revived by clearing the silt from these. It is always advisable in cases like this to construct a durable outfall unless one already exists.

Underdrain outfalls are the subject of many arguments. Much of the controversy is outside the scope of this paper but, as the outfall is such a vital part of the drainage system, some mention of the desirable standards must be included. The drain should discharge clear of the bank some 6 ins. above the bottom of the ditch to allow for a certain amount of silting and a reasonable flow of water down the ditch before the pipe becomes submerged. The end of the drain should be formed of frost-resisting material and long pipes to give added stability. Two glazed, socketed stoneware pipes are satisfactory. The bank of the ditch should be faced with a durable headwall built in such a way that the weight of the structure even if it settles slightly does not rest on the pipe. The headwall not only protects the end of the pipe but prevents vegetation growing over and into the pipe, and marks the position of the outfall should the ditch become silted up and the pipe covered. Compared with the cost of the average underdrainage scheme to-day, the extra cost of an adequate outfall is insignificant where mains are used and the number of outfalls limited.

Failure to find an outfall in the obvious ditch cannot be taken as an indication that no old drainage system is in existence. On many big estates the underdrainage of individual fields were linked together to form a comprehensive system for the area. Main drains were laid across the ditches below their natural bottom joining the drainage of one field to another, and the main outfall might be some distance from the field under investigation. In these cases the problem of locating the system becomes complicated and may involve a visit to the estate office, if still in existence, interviews with the older inhabitants of the village, or, as a last resort, digging trenches at strategic points on the field.

Causes of Deterioration

Having once found the system, the next important step appears to be to decide the reason for its deterioration. Very often this question is ignored or considered unworthy of any prolonged thought, although it should be of major importance. Clearly it is pointless to recondition or replace a system if by doing something different deterioration can be avoided in future. One example will illustrate the point. During the period of increased interest in drainage during the latter half of the last century a tradition developed for layouts with lateral drains, six to eight yards apart, laid in the same direction as the major slope of the field, and connected to a main drain laid across the bottom of the field. Many of these systems have ceased to be effective because the main and lower lengths of laterals have become blocked by silt. The usual remedy is to take up, clean and relay the main drain, or replace it with new pipes and to clean the lower sections of the laterals with drain rods. A little thought shows that layouts of this nature are technically unsound. Water flowing down the laterals laid to a relatively steep gradient must slow down considerably on reaching the main drain which is laid to a much flatter gradient, and any silt or sediment which gets into the drain will tend to be deposited where the speed of flow is reduced. Thus schemes of this type will always be prone to the siltation of the main and will require regular reconditioning. A better alternative would be to lay a series of new main drains at wide intervals and to a reasonable gradient across the fall of the land, cutting the existing laterals into several short lengths in which the volume of speed of the water would not reach troublesome proportions.

The new mains must be laid at the same depth as the old laterals and proper connections made. Where more than one system exists in the field the mains must, of course, be laid at the depth of the deeper system and the shallower system connected either by relaying the last few pipes to a steeper gradient or by making a vertical shaft between the two drains. Only where the channel is very silted up and unlikely to clear itself is it permissible to make the connection by filling the new trench with gravel or other permeable material at the point of intersection.

Iron Content

Underdrainage systems in the Greensands and other soils having a high iron content may fail because the pipes become choked with a red precipitate or jelly. This trouble is widespread throughout the country, and in some cases the system has to be cleaned or reconditioned every ten or fifteen years. At the moment, unfortunately, no positive solution can be offered. The problem is receiving a great deal of attention both here and abroad, and it is hoped that some positive remedy may be found in due course. In cases of this kind, provided that the scheme is satisfactory from other view points, there appears to be little point in changing the layout as it would not help to avoid the trouble recurring, but the problem might be alleviated by building silt traps at strategic points to collect the sediment and facilitate its removal.

As this problem is likely to remain for the time being it is perhaps permissible to digress for a moment and suggest that some thought might be given to finding a more effective way of clearing the drains. The usual method, either to uncover, take up, clean and replace the pipes, or open up the drain every twenty or thirty yards and clear the sediment with drainrods, is a very expensive business these days. The operation can rarely be mechanised to any extent, for even when the precise layout is known slight deviations in line or gradient usually prevent a machine being used with any degree of success or the saving of time. Similarly, drains can only be cleared by rodding if the pipes are accurately sligned. The number of drains which fulfil this condition is limited, nor are the results of rodding always satisfactory, as compressed sediment or very loose slurry are equally difficult to clear, and unless the work is done methodically from the top end of the system towards the outfall, there is always a possibility that silt from the upper sections will find its way into sections already reconditioned and cause further trouble.

The development of plastic pipes and small portable water pumps suggest that it is worth investigating the possibilities of clearing the pipes with a water jet. It should be possible to feed a hose of the desired rigidity with a suitably designed nozzle up the drain whilst pumping a jet of water through it, thus loosening and washing the sediment down the pipe on the outside of the hose. Slight deviations in the drain alignment should be negotiated quite easily by the hose nozzle, and the distance between the points at which the drain has to be opened for the purpose of cleaning could possibly be increased considerably.

Where the trouble is limited to localised wet patches due to a drain becoming blocked or broken the obvious answer is to expose and repair the damage, although there may be some difficulty in areas where springs are common in deciding whether the trouble is due to a natural spring or to a damaged drain.

Often the trouble occurs at the junction between lateral drains and mains. The majority of these junctions were formed in the past by chipping pipes to make the junction and covering the area with broken pipe. The practice is not unknown to-day ! However carefully this is done there is always space for silt to find its way into the system, and it is surprising, considering the vast number of junctions of this type that must be in existence, that so few cases of damage come to light. Manufacturers of agricultural drainpipes make special junction pipes, or would do so if there were an appreciable demand, at a cost very little more than ordinary pipes, and their use is well worthwhile as an insurance against the early deterioration of the system. The main objection against these special pipes seems to be that they are made only to a limited number of angles which rarely coincide with the precise angle between the lateral and the main. However, in most consignments of normal drainpipes there are a sufficient number of slightly curved pipes to alter the direction of the lateral to fit the junction. Second or third quality glazed stoneware junction pipes, similar to those used on house drains, can also be used, and in some cases these are made with an inspection opening and cover over the actual junction so that it is possible to examine the drain without disturbing it in any way.

At major junctions where several main drains meet it may be desirable to build a manhole with the bottom 9 or 10 ins. below the outlet pipe to form a silt trap. The chamber should be large enough to allow for rodding, should that become necessary at any time. The walls below outlet level should be solid and waterproof, whilst above that level they can be honeycombed to allow water from the surrounding soil to enter. The position of the cover is a subject of much controversy. From the drainage standpoint it is preferable for it to be at or above ground level so that access for clearing the silt is relatively simple, but if the chamber is in the middle of the field it is clearly undesirable from a cultivation point of view to have such an obstruction and the cover may have to be sited 18 ins. below the surface.

Blockage by Vermin

Another common cause for drains becoming blocked is vermin entering the pipe and being unable to turn round and leave it. Very few actual cases of damage can be quoted, but it is a matter of conjecture how often vermin have started a train of events which has culminated in the drain becoming choked. The preventive measure in this case lies at the point where the drain discharges into the ditch. Gratings to prevent vermin entering the system can be obtained at reasonable cost. Preferably they should be hinged and so designed that they are fixed to the bank or headwall and not to the end of the pipe which may get broken.

There are occasions when the condition of the field indicates that the system has ceased to be effective, although an investigation of both the channel and the outfall shows that they are in quite a good state of maintenance. Such cases usually occur where the old systems have been laid rather deep in heavy soil. There are various reasons for this state of affairs, but usually an impermeable layer has formed in the soil either from natural or artificial causes. For example, constant ploughing at the same depth tends to consolidate the soil just below the depth of ploughing, forming a plough " pan " which prevents water reaching the drain. Alternatively, the soil which was disturbed when the drain was originally laid and which allowed water to percolate through it has gradually settled and packed until it has again become impermeable. The obvious solution to cases like this, assuming all other factors are satisfactory, is to break up the " pan " so that the water can again percolate through to the drain.

Mole Channels

This raises the very wide and controversial subject of mole drainage and sub-soiling. The temptation to digress to discuss this fascinating subject must be resisted, and comment limited to statements of fact rather than to an explanation or justification of those statements. Although mole drainage is a cheap and simple operation to carry out it is probably one of the most difficult forms of drainage to design. The expense and trouble entailed in making good a mole drainage scheme which has collapsed justifies a considerable effort in preventing the damage occurring.

Mole channels deteriorate quickly and collapse if water stands in them for any length of time, and for this reason it is unwise to use a mole plough to break up the " pan " or increase the rate of percolation through the soil unless an adequate outfall is provided. It is dangerous to rely on the soil between the old drainage system and the mole drain being sufficiently permeable to take the water from the mole drain quickly enough to prevent damage. There are occasions on which this has been tried and worked satisfactorily for a few years, but it is a practice which should be discouraged.

In reviving old drainage systems a satisfacory outfall may be obtained by opening up a sufficient length of old main and covering to within 15 ins. of the surface with highly permeable material such as coarse gravel or clinker, or providing a completely new tile main with permeable filling over. The advantage of this type of outfall is that it is available without further attention when the mole channels have to be re-drawn : The need for an outfall is not so great when using recognised sub-soiling implements, other than the mole plough, which do not leave a defined channel in which water can collect and flow, but it is still advisable.

So far, typical straightforward cases have been quoted where it is reasonably clear what course of action is best. Underdrainage systems which have deteriorated to such an extent that they have ceased to function as continuous channels, or carry an appreciable quantity of water, provide a more difficult problem. Water still tends to collect in the vicinity of the drains and move slowly along the line of the original channels. The course of action in this case is the subject of a great difference of opinion amongst those engaged on field drainage. One school of thought consistently ignores such a system and instals a completely new system to deal with the drainage problem as it exists ; the other school of thought maintains that the only possible method is to recondition the old channels or replace with modern pipes. Both parties quote successful schemes carried out by their method and, in the face of such evidence, it is impossible to be dogmatic.

On steeply sloping land there is obviously a possibility, if parts of the old channels are functioning, that a sufficient pressure will be built up in a short length of drain to force water to the surface wherever the drain has become blocked. On the other hand, on reasonably flat heavy land it seems unnecessarily expensive to open up and replace a close-spaced, intensive system if a mole drainage or combined mole-tile system can be installed which is equally effective. Whatever decision is ultimately reached, the possibility of old drains being present and their probable effect on the drainage problem must be considered at the design and investigation stage.

On the occasions where it is possible to lay a new tile-drainage system at a shallower depth above an old system there must always be a connection between the two systems. In this case the connection can most conveniently be made by " dumb " wells which consist of a vertical column of permeable material between the drains of the two systems wherever they cross. It is an established fact that the disturbance of soil in laying drains and the breaking up of the natural impermeable layer or artificial plough pan often starts an old system working again. These dumb wells provide an escape route for the water from the deeper system to the new shallower system.

In addition to the broad categories dealt with in this paper there are innumerable problems which depend so much on the condition appertaining to the particular scheme that they cannot be dealt with in a generalised way. These are usually small systems with an irregular layout, laid piecemeal at different times and apparently without any overall plan. If the layout is likely to provide a satisfactory answer to the particular drainage problem involved it would seem worthwhile to recondition the system adding whatever is necessary by way of junction pipes, outfalls and similar structures to prevent or delay deterioration in the future. Often, however, such systems merely alleviate the wet condition without removing the cause, and the obvious solution here lies in designing a new system and ignoring the old.

Also in this section of problems for which no general solution can be offered mention must be made of the long lengths of large diameter main drain which carry the water from the drainage system of a low-lying basin through intervening high land to an appropriate outfall outside. Many such drains were installed in various parts of the country during the last century, some a mile or more in length and 15 to 20 ft. below ground at their greatest depth. There seems to be no choice technically, but to recondition the existing drain or replace by new pipes, and in the worst cases it is sometimes doubtful whether the value of the land and its potential productivity justify the expense involved.

An attempt has been made to mention the more common problems connected with old drainage systems. There must be several that have been omitted. The possible effect of the old systems on the condition of field in need of drainage to-day and the importance of considering this factor when designing new drainage schemes has been stressed. It has been stated that the physical reconditioning of the systems is expensive as it can rarely be mechanised, and the operation should only be undertaken when no other remedial measures are likely to be effective. It has been suggested that in carrying out drainage works attention should be given to methods of construction which will prevent or retard deterioration in the future.

Many of the points put forward are open to argument, and if this paper encourages an exchange of ideas and experience between those engaged on field drainage work its aim will have been achieved.

DISCUSSION

MR. H. H. NICHOLSON : I can think of no one who by virtue of his position has had a greater opportunity of getting a balanced picture of field drainage and its problems in this country than Mr. Theobald, because it is now at least ten years since his duties began to bring him in contact with the individual counties and their individual problems and since he began to solve them on the spot. I am therefore not surprised that in his Paper he has indulged in a little looking back, and I think he has found it well worth while, as I have myself.

Mr. Theobald has touched on the development of tiles and said that many people indulged in research on that problem through the middle of the last century, as evidenced by the private tile-making conducted on the estates. They were putting their own ideas into effect on single points. It has got us to the one-foot plain cylindrical clay pipe. Some people say what a primitive thing it is, but the fact is that we have not got anything better yet. It seems that the justification for that rather simple unit is that it combines all the individual points and requirements. Of course, we cannot admit that we have got to the end and later to-day we shall have the pleasure of hearing another attitude towards it, looking forward into the future.

It seems to me that Mr. Theobald put his finger on a vital matter when he stressed the importance of the reconditioning of ditches and drew attention to the fact that frequently there is a comprehensive field drainage system which in its day has worked. Knowing that there have been very long periods of neglect, it is not surprising that if the ditches are put right a great deal of benefit ensues. The proof of the pudding is in the eating, and the statistics for the drainage work carried out on grant since 1939 bear it out as the practical man's view and experience. My opinion is that if in the case of any drainage problem the ditches were to be reconditioned and brought back to what they were originally we should find that the infield problem would disappear. I am certain that many of these drainage problems would obtrude themselves on fewer occasions than they do at present ; as it is, they are not acute every year, but one year out of so many in the great majority of cases.

Mr. Theobald referred to silting of various kinds and drew attention to something which often goes under the name of iron sludge. I mention it because it is interesting in regard to investigation work. It is a real problem which has not been solved. With the advance of knowledge of soils, we know something of the causes of this trouble. It occurs on two classes of soil—those which are very open, such as the acid, sandy lands, and those in bottom land with perennial ground water. They have one thing in common—namely, that the active factor is organic matter arising from root systems dissolving in moving ground water, producing an anaerobic condition and making the iron more soluble and carrying it on. The next factor is that it comes out of solution and is re-deposited when it comes into contact with air, and that happens in the pipe-line or in the ditch. There is one point which is not clear and that is whether it begins inside the pipes or in the joints of the pipes, or outside the pipes in the surrounding soil. It is essential to know where it first begins to form, because if it were inside the pipe the treatment would be different from that applied if it were outside.

Some of these problems will be found to tie up with ordinary soil problems and the soil scientist has a contribution to make in that respect. It is not surprising that some people advocate liming the land or the back-fill on the pipes, but perhaps Mr. Theobald can add something to that. I am a little worried and surprised in case Mr. Theobald is losing faith in mole draining. That, I think, would be very shocking indeed, and I hope that it is not the case. I hope he feels that there is still plenty of scope for it and that it has a part to play at the present time, although I agree that to use it as a cure for the failure of parts of existing pipe systems is a little unsound and is asking a great deal of this rather simple machine.

Mr. Theobald also referred to some of these former estate systems with long culverts or mains which served considerable areas of ground, sometimes a particular field and sometimes a number of fields and which had to be taken through a piece of high land and laid at prodigious depths. That is something which it is very difficult and costly to deal with if it ever breaks down. I would like to ask whether Mr. Theobald has come across any cases where the arrival of power on individual farms has brought a small pump within the realms of practical possibility, whether automatic or not, to lift the drainage of such areas over the intervening obstacle somewhat on the lines of what I think is called a rising main in that other form of drainage more correctly known as sewerage.

MR. R. N. SANDERS : As one who is solely interested in reducing the water table on the North Bedfordshire clay lands, and who has had no experience of drainage elsewhere, may I speak of, and keep to, the land I understand ? The land I am farming was, generally speaking, between 1925 and 1937, sheep and cattle runs. Hence labour was at a minimum ; fields were run together and gateways were only objects, the stock often taking the line of least resistance—that is, through overgrown fences and through or over the once man-made ditches. The fences were sunshades in summer and wind-breaks in winter ; the ditches had become filled and trodden. This partially ruined the old drainage, as the masters were often 4 ft. in the bottom of the ditches.. The only notification of such a drain was a fountain after a heavy rain or melting snow.

With the help of the then Wheat Commission and latterly by Government policy, arable land and its produce was once again in demand. As fields, or rather areas, came under the plough the ditches were the first object, and these were tackled in the winter time by whatever labour was available, either home or Irish. The continuous filling of the ditches by stock meant the removal of many cubic yards of spoil, and it became obvious that no man could dig out and throw far enough away all that was necessary to get below the old drains. The only solution was the excavator or Priestman with an arm bucket.

My policy was to do the worst ditches first and then follow up the adjacent fields with a tile-cum-mole system. It was noted that the deepest drains were still good and running, the pressure of the water having been sufficient to keep them clean, however much soil had collected over them. It was also noted that the minor, shallower drains were completely blocked, with perhaps only a trickle being noticeable from a 4 in. pipe.

At the beginning draining rods were used to try to clear the last 10 or 20 yards, but this soon became a wearisome and unproductive solution. There was only one thing to do and that was to re-drain the whole area, using 6 in. mains with 3 in. or 4 in. laterals at intervals of from 30 yards to 2 chains, but never more. On top of these laterals and, in a number of cases, on the 6 in. mains ballast was placed or, correctly speaking, 1½ in. washed shingle to a depth of 9 ins., using 3 cubic yards of gravel to each chain. I took particular care not to use rejects when mole draining, as the foot or plug of the drainer could press a reject down on to the tile and break it, and the weight of a large cobble-stone leaving the shovel could crack and even break the tile.

When digging these new drains at about 26 ins. to 30 ins. many of the older drains were cut. All that was necessary was to clear the broken parts and remove any of the clay that had been forced into these pipes by the rotary hoe. It was not necessary to make a connection into the new tile, the top ballast making a perfect filter for any water that the old drains might be carrying Here I differ slightly from Mr. Theobald. His practice of connecting would take a considerable time, as it is very difficult to work at the bottom of such a narrow trench, and cutting across the old tiles every 30 yards would necessitate many connections. In a number of cases some of the old drains at 4 ft. that ran under a new scheme were found running many days after the new 6 in. mains had ceased to trickle.

When a field has had the 6 in., 4 in. and 3 in. tiles covered with ballast and the trenches filled, the important part of mole draining starts. A 4 in. plug is pulled across the tiles and through the ballast at 20 ins. deep, 6 ft. apart and at an angle as near 90 degrees as possible, leaving the ground just riddled with underground water carriers. I prefer to do this when the ground is hard and cracked, generally after harvest on the stubble, before ploughing. In fact, when mole draining, the more legs I can wear out the better, as I know that the leg and foot are not only doing the drainage work, but also " shattering "—a wonderful word and so descriptive of the mechanical effects it has on the land. Even in a dry time on clay land at 20 ins. deep there is usually ample moisture to hold the mole. This process is repeated when necessary, perhaps every five or six years.

May I say how essential it is to have gratings over the ends of the ditch masters, as they keep out vermin and prevent rabbits using the drains as living quarters during dry periods. I remember once getting 27 rabbits from a 4 in. tile drain, the last six having been suffocated. Also, I should add that when these 6 in. mains are running full bore the gratings are raised parallel to the ground and the force of the water, in many cases, is making large holes in the opposite banks, in some cases 3 ft. away.

You will notice that I have not mentioned the cost of drainage work. Up to the moment I have drained some 830 acres with the tile-cum-mole system and excavated many miles of ditches. May I conclude by saying that the expense on this land is well worth the investment, in some cases paying for itself even in the first year. I know of no other investment paying such a high dividend and at the same time improving the land for whatever the future holds.

MR. D. R. BOMFORD : Mr. Theobald spoke of various reasons for the failure of old drainage systems, and the reasons given were all in the nature of casualties of some kind. He spoke, for instance, of roots in drains, silting due to various causes, loss of velocity in drains and resultant deposit of silt or the filling up of the ends of the main drains due to silt in the ditch. I should like to hear whether, in fact, there is likely to be any deterioration, chemical or otherwise, of the tile itself. Can we expect a tile that has been in the ground for 100 years to have retained its structural strength and to be as serviceable as when it was put in ?

Amongst Mr. Theobald's possible causes of drainage failures, I think we should note the steam plough. For 50 years steam ploughs were used on the headlands along the sides of ditches. They were often used when the ground was wet and there was wheel sinkage in the ground from 1 ft. to 18 ins. when timbering the engines along in wet places. I think it is always worth while, if you clear the main in the ditch, to have a look at the point at which the steam plough would have run along the headland to see whether the tiles are broken at that point. I have found that to be a frequent place of failure.

Mr. Theobald mentioned tree roots, and I think it is worth making a special reference to the willow, which is the great offender. I can remember drawing roots out, perhaps, 2 ft. long and finding roots completely filling the pipe. Unfortunately, from time to time people have fenced against ditches with willow posts which have subsequently grown, and that, I think, is another point where trouble may be indicated.

The question of whether it is worth reconditioning an old system I think depends to some extent on whether the mains are spring-carrying mains. On some of the lower lias many of the old mains do carry springs, and if for some reason or other one of those mains fails I do not believe it is any use whatever attempting to do anything but clear the main. There is a concentration of spring water at the point of failure, and I have tried all of things to find a way of recapturing the water, but I have not been successful in carrying that water away.

I was a little surprised that Mr. Theobald, in talking about the difficulty of finding an old drainage system, made no reference to water divining. I cannot do this myself, although I have tried, but I would not attempt to restore an old system without getting in a man who can do it. I am fortunate in having one. He is practically infallible.

I should like to know whether, having found the drain by the trial bar or by divining, a mechanical auger has ever been used in order to get down to it and inspect it. Is it a suitable implement for that purpose?

MR. THEOBALD : Mr. Nicholson wanted to know where iron sludge occurs, whether in the pipe or outside. I regret to say that I just do not know. There has been quite a lot of development and trial going on in Finland and elsewhere abroad and we have made one small attempt ourselves in the East Riding of Yorkshire. I was very interested to hear Mr. Nicholson's ideas on the subject. I am at the stage where I think it is something to do with bacteriological action, but that is rather outside my sphere of knowledge. I think it can occur in all three places, because in very many cases we find that the drain is not full of precipitated rust, but is blocked solidly against the entry of water. That seems to indicate that it would be either in the joints or on the outside. I am inclined to think that in the freer draining soils it would be on the outside of the pipe.

That brings me to the question of whether I am losing faith in the mole plough. No, I think that mole draining is probably the biggest factor which can help us in our drainage to-day.

Mr. Bomford asked about the chemical deterioration of tiles. My feeling is that tiles do not deteriorate in the ground. I have at the Ministry a collection of old pipes ; one of them is dated 1827 and it is as sound as any of the modern pipes.

I should like to thank Mr. Bomford for the idea of damage by steam engine. I think that is a very real point and one which I shall be very pleased to bear in mind. With regard to willow roots, Mr. Bomford may be interested to know that so far as I am aware the record is 40 ft. of willow root in one pipe in Worcestershire.

Mr. Bomford also spoke of the use of a water diviner in finding old drainage systems. I cannot do it either, but I have seen somebody find a pipe for me in a position where I would never have thought of looking for it.

MR. H. WRIGHT : In the Weald of Kent on the heavy clays many acres had drainage put in many years ago at 4 ft. deep. Is it worth while worrying about those or can one put in a new system at a shallower depth?

MR. THEOBALD : It is very difficult to know what to do with old 4 ft. systems. In Northumberland and Cumberland they will tell you that you must take them out and recondition them. In Bedfordshire my idea would be to put a mole scheme over the top with suitable tiled outfall mains. I think it depends mainly on the gradient of the field. I imagine that on a steepish field where the drains are only blocked at certain points it would be possible to build up a pressure in the pipe sufficient to force the water to the surface. On a fairly flat field it seems a waste of time to go down to the old system, but I cannot be more definite about it.

MR. E. N. GRIFFITH : I should like to comment on the idea that the old steam plough would do damage to an outlet. Mr. Bomford's experience is mainly in Worcestershire and mine has generally been in Essex, and the old Fowler steam tackle was used over the whole of Essex. Since the war we have put in our moles at the shallow depth of 24 ins., but before the war we always put the moles in at 30 ins. and the tiles at 36 ins., and at that depth I have never heard of any talk of damage to the tiles.

MR. G. C. MOUAT : Most drainage work seems to be done when the land is dry, but I have a suspicion that the only way in which a ditch-cleaner does well is if the material in the bottom of the ditch is wet. We had a demonstration in the Chelmsford district recently and we were worried about whether to call it off or not because the weather was so bad. In fact, I think the machines showed up very well because of the wet nature of the material in the ditch. Should ditch-cleaner work only be done after there has been a fair amount of water running through the ditch?

MR. THEOBALD : Looking at it from the technical point of view, I think these ditch cleaners have to work in both wet and dry conditions. Certainly the reconditioning of a very neglected ditch will probably have to be done in reasonably dry conditions. A lot of the ditches we dig out do not carry water except at limited periods of the year. One of the difficulties we have in finding an ideal machine is in finding one that is cheap, light and which can deal with heavy clay in dry conditions. I think probably we are asking for the impossible. In fact, I am sure we are, but we shall still go on asking for it.

MR. B. ARMITAGE : I should like to ask about the masters—the drains leading directly into the ditches. Does Mr. Theobald think it wise that these drains should project into the ditch ? That would enable the ditch cleaner to see where the drains were, but they would get in the way of ditch cleaning machinery. I was wondering whether there would be any advantage in having them set into the banks with a grating and perhaps non-return valves.

MR. THEOBALD : I certainly think that the pipe should discharge 6 ins. above the bottom of the ditch and clear of the bank. That would be all right with a headwall and a grating, but it would not be necessary to put in non-return valves, except in some very low-lying areas. In the marshes, where the ditch water level is likely to rise for a fairly long period to a dangerous height, it may be necessary but not otherwise. I think it might be advisable to set the headwall and grating just back into the bank to keep the pipe out of the way of the machines.

MR. R. M. CHAMBERS : Mr. Theobald mentioned the preparation of accurate plans of drainage systems. I wonder whether the plans are worked to. If they are prepared before any grant is made, is there any guarantee that the farmer will work to the plans ? I also wonder whether Mr. Theobald has considered using aerial surveys for locating old drains.

MR. THEOBALD : The plans which we insist upon are measured plans of the drains as laid. I have a suspicion that some are made beforehand, although I do not really see how it is possible to make a plan before the final system goes in because so often it is necessary to change the layout when digging. The plans are the actual surveys of the drains as laid.

With regard to aerial surveys, the difficulty is the expense of chartering an aeroplane just to look at one field ; otherwise it is necessary to have an aerial survey of the whole of the British Isles to make sure that you have the one field you want.

MR. H. H. NICHOLSON : There is in Cambridge a department of aerial photography to serve the interests of all branches of knowledge. The curator of that department has taken many thousands of photographs, which are filed and are accessible.

MR. J. H. COCK : Various people have commented on the effect of heavy equipment such as steam tackle on drains in the past. Would it be a fair question to ask about the effect of modern heavy equipment on drainage generally ? In many framing operations to-day every square inch of the soil is subjected to the compression of heavy equipment, by as much as two tractors and trailers and harvesting equipment in rather difficult conditions in the Autumn, when lifting crops such as potatoes or sugarbeet. Does Mr. Theobald regard this solely as a factor affecting soil structure—a problem for the soil physicists—or does it directly affect the efficiency of the drainage system as well ?

Mechanical ditch cleaners have been mentioned, and these, I think, want watching in so far as field drains are concerned unless good headwalls are there to protect the outfalls, but the bulldozer is an even greater menace to drainage efficiency. Perhaps Mr. Theobald would comment on the precautions which should be taken in removing open ditches and in making provision for the existing field drainage systems so that they continue to function without deterioration.

MR. THEOBALD : The speaker has suggested that certain cultivation equipment, probably used at the wrong time or in the wrong conditions, can do some damage. I agree with him wholeheartedly. I think a lot of our mechanical equipment can damage the natural draining properties of the soil and stop the water getting from the surface down to the drain. I think to some extent we can do something with mole drainage. There should not be water standing on the top, and, if there is, re-moling can be done to prevent too much damage being done to the structure of the soil itself.

With regard to doing away with the ditch, that is a very difficult problem. Ditch maintenance is a very troublesome problem nowadays. A well-maintained ditch is the best form of drainage channel or drainage carrier, and it is very pressing that we should find an adequate machine for maintaining ditches. On the other hand, I cannot help but agree that there are a lot of ditches existing to-day which are not serving any purpose.

I think, perhaps, we could in certain cases replace some of those ditches by trunk mains and re-create the old comprehensive estate systems with advantage to everybody concerned. May I suggest that if anybody is thinking about filling in a ditch they should think about it very, very carefully before taking any action ? I can foresee a lot of trouble occurring if there is any haphazard action in this country.

THE APPLICATION OF HYDRAULICS TO AGRICULTURAL MACHINERY

by J. C. McNeice, A.M.I.Mech.E., A.M.I.B.A.E.

A Paper read at an Open Meeting of the Scottish Centre of the Institution on 19th December, 1956.

IN the last ten years the growth of hydraulic applications in all types of machinery has been considerable. This has not happened in one industry, but in machine tools, mining, automobile, aircraft and agricultural machinery.

The advance in hydraulics in agricultural machinery has been most pronounced since the early 1930's. The most pronounced aspect of this development was the introduction of hydraulics as a means of lifting mounted implements on the tractor linkage and also, on some tractors, draught control. Before hydraulics were used for lifting machines out of the working position, the first mechanical power lift was developed for the trailing-type tractor drawn plough in 1910. The mechanical power lifts were clumsy in design and, in some cases, very difficult to operate.

When hydraulics were introduced in the early 1930's for lifting and lowering attached implements, this was one of the greatest advances in agricultural machinery, as any implement could be lifted or lowered with a minimum amount of manual energy. Implements which could be carried to the point of operation were far superior to those that had to be trailed, as very often the trailed machine had to be made very robust so that it could traverse all sorts of terrain in getting to the field where it was to operate.

Firstly, before going into the detailed application of hydraulics to agricultural machinery, it will be beneficial to consider a number of basic units which go to make up all hydraulic systems and also their various characteristics. One must remember these facts are basic, but very important in all systems, and, although some may find these too simple, it will help others who are not conversant with hydraulics. In all the systems we will consider oil will be the medium used because of its stability towards oxidation ; ability to prevent rusting ; ability to release any entrained air readily and resist formation of foam ; the correct viscosity ; proper lubrication ; and also it is practically incompressible. When any fluid is pressurised the pressure acts equally in all directions.

The forces acting radially outwards on the side walls of any cylinder are equal and opposite and thus cancel out, but the thrust on the end plate of the cylinder must be balanced by the thrust on the piston. This gives a lead to the first unit of hydraulic power, or at least to the unit which is so universally used on all types of hydraulic machinery or mechanisms. The ram or hydraulic jack, as it is commonly called, gives a convenient medium for the production of straight line or reciprocating movement. There are two types of ram—*viz.*, the piston type and displacement type. The latter is rod sealed at the top of the stroke, while the piston-type ram is sealed at the piston similar to the bicycle pump. On these rams wiper rings are fitted to keep the ram rods comparatively free of oil and dirt.

Another ram commonly used is a double-acting version which receives pressurised oil on both sides of the piston. The advantages to be gained by this ram will be discussed later. In a single-acting ram it is necessary to provide a means of returning the piston to its original position by pushing the oil out of the ram, but if, on the other hand, a double-acting ram is used, then the piston can be returned to its original position by allowing oil to pressurise the other side.

On double-acting rams the pressure acting on either side of the ram piston is not equal due to the difference in area caused by the rod. If this is a major difficulty it can be overcome by passing the piston rod through the opposite end of the ram and sealing in the usual manner.

While discussing the ram one simple fundamental principle must be borne in mind, and that is the equalisation of pressures throughout any hydraulic system which has no restrictions. Imagine a small cylinder with plunger, the cylinder being a ¼ in. diameter, connected to a larger cylinder with plunger which is 3 ins. in diameter. If a 1-lb. weight is placed on the plunger of the small cylinder, then the large plunger will support 144 lb. While on this simple theory we get the hydraulic intensifier. The intensifier can be likened to a mechanical leverage.

As the hydraulic pressure rises on the large side of the piston the small side will push oil out at several times the pressure of the opposite side.

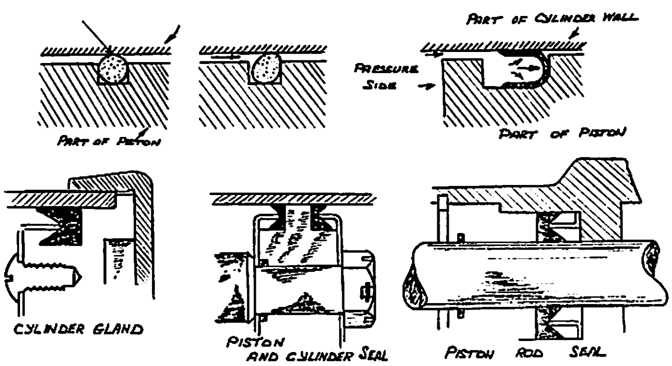
Having discussed the various forms of simple mechanism, let us consider simple forms of seals which are generally used in types of rams and valves.

There are a variety of seals used, each one having characteristics to suit its own purpose, but varying slightly in looks when made by different manufacturers.

The materials used for these seals are synthetic rubber where mineral-base fluids are used in the system ; natural rubber where vegetable-base fluids are used and silicone rubber for high-temperature applications.

A number of seals are reinforced by canvas, and the initial sealing of the gland at low pressure is obtained by radial pressure between the seal and the moving wall. This can be achieved by having the seal lip larger initially than the cylinder bore. At higher pressures the unbalanced area exposed to fluid pressures gives good sealing. In the " O " ring type of seal the ring is slightly deformed under pressure and gives no trouble of leakage.

From the author's experience the fit, clearance and finish of the moving parts is important on all seals, but especially when using " O " rings.



So far the discussion has dealt with hydraulic actuating mechanisms, but to operate these mechanisms pressurised oil is required. There are quite a variety of pumps, but two of the commonest normally used in agricultural applications are the gear pump and the multi-cylinder reciprocating type.

Designers have to think very carefully on this problem before selecting a pump for their hydraulic system. Firstly, it is essential to establish the maximum amount of work the pump is required to do. For example, if it is ram lifting some weight, then it is possible to calculate the work done in lifting the object. If a time limit for doing the work is fixed it is possible, after assuming the maximum pressure, to calculate, allowing for approximate efficiencies, the output of the pump. The maximum pressure attainable by the pump is usually governed by the type of pump used.

The gear pump consists essentially of a pair of intermeshing toothed gears carried in a close-fitting casing and so arranged that the oil is carried around by the teeth from the inlet to the outlet, but is prevented from returning by the intermeshing gears. The advantages of such a pump is the low cost and lack of pulsations, but one large disadvantage is usually a rapid fall in efficiency due to wear. The efficiency of these gear pumps has been improved by the adaption of the hydraulically-loaded balanced gear pump.

The multi-cylinder reciprocating pump is usually four cylinders driven by the P.T.O. shaft in the central housing of the tractor. This pump works very well at 2,500 lb. per square inch and, providing ample care is taken in design, gives very little trouble. The pump used on a well-known tractor of this design delivers about $2\frac{1}{2}$ gallons per minute, and one of the big advantages of this type of pump is its lasting qualities, and its efficiency will remain high longer than the gear pump. When four cylinders are used the pulsation should not cause any trouble. Fig. 1 shows a multi-cylinder pump.

In the various systems on tractors there are different positions for the pump—namely, driven off the P.T.O. shaft or the drive taken off a suitable point on the engine. The big advantage of the engine-driven pump is its continuous operation, but this is also possible with the rear-mounted pump due to the introduction of the " live " P.T.O. It is needless for the author to give the advantages of a continuous-operating pump as anyone connected with loaders or the like is aware of the advantage of being able to change gear and manipulate the tractor while the loader continues to rise to the maximum height without interruption.

After reference to pumps for pressurising the oil it is essential to say a few brief words on valves—namely, selector valves which decide in which direction the oil is sent. The two types commonly used are the piston or poppet valves.

The piston-type valve operates by having a close clearance between the diameter of the piston and the cylinder in which it slides. By moving the piston to the left or right ports are uncovered which allow the oil to flow where required. The valve itself can be balanced, which is a great advantage when operating at high pressures as no binding is experienced with the operation of the valve.

The poppet or plunger type of valve is not usually hydraulically balanced and, because of this, a spring or manual effort is required to retain the valve against the pressure. When high pressures are used it is not very successful as sometimes pulsations are set up in the valve spring due to fluctuations of the pressure. Seat hammering in this type of valve is becoming more rare as newer and better materials are found with new factors of hardness which give very long life to the valve or valve seating.

In a number of applications rotary valves are used, but the clearance of these valves to prevent leakage has got to be very fine, with the result that when used for agricultural machinery difficulties are experienced when the valve has been left unattended for a period of time.

Before leaving valves there is a point which must be mentioned. The majority of systems which require valves have got to be designed for present-day applications which require the valve to be " open centre." In other words, when the valve is in the neutral position oil is allowed to freely pass through the valve back to sump. By using the open centre valve it is possible to keep the pump running continuously, which also gives a slightly faster response when the oil is diverted to any auxiliary. It is important to note in this type of valve that although the pump is running continuously there is no load on the pump.

Pressure-relief valves have been avoided in this article because of the variety used and lack of space to deal with each.

All the components so far discussed can be combined together by suitable plumbing to give a hydraulic system, types of which will follow.

The implement mounting on the majority of tractors is on a three-point linkage, which was first introduced by Mr. Harry Ferguson in 1936, but there is quite a difference between the hydraulic systems which operate the linkage arrangements of the various tractors. They may be divided into three categories :—

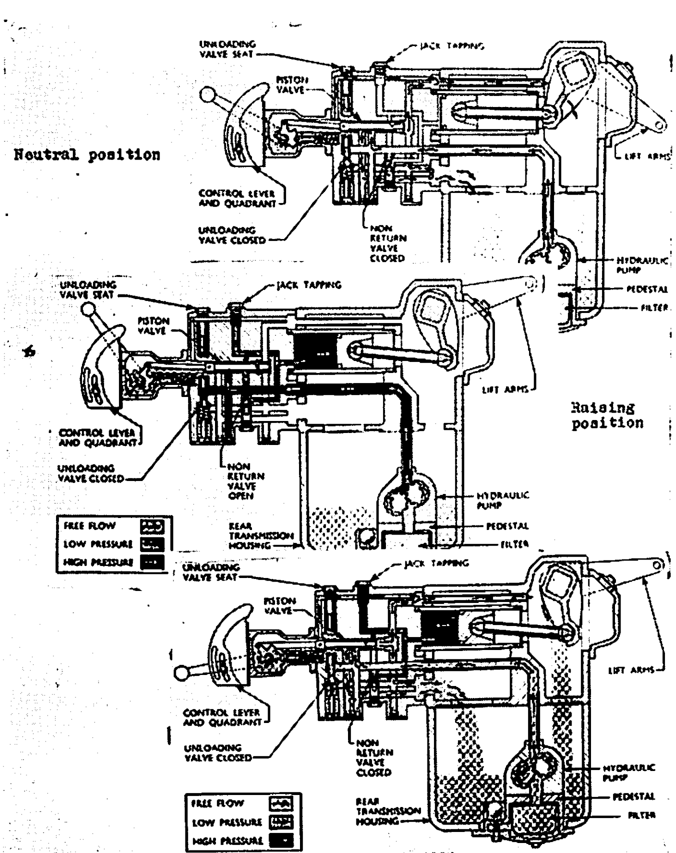
1. Systems which have built-in draft control and position control.

2. Systems which have position control and also use a land wheel.

3. Systems which depend on land wheels for the working depth of their implements.

Farmers are liable to ask why there should be three types of hydraulic systems when they are used for the same purpose. Tractors incorporating draught control when ploughing automatically vary their depth to keep the draught constant. On a tractor which has a depth wheel the ploughing depth is constant, but draught varies as the texture of the soil changes. It is difficult to assess the farmers' interest in these two characteristics, but that which interests him most is the weight transferred to his tractor when ploughing as this enables him to work in most conditions. Such weight transfer is possible with draught-controlled implements.

Let us now consider briefly three tractors which have quite different hydraulic systems. The sketches which will be portrayed are diagrammatical. The first system of a well-known tractor as shown in the diagram obtains its depth control by means of a land wheel ; in other words, the lever controlling the valve is moved to allow the oil to escape from the ram until the implement being trailed penetrates the ground to an extent allowed by the setting of the land wheel.



On this system a single-stage spur gear pump is mounted on a pedestal inside the rear transmission housing and is gear-driven by the P.T.O. shaft. The plumbing can best be studied from the diagram.

When the control lever is in the neutral position the oil passes through the valve and is returned to the sump. If the lever is lifted to the raised position the oil feeds through the non-return valve and into the ram cylinder. As soon as the ram piston has reached its maximum position the non-return valve closes on the pressure of its spring and the unloading valve opens allowing the oil to return to the sump. When lowering the implement the oil is directed from the selector valve direct to the sump. On this tractor there is no draught control and therefore no weight transfer to the tractor. The pressure of the system is 2,000 lb. per square inch. The diagrams of the system are shown.

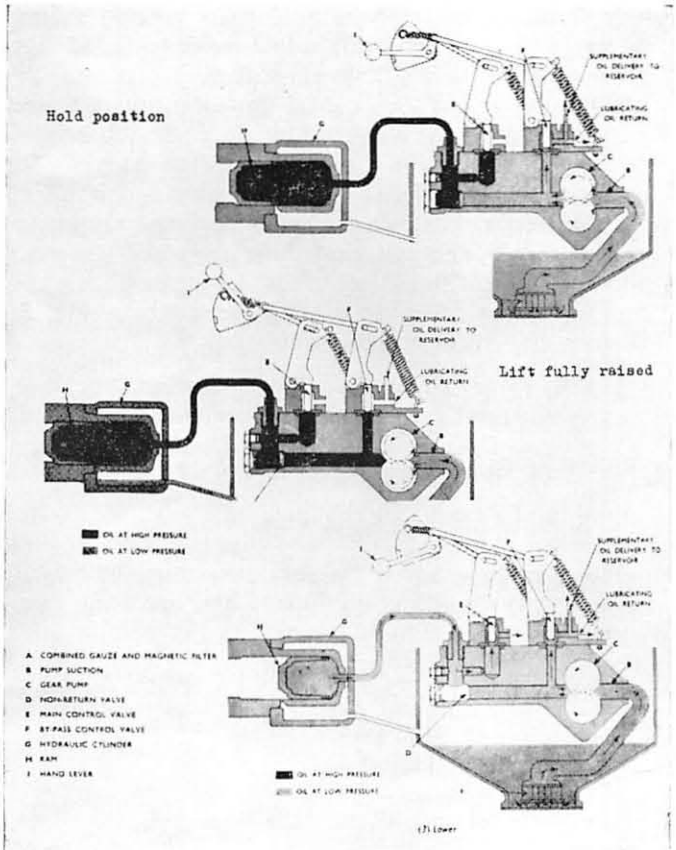
Another tractor which is well known in this country has a hydraulic system with a different layout and different features. Once again a gear pump is used and the system so designed that the implement can be held in intermediate positions whilst the pump is still running, which gives position control of the implement. The main control valve and by-pass valve are both closed when the control lever is in the lift position. Oil from the pump passes through the non-return valve to the head of the hydraulic-ram cylinder, and until the lift is fully raised the pressure in the system is limited to 1,100 lb. per square inch by the by-pass valve. The operator moves the control lever to the holding position when the lift is fully raised. While in the holding position the main control valve remains closed, but the by-pass valve is open, the weight on the draught links is then supported on the column of oil trapped in the system and the pump is under no load.

This system is mostly used with semi-mounted implements—*i.e.*, those with adjustable land wheels.

Layout of system on page following.

Let us consider a tractor which has draught control and position control, in other words a force on the soil-engaging parts of any implement can cause compression in the top link. The top link member is directly connected to the control valve and automatically admits or allows oil to escape, thus allowing the implement to rise or fall, giving a constant draught control. The amount of draught is obtained by the setting of the draught lever. On the other hand by moving the position control lever it is possible to trap the oil in the cylinder, thus giving the links a fixed height. If the lever is always returned to the same position the implement depth will not vary. Position control can be used where it is necessary for an implement to always work at the same height relative to the centre line of the tractor.

A very good feature of this system is the weight transferred to the tractor which improves traction; on the other hand if the implement strikes an obstruction the control valve is pushed straight through to the fully-open position. All weight transfer is removed from the tractor and the tractor wheels spin, thus eliminating breakage of the implement. See Fig. 3 for linkage layout.



There is one common feature with all these systems, and that is that the rams used for lifting the implement is single acting, and it is the weight of the implement which returns the links to their lowest position.

The application of hydraulics is not only confined to tractors and the combination of tractor and implement, but there are a lot of machines or implements such as ploughs, cultivators and trailers which all have auxiliary rams fitted to them for various purposes. In the majority of cases oil for actuating these rams is supplied by the tractor hydraulics, but in some cases an auxiliary pump is fitted to the machine, this idea being particularly applicable to trailers. Most tractors have a pressurised oil take-off point from which the oil can be conveyed to any point on the attached implement.

The necessity for quick-release couplings has encouraged designers to produce a number of sound and reliable couplings and flexible hoses. These have been designed for quick and easy assembly of a pipeline to the tractor. Couplings are made in two classes, (*a*) the type on which male and female parts screw together and (*b*) a breakaway type, the name being self-explanatory—*i.e.*, if the operator forgets to undo the coupling, then tension applied to the flexible hose causes the coupling to unlock itself. The first-mentioned coupling is the most popular type used in this country, principally because of its price and simplicity in servicing. The breakaway type is more expensive and has the added disadvantage of picking up dust when the free end falls on the ground.

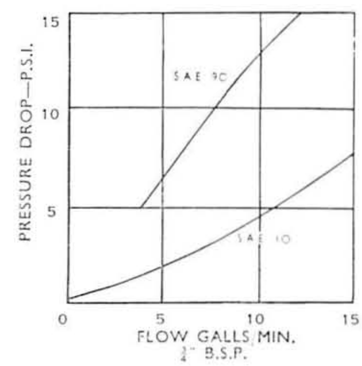
Advantages of quick-release couplings are :—

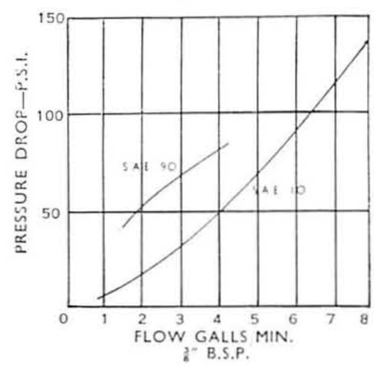
1. When the coupling is disconnected both ends are self sealing.

2. No oil is lost when the coupling is disconnected.

3. If reasonable care is taken no dirt gets into the hydraulic system.

4. Good flow characteristics which can be seen from the following diagrams.





Before leaving the conveyance means of the pressurised oil let us look at the flexible hose itself. Flexible hose, when connected to the tractor, can take up to a reasonable radius when the implement and tractor turn at the headlands. This commodity is often taken for granted, but a lot of work and research has been put into the development of suitable hoses which will stand pressures of 3,000 lb. per square inch. Recent developments have even made it possible to service existing hoses in the field by replaceable ends which the dealer can change himself. A farmer with suitable tools could possibly change the ends of these hoses if necessary.

The pressure drop in a flexible hose is always a little higher than a permanent pipe when comparing similar internal diameters.

On every farm one of the commonest farm implements is the trailer—not all hydraulically equipped, but certainly the majority employ hydraulics for tipping either from the tractor or by means of a hand pump. No detailed explanation is really necessary as these applications are very well known. There are generally two positions for the ram—*i.e.*, slung underneath the body of the trailer, and the other where the ram is placed upright at the front of the trailer and connected to the front cross member of the body. The tipping capacity of the trailer is controlled by the pressure of the system and the diameter of the ram which it is tipping.

What better machine to describe with the trailer than the industrial or agricultural loader—the development of which has progressed tremendously in the last eight to nine years. A lot of the progress in its development has been made possible by improved hydraulic techniques and the increase in the pressures of the hydraulic systems used in tractors. This particular application gives one of the severest forms of usage to most types of tractors. You can well imagine the stresses set up in a tractor and its hydraulic system when a loader is raised to its maximum height fully loaded then allowed to drop suddenly and stopped just a few inches off the ground.

For designers in our audience it is interesting to relate an experience which was encountered with loaders some time ago. While developing a loader for a well-known tractor tests were carried out dropping the load

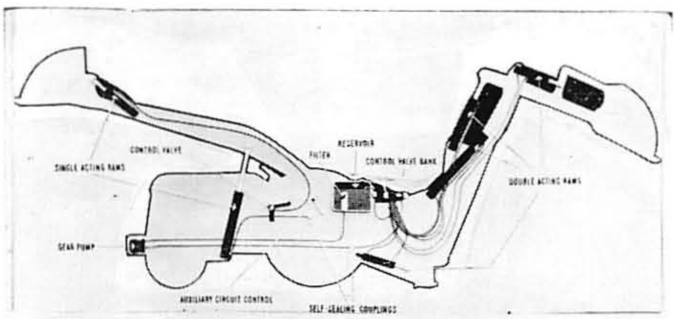


Fig. 5. Loader & Back Hoe

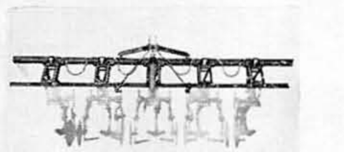


Fig. 6. Steerage Hoe

Fig. 7. Reversible Plough

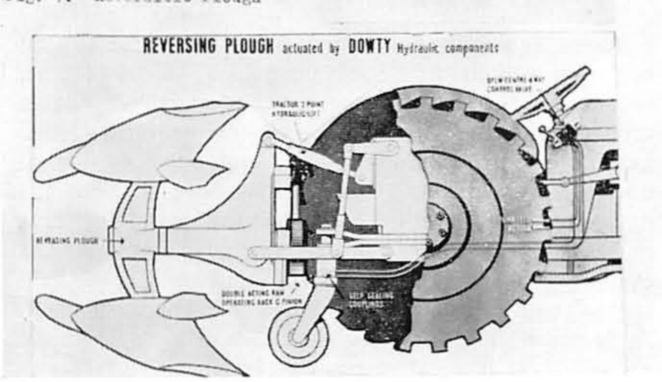


Fig. 4

and stopping it suddenly, but these tests divulged many weaknesses in hoses and their components. The blow-off pressure was set at 2,000 lb. per square inch, which was the setting of the relief valve in the tractor hydraulics. While doing these tests the pressure gauge did not register higher than 2,200 lb. per square inch, but components were failing which had been tested to 3,000 lb. per square inch. We then fitted an oscilloscope to measure the pressure within the system. A camera was fitted to the screen of the oscilloscope and a photographic record made of the pressures registered during the cycle of operations. From these tests we found that the peak pressure in the system reached a maximum of 3,300 lb. per square inch, but this instantaneous pressure wave only lasted for a fraction of a second, too brief a period to register on a normal pressure gauge. To overcome this difficulty a special non-return and pressure-relief valve was put into the system between the pump and the rams. This safeguarded the pump and also gave additional cushioning effect to the system, removing the high stresses which were causing the trouble. Fig. 2, portrays the layout of the scheme.

Fig. 4, shows a large industrial loader and back hoe or digger. The main points to notice are :—

1. The system has a separate pump.

2. Some of the rams are double acting.

It is necessary to have a separate pump as the output of the tractor pump is insufficient, the one used gives about 12 g.p.m.

On a number of loaders and diggers all the rams are double acting. This eliminates large return springs in some cases and also assists the front wheels of the tractor if they get bogged in.

Up to the present systems have been discussed which use pressurised oil supplied by a pump, but it may be of interest to study a sealed hydraulic system as used on a steerage hoe for inter-row cultivation of sugar beet or similar crops.

One of the major problems when using a hoe is to ensure that each gang of the hoe enters the ground to the same depth. Where undulating ground is concerned,

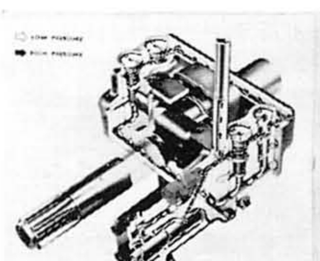


Fig. 1

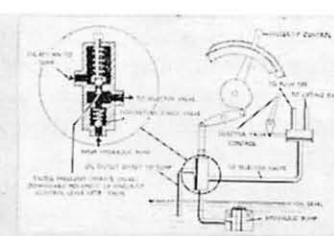


Fig. 2

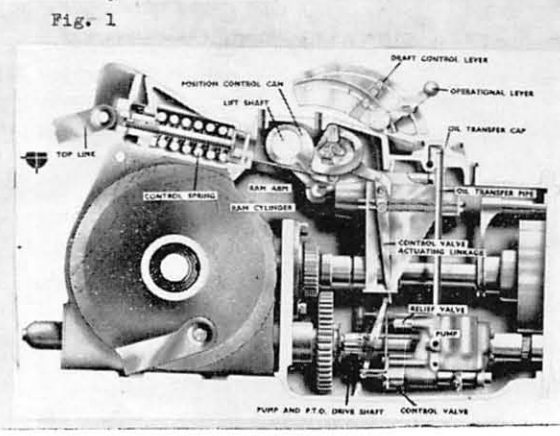


Fig. 3

very often one hoe enters quite deeply, while the other may be right out of the ground. If you study Fig. 6, you will see that by a hydraulic means each gang of the hoe is connected to the other and by lifting any individual gang the oil is compressed in the cylinder at the top of that gang. This increased pressure is soon equalised within the system, thus forcing the other gangs to press down harder. This method ensures that each gang will ultimately penetrate and do a good job of cultivation at a constant depth because if the depth increases the draught will automatically be increased on the machine and the necessary corrections made by the tractor's hydraulics.

A slightly different application, but an interesting one, is the two-way plough. Most people are conversant with the mechanical method of turn over and lock. This plough is turned over by hydraulic means. This is not new, but nevertheless it is not a common application. It consists of a rack and pinion, the rack being attached to the piston on a double-acting ram. By moving the piston of the ram to and fro the pinion is turned and the plough will turn over. A mechanical lock is usually employed with this type of device. The plough is shown in Fig. 7.

The rest of the Paper could quite easily be spent discussing the various applications of hydraulics in agriculture, but such a talk would not be complete without mentioning a development which is very interesting to all people in the agricultural industry. This is a tractor with a hydrostatic transmission developed by the National Institute of Agricultural Engineering, who have very kindly given me permission to refer to it.

It would be impossible to do more than make general reference to the tractor as Mr. Hamblin of the N.I.A.E. gave a full-length Paper on this subject on the 24th April, 1956, in London.

The hydrostatic transmission consists of a pump driven by a prime mover delivering oil through pipes or passages to motors which, in turn, drive the ground wheels. In this particular instance a variable-delivery pump is situated at the rear of the engine. The pressurised oil is conveyed from the pump to the hydraulic motors situated in the wheels. This arrangement gives two unusual advantages.

1. Infinite variation of speed, which can be changed from minimum to maximum without stopping the tractor.

2. The only mechanism in the centre of the tractor is the oil conveyance pipes. This gives plenty of clearance and visibility for any mid-mounted machine. Lastly, while on this tractor, just a brief view of the hydraulic motors themselves.

The motor, which is built in the wheels, consists of a 5-cylinder casing supported on bearings carried in a stationary shaft mounted on the tractor. Part of the stationary shaft is in the form of an eccentric which carries a double-row roller bearing, on the outside of which bear white metalled pads connected to pistons operating in the cylinder. A trapped ball transmits the thrust from each piston through a short column to the associated parts. The pads are retained in contact with the roller bearing by means of a loose ring. Oil passes to and from the cylinder by means of the hollow shaft and is transmitted to the cylinders by an oil passage which is connected to a hole in the outside face of the motor casing. With the N.I.A.E. tractor no difficulty was experienced in obtaining an overall motor efficiency of 80% at a speed corresponding to 3 m.p.h. and 90% is possible without too much difficulty.

The pump used on this tractor was a mock-up, and it delivered 62·5 gallons per minute at an average speed of 1,600 r.p.m. The design of the tractor itself was based on the Fordson Major Diesel, and it used as many components as possible of that tractor.

These examples of the application of hydraulics to agricultural machines merely single out a few for particular mention, but time presses me to omit many more, such as combines, sack lifters, fork lifts, cutter bars and hydraulic tractor top links. There are many more and probably quite a few in the development stage. It is difficult to foresee what developments will take place in the future, but one thing is obvious in the industry, and that is to assist development engineers in the agricultural field, pressures developed by tractor pumps will have to be standardised within a range of several hundred pounds. What advantage is gained by standardising the linkages of various tractors and yet have a divergence of pressures within the tractor hydraulic systems ranging from 1,100 lb. per square inch to 2,500 lb. per square inch ? How can designers of agricultural machines cope with these differences ? One may ask, should we operate on a high or comparatively low pressure ? but surely the answer to this problem is to use as high a pressure as is possible, with mass-produced components and oil sealing of economical proportions. The higher pressures we use, the smaller are the diameters of our auxiliary cylinders and hydraulic motors. The smaller these auxiliaries are, the cheaper they are to produce and handle.

Maybe the day is not far off when tractor pressures will be standardised and variable-displacement pumps obtainable at reasonable prices, with higher outputs than the tractor pumps used at present. When this time comes, then the hydraulics of the tractor will be used to a greater extent and hydraulic motors will be attached to many machines which at present use gearboxes driven from landwheels. By operating a lever on the tractor the speed ratio of the machine will be altered. Some manufacturer may even develop a hydraulic motor which can be moved easily from one machine to another and which may even prove cheaper than buying splined drive shafts.

THE STEERING OF WHEELED TRACTORS

by K. E. Morgan,* B.Sc., N.D.Agr.E., A.M.I.B.A.E.

The problems of efficient farm mechanisation are closely bound to the design of the farm power unit. If we accept the statement that " British agriculture has been motorised but not mechanised " we must look more closely at the present-day conventional agricultural tractor on which our mechanisation is based in order to decide how it can best be altered to meet the demands of the immediate future. This article is concerned with the background to one of many aspects of research on tractor design.

ONE of the most interesting aspects of the development of the agricultural wheeled tractor is the way in which it has followed the development of the automobile. Obviously this is not due to any similarity of function, and the only fundamental reason for this parallel development appears to be that tractors and automobiles have evolved from machines in which engine torque was substituted for horse draught. This common ancestry has resulted in tractors inheriting design features which may be admirable in a road vehicle, but which are a decided disadvantage on the farm. These faults are too obvious to require specific mention, but one noteworthy result is that the driver of a conventional tractor can see neither the ground which he is working nor the implement with which he is working. However, there are reasons for hoping that this situation will improve, because rear-mounted, air-cooled engines are being fitted to an increasing number of automobiles. Once given rear-mounted, air-cooled engines, it is a simple step to mount implements in front of the driver, with all the advantages that this confers. Other equally important advantages would result from the general adoption of the N.I.A.E.-type hydraulic transmission, amongst them being the simplification of four-wheel drive and four-wheel steering.

Of course, there is nothing new or startling in this conception of a tool-carrier type of tractor having a rear-mounted, air-cooled engine, hydrostatic transmission, four-wheel drive and four-wheel steering. But there is a further possibility which is under investigation. This is to provide a steering system which would allow the tractor to " crab " sideways. Such a system would improve the manoeuvrability of any tractor, but fitted to a row-crop tool-carrier it would mean that implements mounted in tandem could be moved sideways between the rows without the swing which occurs with conventional steering. The implements would continue to follow each other precisely, all moving exactly the same distance from the row, and steerage hoes, for example, would become a thing of the past. Incidentally, this system would also answer present objections to ploughing with front- or mid-mounted ploughs.

However, before this " opposed-or-synchronised " four-wheel steering can be discussed, it is necessary to consider conventional steering systems and the developments which have led to them. Once again tractor design has followed automobile design. Both types are steered through the front wheels and, in order to reduce tyre scrubbing, an attempt is made to limit the relative motion between the wheels and the ground surface to one of pure rolling. Reference to Fig. 1 will show that this can only be achieved if the paths of the points of contact between the wheel and the ground surface are concentric circular arcs—that is, if EA produced, BF produced and DC produced intersect at X. The inset diagram shows that centre-post steering provided one way of meeting these requirements. It will be seen that the stub axle BF, on the inside of the turn, has to be displaced through a larger angle (α) than the stub axle EA, if wheel F is to traverse an arc of smaller radius than the radius of the arc traversed by wheel E.

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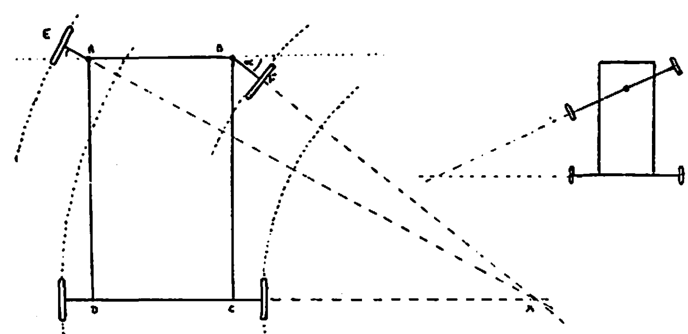


Fig. 1.
Steering conditions for pure rolling motion.

Various mechanical linkages will produce this differential displacement of the stub axles, but of these only one, the Ackermann linkage, is usually employed. Its action will be seen from Fig. 2, which shows it to be a four-bar chain with turning pairs ; two short links of equal length and two longer links of unequal length.

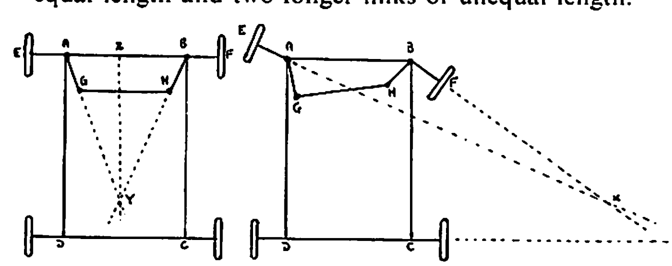


Fig. 2.
Ackermann steering gear.

An alternative steering gear is the Davis linkage, but the limitations of this system, which employs sliding pairs, have discouraged its use in road vehicles. These disadvantages would be even more marked in a tractor than in a road vehicle, if only because the dusty conditions under which tractors operate would increase the friction and wear at the surfaces in sliding contact.

Unfortunately, the conditions for pure rolling motion between the wheels and the ground surface are only achieved by the Ackerman linkage in one steering position ; in Fig. 2 (*b*), for instance, X is seen to be forward of DC produced, so that at this deflection the tyres are being scrubbed. In practice, of course, a

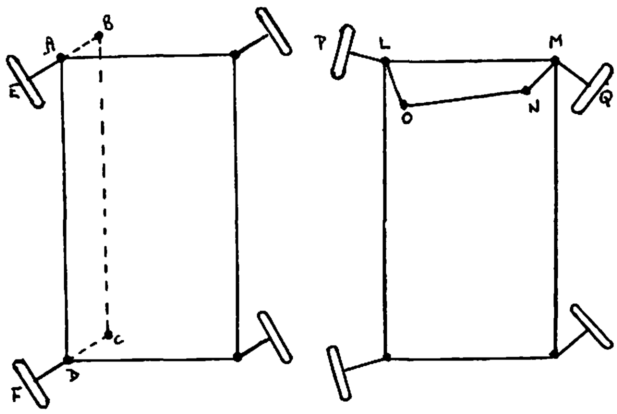


FIG. 4. (*a*) Opposed steering. FIG. 4. (*b*) Synchronised steering.
Proposed Dual Steering Systems

compromise is made, and track arm convergence is such that the centre lines of the track arms AG and BH, when produced, intersect at Y so that ZY = $\frac{2}{3}$ AD. Various authorities[1] quote figures for ZY ranging from $\frac{5}{8}$ AD to $\frac{3}{4}$ AD, so that obviously some latitude is allowable. Final dimensions for any particular chassis are usually determined experimentally, and fortunately the error of differential deflection is small when the steering angle is small. Obviously, small steering angles are usual in a road vehicle and large steering angles, which produce large errors in the linkage and hence tyre scrubbing, are only applied at low speeds.

With agricultural tractors, where large steering angles are frequently applied, the relatively slow speed and soft surfaces prevent undue tyre wear through scrubbing. Low inflation pressures, the large footprint area of a tractor and individual rear wheel brakes all tend to increase the scrubbing wear of tyres, but even so it is preferable to design the linkage so that it is reasonably accurate at steering angles between 0 and 25 degrees, since this is the range that normally will be used in high-speed (20 m.p.h.) transport work on hard-surfaced roads.

Other considerations which affect the steering gear, and which may be briefly dealt with, are those of castor angle, toe in and wheel rake, though none of these will be as important in low-speed tractor operation as they are in road vehicles operating at much higher speeds. Centre-point steering, although it eliminates steering kick, encourages track-rod snatch as wear takes place in the steering linkage. The rolling of the tyre and the consequent release from scrubbing when a steering angle is applied on a stationary vehicle is not nearly as important on a soft surface as it would be on a road, and though a light offset will give this rolling effect it will also increase journal loads on the swivel pins, leading to increased friction and heavier steering when the vehicle is in motion. On balance it seems that a light offset is desirable for tractors, because hydraulic steering boosters can reduce steering effort, absorb steering kick and will encourage turning the front wheels with the tractor stationary. Track-rod snatch, however, could be a very troublesome phenomenon with hydraulically boosted steering. Similarly, tractor designers can take advantage of the benefits conferred by large castor angles (which will be magnified by the relatively high rolling resistance of tractor front wheels), if they are prepared to use hydraulically-assisted steering. The objection to marked castor action—that it makes for heavy steering—can no longer apply. Toe in will still be necessary, of course, to counteract the tendency towards toe out which is met when rolling resistances are large, and to reduce tyre wear. The adoption of hydraulic steering boosters is unlikely to affect drop-arm and drag-link layout, but it should affect steering gearbox design. The hydraulic unit will absorb most of the shock transmitted from the front wheels so that " irreversible " gears and " built in " friction damping in steering columns will be unnecessary. Steering columns and gearboxes should therefore be designed for lightness of operation to take full advantage of the self-centring effect of a properly designed steering linkage.

The problem of determining correct steering ratios can be solved by using hydraulic steering boosters. At one stage it was felt by the author that two steering ratios should be offered on tractors, either to be selected at will by the driver. A wide ratio of, say, 20 : 1 was proposed for accurate row crop work with a close ratio of say, 10 : 1 for road work, where a quick response was required and where steering effort would be less. Two-ratio steering is an inherent feature of the opposed-or-synchronised steering linkage, but it is likely that the close ratio will cover all requirements, providing that steering effort is sufficiently reduced by the hydraulic boost.

Any discussion of hydraulically-assisted steering is a reminder that here is another instance where conventional tractor practice has lagged sadly behind automobile practice, although it would seem that steering assistance is quite as necessary on a conventional tractor as on the average American car. It is difficult to realise that by 1931 the Dewandre vacuum-servo system (patented in this country in 1927) was produced for use in armoured cars, while in America the Vickers hydraulic unit was finding widespread application on a variety of road vehicles. Long before this, however, power steering had been demonstrated—by G. W. Fitts in 1876[2]—and F. W. Davis demonstrated a hydraulic unit as early as 1926[3]. Late in 1956 a British wheeled tractor was offered for sale with hydraulically-assisted steering as an optional extra.

It is safe to assume that in the fullness of time other tractor manufacturers will follow this lead,* and it is profitable to consider the main features of suitable hydraulic units. The essential requirements are stated as:

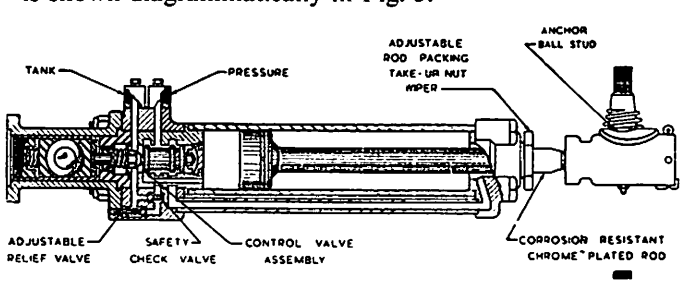
1. A source of power.
2. A means of using the available power.
3. A control valve.
4. Provision to transmit a " signal " to the control valve.

* *This assumption has now been justified by the appearance of the Ferguson 65. Ed.*

Probably the most attractive source of power so far as tractors are concerned would be a constant-flow hydraulic system, although compressed air systems, such as the Bendix Westinghouse and the Clayton Dewandre, or accumulator powered hydraulic systems such as the Lockheed and the Bendix-Mack should not be ruled out. Clearly, the unit must be "live," in the sense of a "live" power take-off shaft or the "live" hydraulic (lift) system of the International B 250. The pump could be driven from the front of the engine from a camshaft or generator drive or from a live power take-off shaft. It is worth noting that the N.I.A.E. hydrostatic transmission system includes a "small pump to draw oil from the make-up tank and pump it, through a filter, into the low-pressure side of the main circuit". This pump could be made to feed an accumulator which would provide hydraulic power for steering, in addition to its present function as a make-up pump.

The usual means of using this power is by a double-acting cylinder. The compactness of this arrangement is an advantage which more than offsets the slight disadvantage due to the differential effective areas of the faces of the piston.

Oil entering the double-acting cylinder is controlled by a valve which may be of the "reactive" or "non-reactive" type. A non-reactive valve gives constant effort steering up to the maximum available hydraulic pressure and obviates shock at the steering wheel. A reactive valve gives much more "feel" to the steering, demanding increased effort at higher fluid pressures, and some shock is transmitted back to the steering wheel. The simplicity of the non-reactive valve recommends it for agricultural tractors, where cornering speeds are low and steering feel is relatively unimportant. A typical unit is shown diagrammatically in Fig. 3.



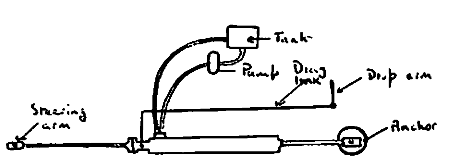


FIG. 3.
(*a*) Section of Vickers' "Detroit" Hydraulic Steering Booster.
FIG. 3.
(*b*) Typical installation.

It is possible now to return to the opposed or synchronised steering linkage which is under investigation. Reference to Fig. 4 will show the wheel deflections under either opposed or synchronised conditions.

The synchronised linkage is based on the Ackermann steering gear, the opposed linkage is based on a four-bar chain—ABCDA—with turning pairs ; BC and AD are of equal length and, similarly, the two short links are of equal length. Thus wheel E moves parallel to wheel F.

The change over from opposed to synchronised steering, and vice versa, can be achieved either by providing variable-length links ON and BC, or by providing double swivel pins in a reversed Lemoine type of steering knuckle. By this means the linkage not in use can be isolated, allowing parallel deflection of all four wheels, or differential, as required.

Following normal practice, a model has been constructed on these principles. In this the steering linkages are mechanical, being built up of pivoted, rigid rods. A more flexible approach would be to use a hydraulic linkage, when tractor layout would not be circumscribed by geometrical considerations, and it is hoped that it will be possible to build this linkage on a full-scale tractor in the near future.

The main problem left to be solved is a human one—after years of driving conventional tractors and cars, watching the bonnet swing comfortably away from obstacles, it is extremely difficult to accustom oneself to the sideways cringe of a crabbing tractor on "opposed" steering. Nevertheless, with practice it was found possible to control the model when on "opposed" steering, provided that the speed of forward travel was low and that small steering angles were applied. These conditions are usual to row-crop work, and with a full-scale tractor, where the driver would sit over the tractor, it would be much easier to estimate the deflection required to "side-step" an obstacle or to adjust the position of an implement with regard to the row.

REFERENCES

1 IRVING, J. S. 1949, *Automobile Engineering*, Vol. III, Section XI, "Steering Gear, Shafts and Universals."

2 CREESON, W. K. 1952, *Trans. Soc. Auto. Eng.*, Vol. 6, No. 4, "Power Steering in 1952."

3 NEIL, E. B. 1951, *Automotive Industries*, Vol. 105, "Power Steering for Modern Vehicles."

4 HEACOCK, F. H., and JEFFERY, H. 1953, I.Mech.E. Automobile Division Proceedings, 1953 - 1954, "The Application of Power Assistance to the Steering of Wheeled Vehicles."

HAMBLIN, H. J. 1956, *The Journal of the Institution of British Agricultural Engineers*, Vol. XII, Issue III, "The Application of Hydrostatic Transmission to Tractors."

I.B.A.E.—The Application of Hydraulics to Agricultural Machy.

ACKNOWLEDGMENTS

The author is indebted to the following Companies who kindly supplied technical diagrams, illustrations and information :—

Ford Motor Company, Ltd.
David Brown Industries, Ltd.
Dowty Hydraulic Units, Ltd.
Oil Feed Engineering Co., Ltd.

The preparation of the Paper was made possible by the co-operation of Massey-Harris-Ferguson, Ltd., who also provided the printing facilities for distribution.

REFERENCE

H. J. HAMBLIN, "The Application of Hydrostatic Transmission to Tractors."

FIG. 1.
FIG. 2.
FIG. 3.
FIG. 4.
FIG. 5.
Loader and Back Hoe.
FIG. 6.
Steerage Hoe.
FIG. 7.
Reversible Plough.

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