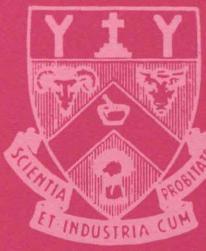

NEW ZEALAND AGRICULTURA
ENGINEERING INSTITUTE

REPORT ON THE BRUFF TG1 TRENCHLESS DRAINLAYER

PROJECT REPORT
P/14

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TRENCHLESS DRAINLAYER

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October 1976

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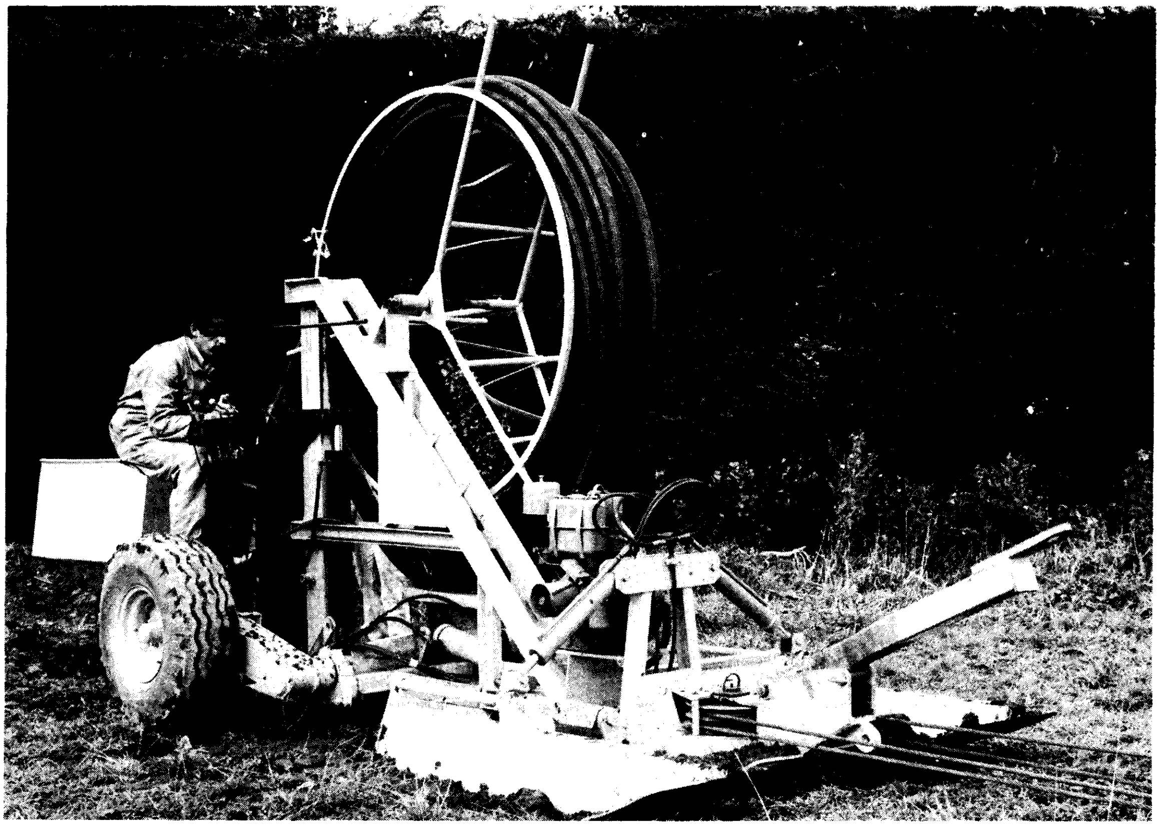
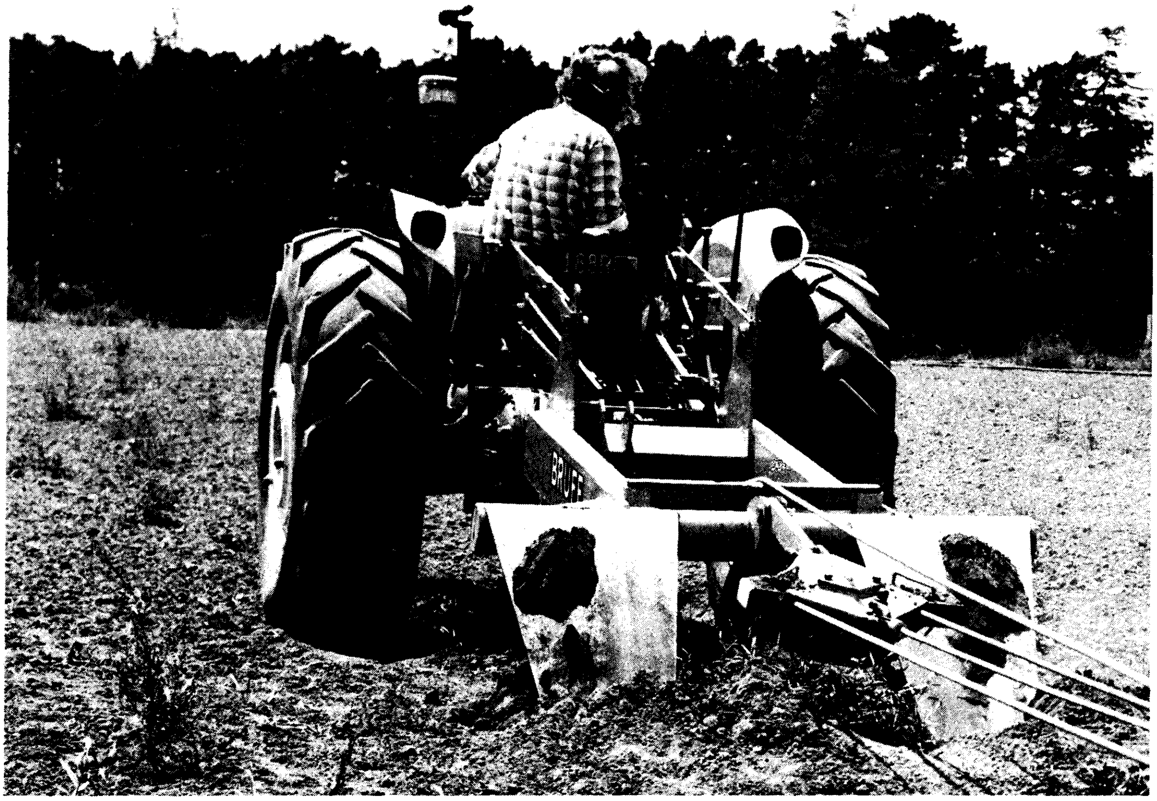


Drainlaying unit



Tractor mounted winch-sprag unit

Frontispiece. TG1 Trenchless Drainlayer

SUMMARY

A series of trials with an imported trenchless drainlaying machine has shown that the machine can operate successfully under some New Zealand conditions. Drains were laid using 100 mm clay tiles and two types of plastic drainage pipe. The results show that the use of trenchless drainlaying methods could make a significant contribution to land drainage in New Zealand.

CONTENTS

1. INTRODUCTION

1.1 TRENCHLESS DRAINLAYING MACHINERY

Since the early 1960's a number of trenchless drainlaying machines have been introduced. They consist essentially of a large mole type plough drawn through the ground either by direct traction or by a winched cable. The drainpipe and envelope material are fed through a chute attached to the mole plough and laid in the ground without removal of the soil, hence the term trenchless.

The direct traction type of machine is large (ten tonnes or more) high powered (greater than 100 kW) and capable of rapid drainlaying (20 - 45 m/min). This type of machine is usually mounted on tracks and additional plant is required for transportation between worksites.

In contrast to these large machines the BRUFF* TG1 (the original machine was built by Thorton and Garnett Ltd) is a small (2.5 tonne) unit drawn by a cable from a winch mounted on a medium size (50 kW) farm tractor. It is easily transported on its retractable road wheels and is able to lay completed drainlines at a speed comparable to that of a fast chain-type trencher (up to 5 m/min). This lower operating speed permits the use of conventional simple guidance methods whereas the high speeds of the large trenchless machines make the use of laser controlled automatic guidance systems almost mandatory.

1.2 SOME ECONOMIC CONSIDERATIONS

It is difficult to provide a specific cost comparison between the TG1 and other drainlaying machinery because of the variations in the types of machine and the situations in which they are used. However, the relevant cost factors will be presented here so that anyone with the appropriate price information can carry out an economic appraisal.

The principal cost factors in drainlaying are:

(a) Speed of laying, that is, the time per length of completed drain.

(b) Fixed costs and operating costs of the plant.

(c) Labour.

(d) Materials.

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*Bruff Manufacturing Co. Ltd., Suckley, Worcester, England.

The TG1 can lay completed drainline (that is, pipelaying, permeable backfill and cover) at the rate of 100 m/hour. It is a rugged machine with a few simple parts. Maintenance and repair costs can be expected to be lower than for bucket trenchers or other machines with multiple cutting edges. The average power requirement for the drainlayer is approximately 10 kW and this is supplied by a lightly loaded 50 kW diesel tractor.

Operation of the drainlayer and winch tractor combination requires two persons.

Additional labour and plant is required for the supply of drainage materials. The requirements range from none for laying plastic pipe with no permeable backfill up to four persons (approximately) plus plant for the laying of clay tiles with permeable backfill. The manufacturers recommend the use of specialised plant for materials handling but in New Zealand this is an area in which use could be made of farmer contribution of labour and plant.

As far as material costs are concerned the major difference compared to other methods occurs when using permeable backfill because the narrow slit cut by the TG1 requires considerably less material than an open trench.

2. DESCRIPTION OF THE MACHINE

2.1 METHOD OF OPERATION

The TG1 drainlaying unit and tractor mounted winch-sprag unit are shown in the Frontispiece.

The layout of the TG1 drainlayer is shown in Figure 1. There are three principal moving parts to the machine.

(a) The bursting blade which is raised and lowered by a hydraulic ram. This blade controls the depth to which the drain is laid.

(b) The front skids are raised and lowered by small rams which are linked to a common hydraulic circuit, that is, they cannot be operated separately. These skids are used to alter the angle between the ground surface and the base and hence the 'angle of attack' of the mole share. They are used in conjunction with the bursting blade control to maintain the machine on grade over undulating ground.

(c) The wheels are used for transport and can be raised by ram for drainlaying. They are not used for angle or depth control, but can be lowered onto the ground surface during laying to maintain the vertical stability of the machine.

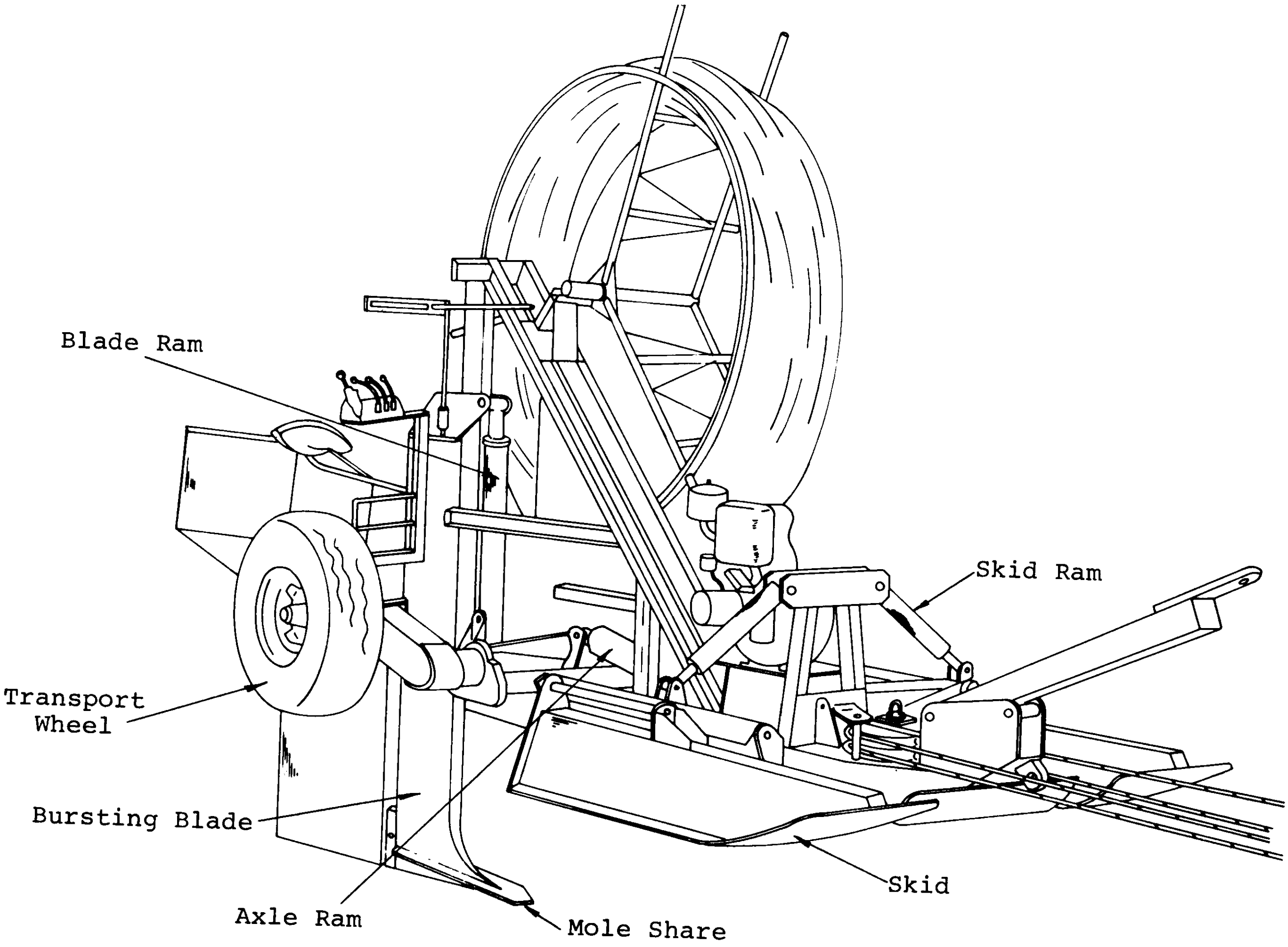

Figure 1. The TG1 Trenchless Drainlayer (winch not shown)

An essential component of the TG1 drainlayer is the 100 kN capacity winch and sprag mounted on a tractor. The use of a winch and three of four falls of wire rope is necessary for smooth operation under the high loads which occur.

The sequence of operations for laying drainpipe is as follows:

(a) At the beginning of the run a starting trench is dug to the required depth of the drain at the drainage outfall.

(b) The drainlayer is then driven over this starting trench and the blade lowered to the required depth.

(c) The tractor-winch unit is uncoupled and driven forward along the proposed drainline paying out the wire rope.

(d) The anchor sprag is lowered and the winch started. As the drainlayer blade is drawn into the ground the front skids and land wheels are set to maintain a level base to the machine.

(e) As the machine is drawn through the ground the skids and blade depth control are operated to keep the drainlayer on grade according to the particular guidance system (see Section 3).

(f) When the drainlayer has been drawn up to the winch unit this unit is moved forward and the operation repeated as from (c) above.

2.2 MODIFICATIONS CARRIED OUT BY N.Z.A.E.I.

2.2.1 Safety link

Throughout all the tests carried out by the N.Z.A.E.I. the machine was used with four falls of wire rope. At the point of attachment of the rope to the sprag a safety link was inserted. This link consisted of a short length of 13 mm wire rope. The end of the main 16 mm wire rope was connected to about 2.5 m of 8 mm chain which was attached to the sprag. In the event of failure of any part of the safety link the chain would restrain the main rope from whipping back towards the drainlayer.

2.2.2 Tile chute

The machine made available to the N.Z.A.E.I. was fitted with a chute for laying plastic pipe up to 100 mm diameter but no chute for laying 100 mm clay tiles. Although a chute for tile laying can be supplied by the manufacturers, it was decided to have one locally made. A situation may occur where the drain tiles being used differ from those specified for the manufacturers' chute and special fabrication may be required. For this reason it may be useful to mention a few important design parameters in the construction of tile laying chutes.

(a) The tile emerging from the chute should be as near to parallel with the bottom of the trench as possible before being released. If this is not done the tile needs to be pushed along the trench by the tiles in the chute until it butts against the previously laid tile. This is, at best, an unreliable process.

(b) During the movement of the tiles from the vertical position at the loading point at the top of the chute to the horizontal position at the outlet considerable friction is generated between the tiles and the curved guide. This friction can be overcome to some extent by the weight of tiles above the point of friction and thus the length of horizontal path of tiles in the chute should be as short as possible.

(c) The tile needs complete protection from cave in of the trench walls and interference by the permeable backfill material (for example, gravel) until it is properly laid in the bottom "V" of the trench butting up against the next tile. This condition is usually met by extending the sides of the chute back from the tile exist point and keeping the gravel exit well behind the tile exit, so that the surface of repose of the gravel does not enter the tile exit area.

(d) The exit for the permeable backfill also needs protection from cave in of the sides of the trench and the sides of the chute should extend back by the required amount.

It cannot be over emphasised that the pipe laying system must be totally reliable as one poor joint in a drain line can mean siltation of the line and consequent failure of the drain.

2.2.3 Guide roller

A rope guide roller was fitted to the top of the main cross arm of the sprag to protect the wire rope from riding on the crossarm. When the sprag is being drawn into the ground or if the ground surface is hard so that the sprag does not penetrate to full depth the wire rope can ride on the sprag and foul the pulley attachment. It was also possible for the rope to remove the retaining clip on the pulley attachment pin, thus leaving it in an unsafe condition. A wooden rope skid had been provided by the manufacturer for this purpose but the wire rope rapidly cut grooves in the wood which prevented the rope from feeding smoothly onto the winch drum.

3. GUIDANCE SYSTEMS

3.1 REQUIREMENTS AND SPECIFICATIONS

There is at present no New Zealand Standard for the control of farm drainage but desirable goals for the accuracy of drainlaying may be found in some overseas standards. The Drainage Guide for Ontario* gives the following requirements for grade control:

(a) No reverse grade.

(b) Deviation from design grade not to exceed 15 per cent of the drain diameter for drains 8 in (200 mm) or less in diameter.

(c) This allowable deviation is to be gradual over a distance of not less than 30 ft (10 m).

For a 100 mm diameter pipe these specifications allow a maximum deviation from the grade line of 15 mm.

The accuracy of a pipe laying system is governed by two factors:

(a) The sighting system error, that is, how closely a sight or sensor mounted on the layer can be kept to the grade line.

(b) The mechanical connection between the sighting point and the pipe exit.

In some pipelayers the movement of the sighting point is damped by a trailing linkage to the chute so that the corresponding motion at the pipe exit is of smaller amplitude and smoother rate of change.

The error at the sight is determined by the resolution of the sight or sensor and the characteristics of the operator-control system.

3.2 TYPES OF SIGHTING SYSTEMS

There are two main types of grade control in use:

(a) Sighting rods, also called boning rods, are set up so that the marks on the rods lie on a line parallel to the required drain. The machine operator keeps a simple sight on the drainlayer in line with these marks by use of the depth controls.

(b) Optical methods make use of special lights or laser beams set to the required grade. The light may be viewed, or in the case of the laser, the beam strikes a target screen or is detected by a sensor.

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* Drainage Guide for Ontario, Publication No. 29, Ontario Ministry of Agriculture and Food.

Sighting rods require more time and staff to set them up than the easily erected light systems. The light or laser is also generally easier for the operator to sight and accuracy is improved.

3.3 METHOD USED FOR THE TG1

For the trials carried out with the TG1 a 'Dataline'* surveying light was used. This instrument consists of the light from a six volt 15 W bulb projected through a special lens system. The resultant beam has a circular cross-section 2° in diameter which is divided into three sectors of 180°, 90° and 90° (that is, the lower half of the circle and the top half divided into two quarter circles). The sectors are different colours and the boundary between the sectors has a width of ten seconds of arc. Thus at a distance of 100 m the beam diameter is 3.5 m and the sector boundary is 5 mm wide. The horizontal sector boundary was used as a guideline. The light was mounted on a surveying instrument base and tripod and was easily moved and set up using the grade adjustments on the instrument. During drainlaying trials the light was used at a maximum range of 40 m and moved each time the winch tractor was moved. At each move the adjustable sight on the drainlayer was reset to coincide with the light beam. Provided the starting depth of the drain and the grade are correctly set then the grade line is unaffected by the height of the instrument. The sighting accuracy of the light decreased with increasing range. A test was carried out using the light as described and laying tiles at approximately 5 m intervals along an 80 m drainline.

The design grade was 1 : 600 and the ground surface contours varied by up to 300 mm. The tops of the tiles were surveyed and found to be within 15 mm of design grade. Within the limits imposed by the small sample the requirements of the Ontario Drainage Guide as stated above were satisfied.

4. PERFORMANCE TRIALS

4.1 PURPOSE OF THE TRIALS

A series of trials was carried out to determine the performance of the drainlaying machine under three common New Zealand conditions. The trials were as follows:

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* Manufactured by Victoria Engineering Ltd., Lower Hutt, New Zealand.

(a) Measurement of the variation of the winch cable load with depth and speed of drainlaying in a silt loam.

(b) Ability of the machine to negotiate bends.

(c) Behaviour in gravels.

4.2 VARIATION OF DRAUGHT WITH DEPTH AND SPEED

These trials were initially carried out to verify that the capacity of the winch-sprag unit was adequate. A dynamometer spring scale was inserted at the joint between the safety link and the main cable. Four falls of wire rope were used at all times. Measurements of the load in the wire rope were taken for a range of depths up to 1 m and several haulage speeds. The soil was a silt loam and moisture content during the trials was near to field capacity. The draught was found to be linearly related to the depth as shown in Figure 2 and independent of the haulage speed. The scatter of points is due to varying soil conditions and changes in soil frictional forces as different parts of the machine contacted the ground. Most of the draught is due to the bursting force of the mole share and changing from tile chute to plastic pipe chute or removing them altogether did not make a signficant difference.

4.3 ABILITY OF THE MACHINE TO NEGOTIATE BENDS

For the kind of farm drainage techniques currently being used in New Zealand it is particularly desirable that a drainlaying machine be able to lay drains which are curved in plan. The manufacturers' literature did not indicate that the machine could be used in this fashion and so a trial was necessary.

The winch unit was offset from the longitudinal axis of the drainlayer to give a pull up to 8^o from this axis. Care was taken that the pull on the winch was always straight. The angle of 8^o was the maximum obtainable without fouling the wire ropes on the front of the drainlayer.

The load on the wire rope and the distance travelled by the machine were measured during the turn. The dimensions of the turns for the two trial angles of 6^o and 8^o are shown in Figure 3(a). The length of the turn and average radius of curvature shown in Figure 3(a) would probably not be the same for other soil types because these dimensions are controlled by the soil resistance to the turning motion of the drainlayer. For general use a maximum angle of 5^o with a 10 m length of turn as shown in Figure 3(b) would be within the capability of the machine. For negotiating large angles a series of 5^o shifts can be used to give a curve with a minimum radius of curvature of approximately 115 m.

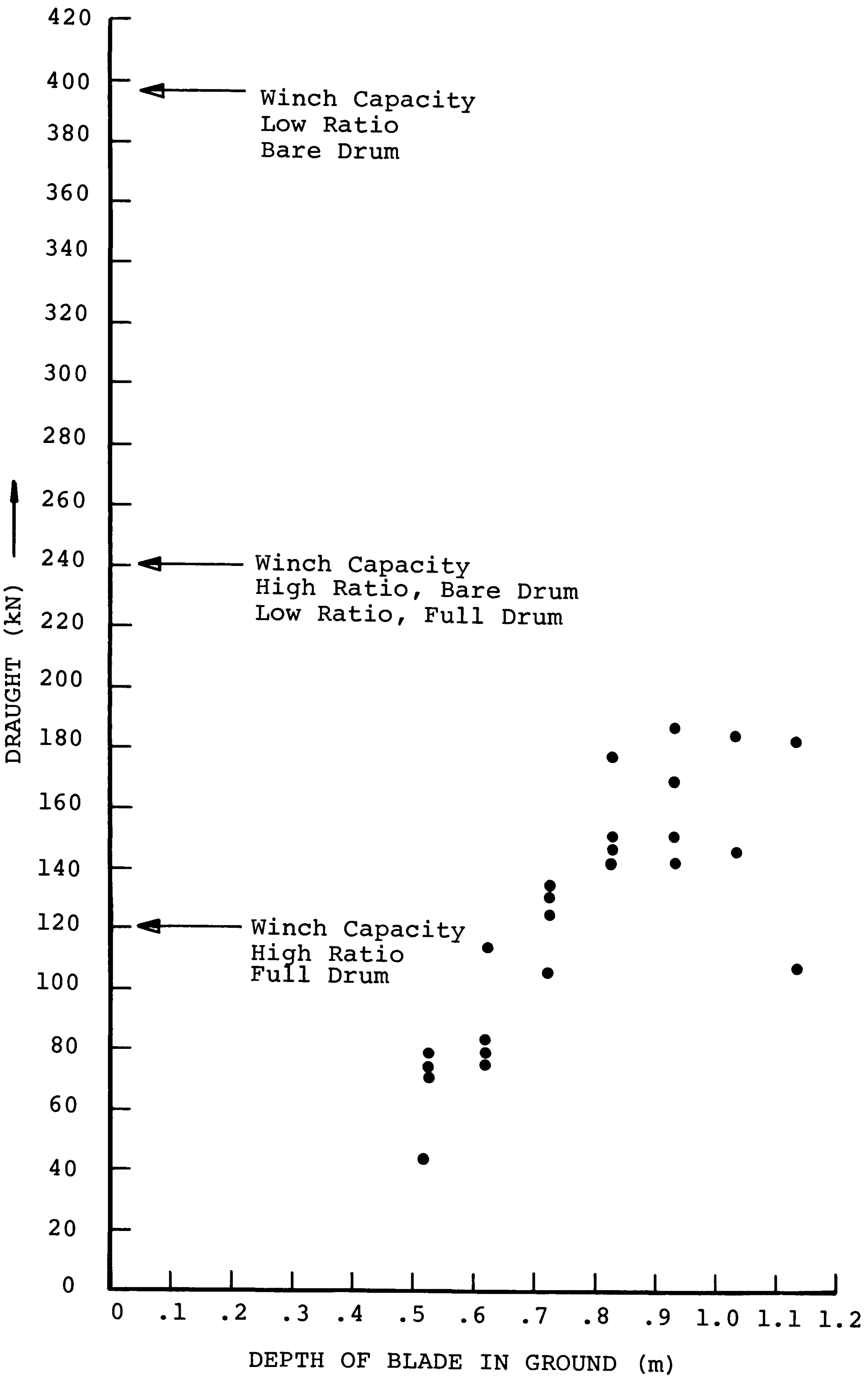

Figure 2. Draught trial results - silt loam

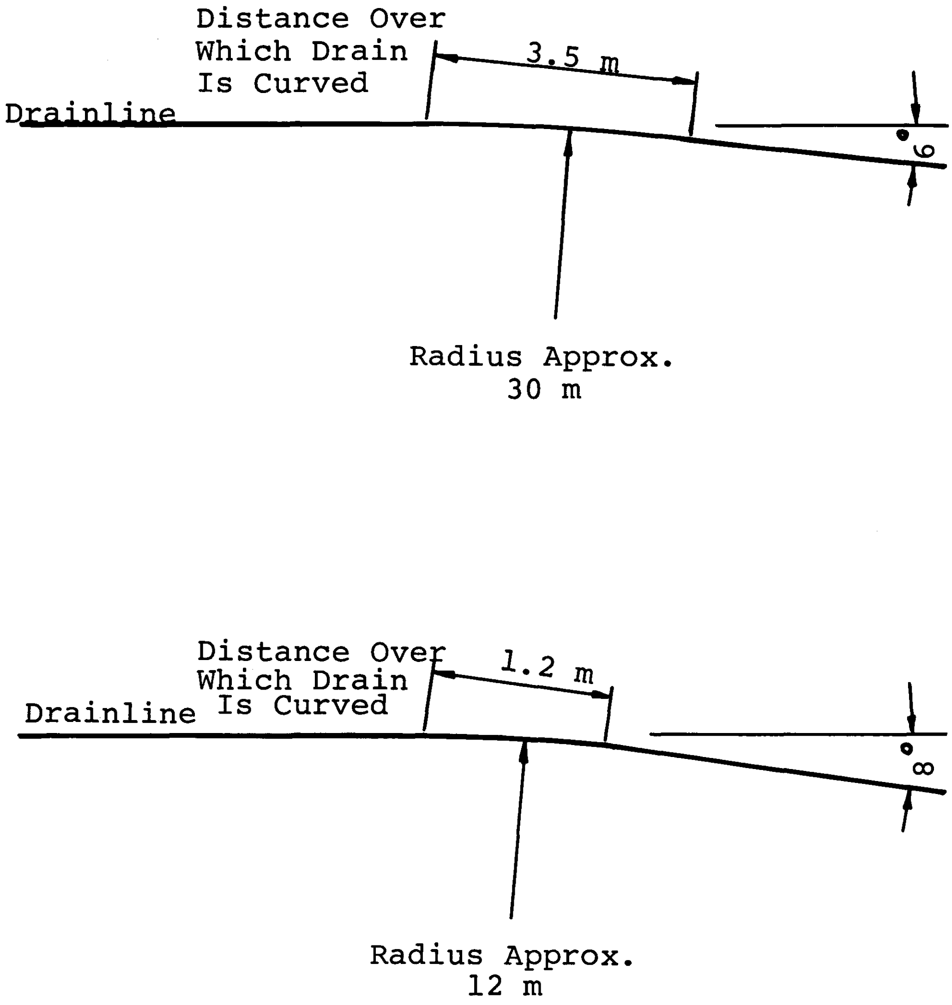

Figure 3(a). Drainline curve trial dimensions

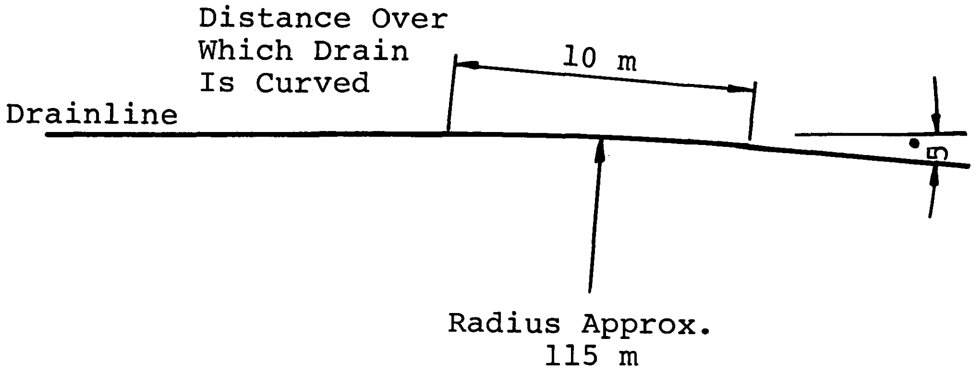

Figure 3(b). Recommended drainline curve dimensions

During the trials the measured haulage load did not increase significantly and the machine did not suffer any visible damage.

4.4 BEHAVIOUR IN GRAVELS

Problems occur in New Zealand when drainage machines are used in soils containing a high proportion of gravel. Trenching machines with moving parts wear rapidly and the instability of some gravels make open trench methods very difficult. This latter problem can be solved using a trenchless drainlayer such as the TG1 and the effect of wear on the large non-moving parts is minimal. For the trial the site selected was a gravel borrow area. The topsoil had been stripped off and the remainder of the soil consisted of sands and gravels up to 50 mm diameter. The machine was drawn easily through this material at normal operating depth and speed without any apparent damage. The sprag did not easily obtain a purchase on the gravel but under normal circumstances where the topsoil would not be removed, no problems are anticipated.

4.5 SOIL FORCE CONSTRAINT ON MAXIMUM DEPTH

In some soil conditions it was found that the main beam (Figure 4, p. 17) of the drainlayer would not sit flat on the ground. because the tail end had been forced up by about 100 - 200 mm. If the machine is not levelled by lowering the front skids then the tail of the pipe chute is lifted off the formed "V"-bottom of the trench and pipe laying becomes haphazard. During the trials the top link on the chute was removed to try to avoid this problem and also to improve the 'trailing linkage' effect (see section 3. 1). However, this caused the chute to rotate about the bottom linkpin and lift the tail of the beam about 250 mm above the ground surface. The best position for the top link was found to be that which allowed the chute to hang back from the blade by about 5°. This setting ensured a firm contact between the chute tail and the trench bottom as well as minimising the lifting effect. This lifting of the beam of course reduces the maximum operating depth of the machine. Thus although the bursting blade can be lowered 1.22 m below the bottom of the main beam the usual maximum operating depth below the ground surface is about 1.10 m as claimed by the manufacturer. An explanation of this phenomenon is presented in Appendix C.

An attempt was made to counteract this effect by increasing the angle of attack of the mole share. Slight improvement resulted but the draught force also suffered an undesirable increase.

4.6 BURIED OBSTACLES

No trials were carried out on the ability of the machine to negotiate buried boulders or tree stumps. However, in many drainage situations the possibility exists that the drainlayer will be brought to a halt by a large obstacle and a procedure for recovery should be available. A few suggestions are offered here as a guide to the operator wishing to form his own plan of action.

In most soils the mole blade cannot be raised from normal operating depth while the machine is stationary as the hydraulic system is not strong enough. It is possible also for the mole share to be hooked under the obstacle which further precludes raising the blade. Hand digging from the side just forward of the wheels will expose the obstacle. If it cannot be removed or cut from this position then the machine will have to be moved backwards. In order to do this a trench needs to be dug behind the chute and the appropriate length of drainpipe removed. A backhoe, if available speeds up this operation. The drainlayer can then be towed backwards and the obstacle cleared.

5. DRAINLAYING TRIALS

5.1 LAYOUT OF THE TRIAL

Three types of drain were laid in a silt loam field at Lincoln College. The drains were:

(a) 240 m of 100 mm I. D. clay tiles each of 300 mm length.

(b) 30 m of 100 mm 'Novaflo' plastic drain pipe.

(c) 400 m of 50 mm 'Draincoil' plastic drain pipe.

All drains were laid to a gradient of 1 : 300 at a depth of 0.8 m - 1.0 m depending on surface topography and backfilled with 20 mm crushed gravel to within about 300 mm of the surface.

The results of the trials are best presented as a set of recommendations firstly in a general sense and then for the particular types of drain.

5.2 GENERAL GUIDELINES FOR TRENCHLESS DRAINLAYING

Trenchless drainlaying requires good organisation and constant attention to careful machine operation. The drainlaying process is a one-pass operation and the supplies of drainpipe and permeable backfill material must be fed to the drainlayer in sufficient quantities so as not to impede the rapid laying which these machines are capable of. It is not feasible to inspect the whole length of the drain line as in open trench laying and it is therefore crucial that the machine operator keeps the layer on grade at all times. The settings of the guidance system must be double checked.

The organisation aspects may make it more difficult to use farmer contributions of plant and labour because of the requirements of working with the contractor during actual laying.

Supply of gravel to the drainlaying machine was found to be the principal constraint to the otherwise rapid progress of the TG1. The depth control for the gravel chute needs to be carefully adjusted to minimise wastage as even a couple of centimeters extra depth of gravel means a large increase in supply.

5.3 TILE DRAINS

The major problem in trenchless laying of tile drains is the supply of tiles. Even in heavy soils the TG1 will move at an average speed of at least 3 m/min while laying pipe. The use of 300 mm long clay tiles means that a tile is fed down the hopper every six seconds. Allowing for moving the winch unit, 400 tiles can be laid in every hour. These are conservative figures but even the supply of 400 tiles/hour to the machine would require either plenty of labour or special handling equipment and tiles supplied in bales. Since tiles are not yet baled in New Zealand, the supply of tiles to the machine will depend heavily on farmer contributions of labour and plant such as trucks or tractor hauled trailers.

If permeable backfill is being used then the supply of this material at the same time provides an additional problem.

An important factor in the life of a tile drain is the gap between adjoining tiles. In trenchless laying the only practicable control over the size of the gap is to butt the ends of the tiles together and rely on the surface roughness at the ends to provide the gap. Even one excessive gap can shorten the life of a whole drainline and hence it is very important that the person who feeds the tiles into the chute makes sure that the tiles are butting together as they are laid. This ususally requires gentle pressure on the top tile in the chute to overcome friction between the tiles and the chute.

5.4 PLASTIC DRAIN PIPE

Two types of plastic drainpipe were used in the trials:

(a) 50 mm diameter thick walled relatively inflexible supplied in 2 m diameter coils.

(b) 100 mm thin walled corrugated - very flexible - supplied in 2 m diameter coils.

Plastic drainage pipe is particularly suitable for trenchless laying for two reasons:

(a) It is easily transported in coils of considerable length and hence the problem of supplying drainpipe to the layer is minimal.

(b) Plastic drainpipe is difficult to handle in open trenches and usually requires additional labour for this reason. In trenchless laying none of these problems occur.

APPENDIX A

OPERATING INSTRUCTIONS FOR THE TG1

Operation of the TG1 is quite different from other trenching machines in current use. Very large forces are involved in drawing the machine through the ground. For safety and efficient operation the correct equipment must be used in the proper way. It is essential that the operator study carefully the Instruction Manual supplied by the manufacturer for the TG1.

Under most New Zealand conditions the TG1 should be hauled only by a 100 kN capacity winch with the properly designed sprag system. The operator must be familiar with the Instruction Manual for the winch being used.

It cannot be over emphasised that ignorance of the proper operating procedures can result in damage to the machine and dangerous working conditions for the operators.

In addition to the directions supplied in the above mentioned instruction manuals the following recommendations for operation are based on the Institute experience with the machine:

(a) The main beam of the drainlayer should be kept approximately parallel to the grade line during laying so that the mole share can be kept on grade with minimum use of the controls. In practice this requires the use of the front skids to keep the machine level. Under high draught loads it may sometimes be impossible to lower the front skids because of insufficient power in the hydraulic system. In this case the winch should be stopped briefly while the adjustment is made.

(b) When transporting the drainlayer on its road wheels the wire rope should have sufficient slack and yet be stowed securely so that the tractor-drainlayer unit can negotiate corners without the wire rope fouling any part of the machine. Failure to take care on this point can lead to loss of steering control on the road.

(c) After laying the drainline the TG1 leaves a slit trench in the ground and some heaving of the surface on each side of the slit. The degree of heave and the size of the slit depends on the soil conditions. The slit can be closed and the heave satisfactorily flattened by judicious use of a wheel tractor. To achieve the neatest finish the tractor wheel should be run along each side of the slit on the heaved up surface and not directly over the slit itself.

APPENDIX B

DRAINAGE DESIGN FOR THE TG1

Because of the mode of operation of the TG1 the design of a drainage system to make use of this machine should take into account its possibilities and limitations.

DEPTH CONTROL

The TG1 has a limited range of operating depths (0.50 m - 1.1 m for the model used) and it is not possible to lay drains at depths outside that range. The depth of the outfall and gradient of the drainline must be chosen carefully so that the surface contours do not try to force the machine off the grade line.

HORIZONTAL CURVES

The TG1 can negotiate horizontal curves in a series of short straight sections. The maximum angle between each section should not exceed 5° and a 10 m length of drainline should be allowed for turning through this angle. Each section pulled requires the winch tractor to be moved to a new position and thus to avoid too many time consuming moves the designer should try to express the required change of direction in as few sections as possible.

APPENDIX C

MOLE PLOUGH MECHANICS

In order to explain the behaviour described in section 4.5 it is necessary to consider the forces acting on the machine as shown in Figure 4. If the moments of these forces about the cable attachment point A are considered then the clockwise moments of the machine weight and vertical soil force on the mole share are opposed by the moments of the soil drag on the blade, mole share and chute as well as the passive soil resistance on the underside of the beam and chute. When the beam is riding clear of the ground the TG1 is behaving as a floating beam mole plough.

The limit to the operating depth occurs when the moment developed by the downward acting soil force on the mole share and the machine weight becomes insufficient to counteract the moment due to the horizontal soil drag forces. In some soil conditions the increase in horizontal drag with depth overtakes any increase in the vertical soil force at a depth which is less than the maximum reach of the bursting blade. By altering the angle of the mole share (see Section 4.5) it was hoped to break this impasse but the horizontal drag also increased. Lengthening the main beam may increase the limit depth but at the expense of the general handling characteristics of the machine.

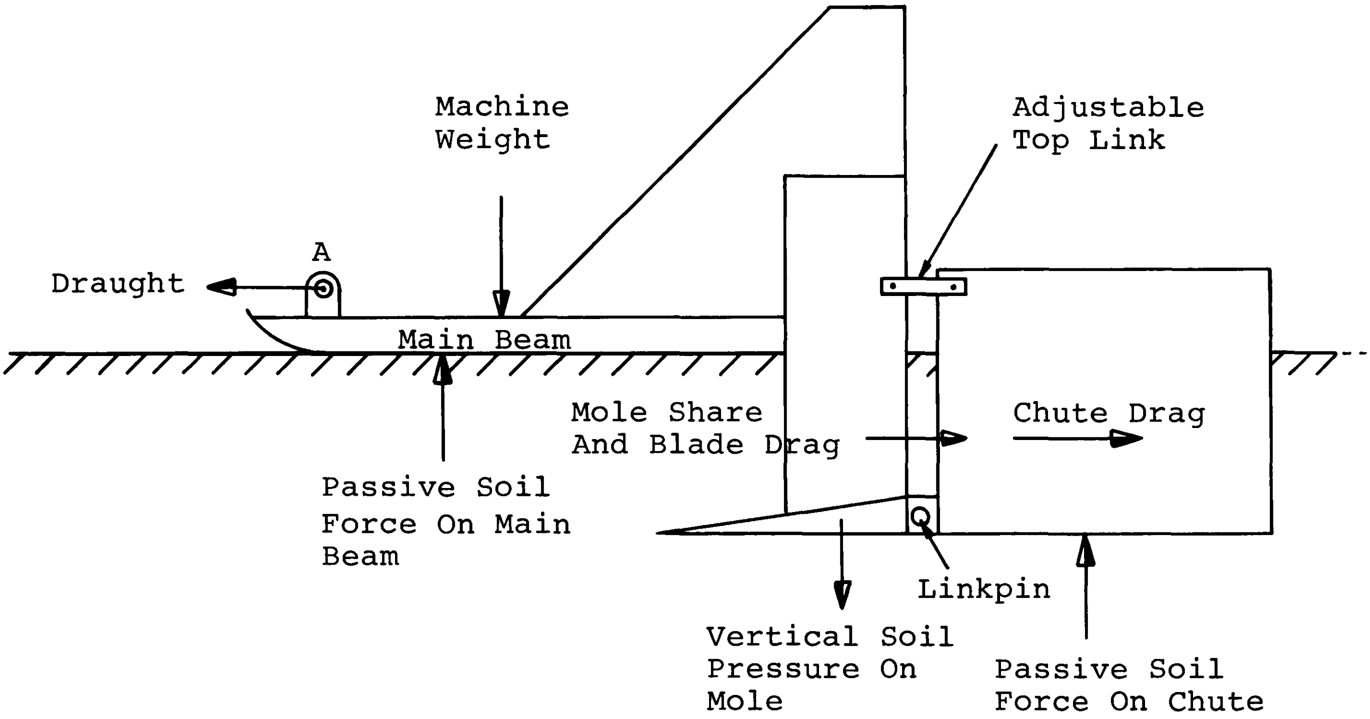

Figure 4. Force diagram for the TG1

OTHER N.Z.A.E.I. PROJECT REPORTS

P/1 The Effect of Fire on Standard 8 S.W.G. and High Tensile 12 S.W.G. Plain Fencing Wire: G.M. Garden (August 1967).

P/2 The Hydraulic Performance of Trough Valves: T.D. Heiler (July 1968) (2nd Edition May 1971) (out of print).

P/3 Procedures for testing trench laid plastic drain pipes up to 4" diameter: T.D. Heiler (July 1968) (out of print).

P/4 A Provisional Test Procedure for Crawler Tractor Safety Frames: E.M. Watson and G.M. Garden (July 1971).

P/5 Procedure for testing Broadcast-type Distributors used for the application of granular insecticide: J.E. Hager and K.R. Humphries (August 1969) (out of print).

P/6 Procedures for testing Broadcast-type Fertiliser Distributors: K.R. Humphries (February 1971).

P/7 Tractor Safety Frame Noise Levels: G.M. Garden with Medical Assessment by J.F. Copplestone (March 1971).

P/8 The Spinning Disc Distributor Part 1: G.R. Davies (February 1972) (out of print).

P/9 The Spinning Dics Distributor Part 2: G.R. Davies (February 1973) (out of print).

P/10 Flow Characteristics of Plastic Drainage Pipe available in New Zealand: M.S. Humphris and G.J. Harrington (June 1973).

P/11 The Flow Characteristics of some Pressure Reducing Valves: G.J. Harrington (October 1975).

P/12 Liquid Manure Pumps: Procedure for Clean Water Hydraulic Testing: A.J. Dakers (July 1976).

P/13 Contouring by Computer from Stadia Field Data: G.J. Harrington (May 1976).

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