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8 Drain Tube Materials and Installation

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I. INTRODUCTION

Advances in drainage practices are often described in terms of changes and improvements in drainage materials and/or installation methods. New drainage materials, installation techniques, and modernized equipment are being developed almost continuously to take advantage of technological advances provided through research and development. Progress occurred even before 1900 in the USA according to Weaver's (1964) *History of Tile Drainage*. Recent developments include plowed-in corrugated-wall plastic drainage tubing (Fouss, 1968; J. L. Fouss, 1971. Dynamic response of automatically controlled mole-drain plow. Unpublished Ph.D. Diss., The Ohio State Univ. Library, Columbus.) and use of the laser beam—a development of space age science—to automatically control drainage machines for installing subdrainage at the proper depth and grade (Fouss & Fausey, 1967; Studebaker, 1971).

Clay and concrete drain tile have been the principal drainage materials for many decades, but these products today are much improved over the tile used in the early 1900's. Edminster (1965) stated that

> The clay-tile industry has done an outstanding job in product improvement. Continuous study and testing have resulted in tiles being available today that are unsurpassed in quality; uniform in diameter and roundness; uniform in length; sharp, clean-cut edges; increasing reliability in density; low absorption qualities uniform in bearing strength; absence of strength-reducing foreign material; etc. Continuous-process machine manufacture has reduced manufacturing costs, and palletized storage and transportation to the field has further reduced handling costs. The outstanding research of Manson and Miller (1948, 1954), Miller and Manson (1948a, 1948b), and many others on the chemistry of concrete tile manufacture has resulted in an unprecedented quality and reliability for this drainage product. Recognition of the chemical problems involved in adapting concrete to a host of adverse soil conditions has resulted in a whole new series of specialized cements, new curing techniques, and improved formation techniques and equipment. [Also see Alpers and Short (1965), and Manson (1965, 1971)].

It seems reasonable to assert that more change and modernization occurred in the practices of agricultural drainage during the 1960–1970 decade than all other improvements before 1960 combined. Since the more conventional drainage practices used up through the mid-1960's are well covered in other texts (Schwab et al., 1966; Luthin, 1957), most of the material in this chapter will be devoted to the newer drainage materials and installation equipment which will be coming into increasing use in the future.

II. HISTORY OF DRAINAGE MATERIALS AND METHODS RESEARCH

The development of a rapid and low cost technique for subsurface drainage has presented a challenge to engineers and inventors for centuries. Many ideas have emerged, but only a few have ever found widespread application. With the advent of the power trenching machine about 1875, the objective of mechanized drain installation seemed to have been reached. However, the extremely large amount of drainage work to be done in many countries forced further study to find even less labor-consuming and lower-cost methods. Most studies have involved some modification of the "mole drainage" method because of its inherent high speed and its elimination of the usual slow ditching and backfilling operations. Because the "mole-drain" collapses after a short time in many soils, much of the research pertained to devising ways of stabilizing the mole-channel with a tube or liner.

A. Inventions and Research Before 1940

French (1859) gave one of the earliest accounts of using a plow-type drainage machine—the "Fowler Drainage Plow" developed and tested in England. French described the plow's operation and the 'claims' for it as follows:

> The pipes, of common drain tiles, are strung on a rope, and this rope, with the pipes, is drawn through the ground, following a plug like the foot of a subsoil plow, leaving the pipes perfectly laid, and the drain completed at a single operation. The work is commenced by opening a short piece of ditch by hand, and the strings of pipe, each about 50 feet long, are added as the work proceeds; —Drains, 40 rods long, are finished at one operation.

Fowler's plow was pulled by a horse-powered cable windlass, and the plow blade could be adjusted to control the grade on the drain line being pulled in. A schematic drawing of Fowler's plow is shown by French (1859, p. 246) and by Weaver (1964, Fig. 102). Weaver (1964) relates that "Mr. B. B. Briggs, of Sharon, Medina County, Ohio, in 1859, invented a machine which looks not very unlike a mole plow, to lay tile without digging a ditch." The operation described was similar to that given for Fowler's drain plow.

Both of these plow-type drainage machines were probably well ahead of their time for three reasons: (i) the lack of an adequate source of power, such as steam traction engines; (ii) the high cost of such heavy equipment; and (iii) the attempt to use existing drainage material, ceramic tile, rather than some conduit material that would have been easier to handle.

There were many ideas tried regarding the combination mole-tile drainage method. Wallem (1931) reported on the "Poppelsdorf Mole-Tile Drainage System" developed in Germany, which was one of the later attempts to improve the scheme for practical use. However, just prior to World War II, German investigators did considerable work to develop continuous linings for mole drains. One such technique, using a tube formed from varnish-coated sheet metal, was patented by Sack (1933). Sack's sheet metal mole liners failed rather quickly from corrosion, but forming drain tubing from coiled sheet materials was a new idea that led to much additional research. Sack also developed a light beam projection instrument to establish the desired grade line, and a machine-mounted receiver for the light beam to aid the operator in controlling the depth of the drainage plow (G. O. Schwab, 1951. Subsurface drainage with small perforated flexible tubes in mole drains. Unpublished Ph.D. Diss., Iowa State College Library, Ames). Schwab describes a mole plow with special attachments developed about 1934 by Janert, another German engineer, for laying continuous porous concrete lining in a mole channel. Although a commercial version of this drainage machine was produced in Germany before World War II, it evidently never met with great success. Later developmental research by Ede (1957) on a continuously formed concrete tube for drainage also was never put into practical use, mainly because of materials-handling problems and the heavy machinery required.

B. Plastic Drain Tubing

About 1941, polyethylene plastic, a British development, was made available for manufacture in the USA. According to Schwab, in his thesis cited above, the U. S. Corps of Engineers investigated as early as 1946 the use of "perforated plastic tubing" installed with "cable-laying machines" for airport drainage. However, Schwab's research from 1947 to 1954 (Schwab, 1955) is considered the beginning of the development and use of plastic drain tubes in the USA, if not the world. He installed several field experiments where polyethylene plastic tubes of various diameters and wall thicknesses were pulled into a mole-drain channel with a mole plow. Schwab (1955) indicated that it was necessary to handle the smooth-wall plastic drain tubing in 6-m straight lengths, because the tubing would "kink" when coiled. From these studies, he provided guidelines as to the minimum tube-wall thickness for various drain diameters to insure drain conduit deflection of less than 20% of the original diameter. When in-

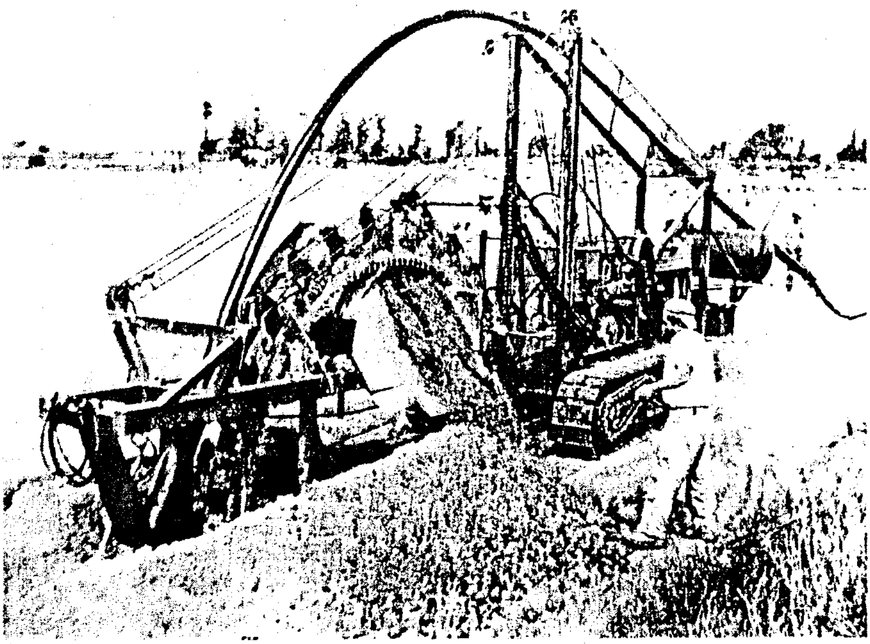

Fig. 8—1. Special narrow-wheel trencher installing smooth-wall plastic drain tubing in the Rio Grande Valley of Texas.

spected in 1966 (17 years after installation), these test drains were still in very good condition (Fouss, 1968). The results from these early field experiments provided much of the background data for today's minimum plastic drain strength requirements.

De Jager (1960) conducted experiments in The Netherlands with polyethylene tubes pulled into mole drains. The studies were abandoned because silt clogged the water entry "slits" in the tube walls during installation. De Jager (1960) also developed a method of installing 6-m lengths of rigid vinyl plastic drain pipe in a narrow trench dug with a high-speed trenching machine. This latter method received notable acceptance and use throughout The Netherlands during the 1960's (van Someren, 1964). During the mid-1960's, 10-cm-diameter polyethylene plastic drainage tubing, installed as deep as 2.7 m with a special narrow-wheel trencher (Fig. 8—1), was adopted for use in the Lower Rio Grande Valley of Texas (Myers et al., 1967; Rektorik & Myers, 1967).

C. Plastic-Lined Mole Drains

Janert (1952, 1955) developed a machine which formed and installed a semirigid vinyl plastic drain from rolls of sheet film. The plastic strip was heated to provide sufficient flexibility for forming it into a circular drain.

The plow-type drain-laying machine was equipped with an inclined digging-blade which functioned like a wood plane and opened a trench almost twice the diameter of the drain. Production models of this machine were reportedly sold in East Germany in the late 1950's.

In 1956, a modified mole plow was developed by Busch (1958; also see C. D. Busch, 1960. An investigation of mole drain deterioration and a method to extend drain life. Unpublished Ph.D. Diss., Cornell Univ. Library, Ithaca, N. Y.) for feeding a plastic strip into a mole-drain channel and forming it into an "arch-shaped" mole liner. This development was the beginning of a series of refinements and modifications by both USA and foreign investigators. These further studies led to the concurrent development and testing of the "zippered-type" plastic mole liner by Fouss (Fouss & Donnan, 1962; J. L. Fouss, 1962. Material and equipment for installing zippered plastic-lined mole drains. Unpublished M.S. thesis, Ohio State Univ. Library, Columbus), Ede (1963), and Boa (1963). Fouss (1965) and Ede (1965) later reported that the thin-walled plastic mole liners, even of the zippered-type, were not strong enough to withstand deformation over even a 4- or 5-year test period. The plastic-lined mole drain was largely abandoned in favor of corrugated plastic tubing placed in the mole channel.

D. Miscellaneous Drainage Conduit Materials

Concurrent with the research work on various kinds of flexible plastic drains, several other types of drainage conduits were developed, some of which are commonly used in special applications. Examples are: (i) Bitumenized fiber perforated pipe in about 1.5- to 2-m lengths is commonly used in unstable soil conditions and where clay and concrete tile are not readily available; (ii) rigid plastic perforated pipe, an expensive material, used in 3-m lengths where high strength is needed or where soils are unstable; and (iii) corrugated-wall metal conduits in 3- to 6-m lengths, or reinforced-concrete conduit in 3-m sections, are commonly used where larger drain diameters are needed (such as in mains) and high strength is required because of severe surface loads or unstable soils.

Several other drainage materials and methods emerged during this period but, although they may be used occasionally for special applications, none has received widespread acceptance and use. Examples are: (i) Stone or gravel placed in the mole-drain channel to maintain a porous channel for flow of water—a few plow-type tools were developed for placing the gravel in the mole-channel as it was formed; and (ii) "vertical mulching" by backfilling a mole-plow blade opening or an excavated trench with gravel, stones, corn cobs, fodder, or trash, to maintain a porous channel for water flow and storage of surface runoff. [Renewed interest has emerged in this concept, particularly in areas of limited rainfall but with significant loss due to runoff during high intensity storms; Ref.: *Irrigation Age*, February 1972, Water savings claimed by vertical mulching 6(7):56–58].

In other investigations, various methods and techniques were developed and tested for stabilizing the mole-drain channel, including: (i) inpregnating the mole-channel walls with a tarlike substance; (ii) chemical treatment of the soil in the mole-channel walls; and (iii) "firing" the soil-walls of the mole-channel with a high-intensity flame. None of these techniques was sufficiently developed to be put into practical use.

E. Corrugated Plastic Drainage Tubing

By the mid-1960's, most of the research on drainage materials had begun to focus on corrugated-wall plastic tubing. Continuous extrusion and molding equipment had been perfected by German industry to fabricate corrugated-wall plastic tubing and underground drainage with the new conduit caught on rapidly in Germany and soon spread to other parts of Europe. In the USA, the first users of the new tubing were the underground electrical and telephone conduit industries. Research in the USA on using the corrugated plastic tubing as an agricultural subdrain was begun in 1965 (Fouss, 1965, 1968). By 1967, corrugated plastic drainage tubing was being fabricated commercially in the USA, and this new industry has grown rapidly since. Many clay and concrete tile manufacturers also have set up plastic drain extrusion plants.

Corrugated-wall plastic draintubes are stronger, lighter weight, less expensive, and easier to handle because of better longitudinal flexibility than are smooth-walled plastic pipes. Structural parameters to be considered in design or strength analyses will be discussed in the following section.

III. FLEXIBLE DRAINAGE CONDUITS

Most of the newer drainage materials, such as the corrugated-wall plastic tubing, are flexible-type conduits rather than the classical rigid conduits such as clay, shale, or concrete drain tile. A typical flexible drain conduit gains part of its vertical soil load-carrying capacity by lateral support from the soil at the sides of the conduit. For a trench-installed drain, this lateral support is provided by the soil sidefill along the tube, and for a "plowed-in" drain, the side support is provided by the soil walls of the mole-drain channel. Thus, the stiffness of the conduit wall and the rigidity of the soil surrounding the tube are both structural parameters. For conventional ceramic or concrete tile, conduit wall rigidity is the principal parameter.

A. Flexible Conduit Failure Theories

Various theories have been developed or proposed for analyzing soil loads on, or the strength of, flexible-type underground conduits (Watkins, 1967). Most of the flexible conduit theories were formulated to aid in the study and design of large-diameter flexible pipe, such as used for road culverts. However, many of the concepts involved are directly applicable to the smaller diameter pipe used in land drainage. Conduit failure is generally characterized as being the result of: (i) excessive deflection, (ii) excessive ring-compression in the conduit wall, and/or (iii) buckling of the tube wall.

1. CONDUIT DEFLECTION

Early investigations by Spangler (1941) led to the derivation of the "Iowa formula" for predicting the deflection of buried flexible pipe. Subsequently, Watkins and Spangler (1958) examined the Iowa formula dimensionally and discovered that the soil modulus term had been previously defined with incomplete units. The "Revised Iowa Formula" is given by Eq. [1] below and the soil pressure distribution on the conduit originally assumed by Spangler is shown in Fig. 8–2. This formula is generally considered applicable for predicting deflections less than or equal to 5% of the original diameter.

$$\Delta x = D_1 \frac{K\, W_C\, r^3}{EI + 0.061\, E'\, r^3} \qquad [1]$$

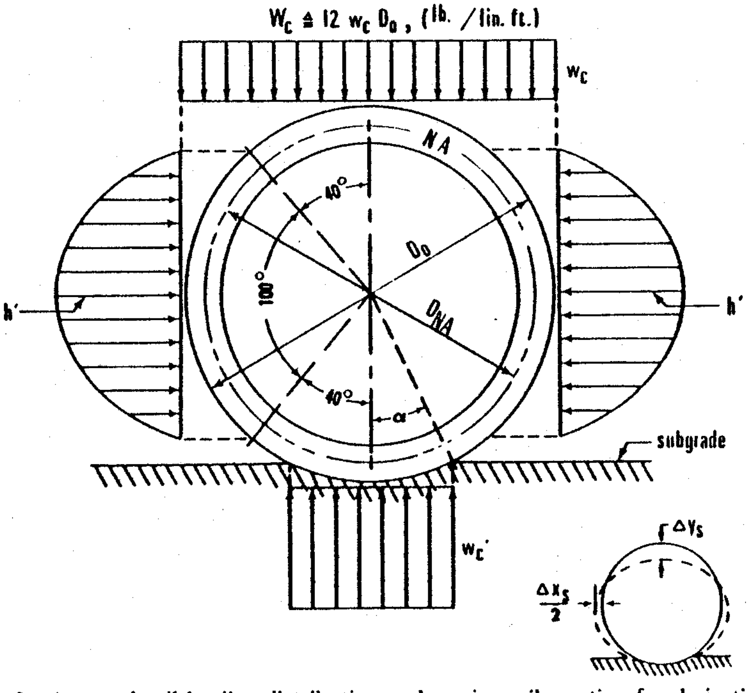

Fig. 8–2. Assumed soil loading distribution and passive soil reaction for derivation of revised Iowa Formula.

Table 8–1. Values of bedding constant (after Spangler, 1960, p. 433, Table 25–44)

Bedding angle,* degrees	Bedding constant, K
0	0.110
15	0.108
22.5	0.105
30	0.102
45	0.096
60	0.090
90	0.083

* See Fig. 8–2.

where

Δx = horizontal deflection (change in diameter) of the pipe, cm,
D_1 = deflection lag factor, typically from 1.0 to 1.5,
K = a bedding constant, its value depending on the "bedding angle", see Table 8–1,
W_c = uniformly distributed vertical soil load on pipe, g/linear cm of pipe,
r = radius from the centerline of the pipe to the neutral axis (N. A.) of the pipe wall, cm,
E = modulus of elasticity of the pipe-wall material, g/cm^2
I = moment of inertia per unit length of the pipe-wall cross section, cm^3,
0.061 = dimensionless constant, and
E' = soil modulus, g/cm^2.

The soil modulus term is defined as

$$E' = h'/(\Delta x/D), \qquad \text{in (g/cm}^2) \qquad [2]$$

where h' is the maximum unit soil pressure at the side of the tube (see Fig. 8–2) and D or D_{NA} represents the neutral axis diameter. This structural property of the soil is illustrated in Fig. 8–3. A numerical value of E' to use in conduit design has been the quest of much investigation. Spangler (1960, p. 435) recommended a value of E' = 700 lb/in^2 [49.2 kg/cm^2] for E' in design if the sidefill soil is compacted to 90% or more of Proctor density for a distance of two pipe diameters on each side of the pipe. He stated, however, that the value of E' appeared to decrease rapidly for lesser soil densities. Watkins and Nielson (1962) developed the "Modpares Device" to measure E' for a given soil to assist in conduit design but the investigations have not been carried far enough to date to clarify the "confining pressure" required in order to simulate the installation conditions for a given soil-conduit system. Soribe et al. (1972) discussed some possible problems with using the E' values determined by the Modpares Device, and gave comparative values of E' determined by soil pressure measurement (See also F. I. Soribe, 1969. Load-deflection characteristics of corrugated

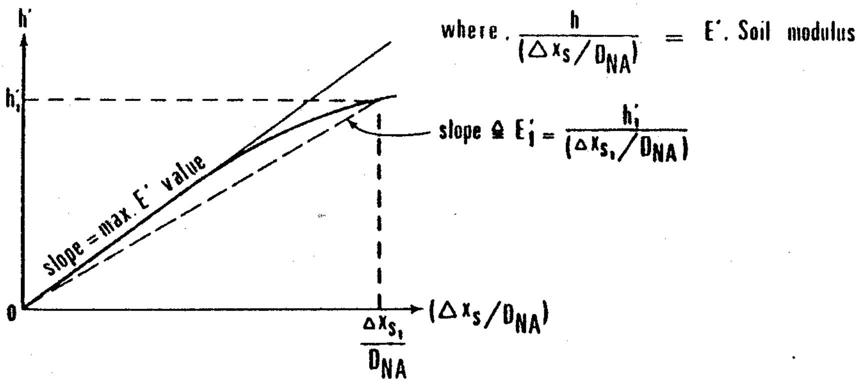

Fig. 8–3. Soil modulus E', defined by slope of the soil pressure and conduit deflection curve.

plastic drainage tubing. Unpublished M.S. thesis, Ohio State Univ. Library, Columbus). For small diameter flexible drain tubes installed in a trench, where the backfill is not compacted, the supporting strength of the soil at the sides of the tube is certainly very little until the fill becomes more compacted by wetting and settling. Thus, in design for such trench-installed tubes in a saturated clay soil, a very low value of $E' = 14$ to $28\ \mathrm{kg/cm^2}$ might be justifiably assumed. For a noncohesive soil, such as sand, a much higher value can be used (e.g., $E' \approx 42$ to $56\ \mathrm{kg/cm^2}$) if the backfill operation is done carefully.

Watkins (1967) noted that

> Ring deflection is not the only condition for failure of a flexible pipe. It has been assumed previously that the pipe would deflect up to about 20 percent and then would begin to collapse by reversal of curvature. Model tests showed, however, that the pipe wall could cripple [crush in compression]. Moreover, it could cripple at a ring deflection much less than 20 percent or even less than 5 percent if the soil were well compacted and the ring were very flexible.

This phenomenon was confirmed, related Watkins, by such failures in field installations.

2. RING COMPRESSION

White and Layer (1960) presented the "ring compression theory" to explain conduit failure by wall crippling. To use the ring compression theory in design, White and Layer stated that:

> The normal corrugated metal conduit is designed to have sufficient moment [bending] strength to permit handling and installation without being unduly flexible. Once it has been installed in a compacted backfill capable of taking reaction pressures, its strength can then be determined as a thin ring in compression.

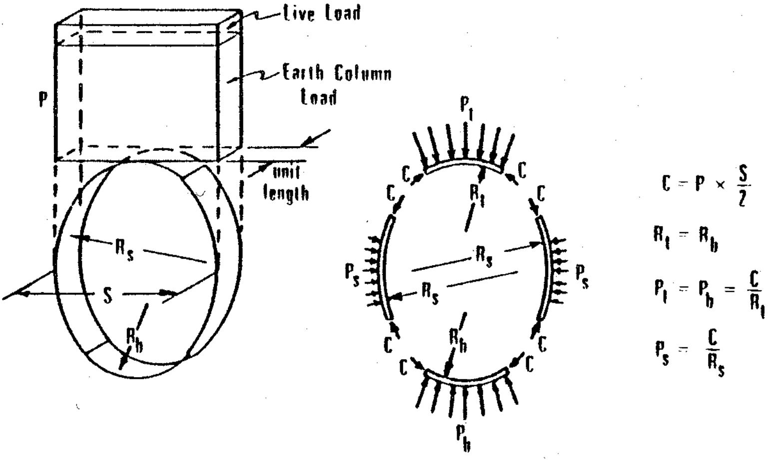

Fig. 8–4. Ring compression theory applied to an elliptical conduit.

This theory is illustrated in Fig. 8–4 for a typical elliptical conduit. The vertical unit load on the conduit was conservatively estimated by multiplying the height of cover by the fill density. The compression *C* within the ring was computed by multiplying the unit vertical load *P* by half the span *S* of the conduit. Then from the formula that the normal soil forces on the circular arc times the radius of the arc equals the compression *C*, the normal soil forces on each arc in the conduit are determined.

By this theory, two factors will permit the conduit to deflect vertically: (i) Displacement of the sidefill material outward; and (ii) a load exceeding the compressive strength of the conduit wall material and seams, or both. The pressure on the sidefill material can be controlled to some degree by selecting the proper conduit cross sections. For example, elliptical cross section requires less side pressures on the larger radii side arcs than those for a circular structure of the same periphery. This illustrates why the elliptical conduit (Fig. 8–4) often deflects less vertically under the same fill loading than a circular conduit.

The ring compression theory was checked with model tests conducted by Meyerhof and Baikie (1963) and Watkins (1963). The theory described conduit failure reasonably well when the soil could be assumed rigid, a condition which probably does not exist for the conventional trench-installed agricultural subdrain. However, when the soil was "fluid" (e.g., model tests with spherical grains of soil or plastic beads for soil medium), failure occurred from "buckling" of the tube wall.

3. RING BUCKLING

A buckling failure is best described by the classical hydrostatic pressure theory for externally loaded cylinders; the critical pressure is called the "hydrostatic buckling pressure" (Watkins, 1967) and is given by the formula:

$$P_r = 24\ EI/D^3 \qquad [3]$$

where P_r = radial hydrostatic pressure, g/cm^2, beyond which the pipe will collapse; and D = neutral-axis (N.A.) diameter of the pipe, cm.

Conduit failure by buckling is governed by the pipe wall stiffness, EI, rather than the crushing strength of the pipe wall or seams as in the case of ring compression failure. A mathematical analogy between conduit-wall buckling and the buckling failure of slender columns can be developed as expressed by the conventional Euler hyperbola (Watkins, 1967). The familiar column slenderness ratio L/k is analogous to the conduit's D/k ratio, where L is the column length, D the conduit diameter, and k the radius of gyration of the conduit wall cross section or column cross section. The term, EI/D^3, is called the ring or conduit stiffness factor; two conduits of different size but with the same pipe stiffness will be subject to buckling failure at the same critical pressure. Similarly, it can be shown from Eq. [1] that two different sizes of conduits will deflect the same proportional amount (i.e., $\Delta x/D$) for a given soil rigidity (i.e., E' = constant) and unit soil load (W_C/D), if both have the same pipe stiffness. Thus, the conduit stiffness factor is an important parameter when considering deflection or buckling failure modes, and consequently it is useful in characterizing the strength of flexible conduits, as is discussed in more detail in a following section.

B. Soil Loads on Flexible Conduits

Loads imposed on underground conduits include the weight of the overburden soil, and the surcharge resulting from surface loads such as caused by the passage of equipment wheels. For shallow drains, surface loads mainly determine the strength requirements of conduits; for deeper drains, the weight of the overburden soil is more important.

The overburden soil load for most agricultural subdrains can be approximated by use of the classical procedures which are described in many texts and publications (Schwab et al., 1966; Spangler, 1960). The computed soil load is assumed to be uniformly distributed over the projected horizontal diameter of the conduit. One distinction which needs to be recognized in computing the soil load on a flexible conduit is the ratio between the allowable or predicted conduit deflection and the trench backfill settlement; see Spangler (1960, p. 409) for a discussion of "settlement ratio." This settlement ratio relates to the soil pressure concentration on the top of the flexible conduit; the more rigid the conduit, the greater is the pressure concentration. For flexible conduits in wide trenches, the concentration factor is from 1.0 to 1.5; for rigid pipe (conventional tile), it becomes 2.0 (Watkins, 1967).

For many installation and soil conditions, the effects of surface loads on agricultural subdrains, particularly small-diameter lateral lines, can be neglected. Generally, additional loads caused by surface traffic are small where lateral drains have 0.7 m or more of cover (Schwab et al., 1966; Negi & Broughton, 1971).

C. Flexible Conduit Design

With the advent of corrugated-wall plastic drainage tubing, much attention has been given to the development of corrugation profile shapes that will provide: (i) high structural strength, (ii) efficiency (i.e., high strength/low tube weight-ratio), (iii) coilability of the continuous tubing, and (iv) suitable locations for water-entry openings. Fouss (1973) presented a detailed, step-by-step design and analysis procedure to select an optimum corrugation shape to meet specified performance requirements. As typical in design work, a severe or maximum soil loading condition is assumed so that the drain will be functional for a wide range of conditions. Likewise, the lateral support provided by the soil surrounding the flexible tube is assumed small, e.g., $E' \approx 14$ kg/cm^2, and a flat-bottom trench is often assumed. The deflection design limit must be set at a 5% change in conduit diameter. Thus, the revised Iowa Formula (Eq. 1) can be written as follows to compute the required conduit stiffness:

$$\text{Conduit stiffness required} = \frac{EI}{D^3} = \frac{1}{8}\left[\frac{D_1 K W_c}{\Delta x} - 0.061\, E'\right] \qquad [4]$$

For a given plastic material, the modulus of elasticity E is fixed and known, and the diameter of the tube measured to the neutral axis of the corrugated wall can be closely approximated for a given inside tube diameter; thus the numerical value of the remaining unknown term I can be computed. The value of I depends solely on the corrugation profile shape and is thus controllable by design. To illustrate *one* analytical method to compute I, consider the corrugation profile in Fig. 8–5A. To simplify the computations involved, assume that the schematic profile shown in Fig. 8–5B is structurally "equivalent" to that above. Thus, the equation for calculating the value of I can be written:

$$I = \frac{1}{P}\left[\frac{2\, T_w H^3}{12} + \frac{L_i T_i^{\,3}}{12} + L_i T_i \frac{H^2}{2} + \frac{L_o T_o^{\,3}}{12} + L_o T_o \frac{H^2}{2}\right] \qquad [5]$$

where I has units of (cm^4/linear cm), and all other dimensions are in cm. All geometrical symbols used are shown in Fig. 8–5A. It is evident that

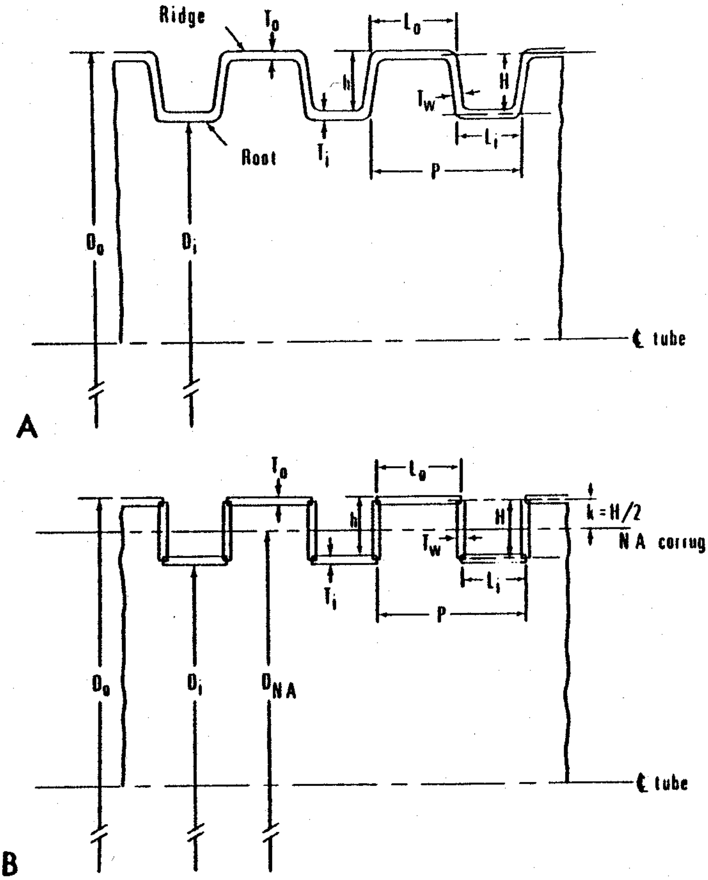

Fig. 8–5. Example corrugation profile: (*A*) actual shape (*B*) assumed structurally "equivalent" shape.

many combinations of these parameters will give the required I value. Thus, the use of practical bounds on all parameters, graphical representations comparing projected tubing weight with different parameter combinations, stress-strain levels in the tube wall for the design load conditions, and other similar relationships are useful in selecting a suitable corrugation profile. Fouss (1973) proposed an analytical method to estimate stress in the tube wall caused by both deflection and ring compression; design within the proportional limit strain is recommended. Finally, the buckling resistance of the selected corrugation design is checked in accordance with Eq. [4]. In addition, the coilability of tubing made with the selected corrugation shape can be analytically predicted.

The following general statements summarize the design considerations for corrugated plastic drains. The conduit's soil-loading resistance W_C is directly related to the tube-wall moment-of-inertia I, and I varies nearly linearly with plastic thickness T, approximately as the cubic power of corrugation depth H, and inversely proportional to corrugation pitch P. Therefore, an efficient corrugation design (one providing the lowest cost tubing) has the maximum practical corrugation depth, with a corresponding large pitch, and the thinnest possible plastic material in the walls that will withstand the bending and compressive stresses at the design soil load. Other factors, however, must enter the corrugation selection, such as molding and extrusion properties of the plastic material used and coilability and/or stretch resistance of the finished tubing.

IV. SPECIFICATIONS AND STANDARDS

Conventional clay and concrete drain tile are rigid-type conduits, whereas corrugated plastic drainage tubing forms a flexible-type conduit. Because these two types of conduits support the overburden soil load in different manners, specifications and standards must be based on different testing methods. For many years, the strength of clay and concrete tile has been tested using a three-edge bearing device in accordance with ASTM Standard Specifications C4 and C412, respectively. (American Society for Testing Materials, 1916 Race Street, Philadelphis, Pa. 19103.)

A. Sand-Box Test

An interim specification was issued by the U. S. Dep. of Agriculture for corrugated plastic tubing, namely: "Specification for Corrugated Polyethylene Drainage Tubing contained in Soil Conservation Service Engineering Practice Standard for Drain, Code 606." This specification is based upon a sand-box loading test. Dry Ottawa sand is used to surround the test specimen. The minimum dimensions for the test box are $3D$ square (where D is the tubing inside diam) by 3.75 D deep. The top loading plate size is $2D$ square. The specification calls for a minimum crushing strength of 2,460 g/cm^2 ($\approx$ 35.0 lb/in^2) unit loading under the steel loading plate.

The sand-box test method proved workable for the 10-cm inside diam tubing and filled a valuable need during the early development and use of the corrugated plastic tubing. The size requirement for the box, and the validity of the minimum crush strength value for larger diameter drains, have presented problems (Fouss, 1971).

B. Possible Future Test Methods

Proposals have been made to replace the sand-box test with a parallel-plate deflection test for smaller drains (7.5 to 20 cm) since deflection resistance appeared to govern field performance. An early test of this type proposed by Ede (1965) was adopted as a tentative standard in England for small diameter, smooth-wall plastic drains. In 1971, Drablos and Schwab (1971) made many field inspections of corrugated plastic drains which had been installed as early as 1967; their data, and others, formed the basis and background for the new strength tests proposed (Fouss, 1971). The principal features of the proposed specifications for material and testing methods of corrugated plastic tubes are given below.

1. TYPES OF PLASTIC

The most common plastics used for corrugated tubing are high-density polyethylene (HDPE) in the USA and polyvinyl chloride (PVC) in Europe. Because of the supply-demand relationships, HDPE costs less than PVC in the USA and the reverse is true in Europe. PVC plastic material is considerably stronger than HDPE. HDPE has been used successfully in small diameter corrugated plastic drains (e.g., 7.5 to 15 cm inside diam), but with the higher strength requirements for the larger tubes (especially the need for increased ring crush resistance), the use of PVC or other material may be considered in the future. The strength of thermoplastic materials varies with temperature and can result in some materials handling problems, especially during installation. PVC plastic pipe tends to become brittle at low temperatures (e.g., 0°C), whereas HDPE pipe generally does not. On the other hand, HDPE corrugated plastic pipe loses considerable strength and stretch resistance at higher temperatures (e.g., approaching 40°C), whereas PVC does not.

Other materials problems have also plagued the early developers of corrugated plastic drainage tubing. For example, the density of HDPE had to be kept below 0.96 specific gravity to prevent thermal stress cracking of the tube walls. Most of the tubing has been extruded from virgin plastic resin material; however, there has been much interest in using reprocessed to regrind plastic material to fabricate the tubing. Quality control of the finished product presents a technological challenge, as stress cracking is common when a poor grade or regrind material is used. However, the future holds the possibility of an even lower cost product by the proper reprocessing of suitable plastic material, and our ecology-minded society may also benefit.

2. LOAD/DEFLECTION CHARACTERISTICS

For most flexible plastic drains from 7.5 to 15 cm in diameter, and perhaps as large as 20 cm in diameter, the principal mode of failure is excessive deflection. If plastic corrugated tubing in this size range has sufficient bending resistance in the walls to prevent excessive deflection, the

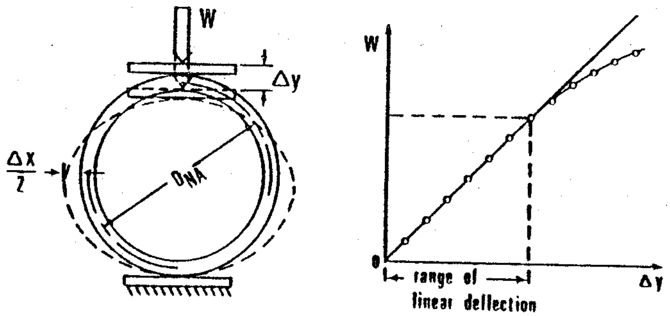

Fig. 8–6. Schematic of parallel-plate, load-deflection method of testing flexible drainage tubing.

added wall stress caused by ring compression under soil loading is not significant. Thus, the use of a parallel-plate loading device to measure deflection resistance of the plastic tubing seems justified. A standard specification is already available for such a test procedure, namely, ASTM Designation D 2412-68, "External Loading Properties of Plastic Pipe by Parallel-Plate Loading." One main exception proposed for this test procedure is to reduce the rate of advance of the parallel plates toward each other to deflect the tube specimen below the 1.27 cm/min (0.5 inches/min) rate specified. A rate of $D/80$ cm/min, where D is the tube diameter in cm, has been suggested (Fouss, 1971) as being slow enough to give meaningful results even for polyethylene plastic tubes, which tend to relax internal wall stress and strains the first few minutes after loading. The parallel-plate load/deflection method of testing is shown schematically in Fig. 8–6; the vertical deflection Δy of the tube specimen is measured as well as the applied load. Results of representative 10-cm diameter corrugated HDPE plastic drain tubing tests are shown in Fig. 8–7 for two types of loading: (i) load was applied incrementally such that about 0.05 cm additional deflection occurred at 3-min intervals, and (ii) plates advanced at a constant rate of 0.5 cm/min. At the higher than recommended rate of deflection, the indicated load/deflection ratio ($W/\Delta y$) at a given deflection is greater. It is noted that the load-deflection curve is linear to about a 5% deflection, at which point the proportional limit deflection is reached. For many corrugated tubes, the load-deflection curve can be closely approximated as a linear function up to nearly 10% deflection. The parallel-plate strength of the test specimen is expressed in terms of $W/\Delta y$ at a specified percent deflection, $100\Delta y/D$, where W = parallel-plate load, g/cm of tube length, and Δy = vertical deflection, cm. In ASTM D 2412, the ratio $W/\Delta y$ is called the "stiffness factor" (SF), and it is to be computed from the test data for both a 5 and 10% deflection.

It can be easily shown that the stiffness factor is also very useful in design, because it can be related to the conduit stiffness defined earlier. From the theory of strength of elastic materials, the vertical conduit diam-

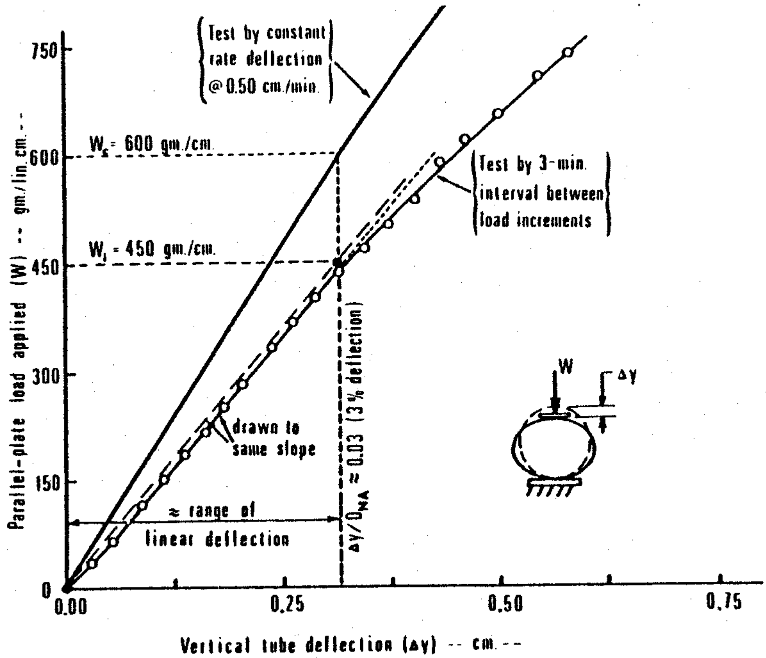

Fig. 8—7. Parallel-plate, load-deflection method of testing flexible drainage tubing.

eter changes, up to the linear deflection limit, can be related to the applied concentrated load W by the following theoretical equation (Boyd & Folk, 1950; Spangler, 1960):

$$\Delta y = 0.149\ W\ D^3/8\ EI \qquad [6]$$

which may be written in the more usable form

$$W/\Delta y = 53.7\ EI/D^3. \qquad [7]$$

Thus with a known or specified stiffness factor, $(W/\Delta y)$, the only unknown required is the moment of inertia, I, which can be computed directly. The earlier section on designing corrugation shape to obtain the required I is again applicable. Finally, by specifying required tubing strength in the form of the "stiffness factor", $(W/\Delta y)$ in g/cm^2, the numerical value applies to all sizes of drains where deflection resistance is the performance parameter of importance.

3. IMPACT RESISTANCE

In addition to the deflection resistance test, Fouss (1971) proposed an impact test to detect excessively brittle or poor quality plastic drain tubing, especially that with nearly invisible stress cracks or faults. To improve the effectiveness of the impact test, all tube specimens should be preconditioned and the test conducted at a low temperature (e.g., 0°C). A standard specification for such a test is outlined in ASTM Designation D 2444-67, "Impact Resistance of Thermoplastic Pipe and Fittings By Means of a Tup (Falling Weight)." For corrugated plastic tubing, a Type B Tup was proposed, which has a 5-cm radius of curvature on the striking surface, rather than the pointed Type A Tup commonly used for testing smooth-wall plastic pipe. An alternate proposal is to use a striker similar to that specified in the English Tentative Standard (Ede, 1965), namely, a 1.25-cm diameter steel rod about 7.5 to 10 cm long, which is aligned to impact longitudinally along the top of the tube specimen so that several corrugations are struck at once. A tentative minimum impact resistance of 1.5 kg·m was specified, which is typical for PVC corrugated plastic tubing fabricated and used in Europe. This type of test may also prove valuable in maintaining quality control for tubing made from reprocessed or regrind plastic material.

C. Installation Conditions

The early installations (mid-1967) of corrugated plastic drainage tubing in the USA were made with conventional trenching machines. The usual small V-groove in the trench bottom, used to help maintain conventional draintile joints in alignment, did not provide adequate bedding support for the new flexible-type plastic drains to prevent excessive deflection by conventional backfilling, or during the first soil wetting and settlement after installation. Therefore, a requirement was included in the SCS Engineering Code 606 for cutting or forming an 180° semicircular groove in the trench bottom. With improvements in backfilling methods, this grooving requirement was reduced to an effective 120° bedding angle in 1971. An alternative procedure in the Code 606 specification permitted the use of a gravel envelope or bed under the tubing. It is desirable to install the corrugated plastic drains in as narrow a trench as possible, thus reducing the soil load imposed on the drain. That is, the "ditch condition" occurs, where friction along the vertical sides of the trench help support the soil backfill weight.

Specifications are not available for corrugated plastic drains installed with plow-type equipment. Some of the plows in use provide a bedding angle of about 120° or more and open the ground only enough to feed the plastic tubing down into the "mole" channel. The erupted soil and slit opening left by passage of the plow blade are usually recompacted with one track of a crawler tractor. The absence of the trench and backfill settlement results in less apparent soil disturbance (many farming operations are not hampered), and the maximum soil load on the installed drains are probably reduced.

V. INSTALLATION EQUIPMENT

With the increasing use of corrugated plastic drainage tubing in the late 1960's, many improvements were made in drainage equipment, and some new, high-speed machines were developed. New and improved methods for grade control were developed by using the laser beam. Also, a total new look was given in installation costs, and many revisions were made in field operational procedures.

A. Modified Trencher

It is probably safe to state that most trenching machines in operation today for installing agricultural subsurface drainage have been modified in one form or another by their contractor-users. Drainage contractors are innovative individuals, and have often provided the ideas behind new machine design changes. Since the introduction and use of corrugated plastic drains, several design changes have been made in trenching machines. They include: (i) tube feeding and guiding devices, (ii) grooving-devices for trench bottom, (iii) "blinding" attachments, (iv) machine-mounted automatic backfillers, and (v) automatic grade-control systems. Figure 8–8 shows a wheel-type trencher that has been modified to install corrugated plastic

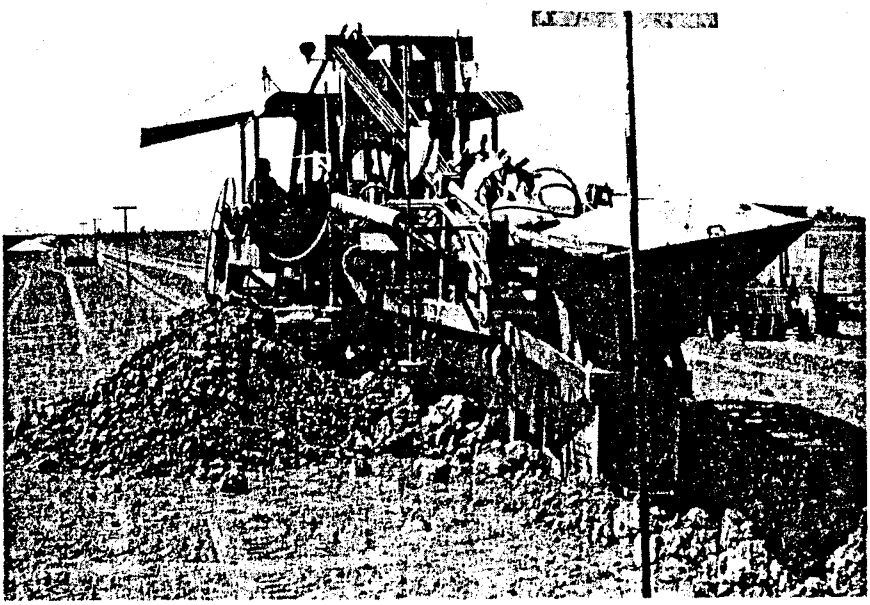

Fig. 8–8. Wheel-type trencher modified to install corrugated plastic drain tubing with a gravel envelope; Imperial Valley, California.

drainage tubing, including feeding the drain tubing directly from the coil. Several types of trencher "shoe" attachments have been developed for 'cutting-and-forming' a 120° groove in the trench bottom. One of the better designs is a device that is mounted beneath the leading point of the "shoe", and thus excavates the soil material to make the groove, rather than compressing the soil to form a groove.

B. High-Speed Trenchers

It became possible to speed-up the trenching operation where corrugated plastic tubing was being installed because of the simplified materials handling. High-speed trenchers (faster than 7.5 m/min) became practical, however, with the development of the laser beam automatic grade control system and involved totally new concepts heretofore unthought of for farm trenchers, namely, supercharged engines and hydrostatic transmission drives. A modernized high-speed wheel-type trencher and a high-speed ladder-chain-type trencher are shown in Fig. 8–9 and 8–10, respectively; both are equipped with a laserplane-type of automatic grade control system. Their digging speeds range from 9 to 15 m/min depending upon depth of cut, soil type, and soil moisture conditions. Some attention has been given to developing narrow-wheel trenchers; however, to excavate trenches narrower than 15 cm may actually increase power requirements and present new problems in backfilling.

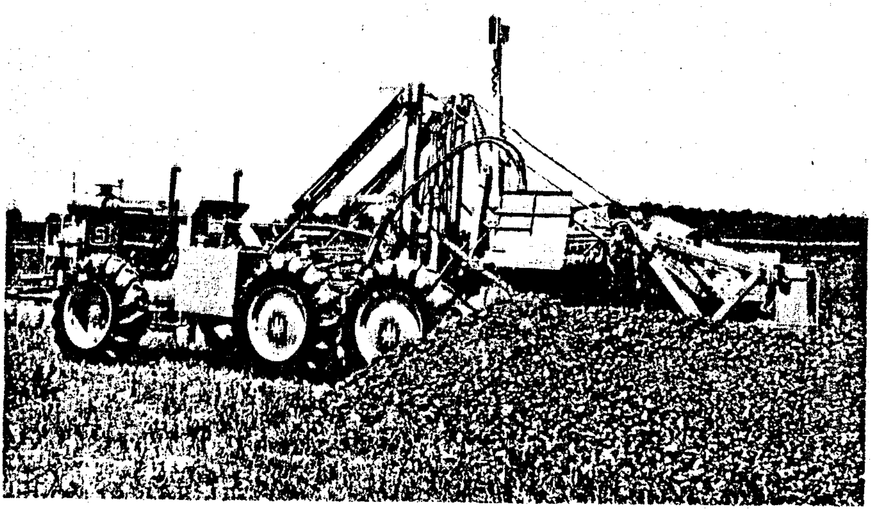

Fig. 8–9. High-speed wheel-type trencher; equipped with laser-plane type automatic grade control system.

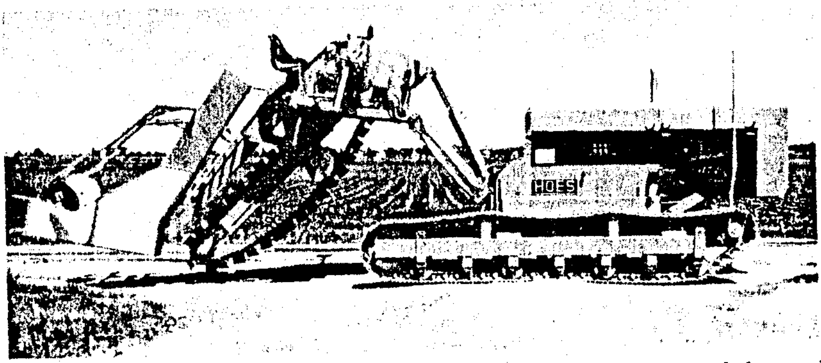

Fig. 8–10. High-speed ladder-chain-type trencher; equipped with automatic laser guiding system.

C. Drainage Plows

The "plowing-in" of drains, although not a new idea, became practical with the introduction of the coilable, corrugated-wall plastic drain tubing. With this material, the drain tube is merely fed into the ground through a slit opening created by passage of a blade through the soil, thus eliminating the slow and costly trenching. Backfilling is not required; soil erupted by passage of the plow blade is merely pressed down by running one crawler track over the slit opening after installation.

Several types of plow-type drainage machines have been developed, but basically they fall into two classes as to the method of depth control: (i) depth-gauge wheel, and (ii) floating-beam. The depth-gauge wheel is best suited where the land slope is uniform and constant depth operation can be used. Figure 8–11 shows a modified wheel-controlled "ripper" plow laying 7.5-cm corrugated plastic tubing 1.7 m deep in the Imperial Valley, Calif. On irregular ground surface, it would be extremely difficult to con-

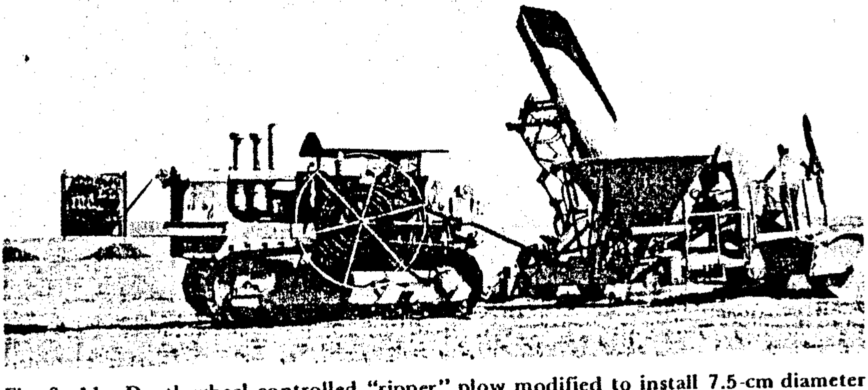

Fig. 8–11. Depth-wheel controlled "ripper" plow modified to install 7.5-cm diameter corrugated tubing with a gravel envelope; Imperial Valley, California.

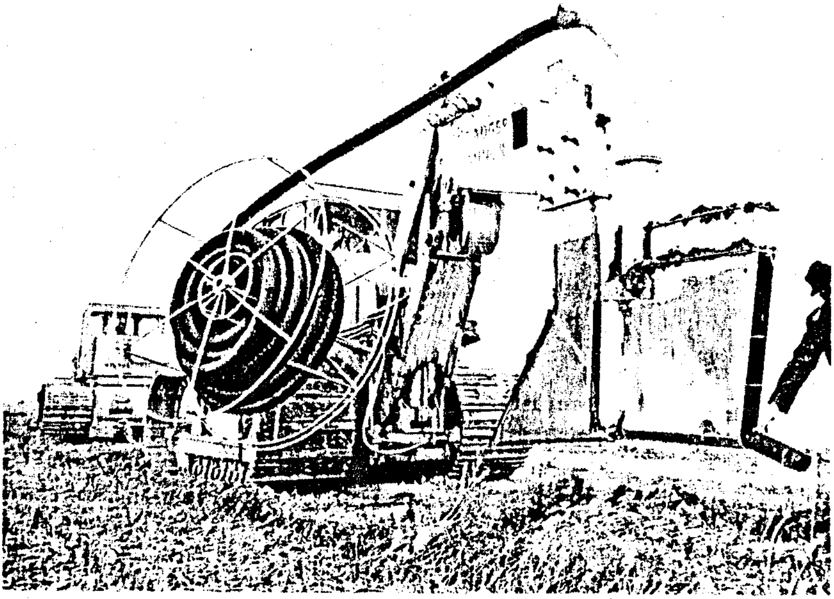

Fig. 8–12. English developed "Badger Minor" plow for installing corrugated plastic drainage tubing; equipped with an automatic laser grading system.

trol the depth-wheels fast enough to maintain accurate grade in the drainage channel, especially at normal ground speeds of 20 to 45 m/min. A floating-beam type plow is better suited for operation on the irregular ground surface commonly encountered on farmland. Mole plows, which operated with the floating-beam principle, were developed and used in New Zealand about 1930.

A few crawler tractor drawn plows developed by the early 1970's for the installation of corrugated plastic tubing utilized the floating-beam principle. One of these plows, originally developed by Ede (1961) in England, was called commercially the "Badger Minor" (see Fig. 8–12). Actually this plow might be said to operate with a "floating blade." The blade and tractor are connected by a pair of rollers which run in a curved track mounted on the rear of the tractor. The center-of-curvature of this roller track acts as a virtual hitch point which coincides approximately with the center of the crawler tracks. The plow blade is thus nearly isolated from most pitching movements of the tractor. Depth and grade are controlled by raising and lowering the imaginery hitch point; this is done by hydraulically moving the roller track frame. A laser plane automatic grade control system has been successfully used on this plow. A similar plow developed in Ontario, Canada, called the "Zor Plow", uses two nonparallel "floating" links instead of the roller track to make the connection with the blade.

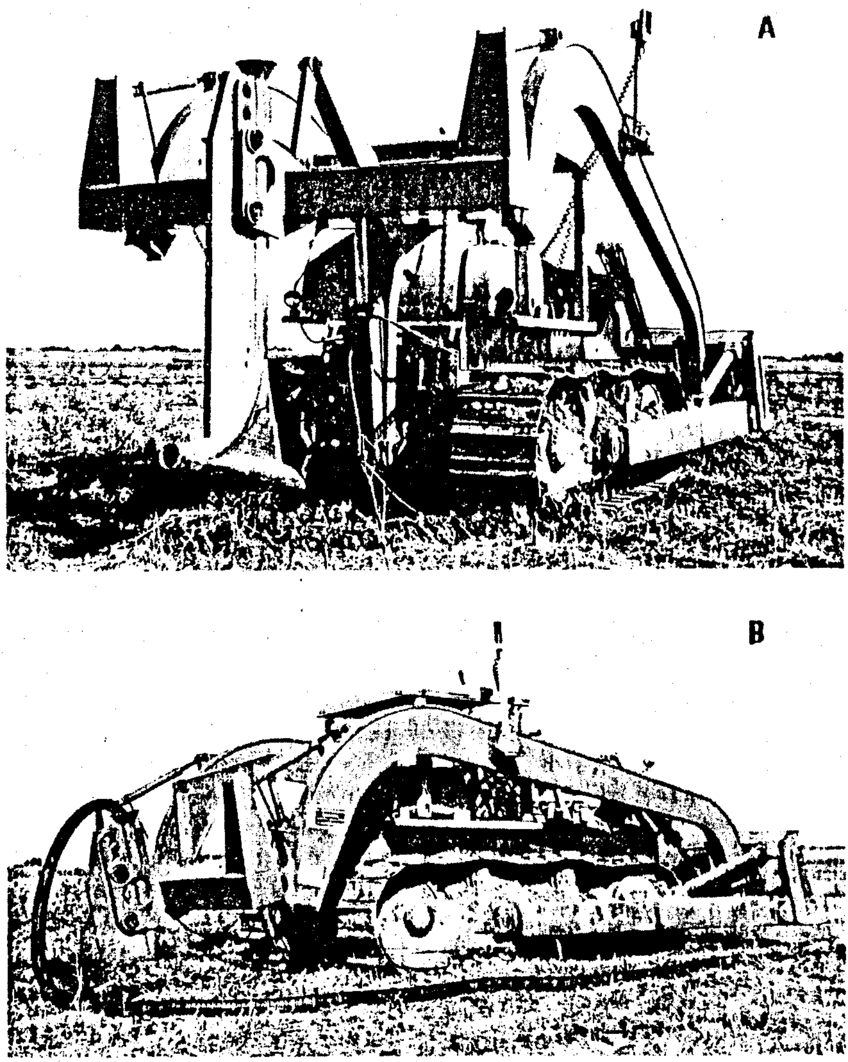

Fig. 8–13. ARS-USDA prototype draintube plow, equipped with a laserplane-type automatic grade control system. (*A*) transport position; (*B*) operating position. Maximum depth 1.8 m.

Another type of plow, called the "draintube plow", was designed and developed by the USDA's Agricultural Research Service (Fouss et al., 1971); the prototype, shown in Fig. 8–13, was designed to install drains to a 1.8-m maximum depth. Two smaller versions of this plow design are envisioned–a medium depth plow (1.2-m depth) and a shallow depth plow (0.9-m maximum depth). This plow has a double- or split-beam, each extending above the crawler tracks and hitched to the rear side of the bull-dozer blade. The plow's operating depth is regulated by raising or lowering the hitch points with the dozer blade; the same hydraulic cylinders used to position the dozer blade thus control the plow depth. These forward hitch points improve traction efficiency and dynamic stability of the crawler tractor. For the prototype plow, the hitch is about 7.3 m forward of the plow blade. The counteracting rotational moments about the hitch pivot due to the plow weight and soil resistance (draft) balance each other and the plow operates with a "floating-beam action." Changes in the vertical position of the hitch relative to the ground surface are not immediately reflected in the plowing depth. The plow blade adjusts or "floats" to a new equilibrium depth as the tractor moves forward.

Fouss, as reported in his doctoral dissertation cited in the Introduction, mathematically modeled the floating-beam plow and simulated its response on an analog computer. Basically, the plow could be modeled either as an overly damped nonlinear second-order system or approximated as a very heavily damped nonlinear first-order system. Fouss' results showed that changes in plowing depth in response to changes in hitch height were approximately linear but not directly proportional; for example, a 2.5-cm vertical displacement of the hitch might result in about a 3.1-cm change in plow depth (after steady state was reached). This type of characteristic response will occur for all drainage plows, but the actual performance will vary with plow design, soil type, and draft relationships. In general, the draft on the plow could be expressed as a power function of depth; typically one might expect the draft to vary with the second or third power of depth for many soils. To give a general idea, for a heavy clay soil one might find about 450 kg of additional draft required for each 2.5 cm of additional depth. These performance characteristics must be taken into consideration to properly adapt and use laser beam or laserplane automatic grade control systems for a plow.

As alluded to above, the speed with which drains can be "plowed-in" ranges from 20 to 45 m/min. Under many field conditions, 600 m of drain can be installed per working hour; experience indicates a range of 450 to 900 m/hour for a wide variety of conditions. Thus, this type of equipment has high production capabilities and is best suited for large-scale projects. The expected equipment investment costs for the drainage plows do not differ greatly from those for high-speed trenchers, assuming that a new crawler tractor is not used on the plow. (Older model tractors usually perform quite satisfactorily because the duty cycle is not as severe as with other kinds of construction or earthmoving.) An average unit cost for installing drainage systems with plow-type equipment has not yet been established. However, it has been estimated that "plowed-in" drains can probably be installed for about one-third to one-half of the installation charge for trenching in drains, excluding cost of materials. Such a cost reduction would greatly lower the cost of agricultural drainage. If shallow subsurface drainage systems are found to be functional in heavy or layered soils, the rapid "plow-in" equipment will undoubtedly provide a very competitive installation method; smaller equipment and lower investment will be involved.

The operation of a drainage plow is affected by various soil conditions such as moisture content and rocks, but operational problems with plows are not necessarily similar to those for trenchers. In general, a few buried rocks do not create as many problems with the plow as with a trencher, particularly if the plow has a laterally steerable blade (Fig. 8–13) which allows it to be maneuvered around larger rocks. Smaller rocks are almost always merely pushed out of the way as the plow blade passes through the soil. The performance of most plows varies considerably with soil moisture content, particularly for cohesive soils. Draft requirements decrease with increasing soil moisture and a moist soil is best for "plowing-in" drains; however, excessively wet soils may result in a serious loss of traction for the crawler tractor. If the cohesive soil becomes very dry, the high draft requirements may make "plowing-in" drains impractical. In future plow designs, vibrating blades may be used to reduce the draft requirements for dry soils. For the present, however, a seasonal operation of the drainage plow is followed, similar to the practice of trenching contractors in many areas.

Since drainage plows are relatively new, several other operational and functional questions remain unanswered. For example, how are the larger sizes of drain pipes to be installed? A common approach has been to attach a separate tube-feeding device behind the plow blade to install the larger sizes of plastic tubing. It seems questionable at this time that plastic tubing larger than 15 cm in diameter can be "plowed-in" with such simple "add-on" devices. Therefore, large diameter tile or plastic tube mains continue to be installed in a trench. The plow of the future may have a digging wheel or chain as an attachment to enable it to handle the larger size conduits.

D. Automatic Grade Control

The laser beam automatic grade-control system was developed to meet the specific needs of high-speed plow-type drainage equipment because previous grading methods using sight-bars or stretched wires were slow, costly, and unsatisfactory (Fouss & Reeve, 1968). Commercial versions of the laser grading system became available, however, before operational drainage plows did, and the new automatic systems began to be used on regular tile trenching machines (Studebaker, 1971). The basic system components (Fig. 8–14) consist of: (i) a portable, tripod-mounted, low-power laser beam projector to emit an elevation or grading datum, or both; and (ii) a machine-mounted electronic tracking-receiver which hydraulically adjusts the plow's hitch height to automatically control plowing depth and drain channel gradient. By 1971, three different types of projected laser systems were in use and available from a number of commercial sources: (i) a single laser light beam or line projected parallel to the desired grade

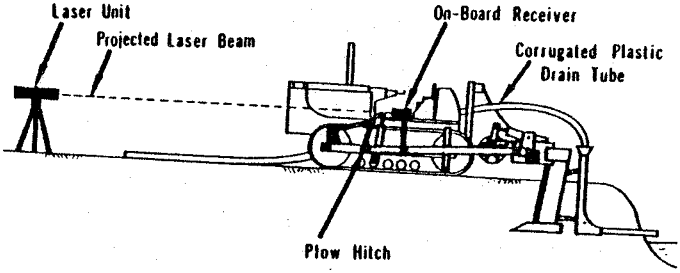

Fig. 8–14. Principle of laser-beam automatic grade control system for a floating-beam draintube plow.

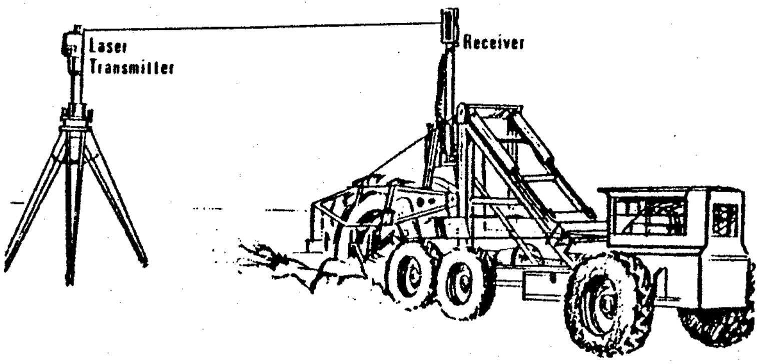

Fig. 8–15. Schematic of laser plane-type automatic grade control on a trenching machine.

and along the direction of travel[1]; (ii) a partial-plane or segment of circle projected parallel to desired grade in the direction of travel and to the cross-slope level[2]; and (iii) a circular laser plane reference described by rapidly rotating the laser source much like a lighthouse beacon, where one axis in the plane is aligned parallel with the desired drain gradient and the cross-axis is aligned either horizontally or parallel to the general land slope[3]. The third laserplane reference system, shown schematically in Fig. 8–15, has become very popular because the elevation or grading datum covers a large field area, on the order of a 40-ha circle, with each set-up of the laser transmitter unit.

Most of the laser tracking-receivers consist of a vertical array of closely spaced photocells, which are connected to a logic and controller circuit. The controller in turn operates the machine hydraulics to provide the cor-

[1] Almost all such systems utilize a helium-neon gas laser unit.

[2] This type of datum is projected in at least two ways by commercially available units, namely, by either optically spreading the laser beam in the horizontal direction, or by oscillating the laser beam back-and-forth to describe a segment of circle.

[3] In one such system, used for both surveying and machine grade control, the "laser beacon" is rotated over the field at several revolutions per second.

rective feedback motion, and thus automatically keeps the receiver centered on the laser-beam or laser-plane reference. For most tile trenching machines, a digital or step-wise hydraulic feedback correction or mode of control has proved adequate; for the faster plow-type equipment, a pure on-off mode of control, with a "hunting" frequency of about 0.5 to 1.0 Hertz, has been found satisfactory.

Most of the receivers are very sensitive and can electronically detect the center of the reference laser beam or plane within ± 0.15 cm or, at the most, ± 0.65 cm. However, the proper use of this electronic detection signal in the feedback control system is very important to achieve accurate automatic grade control. Undoubtedly one of the more critical factors for any given drainage machine is to determine the best position for mounting the laser tracking-receiver on the machine's frame. Note in Fig. 8–13 that the laser receiver unit is mounted closer to the plow blade than to the hitch point. This method of mounting the receiver permits some anticipation of ground surface irregularities traversed by the tractor, so that the plow hitch point can be adjusted before the "mole" point deviates from the desired line (grade) or travel. Furthermore, the effects of changing soil conditions, which may alter plowing depth as well as the nonproportional relationship between hitch height and plowing depth, are compensated for in the feedback control system. Fouss (1971) offered the general guideline that for a floating-beam-type draintube plow a laser receiver mounted forward of the blade about one-sixth the plow beam length should hold the "mole" channel close to the desired grade line. For the floating-blade-type plow shown in Fig. 8–12, a forward extending arm attached to the blade serves as the laser receiver mount. On a conventional wheel-type trenching machine, the laser receiver is mounted just forward of the center (axle) of the digging wheel (Fig. 8–9).

Although it is beyond the scope of this text to cover the various ways that laser depth and grade control systems can be used, one additional point regarding operational features needs to be mentioned. Some of the commercial systems include a device for changing grade without resetting the projected laser beam or plane reference. This device causes the tracking-receiver unit to slowly move vertically, relative to its machine mounting, as a function of ground travel distance. Thus, any desired grade can be created for a given (preset) laser beam or plane slope. The device also permits changing the drain gradient at any point of travel along the drain line, thereby eliminating the need to reset the laser beam or plane slope for each drain gradient change.

VI. DRAINAGE MATERIALS HANDLING

Along with the many innovations and improvements made in drainage equipment and materials during the past decade, many changes have necessarily been made in drainage materials handling techniques. Even the familiar piece-by-piece handling of conventional tile during manufacture, shipment, and installation received much attention, and the improved, labor-saving method of palletized handling was developed. This and other examples are described below.

A. Palletized Tile

By the late 1960's most of the clay, shale, and concrete drain tile installed (particularly in the Midwestern USA) were handled on pallets, each containing about 100 m of tile. This packaging method permitted manufacturers to use fork-lift trucks to store and load the tile for shipment, thus reducing costs and speeding up operations. Furthermore, the use of self-unloading trucks at the job site reduced labor costs. During installation, a chariot or wagon designed to haul one or two pallets was pulled alongside the moving trencher. The tile sections were manually removed from the pallet and placed into the tile-laying chute as shown in Fig. 8–16. This mechanized tile handling reduced the work crew, but maximum speed of installation was still limited to the rate at which tile could be inserted into the tile chute—about 7.5 to 9 m/min.

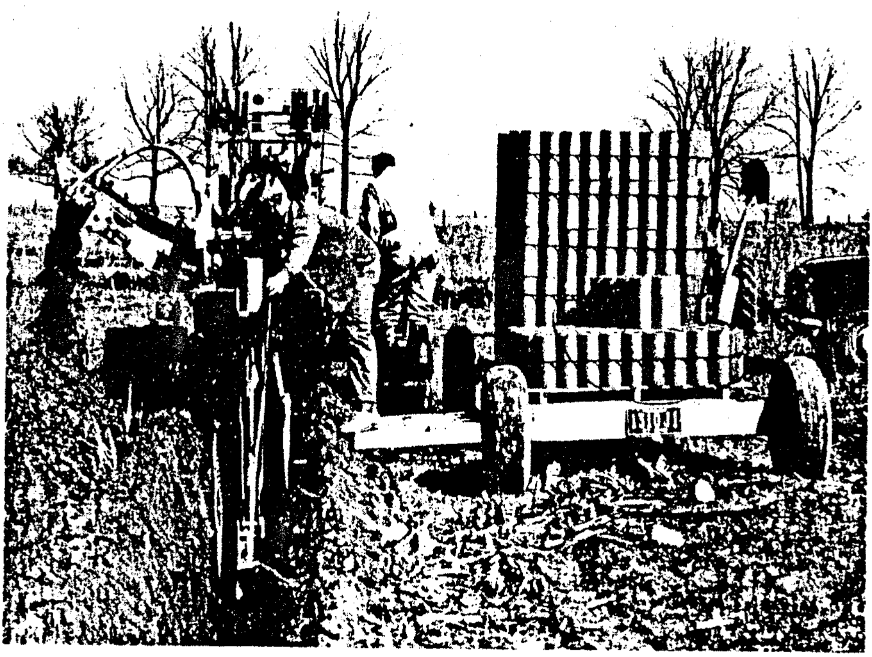

Fig. 8–16. Palletized handling of ceramic tile during field installation.

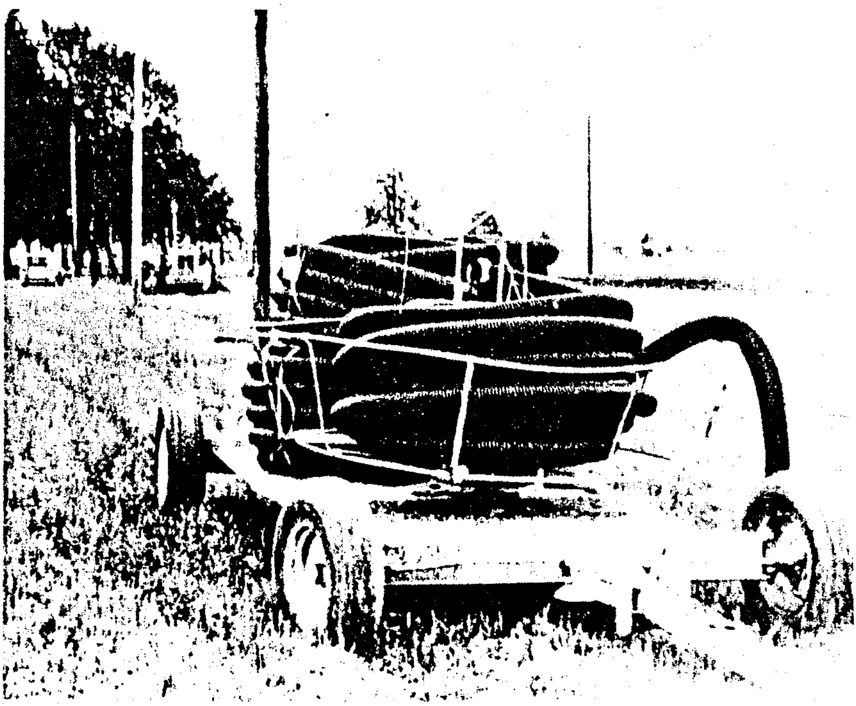

Fig. 8—17. Wagon-mounted uncoiling mechanism for corrugated plastic drain tubing.

B. Coilable Plastic Tubing

Corrugated-wall plastic drainage tubing from 7.5 to 15 cm in diameter is normally shipped and handled in about 1.4- to 1.8-m-diameter coils, each containing from 70 to 90 linear m. A typical 10-cm-diameter corrugated plastic draintube weighs about 0.45 kg/m, which is only about 4% of the weight of 10-cm-diameter ceramic tile.

One practice of handling the corrugated plastic drainage material in the field is to uncoil the tubing and lay it offset but parallel to the proposed drain line, as shown for installation with the draintube plow in Fig. 8—13a. Several types of uncoiling devices have been devised to speed up this operation; an example mechanism mounted on a wagon frame is shown in Fig. 8—17. With such a mechanized uncoiling device, one man can keep tubing laid out on the ground ahead of the drainage machine. The tubing manufacturer usually provides a simple coupler to connect the ends of the tubing from one coil to the next. Another practice is to place the coiled tubing on a spindle mounted on the drainage machine from which it feeds directly into the laying guides of the trencher or the plow's hollow-bladed installation tool (see Fig. 8—8 and 8—12). More than one coil of the plastic tubing can be carried on the machine, and as one roll is nearly installed, a pause in forward travel permits coupling to the next roll so installation can continue.

With the high-speed drainage plows, laying the tubing on the ground in advance results in a much more efficient field operation because it is not necessary to stop the plow to couple on each roll of tubing. Considering an average ground speed of 38 m/min with the drainage plow, one roll of tubing is installed about every 2 min of ground travel time. With the slower trenching machines either method of handling the tubing is satisfactory, but many contractors prefer to have the tubing laid out on the ground in advance.

The in-field plastic drain tube handling methods often need to be altered for installation made during either excessively cold or hot weather, since temperature variations affect the mechanical properties of most plastic drain tubing. During cold weather, the more rigid (coilable) corrugated tubing must lie on the trench bottom groove properly; this usually can be done by immediately "blinding" the tubing as it is installed. For some types of plastics (such as PVC), brittleness at low temperatures presents problems, and may even preclude their installation at temperatures below a critical value. Installations during extremely hot weather (35C and up) can create problems of excessive tubing stretch and excessive initial deflection by blinding and backfilling. To minimize the stretch of the corrugated tubing during installation, the tube guides and feeding devices should be designed to reduce the frictional drag as much as possible. The stretch problem can be alleviated by feeding the tubing directly from the coil rather than laying it out on the ground in advance; this keeps the tubing cooler since it is not exposed to the sun before installation. In extremely hot climates it may even be advisable to provide a sun shield over the tubing coils carried on the machine. To prevent excessive initial conduit deflection once the tubing is in the ground, for a trenched-in drain, a carefully placed light "blinding" will shade it and allow it to cool to soil temperature; for a plowed-in drain, several minutes should be allowed to elapse before the installation slit is closed by compaction.

C. Rigid and Semirigid Plastic Drain Pipe

In the past, bitumenized fiber pipe and smooth-wall plastic tubing have been used for subsurface drainage. Generally these pipe materials are not coilable and thus have been handled in lengths of 6 to 12 m. Some of the plastic tubing is flexible enough to simplify installation as shown in Fig. 8–1; however, this type of conduit is not flexible enough for installation with most drainage plows. These materials are not widely used in agricultural drainage in the USA.

Corrugated plastic drain tubing 20 cm or greater in diameter is quite flexible in long lengths, but is generally not coiled for shipment because a large diameter spool would be required. Usually 12-m-long sections are strapped together to form a fairly tight "bundle" for handling and shipment. Much of this larger diameter corrugated tubing can be fed around a moderate radius in the installation equipment, so that the tubing sections can be coupled before installation. For slow-moving trenching machines (e.g., 1.8 m/min digging speed), the large tubing can be carried in a rack on the machine and tubing sections coupled on one at a time as the machine moves.

D. Drain Envelope Materials

The design and use of drain filters and envelopes is covered in the next section of this chapter. The placement of gravel around the drainage conduit to form an envelope is a common practice in much of the Western USA. Particularly for the newer floating-beam plows, the design of the gravel feeding mechanism is important. A large gravel hopper on a drainage plow may significantly change the machine's weight, and thus its natural floating action, as the hopper empties during drain installation. This problem can be compensated for by continuously conveying gravel into a smaller hopper from a truck driven alongside the machine. Alternatively, the hopper's weight can be supported by wheels and not by the plow frame. If neither of these latter procedures is followed, then one must ensure that the plow's control system can adequately compensate for the change in plow weight, particularly as the hopper is refilled. Generally where gravel envelopes are used, the speed with which drains can be installed is limited by the rate at which gravel can be fed into the ground.

LITERATURE CITED

The literature references for this chapter have been combined with those from the other chapters in this section of the book and appear at the end of the section, pages 197-200.

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