ARS Story on the R&D for the American version of Corrugated-Wall Plastic Drainage Tubing and Plow-In Method of Installation

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Preface:

The U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) is the scientific and engineering research agency whose mission is to develop new and improved technologies to enhance agriculture and food production for public benefit. One of ARS's principal areas of research is soil and water management and conservation which are carried out at a national network of Federal research laboratories, many of which are co-located and cooperative with major Universities. The new knowledge, concepts, and technologies developed and demonstrated by ARS research are transferred to private sector agricultural producers and service providers (e.g., manufacturers) for implementation and delivery of improved products and services to the public.

Foreword:

This is a story about activities of USDA-ARS researchers, namely myself, James L. Fouss (Research Agricultural Engineer), and my technician and co-worker, Norman R. Fausey (Engineering Technician), other ARS and university colleagues, and a few industry cooperators, on our research and development of new subsurface drainage materials and methods of installation that helped to revolutionize the subsurface drainage industry in the early 1970s. Many of the activity details covered in this story have not previously been written down or published, but some of the special events that occurred were talked about a number of times by Jim Fouss over the years to selected colleagues and friends.

Background and Introduction:

By the mid-1960's, most of the research to develop new agricultural drainage materials had begun to focus on corrugated-wall plastic tubing. Continuous extrusion and molding equipment had been perfected by W. German industry (e.g., Drossbach Industries) to fabricate small diameter (e.g., 2-3/8 in. I.D.) corrugated-wall plastic tubing (primarily using PVC plastic), and underground drainage with the new small-diameter conduit caught on in W. Germany and soon spread to other regions in Europe. In the USA, the first users of the new corrugated-wall plastic tubing [mostly using high-density polyethylene (HDPE) plastic] were the underground electrical and telephone conduit industries. Research in the USA on using the corrugated-wall high-density polyethylene (HDPE) plastic tubing as an agricultural subsurface drainage conduit was begun in 1965 (Fouss, 1965, 1968), and research to develop new higher speed methods of installation focused on adapting mole-plow type equipment and not the trenching machine. By 1967, 4-in. diameter corrugated-wall plastic drainage tubing was being fabricated commercially in the USA by Advanced Drainage Systems (ADS), and as other manufacturers followed this new drainage industry grew rapidly in the U.S. By the late 1960's many U.S. clay and concrete drain tile manufacturers began setting up corrugated plastic drain tube extrusion plants, and most of the clay and concrete drain tile plants were phased out over a period of years and closed.

ARS Drainage Materials Research Prior to 1965:

ARS drainage materials research prior to 1960 was conducted by Charles Busch located at Cornell University, and his research was focused on the concept of installing a stabilizing PVC plastic liner (arch-shaped or circular) in a mole drain channel behind a mole plow (Busch, 1958). After 1960 the ARS plastic-lined mole drain research project was assigned to James L. Fouss (agricultural engineer)[1], stationed at The Ohio State University. Fouss and his research assistant, Norman R. Fausey (engineering technician), expanded the research in cooperation with an Ohio Agricultural Experiment Station research professor (Dr. Glenn O. Schwab) to evaluate the structural stability of several PVC plastic-liner configurations (Fouss and Donnan, 1962). Fouss and Fausey developed a method to install within the mole-drain channel a completely closed circular liner formed from a coil of semi-rigid PVC plastic sheet. A 3-in. diameter mole-drain liner was formed with a 10-in. wide, 15-mil thickness, PVC plastic sheet that had interlocking tabs pre-stamped along both sides. The new drain channel was named the "Zippered" plastic-lined mole drain. The expanded research was designed to also evaluate different methods for controlling the depth and gradient for the plowed-in plastic-lined mole drains. A final report on this phase of the research (Fouss, 1965) was presented at the first National Drainage Conference sponsored by the

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[1] See the Story in Appendix-II on how the ARS plastic-lined mole drain project was assigned to James L. Fouss.

American Society of Agricultural Engineers (ASAE) held at Chicago, IL in December 1965. Fouss presented that paper and reported that the thin-wall PVC plastic mole liners, including the stronger “zippered” liner, were not strong enough to withstand deformation from soil pressure over a 4- or 5-year field test period. It was also reported in that 1965 paper presented by Fouss about the first promising field test for the corrugated-wall HDPE plastic tubing for the plowed-in subsurface drainage conduit. Therefore, the plastic-lined mole drain was abandoned in favor of corrugated-wall HDPE plastic tubing placed in the mole drain channel.[2] PDF printed copies of both the 1962 and 1965 ASAE published papers are included in Appendix-I; the reader is encouraged to review those papers for additional details and conclusions from the 1960-1965 research studies. The details of the subsequent research program on the development of what I have termed the “*American version*” of corrugated-wall plastic drain tubing in the USA are given below.

<u>Highlights of Corrugated-Wall Plastic Drain Tube Development Research:</u>

In June of 1965, the Columbus, Ohio ARS research team[3] was contacted by representatives of Haveg Industries, Inc. of Wilmington, Delaware, regarding the possible use of corrugated-wall plastic tubing for subsurface drainage. Haveg Industries, at that time, had fabricated 2- and 3-inch diameter corrugated-wall tubing for use as an underground electrical conduit in new housing subdivision developments, primarily in the western U.S. Haveg Industries had acquired their corrugated tubing extrusion equipment from Drossbach Industries in W. Germany. Although the original samples of tubing were much stronger than appeared to be necessary for agricultural subsurface drains, the idea showed immediate potential for our ARS research team. The corrugated-wall plastic tubes were found to be stronger (resistance to deflection), lighter in weight, less expensive, and easier to handle because of better longitudinal flexibility (coilability) than comparable strength smooth-wall plastic pipe.

The mole plow used to install plastic-lined mole drains was modified with an attachment in July of 1965 to install 2-inch diameter polyethylene plastic tubing provided by Haveg Industries. Since the tubing had been fabricated for use as shielding for an underground electrical conduit, it

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[2] Following my presentation in 1965 that the plastic-lined mole drain concept was being abandoned, I received thank you letters from about 3, perhaps 4, European countries for reporting those research results because they had planned to begin research on plastic-lined mole drains; they changed plans to begin work on corrugated plastic pipe.

[3] J. L. Fouss (agricultural engineer), N. R. Fausey (engineering technician), R. C. Reeve (ARS research investigation leader), G. O. Schwab (OSU professor of agricultural engineering), and L. S. Willardson (ARS agricultural engineer).

did not have perforations for water entry. Therefore, slots were "sawed" in the outside "crowns" of the corrugated-wall plastic tubing to provide water entry openings. The first field test installation involved subsurface drainage of a side-hill seepage area at the Coshocton, Ohio ARS Hydrologic Research Station.[4] It was immediately apparent during the installation of this initial field trial that the special tube feeding device behind the mole plow worked exceptionally well, and eliminated many of plastic sheet feeding difficulties and special materials handling problems experienced with the Zipper-type plastic mole-drain liner installed earlier. Although the modified mole plow was required to open the ground gap up wide enough to feed the full diameter of the tubing into the ground, the draft requirements were not significantly increased over that for the narrow blade machine used to install the sheet-plastic mole-drain liners. The initial installation field trial for corrugated-wall drain tubing "plowed-in" behind our research mole-plow is shown in Fig. 1.

Fig. 1. Small-Diameter Corrugated-Wall Plastic Drain Tubing being Plowed-In behind a Mole-Plow; 1965, Coshocton, OH.

After a few months performance of these small-diameter corrugated-wall plastic drains in the soil, it was apparent that the structural strength and hydraulic performances of the drain were more than adequate. Some sediment was observed in some of the drain lines installed in the silt loam soil, but it was not considered serious. It was also observed that initial sediment in the drains was flushed out by the first heavy rain; the turbulence within the corrugated wall tubing kept the

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[4] This site was selected to avoid possible press coverage of the initial field trials with the new drain pipe product.

material in suspension and allowed it to flow with the subsurface drainage water to the outlet.

In addition to representatives from Haveg Industries, a representative from the Corrugated Metal Pipe Division of Armco Steel Corp. of Middletown, Ohio was also present for the initial test installation, namely, Mr. Ted Morton (engineer). Nearly continuous communications with both of these firms occurred over the next few months. When Haveg Industries realized that we had already decided that some design changes in the tubing's corrugation profile shape would be required in order to make it adaptable for agricultural drains, their interest decreased. Armco Steel Corp., on the other hand, with their vast experience in corrugated metal culverts was quite interested in expanding their field of expertise into the area of corrugated-wall plastic drainage tubing. It was at this stage in the investigation that I began to make some theoretical analyses of the structural strength of a corrugated plastic tube wall. Armco Steel provided some input from their experience in the corrugated metal culvert field, in particular information provided by Mr. Howard White (engineer). The corrugated-wall HDPE plastic tubing was a flexible-type conduit, that is, it deflected some under soil loading and was subjected to a different soil loading condition than a rigid drain tile (clay or concrete). A flexible conduit gains part of its vertical soil load-carrying capacity from the lateral support (passive resistance) from the soil at the sides of the conduit as it deflects (flattens) outward slightly and presses against the soil at the sides of the conduit. The vertical soil load on the top of a flexible conduit is typically less than on a rigid conduit buried at the same depth. A formula, called the Iowa Formula, was developed by Prof. M. G. Spangler at Iowa State University to predict the deflection of a flexible conduit under soil loading. One of Prof. Spangler's students, Dr. R. K. Watkins, found an error in the original formula derivation and the *Revised* Iowa Formula was developed and published jointly by Watkins and Spangler. The *Revised* Iowa Formula for soil loading, and the theory for deflection of flexible conduits when loaded between parallel plates, was used in my initial design analyses of the corrugated-wall HDPE plastic draintube. A few months were spent in conducting computer simulation studies to determine various corrugation configurations which would provide the strength to resist significant pipe-diameter deflection under soil loading of the plastic tubing for agricultural drainage conduit applications. Subsequently, it was decided that some experimental tubing was needed in order to verify or confirm the theoretical corrugation design method in terms of actual and predicted pipe strength (e.g., laboratory test for pipe deflection resistance under parallel-plate loading). It was also intended that the experimental tubing would be evaluated to determine how close the predicted strength could be realized in manufactured tubing (i.e., not just short-length samples). In order to accomplish this, special molding blocks needed to be fabricated to make long coiled lengths (e.g., 150-ft. or more per coil) of the corrugated tubing with our proposed corrugation profile design.

It was proposed that experimental corrugated-wall tubing was to be fabricated with three different plastic resins [PVC, High Density Polyethylene (HDPE), and Polypropylene], and with different pipe-wall thicknesses to provide pipes of variable strength (deflection resistance). Two types of tests were proposed to evaluate the experimental tubing**: (1)** Short (1-ft. long) samples for physical laboratory pipe-diameter deflection testing via parallel-plate loading to check against the theoretical analysis; and **(2)** Coiled tubing installed with the mole-plow to evaluate performance under soil loading for tubes with variable strength (deflection resistance); i.e., tubes made from the three different plastic resins and tubes with different pipe-wall thicknesses to provide a range of pipe strength (deflection resistance).

Armco Steel Corp. agreed to cooperate with ARS in this research evaluation project, each providing approximately one-half the funds necessary to have the molding blocks fabricated and the test tubing manufactured. In late 1966 and early 1967, ARS entered into an agreement with Armco Steel to have the necessary research tubing fabricated. An ARS purchase order was issued to Armco Steel Corp., contributing about $2,000 for the ARS portion of the work. Armco Steel Corp. engineers made the decision to contact the best experts in W/ Germany at that time relative to making the corrugated tubing for our research purposes. The W. German firm, Drossbach Industries, agreed to fabricate the required die mold blocks in accordance with our specification and standards and to manufacture the required coiled lengths of plastic pipe using the three types of plastic resin and at two or three different pipe-wall thicknesses. ARS provided the corrugation [profile] design to be used based upon computer simulation and modeling results that we had accumulated at our Ohio State University facilities over a period of months. The corrugation profile shape used was basically a square-wave corrugation in order to simplify the mathematical analysis and to make accurate comparisons with actual tubing when it became available. A more complex corrugation shape, such as one including parts of circles, or perhaps a sine-wave, may have provided a profile easier to mold with the corrugation extrusion equipment, but would have been more complex to theoretically compare directly with physical strength test results. The main objective at that stage of the work was to determine the reliability of theoretically designed corrugated tubing and to determine the minimum strength requirements (deflection resistance) for acceptable field performance at typical depths in the soil for subsurface drainage conduits.

`Several months were required in order to have the molding blocks fabricated and the tubing produced in order to carry out the research project. It was during this time that the ARS project engineers concentrated on developing the laser-beam automatic grade-control system for the drainage plow (discussed in a separate ARS and Industry cooperative R & D "story"). The development of the laser-beam grade-control system was very important to the project, because without a suitable and accurate method of controlling depth and drain grade for the drainage plow, the plow-in method for installing subsurface drains would not have been practical or acceptable.

The experimental corrugated plastic drainage tubing was finally received in the Fall of 1967. All the experimental tubing was of 3-inch diameter, which at that time was considered a practical size for plowing into the ground, and was made of three types of plastic material specified, namely: (1) PVC, (2) High-Density Polyethylene (HDPE), and (3) Polypropylene.[5] These three types of plastic provided a range in strength, the strongest tubing being made with PVC to the weakest with HDPE. Test lengths (1-ft.) of the corrugated-wall tubing samples were tested for deflection resistance in the laboratory using the parallel-plate load-deflection method. Based on these laboratory tests, and the theoretical analysis of the corrugation shapes, agreement between the predicted strength and the actual strength was within 10 to 15% in most cases. This was considered adequate and acceptable for this type of engineering design work. The field testing phases with this experimental tubing were never carried out for two reasons: (1) project funding to initiate the field project became quite limited in early 1968, and therefore, the project was temporarily postponed; and (2) in late 1968, a field grass fire spread and destroyed the storage area where the experimental tubing was kept--the tubing was damaged beyond the point of being useful.

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[5] After our experimental tubing was delivered from W. Germany, I received a personal visit from the President of Drossbach Industries, Mr. Max Drossbach. He asked me why I did not use PVC plastic for all the experimental tubes, and why I did not use his sine-wave type corrugations. I explained that PVC cost about 3X more in the. U.S. than in Europe, and PVC had brittleness and stress cracking problems that I wanted to avoid (thus chose HDPE for my preferred tubing). I also reviewed my corrugation profile design work and the importance of corrugation depth, especially for the weaker HDPE plastic vs. PVC, to obtain the pipe strength I needed. He understood my thinking.

However, by that time, the American Industry was beginning to get under way as outlined below, and tubing of various strengths was obtainable from them for our planned field installation project.

The Beginning of the Corrugated Plastic Pipe Drainage Industry in the U.S.:

It was in January 1967 that several representatives of a new firm being organized under the name Advanced Drainage Systems, headquartered in Delaware, Maryland, came to visit our research staff at Columbus, OH. They had been reading of our research work with corrugated plastic drainage tubing, and had attended the December, 1965 National Drainage Symposium in Chicago, Illinois in conjunction with the American Society of Agricultural Engineers' Meeting. It was at that Symposium where I first reported our team's progress in preliminary field testing of "plowed-in" corrugated-wall HDPE plastic drain tubing for agricultural subsurface drainage applications. Results from the Coshocton, Ohio initial field trials were given at that time. The ADS representatives (Ron Martin and Marty Sixt) inquired about the minimum strength requirements for corrugated plastic drain tubing and the kinds of corrugations we would recommend for a 4-inch diameter tubing. It was at that time we recommended they stick with the 4-inch diameter tube rather than the 3-inch tubing we were exploring for plowed-in drains. This recommendation was made because it was apparent that changing the drainage pipe materials (i.e., from clay or concrete to plastic) would create considerable discussion in the field of drainage, and to change diameter of drain pipe at the same time would add to the problems of marketing the new product. Recommendations were made regarding the general shape for the corrugation, namely, that they be somewhat rectangular in shape with slightly rounded corners, and not the small sine-wave type corrugations that we had seen on some of the European PVC pipe, particularly that coming from W. Germany. Recommendations were also made regarding minimum strength requirements based on field tests conducted in Ames, Iowa during the 1950's by Dr. G. O. Schwab with smooth-wall polyethylene plastic pipe pulled into mole-drain channels. We had made digging inspections of those plastic drains in Iowa during mid-1966 and evaluated their structural strength in terms of deflection resistance under parallel-plate loading. It was concluded from the Iowa experiments that a 4-inch diameter tubing that had a parallel-plate load deflection resistance of 30 pounds of parallel-plate load applied per linear foot of tubing per 1/8 inch of vertical pipe deflection should provide adequate strength for subsurface drainage applications in most soils. It was about this stage in the discussions and recommendations with ADS representatives that I probably began calling the recommended 4-in. corrugated-wall drain tubing the "***American version***" (i.e., it was a 4-in. I.D. corrugated-wall HDPE plastic tube and had rectangular-shaped corrugations with slightly rounded corners).[6]

Communications were maintained with the ADS representatives (Martin and Sixt) over the next several months and the first production tubing from the ADS facilities was realized during August 1967. The company provided us several pipe samples over the preceding months for test and evaluation with regard to our analysis procedure for corrugated-wall plastic tubing design. Those pipe samples provided by ADS were very beneficial additional evidence on the accuracy of the analytical design procedure along with the 3-inch plastic tube samples which had been fabricated for us in W. Germany.

In August of 1967, I had a speaking engagement at the North Eastern Section of the American Society of Agricultural Engineers, held at McGill University in Quebec, Canada. The Canadian Engineering and Agricultural representatives in attendance at the meeting were quite interested in the corrugated-wall plastic drainage tubing idea, and maintained communications with our research team for the next few years. In 1968 the first of several clay and concrete drain tile manufacturers in the U.S., namely The Hancock Brick & Tile Co. of Findlay, OH and its newly formed Hancor Division began to develop production facilities for 4-in. diameter corrugated-wall HDPE plastic drainage tubing.

In August 1969 I was invited back to Canada to make a special presentation at Macdonald College near Montreal, Canada, again to a group of Canadian Agricultural Engineers, representatives from a few drainage firms, and several farmers. The special invitation was to present an engineering report on a large drainage plow I had designed to install corrugated drain pipe at a depth of 6.0-ft.[7] Before returning to the U.S. on that trip, I toured one of the corrugated pipe manufacturing plants (Daymond, Ltd.) at Ridgetown, Ontario. Following the 1969 meeting, I maintained communications with several Canadian university and industry representatives during

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[6] In terms of the current ASTM F-405 standard specification format for the 4-in. dia. corrugated-wall tubing, this original recommendation would have been 20 pii (i.e., 20 lb./in. of pipe length/in. of vertical deflection). Thus, our 1967 recommendation was lower than the current ASTM Pipe Stiffness spec for 4-in. dia. tubing of 35 pii. However, the Pipe Stiffness in the ASTM F-405 specification was increased in increments over the years from 1974 to 2015.

[7] A separate R&D "story" has been written about this large drainage plow project; "*Story behind the Story on the Development of the ARS "Big Red" Draintube Plow with Laserplane Automatic Grade Control System*".

various stages of their development of specifications and standards for corrugated HDPE plastic drainage tubing which was eventually developed in Canada.

Engineering Report on Design Procedure for Corrugated-Wall Plastic Drainage Tubing:

During 1968-1969 I drafted an extensive engineering report to document my work and thinking on the design of corrugated-wall plastic drainage tubing. The report was titled: **"Structural Design Procedure for Corrugated Plastic Drainage Tubing"**, but it was not available in published format as USDA Bulletin No. 1466 until July 1973. That corrugated-wall plastic pipe design report presented a systematic, analytical procedure for designing an efficient corrugation shape (cross-sectional profile) for the pipe-wall of the plastic draintube. Each step of the design procedure was discussed in considerable detail. In principle, the design method followed very closely the procedure typically used for the optimized engineering design of a structural I-beam. That is, within the confines of practical dimensions and within the bounds of allowable tube-wall stress and strain, the pipe-wall cross-section was designed to obtain maximum moment-of-inertia and maximum strength-to-weight ratio for the fabricated plastic draintube. Although the design procedure utilized the established requirements for draintube strength and deflection under soil loading, the design analysis and selection technique simplified the engineering evaluation of various corrugation profiles by the use of an equivalent parallel-plate load and deflection performance parameter for the draintube. Throughout the report, the derivation of all equations needed for the design analysis and computations were given in detail.

The original draft engineering report on the corrugated-wall plastic drain pipe design procedure was submitted to the Ohio State Board of Engineering Registration (with ARS concurrence) to complete the final qualification requirement for my Professional Engineer License in the State of Ohio (January 1970; P.E. #34419; OH).

A complete PDF file copy of the USDA Bulletin 1466 is included on the CD or Flash Drive in Appendix-III. After the pipe design report was published by USDA, approximately 3,500 copies of the USDA Bulletin 1466 were provided to individuals, firms and organizations world-wide that had contacted our office at Ohio State requesting the Bulletin. The original 2,500 copies provided by the USDA printing office were distributed rather quickly, and we had an additional 1,000 copies made to fill continuing requests for more than an additional year. The pipe design equations shown in the report were programmed into desktop computers by corrugated pipe designers and consultants, *including myself*, to facilitate use of the equations and design procedures in conducting pipe design consulting projects for the corrugated plastic drainpipe industry in the U.S. and also some firms in Canada.

Specifications and Standards Development

During the late 1960's and the early 1970's, great effort was put into the development of specifications and standards for the new corrugated plastic drainage tubing. I was assigned as the lead author in an initial draft for a proposed standard for corrugated plastic drainage tubing in a committee formed by the U.S. Bureau of Standards. In the early 1970's a new American Society for Testing and Materials (ASTM) committee was formed under the jurisdiction of the F-17 Committee on Plastic Piping Systems to handle the development of a Specifications and Standards for Corrugated-wall Plastic Drainage Tubing**;** the responsible Subcommittee was F-17.65 for Land Drainage. The initial draft prepared under the U.S. Bureau of Standards committee structure was turned over to this new ASTM committee as a starting point. The efforts and key leadership of Mr. Walter J. Ochs, National Drainage Engineer with the USDA-SCS in Washington, DC, were instrumental in getting this product specification approved and released during 1974 as F-405 "Specification for Corrugated Polyethylene (PE) Tubing and Fittings."

I was selected as the Chairman of the F-17.65 Committee after Mr. Ochs' tenure, and was responsible for implementing some needed updates and corrections to the original F-405 Standard. The specification has undergone several revisions and updated performance (e.g., Pipe Stiffness) specifications since 1974 to expand its scope and include additional pipe testing procedures, such as cold temperature impact testing, and high temperature tests to accelerate aging of the HDPE plastic resin. I did attempt to have the speed reduced that the parallel-plate strength test load was applied to pipe samples being tested. A standard Instrom Testing Machine was used to apply the parallel-plate loading, and the default speed that the parallel plates deflected (flattened) the test pipe was 0.5-in**.**/min. Based on the many laboratory tests we had conducted when collecting data to include in the USDA Technical Bulletin 1466 on the corrugation design procedure, I concluded that a parallel-plate loading speed of 0.5-in./min. was somewhat too fast for a 3-in. or 4-in. dia. tubing. My laboratory test results indicated that the rapid parallel-plate test gave a notably higher Pipe Stiffness strength value, especially for the smaller 3- and 4-in. dia. drain pipes, than a slower speed, e.g., a rate of 0.010- to 0.125-in./min. As larger diameter corrugated-wall HDPE pipes were manufactured a few years later, the parallel-plate testing speed remained at 0.5-in./min. I noted to the committee that for the larger pipes anticipated for production in the future, for example, larger than 8.0-in. dia., the speed of testing between parallel plates would not present a serious problem with distorting (increasing) the Pipe Stiffness results. However, with the drainage industry membership on the ASTM F-17.65 committee, the longer time required for such a revised parallel-plate test on a 4-in. dia. tubing was a significant barrier in their operations, because of the large number of pipe samples typically tested for Quality Control purposes in their plants. Thus, my recommended change in the parallel-plate test was not approved for the F-405 specification standard. To my knowledge, the speed of the parallel-plate test has never been modified in the ASTM F-405 specification.

The ASTM F-405 specification has continued to be a "performance standard" for HDPE plastic pipes less than 12-in. in dia., and the specification has not limited manufacturers in making design changes to improve the corrugated-wall plastic pipe. Similar ASTM specifications and standards were developed for corrugated-wall HDPE plastic pipes of 8-in. dia. and larger, but those are not discussed here.

Corrugated Plastic Pipe Industry Expansion to produce Large-Diameter Plastic Pipes:

Within a few years after the corrugated plastic tubing and pipe industry began, there was an ever increasing demand for larger diameter corrugated-wall plastic pipe. Soon HDPE plastic pipes up to 24-in. diameter became common among most manufacturers. The hydraulic roughness of the large and deep corrugations in the larger diameter pipes began to be a concern because larger and larger corrugated-wall pipes were required to meet hydraulic flow capacities needed in many applications. By the mid-1980's, attention was given by the industry to design and produce a corrugated-wall HDPE pipe with a smooth-wall interior core. In fact, my first work on the corrugated-smooth HDPE pipes was as an ARS approved short-term private consultant in 1985 to assist one pipe firm design 18- to 36-in. dia. corrugated-smooth pipe-wall profiles for their initial production pipes.[8] The smooth-wall core for the corrugated-wall pipe vastly improved the

[8] I, along with a colleague, published one technical paper on the structural and hydraulic advantages of the corrugated-smooth pipe-wall configuration for the large-diameter HDPE pipes. See appended list of references.

hydraulic flow characteristics for the new HDPE pipe. Most of the large-diameter corrugated-smooth pipes were used in culvert pipe applications, but it took several years before product and regulatory (ASTM) standards were developed that permitted the HDPE plastic culvert pipes to be used as highway culverts (eventually covered in AASHTO specifications and standards). The HDPE culvert pipes eventually produced by many of the manufacturers increased in diameter up to the largest size of 60-in.diameter. Such large diameter pipe could be supplied in different lengths to meet customer requirements. The industry started calling the regular corrugated-wall HDPE pipes, "Single Wall", and the corrugated-smooth HDPE pipes, "Double Wall." All customers soon followed suit and used the new terms in ordering pipe products. Only old-time consultants (e.g., yours truly) have continued to use corrugated-wall and corrugated-smooth pipe-wall to describe and talk about these HDPE pipe products. (ha)

Corrugated HDPE Pipe Products Materials Handling Improvements:

Several important changes and improvements in tubing and pipe materials handling methods have been made by the industry since its earliest days in production. For the typical drainage tubing of 4.0-in. diameter, the size of coil used to ship and handle the product increased from the original 350-ft. per coil in the early days of the industry to a 3,000-ft. long coil of tubing. The large-size coil was typically transported on the field on a trailer-type coil rig to uncoil before installation, or a drainage machine mounted coil that was uncoiled as the tubing was installed with a trencher or drainage plow. One manufacturer developed a maxi-coil of 5,000 ft. for the 4-in. dia. corrugated-wall tubing. Typically 6-in. dia. corrugated-wall tubing was shipped coiled, and occasionally some 8-in. dia. tubing was coiled, but larger diameters were typically shipped in 20-ft. lengths. Manufactured fittings and couplers were developed to connect the end of one coil to tubing in the next coil to insure a good connection without disruption of internal water flow. For the regular corrugated-wall tubing (single-wall), the internal coupler was popular with contactors (I was the senior inventor for the Internal-Coupler product, and it was patented as a Hancor, Inc. product). External couplers were used on the corrugated-smooth pipe-wall (double-wall) pipes.

A great deal of attention was given by the industry to materials storage and handling for the large-diameter pipe products, and especially for the corrugated-smooth pipe-wall products produced in various pipe lengths, e.g., 20-ft. For product designers, the ability to "nest" the various diameters of large-diameter corrugated-smooth (dual-wall) HDPE pipes for shipment and storage was required by most manufacturers, dealers, and customers (i.e., a Dual-Wall pipe of given diameter was required to allow the next smaller diameter pipe to be placed inside its diameter, and the given pipe needed to fit inside the diameter of the next larger size pipe). This “nesting” property for the corrugated-smooth HDPE pipes provided great advantages and saved costs in storage and shipping of the products.

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APPENDIX-I

PDF printed copies of the following two ASAE published Papers on the 1960-1965 research:

Fouss, J. L. and W. W. Donnan. 1962. Plastic-lined mole drains. AGRICULTURAL ENGINEERING 43(9): 512-515. [*PDF scanned & printed copy included in this Appendix-I*]

Fouss, J. L. 1965. Plastic drains and their installation. Proc. of the ASAE Conf.: Drainage for Efficient Crop Production, pp. 58-61; Chicago, IL, Dec. 6-7, 1965; ASAE, St. Joseph, MI 49085.
Fouss, J. L. 1968. Corrugated plastic drains plowed-in automatically. TRANSACTIONS of the ASAE 11(6): 804-808. [*PDF scanned & printed copy included in this Appendix-I*]

EXHIBIT 1b, #5

Plastic-Lined Mole Drains

Promising answer to low-cost subsurface drainage

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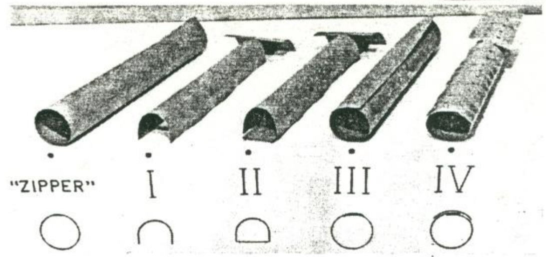

Fig. 1 Various types of PVC plastic mole drain liners under field test are: Positively closed "zipper" type, (I) Busch type arch, (II) arch type with 7½ mil plastic floor, (III) caterpillar-type overlap, and (IV) caterpillar-type overlap with "cap"

IN THE past fifteen years considerable research has been conducted to develop techniques for utilizing new materials to lower the cost of subsurface drainage. A new type of plastic mole drain liner and improved equipment for more accurately installing plastic-lined mole drains have been designed to provide a low-cost method of subsurface drainage particularly in slowly permeable soils and in soils with shallow impermeable strata requiring narrow drain spacings. Most of the research in this area has been centered around stabilizing a conventional mole drain channel with various types of lining materials and, to date, plastics have shown considerable promise.

Mole drainage has been attempted in the United States, but has not been particularly successful, except in certain organic soils where, at best, it serves only as a temporary drain. Stabilizing mole channels with shellaced metal tubes (16)*, bitumenized fiber material (11), and various forms of plastic (12) have been investigated in Germany. Recently in England (8, 9), a method was developed to extrude a porous concrete lining within a mole channel. In the United States as early as 1948, Schwab (17) succeeded in pulling pre-extruded and perforated polyethylene tubing into a mole channel. Techniques have recently been developed for installing semirigid sheet plastic liners in mole drain channels (2, 13). Investigators in England have made considerable progress in developing an interlocked circular plastic mole liner.‡ Each of these reports shows considerable success in reducing the cost per unit length of drain. However, durability of the various mole liners, problems of achieving uniform drain size and gradient, and equipment limitations all point to the need for more intensive study.

Busch (4) found in preliminary field studies that unlined mole drains tend to fail because of soil falling from the roof of the channel, thus plugging the drain, rather than because of the channel collapsing from surface loads. Therefore, the major function of the plastic mole liner is to resist those forces that cause the roof of an unlined mole channel to deteriorate. The mole liner also improves the drain's hydraulic characteristics and prevents sediment from entering the channel. Manley (14, 15) demonstrated that the "bridging" phenomenon of soil tends to transfer internal soil pressure caused by surface loads to the soil on the sides of the mole channel. He found that the tendency of a soil to "bridge" increases as the bulk density of the soil increases. He reported that lined or unlined mole channels were collapsed by surface loading only after considerable depression on the soil surface.

Types of Plastic Mole Liners

A semirigid sheet of polyvinylchloride (PVC) plastic, 15 mil in thickness, was used in this study for the mole lining material. It has a tensile strength of 7700 psi, modulus of elasticity of 450,000 psi and an Izod impact strength of 0.5 ft-lbs (all at 77F). It is a thermal plastic with high chemical resistance and good dielectric properties. The plastic material will withstand considerable bending, twisting, and tensile pull.

A method was developed to install within a mole channel a completely closed circular liner formed from a coil of sheet PVC plastic. A 3-in. diameter mole liner was formed from a 10-in. wide sheet of plastic that had interlocking tabs prestamped along both edges. A short section of formed "zipper" type mole liner is shown at the left in Fig. 1. It was nicknamed zipper mole liner because the interlocking tabs were fastened together with a zippering action by a special die mounted in the installation equipment.

The additional types of plastic mole liners shown in Fig. 1 are being studied also. The earliest mole liner formed from a sheet of plastic was the Busch-type arch (I), which was merely a plastic roof in the mole channel. Through further study in Ohio a 7½ mil PVC plastic floor was placed in the arch type liner (II). Such a floor reduced soil erosion from the bottom of the mole channel and improved hydraulic characteristics of the drain. An overlap circular mole liner (III), and later an overlap type with a "cap" (IV) to prevent sediment from entering the overlap joint were developed and tested†. These liners were formed from sheets of plastic by merely overlapping the edges at the top of the drain. The overlapped edges were not bonded together.

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The authors — J. L. FOUSS and W. W. DONNAN — are, respectively, agricultural engineer, Corn Belt Branch, and chief, Southwest Branch, (SWCRD, ARS) USDA, Columbus, Ohio, and Riverside, Calif., respectively.

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*Numbers in parentheses refer to the appended references.

‡Personal visit by A. N. Ede, Ministry of Agriculture, England, August 1960.

†Unpublished material supplied by the Caterpillar Tractor Co.

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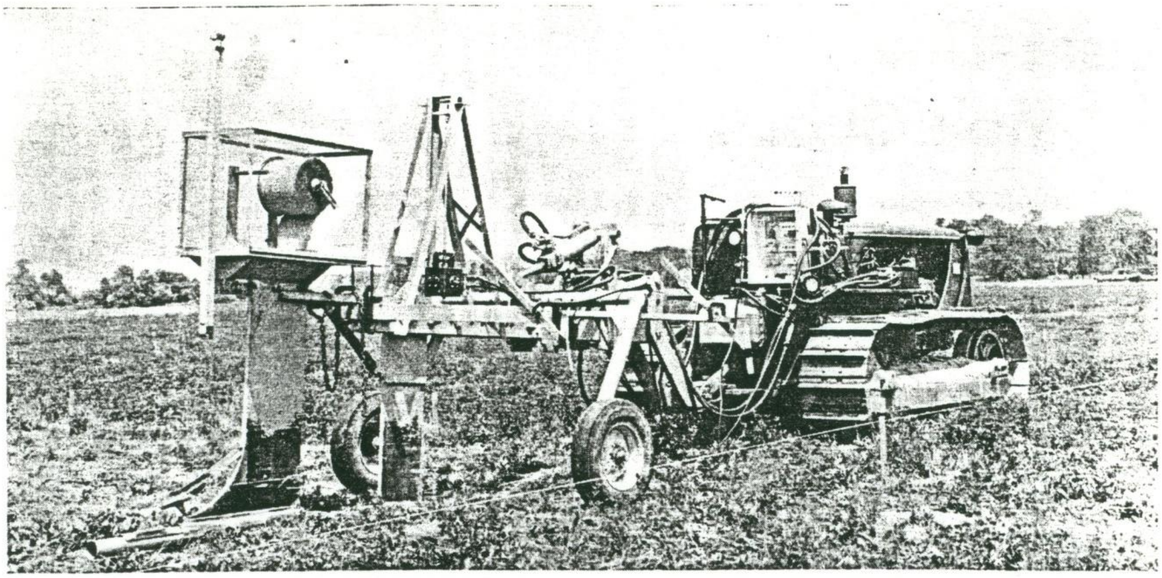

Fig. 2 Mole plow and attached mole-lining implement developed to install plastic lining in a mole drain channel. Completed "zipper" mole liner is shown at the lower left

Installation Equipment

Fig. 2 shows the mole plow and equipment developed for installing the plastic lining in a mole drain channel. Fig. 3 illustrates the progressive transitional forming of the zipper mole drain liner by the mole-lining implement. As the plastic material unwound from the 600-ft supply roll (A), it was folded into a tight U (B) and pulled down a vertical chute to the tubular base of the mole-lining implement; there it was pulled around a specially designed 45-deg directional change roller (C); then the interlocking tabs were fastened by the "zippering die" between (D) and (E), and the plastic liner emerged from the machine in a circular shape (F). The soil slit left directly above the mole liner by the plow blade was closed by a soil displacement device attached to the mole lining implement, shown at the lower left in Fig. 2. This initiated "bridging" of the soil over the mole liner. To prevent brittleness of the plastic during cold weather operations (35 to 50F), the supply roll was maintained at a 75F temperature in a heated chamber on the installation equipment.

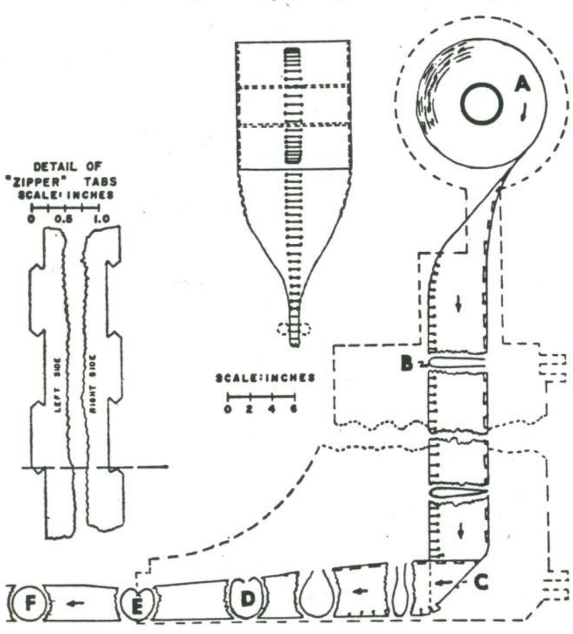

Fig. 3 Progressive transitional forming of the "zipper" plastic mole drain liner by special guides in the mole-lining implement

An operating speed of 100 to 125 fpm and a penetration depth of 28 in. were successfully used in heavy clay soil. At that depth a track-type tractor capable of developing 15,000 to 24,000 lb of drawbar pull (varied with soil and moisture content) was required to pull the machine. By interchanging parts and devices in the mole-lining implement, it was possible to install the various other types of liners shown in Fig. 1. With this versatility, only one basic machine was required to install the various types of mole liners for comparison in replicated field tests.

A floating-beam type of mole plow was adapted to pull the mole-lining implement. The two-wheel dolly shown on the plow in Fig. 2 was used only for lifting and transporting the machine. The wheels were allowed to "float" during field operation. The mole plow operating depth was adjusted by hydraulically changing the angle between the hitch linkage and the plow beam.

An automatic, grade-control system was developed and tested for the floating-beam mole plow. It operated similarly to an automatic leveling device in that it maintained the plow beam at a constant slope (parallel to the drain gradient) regardless of ground-surface irregularities the tractor and machine passed over. A fluid-dampened pendulum (mounted on an A frame on the plow beam, Fig. 2) was used to maintain a vertical reference from which changes in slope of the plow beam were "sensed" as the machine moved forward. The pendulum activated electrical switches that controlled hydraulic cylinders for raising or lowering the front of the plow beam. This maintained the beam at the desired slope. In preliminary field tests the automatic grade-control system worked satisfactorily flat gradients of 0.2 percent and at speeds of 80 to 100 fpm. The performance of the system was evaluated by taking level readings on the rod attached to the machine as it traveled across the field (Fig. 2). The grade string stretched alongside the machine and the string pointers attached to the plow beam were used for visual reference. A few design modifications are being made on the automatic grade-control system, and further testing will be conducted in 1962.

Field Evaluation of Plastic-Lined Mole Drains

Experimental field installations for comparing the various types of plastic mole liners under varying soil types were made in Minnesota, North Dakota, Ohio and Indiana during 1960 and 1961. Results were not available from all these sites in 1961. The experiment discussed in this paper was installed at the North Central substation of the Ohio Agricultural Experiment Station at Vickery, during November, 1960, to compare the zipper, overlap with cap, and plain overlap types of mole liners. The experimental site is on a slowly permeable Toledo silty clay soil, a typical "lakebed" soil, which is very sticky when wet and difficult to till when too wet or too dry. A second-year meadow was in the site at the time of installation, and soil moisture was about 28 percent.

Experimental design. The experiment included three 400-ft drains for each type of liner tested, or a total of nine experimental lines. Two plastic-lined boundary drains and two unlined mole drains were used as controls. The drains were spaced 15 ft apart and were installed 25 to 27 in. deep on a 0.2 percent gradient. All drain outlets discharged into a canal. A stainless steel wire was pulled into each drain during installation to facilitate pulling cross-sectional and grade-alignment measuring equipment through the drains. The inside diameter of each plastic-lined mole drain was measured periodically with a strain-gage "measuring mouse", similar to the one developed by Busch (3). A grade-alignment probe (1) was used to determine the uniformity of the drain gradients.

Results. The diameters of the plastic-lined mole drains were measured nine months after installation and the results are shown in Fig. 4. These results are for only one replication in the experiment, but they are considered typical. The partially collapsed section of the drains shown at

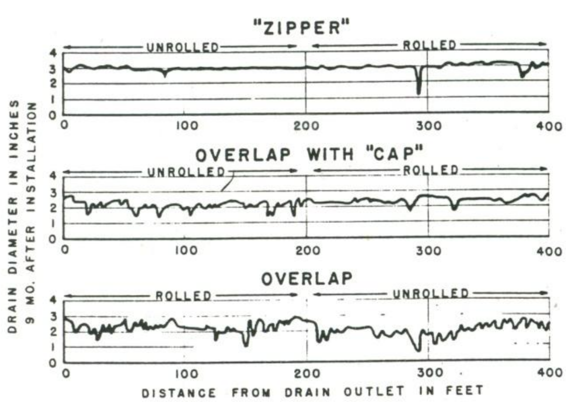

Fig. 4 Diameters of three types of plastic-lined mole drains nine months after installation (Ohio)

290 ft from the outlet, for all three types of liners, was located at a field surface ditch. The mole liners were approximately 12 in. deep at that point. The plastic mole liner wall irregularities observed in September 1961 were unchanged from those observed in March 1961. The plastic drains flowed for the first time in March 1961. The "mouse" could not be pulled through the unlined mole drains because they were almost completely closed with loose soil.

Fig. 4 also shows the effect of surface "rolling" one-half of each drain immediately after installation to close the vertical soil slit left by the machine. One track of a large track-type tractor (7-psi unit pressure) was used to "roll" the slit closed. In general, the rolled sections of the overlap with cap and the plain overlap types of plastic-lined moles were larger in cross section than were those sections not rolled. Surface rolling did not show a significant effect on the zipper-type liner.

The experiment was irrigated in September 1961 with 5.25 in. of water at a rate of 0.25 in. per hour. Immediately after irrigation 0.8 in. of rain fell at a rate of 1.2 in. per hour. Although considerable variations in the diameters of the various types of plastic-lined drains were found, significant differences were not found in the outflow rates or volume of flow from all the plastic-lined drains, including the lined boundary drains. The flow rate from the plastic-lined moles during irrigation was compared with that from 4-in. tile drains in a very similar soil type on the same farm. Under the same application rate of irrigation, the outflow rates per unit length of drain from plastic drains and tile drains were essentially the same.

The plastic-lined drains removed water at a rate of 4.8 in. per day (12.5 gpm for a 400-ft drain) once equilibrium conditions were reached during irrigation. Immediately after the rainfall ceased, an average peak flow rate of 8.5 in. per day (22 gpm for a 400-ft drain) was measured from the plastic-lined drains. Only one of the two unlined mole drains in the experiment flowed, and it was at a much lower rate – 0.2 in. per day (0.5 gpm) during irrigation, and 0.3 in. per day (0.7 gpm) following the rainfall. The total 400-ft length of unlined mole drain probably did not contribute to the outflow since loose soil plugged most of the channel.

Only preliminary field results on the arch types of plastic mole liners were available for this report. Arch-type liners installed in Ohio during June 1961 were more irregular in cross-sectional size than the other types of liners studied.

Field Studies of the Plain Overlap Mole Liner

In the spring of 1959, the plain overlap-type plastic-lined mole drain was installed at eight different locations in California, Nevada, Utah and Colorado. The plastic drains were installed 27 to 29 in. deep in several soil types represented in the various sites. In one installation on a rice plot, an average of 15 tons of salts per acre were removed through the plastic-lined moles by 120 days of flooding. This trial demonstrated that this type of drainage can be employed successfully in a leaching and reclamation program.

Following two seasons of observations it was concluded that the plastic-lined moles were successful in the heavy clay types of soils, partially successful in the silty clay and loam soils, and unsuccessful in the sandy soils. The most critical problem in clay soils appeared to be the management practices immediately after installation. Flooding disintegrated the clods and hastened the repose of the soil around the mole liner. The earlier machine (13) used for these installations did not employ a soil-displacement attachment to close the soil slit directly over the mole liners. The most critical problems in sandy soils appeared to be the prevention of sand entry into the drains through the perforations or along the top overlap, and/or their collapse because of sand entry or hydrostatic pressure of the saturated sand. In general, it was concluded that an installation depth of 42 to 48 in. would have resulted in better performance of the plastic drains in the fine-textured soils.

Laboratory Sand Tank Studies

The field tests in sandy soils led to an investigation in California to study the thin-walled plastic mole liners in laboratory sand tanks. The objectives were to determine stability of the zipper-type mole liner against collapse in saturated sand, and to obtain an opening for water entry into the drain that would exclude the sands but would not appreciably restrict entry of water. Preliminary results indicate that almost any size hole used in the fabrication or conformation of the plastic mole liner will admit some sand into the drain. It was found, however, that the small opening resulting from the interlocking tabs on the zipper mole liner excluded the sands. Further studies will be made prior to field testing the zipper-type mole liner in sandy soils.

Comments and Interpretations

Experience with the mole-lining machine during 1960 and 1961 showed that the zipper plastic mole liner could be installed with as much ease and trouble-free performance of the machine as the simpler overlap or arch types of mole liners. After nine months of field testing, the zipper mole liner had maintained its cross-sectional size and shape better than the overlap types. However, to make a sound evaluation of the various types of plastic mole liner, a long-term study of these drains under field conditions is needed, possibly four to six years.

This application for plastic may have an extremely important function in future drainage developments. Costs for installing the zipper mole liner 28 in. deep in a heavy clay soil are estimated at 10 to 12 cents per linear foot, 8 cents of which is for the plastic material. With further improvement in equipment, grade-control devices and plastics, it may be possible to install 3-in. diameter lined moles up to 4 ft deep in many soils. As depths increase, installation costs increase, but probably not to exceed 17 to 18 cents per linear foot.

If this method of subsurface drainage proves successful, it will have many applications. Probably its most important application would be in heavy clay soils, since the lower cost of installation would permit closer lateral drain spacings resulting in better water-table control. Because the drain size is limited to smaller diameters, these plastic drains would be applicable only for laterals and not mains. They may have extensive use throughout much of the West for leaching saline soils. Their use in the distribution systems of subsurface irrigation in the West may be another application. Many other applications are apparent, such as interceptor drains on hillside seeps, drainage of long narrow waterways, random drains to depressional areas in a field, drainage and water table control of muck soils, etc. Another desirable characteristic of such subsurface drainage systems is that they can be installed in many areas without disrupting normal farming operations or disturbing the crop.

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Plastic Drains and Their Installation

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PLASTIC materials are now showing notable promise for use in subsurface agricultural drainage, even though the material costs for some types of suitable plastic tubing are higher than for ceramic or concrete tile. This is because recent research has provided knowledge of materials-handling and placement techniques for the rapid installation of flexible plastic drain tubes. The new methods will require a lower unit installation charge, and thus result in a lower total cost for the complete drainage system.

Types of Plastic Drains

Two basic types of plastic drains are being evaluated in current research and development programs: (**a**) formed-in-place drains in mole drain channels and (**b**) preformed smooth or corrugated wall tubing in coilable lengths or in 20- and 30-ft straight lengths that can be pulled into a mole channel or laid in a narrow trench.

This paper is concerned primarily with flexible plastic drain tubes. A flexible drain conduit gains part of its vertical soil load-carrying capacity by lateral support from the soil walls of the mole-drain channel or compacted soil sidefill. This lateral support (passive resistance of the soil) occurs as the drain tube deflects outward (flattens) against the soil at the sides of the tube. The use of flexible-tube principles for designing these drains results in a more efficient use of expensive plastic material than relying completely on bending resistance in the pipe sidewalls, as is done with rigid or thick-walled tubes. In general, the experimental plastic drains in the United States have been 2 to 3 in. in diameter when installed by a mole plow, and 4 in. when installed in a trench.

Plastic Sheeting for Mole Liners

Research in Ohio led to the development of a "zippered" plastic mole-drain liner (3, 4)*. This is thin-walled drain 3 in. in diameter which is formed from a 0.015-in.-thick by 10-in.-wide sheet of polyvinyl chloride (PVC) plastic that has interlocking tabs prestamped along both edges. Fig. 1 shows the special floating-beam mole plow and mole-lining implement developed for installing the zippered plastic lining. The

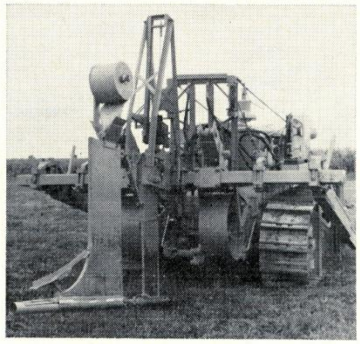

FIG. 1 Floating-beam mole plow with attached mole-lining implement to install zippered plastic lining in the mole drain channel

sheet plastic material is fed from the roll, guided into the ground by the special hollow-blade tool, then formed and "zippered" into a circular tube by the installation tool to form a structural liner for the mole-drain channel. During installation of the plastic mole liner, a soil-compaction wedge on the rear of the mole-lining implement (Fig. 1) closes the plow blade slit immediately above the drain. This completely surrounds the plastic mole liner with soil. The replacement and partial compaction of soil surrounding the liner is important so that soil loads are applied uniformly around the flexible drain tube. If the soil is too dry it cannot be recompacted properly above the drain. The structural stability of the zippered liner depends to a large extent on the moisture condition of the soil at the time of installation and on the inherent stability of the soil surrounding the liner.

The normal speed of drain installation with this equipment is about 125 fpm (ground speed) for drain depths of 30 to 33 in. in clay soils. Under these conditions, a track-type tractor capable of developing up to 30,000 lb of drawbar draft is often required to pull the equipment. About 2,000 lineal ft of plastic-lined mole drains can be installed per hour under good field conditions. The use of coiled-sheet plastic as a drainage material, rather than preformed drain-tube sections, greatly reduces the time, labor, and cost for materials handling from the supplier to the field and during installation. The cost of completely installed zipper-lined drains is estimated at 10 to 12¢ per lineal foot, with about 8¢ of this to cover the cost for the plastic-lining material. The greatest cost savings are derived from the method of installation and not from materials.

Similar types of "zippered" plastic, mole-drain liners have been developed in England (1, 2).

During the past five years in the United States, the zippered plastic mole-lining material has been extensively field tested. These experiments have shown that the circular cross-sectional shape of the mole liner gradually deformed; a pointed-on-top and an inward buckling of the upper sidewalls were typical deformations. Two prime factors were believed to have caused this gradual collapse: (**a**) nonuniform closure of the slit opening above the mole liner, which resulted in localized deformed sections in the drain tube, and (**b**) localized "kinks" in the walls of the plastic liner which were caused during installation by apparent changes in drain line direction or gradient. These initially localized deformed places in the drains seemed to propagate in both directions in the drain line, thus causing the gradual collapse of large segments of drain. This progressive channel collapse is indicated in Fig. 2.

These results are from a field test in Ohio and show the percent of total drain length through which 1½ and 2-in. diameter wooden plugs could be pulled for successive years. The data represent a total of 1200 ft of zippered plastic-lined mole drains, and access to the drain was possible once every 200 ft for internal gaging with the wooden plugs. These experimental results show the need for use of stronger wall material in the zipper liner; also longitudinal flexibility of the zippered tube is needed to permit more freedom in going around gradual bends in the drain line, and in making gradient changes. As suggested by Edminster in his paper in this conference the use of shallow ridges or corrugations across the plastic sheet may solve these problems, but it might be added that the plastics industry's help is needed in this refinement.

The field test results in Ohio have also shown that zippered plastic-lined mole drains should be installed at a depth of 30 in. or greater to prevent damage by deep plowing when the subsoil moisture content is high. In general, more deformations of the mole liner walls occurred during periods of high water-table conditions than dur-

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ing normal farm field operations when the soil was drier. This I believe means that loads imposed on the plastic mole liners by saturated soil may be more severe than those imposed by surface traffic above the drain.

Plastic-lined mole drains were as effective as conventional draintile for lowering the water table in the soil. The deformations of the plastic mole liners over the 5-year test period did not appreciably affect their functioning as a subsurface drain channel. However, the structural stability of the zippered plastic mole liners, as presently designed, leaves much to be desired.

Preformed Flexible Plastic Tubing

Smooth-wall tubing – Although smooth-walled plastic tubing is generally considered expensive, there are certain applications where it can be used effectively and yet remain competitive with conventional drainage materials. This plastic tubing is generally best handled in either large diameter coils or in straight lengths of 20 to 30 ft each. Since this material does not have good characteristics for coiling or for feeding around sharp corners, its major drawback is handling during the installation operation. If the smooth-walled tubing is to be installed by the mole plow method, the most satisfactory procedure is to pull it into the mole channel behind the plow from the outlet end of the drain. Actually, this technique of installation was used by Schwab (6) in the 1940s; this early research was the first of many plastic drainage approaches which have followed. This method of installation is probably limited to maximum drain lengths of 400 to 600 ft in most soils.

If the tubing is installed in a trench, the bottom of the trench should be shaped into a semicircular cradle to support the walls of the flexible plastic tube. Research has been conducted in Texas to properly install such a tube by a modified trenching machine. The machine digs a narrow trench so that the installation operation can be speeded up. By connecting 30-ft lengths into a continuous tube, the installation can be accomplished with fewer crewmen. The high rate of installation with less labor reduces the total cost even though the plastic tube itself is generally more expensive than the same diameter conventional draintile. This method of drainage with suitable plastic material has been well accepted by various groups and agencies in the lower Texas area, and is now a certified practice which qualifies it for cost-sharing between the farmer and the government.

The kind of plastic used for the smooth-walled tubing is quite important. The material should have good

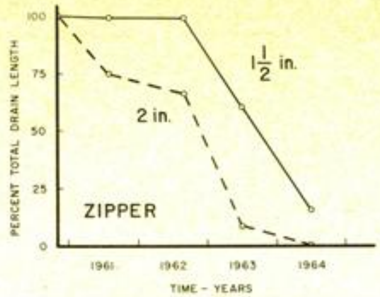

FIG. 2 Percent of zippered plastic-lined mole drain length through which 1½ and 2-in. diameter wooden gage plugs would pass in successive years (northern Ohio)

creep resistance so that the tube will not gradually sag (or deflect) under soil loading. For example, low-density polyethylene plastic generally does not possess good creep resistance; PVC and high-density polyethylene are much better in this regard. From a cost standpoint, for the smooth-walled tubing, the wall thickness should be as thin as possible to obtain the required soil-loading capacity so that the cost is held to a minimum.

Corrugated-wall tubing – When compared to smooth-walled plastic pipe, a corrugated tube-wall provides equal crushing strength with much less plastic material per unit of tube length. Since the cost of plastic tubing is almost directly related to the amount of material used, the corrugated tube would be considerably lower in cost. The corrugated plastic tubing can also be coiled for shipment and handling on smaller diameter spools than smooth-walled pipe without kinking problems. The corrugated tubing can be installed with either a trencher or a mole plow, but the mole-plow method of installation seems most promising because of its faster field operation. Since the corrugated tubing can be easily fed around sharp curves, it can be installed with a hollow-bladed tool pulled directly behind the mole plow (Fig. 3). Such an installation tool guides the tubing through a sharp curve to insert it in the mole drain channel. The blade of the tool must be slightly thicker than the tube diameter, which may limit maximum drain size with this method

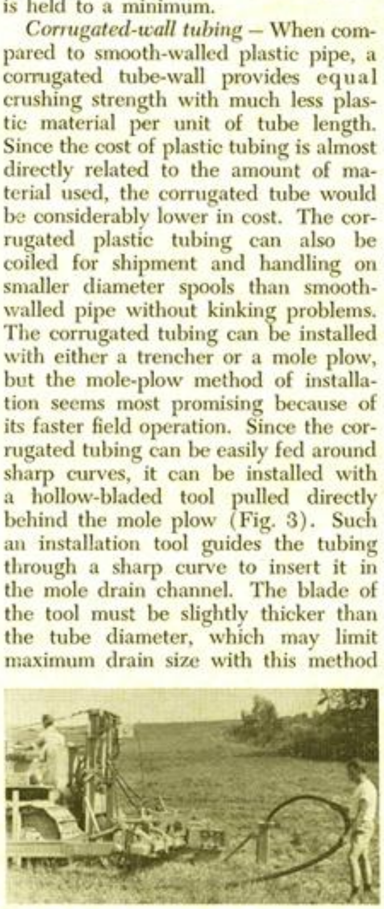

FIG. 3 Corrugated plastic drain tubing being installed with hollow-bladed tool drawn behind a mole plow. This material could be fed from a coil mounted on the equipment

to less than 4 in. It has been demonstrated in field trials that the soil erupted by the passage of such a thick blade during installation of corrugated plastic pipe can be adequately recompacted with two passes of a crawler-tractor track, one pass on each side of the soil slit.

If the corrugated plastic pipe is fed from a coil mounted on the tractor, the installation of this material is even easier and faster than that of the zippered plastic mole liner. Also, a valuable feature is that either perforated or nonperforated corrugated plastic tubing can be installed – the zippered plastic mole liner material requires perforations and slits to provide flexibility during installation. More than one diameter size of corrugated plastic tubing can be installed with the hollow-bladed tool (Fig. 3), but with the zippered tube only one diameter size can be used in any given tool. These are practical considerations that have been taken into account when evaluating the various drainage methods and materials.

The speed of installation is not governed by materials handling for the corrugated tubing, but rather by the maximum machine speed for which adequate depth and grade control can be maintained. This latter item will be discussed below in more detail.

Foamed-Plastic Drain Tube

Preliminary research results have shown considerable promise for foamed polystyrene plastic material for use as plastic mole liner or plastic drain tube. In a recent patent disclosure by Dow Chemical Co.†, a possible method was illustrated for installing a foamed-plastic mole liner by in-place extrusion within the mole drain channel directly behind a mole plow. This idea would conceivably involve pumping a heated polystyrene plastic "gel" down a tube and through an extruder die mounted behind a mole plow. Within the mole channel, the "quick-setting" plastic would expand (foam) into a finished drain tube, and then it would be perforated for water entry by some device behind the extruder die. It is reasonable to expect that this method of installation would be possible in today's technological world; however, specialized equipment needing very precise operation and control would be required. For the present, more practical promise is offered for a preformed foamed-plastic drain tube installed in a trench.

If the foamed-plastic drain tubing is preformed (manufactured), it offers several advantages. For example, it is lightweight and the material cost would

† Company names are included for the benefit of readers and do not imply product endorsement by the USDA.

be considerably less than for other plastic-drain materials discussed in this paper and even less than the cost for conventional tile. A 10-ft section of 4-in.-diameter tube with ½-in. wall thickness, made from standard density expanded polystyrene, would weigh only about 3 lb. Sections of the tube 10 to 15 ft long would be rigid but could be carried on the ditching machine and placed in the trench mechanically or by hand. For such trench-laid foamed-plastic drains, the backfilling operation would have to be performed with care to prevent damaging the drain tube.

Since this foamed-plastic drain is made of relatively low-strength material, special attention must be given in its installation to insure a structurally successful drain. The bottom of the trench should be shaped to provide a semicircular cradle of support for the flexible drain tube as was discussed for the smooth-walled plastic pipe. The density of the foamed plastic material in the tube wall is also important in determining the amount of deflection the drain can undergo without rupture of its walls. If the plastic density is too high, the foamed plastic tube will be brittle and only a slight tube deflection can cause the wall to rupture.

Drainage Equipment Innovations

With new drainage materials coming into the picture, new and modernized methods of installation are also essential to provide for a faster installation at a lower cost. The use of the mole plow for installing several types of plastic drain tubes is showing very impressive advantages in drainage equipment innovations. A mole plow which can be operated with a floating-beam principle and/or constant depth operation using depth gage wheels provides the versatility to meet a variety of field conditions. The mole-plow method of installing plastic drain tubes has been satisfactory even under such adverse field conditions as 20-percent sideslopes with large sandstone rocks beneath the soil surface. Such conditions of excessive slope and rocks in the soil make the use of conventional tile-trenching machines impractical. When numerous rocks are present, a preliminary pass of the mole plow is made to break or move the rock. The plastic drain is installed during the second pass of the machine.

At the high ground speeds possible with the plastic mole-lining equipment, grading by manual control is not adequate. An automatic depth- and grade-control system is needed for the drainage method to be put into practical use. A grading system is needed that will greatly reduce or even eliminate the required multitude of grade targets or string references characteristic of most grading systems presently used. If such grading references were needed, it could take up to three teams of three men each to set grade string (or wire) references fast enough to keep ahead of the plastic mole-lining equipment.

One system of automatic grading that has been tested on a floating-beam mole plow and a wheel trenching machine was based on a fluid-damped pendulum (5). The pendulum device was mounted on the mole plow beam (Fig. 1) or trencher frame to detect changes in its slope. It operated similarly to an automatic leveling system in that it maintained the plow or trencher beam at a nearly constant slope (parallel to the desired drain gradient) regardless of the ground-surface irregularities the tractor or machine passed over. This grading device functioned quite well on the slow-moving trenching machine under a variety of field operating conditions. The use of the pendulum automatic system on the high-speed mole plow gave better drain grades than those accomplished by manual control; however, it was not dependable under many field conditions. Since the pendulum was an on-machine referencing device, its dynamic stability and its tendency to make accumulative errors were its major limitations. Research is continuing in the United States to develop a grading system based on an off-machine referencing device. An example of such a device is a narrow light beam projected across the field and detected by an instrument mounted on the plow beam. In this system the grading reference (the beam of light) would not be subjected to machine vibrations and motions, as with the pendulum device. A gas laser light beam, which has received much publicity lately, may be applicable in this system. A light-beam grading system has already been successfully developed and tested in England, and in another paper during this conference Dr. Ede discusses its features. It is well to point out that automatic grading on any drainage machine is not merely accomplished by hooking up some new pendulum or light-beam device. The hydraulic depth-control mechanism, its speed of response and sensitivity, and other factors must be considered in the design of the grading system for the drainage machine. Conceivably many present-day trenching machines would require alterations in their hydraulic-control components before acceptable automatic grade control could be achieved, regardless of the grade-referencing device.

Comments

These new materials and methods for subsurface drainage offer but a sample of the developments possible under intensive research and development programs. Structural stability of the plastic drains is the prime concern —most of the plastic materials under consideration are inert to microorganisms and chemicals found in the soil.

For the small-diameter plastic drains, grade control is probably more important than hydraulic capacity. This is particularly true in areas requiring intensive drainage when close lateral drain spacings are needed; the closer the laterals are spaced, the less water each drain must carry for a given drainage coefficient. In many clay soils, the hydraulic conductivity of the soil rather than the hydraulic capacity of the drain limits outflow of the drain. Most of the experimental plastic drainage materials discussed in this paper would only serve as lateral drains; sizes large enough for mains would not be practical or economically feasible for many of these materials.

In the area of drainage equipment developments, the modified mole plow shows good potential because it can be operated at higher speeds than conventional trenching equipment. If the mole plow method of installation is to receive acceptance for practical use, a foolproof and economical automatic grading system must first be developed for the mole plow. For drain depths greater than 4 ft in very heavy soils, the mole plow method may not be so practical because of excessive draft requirements.

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APPENDIX-II

Assignment of the ARS Plastic-Lined Mole Drain Research Project to James L. Fouss - 1959:

I first learned about the ARS Plastic-Lined Mole Drain research project during my interview (in August 1959) for the new engineering research position being created at The Ohio State University to continue the project. The earlier phase of the project had been conducted at Cornell University, but the engineer on the project (Charles Busch) was leaving ARS for a foreign assignment. ARS, in particular, Mr. T. W. Edminster [Associate Director of the Eastern Branch of the Soil and Water Conservation Research Division of the Agricultural Research Service (ARS), located in Beltsville, MD], made the decision to relocate the project to The Ohio State University so that the new engineer could work under the general guidance of Dr. Glenn O. Schwab (Professor of Agricultural Engineering at OSU), who had earlier research experience (at Iowa State Univ.) with smooth-wall PE plastic pipe pulled into a mole drain channel from the outlet end of the drain with a mole plow. At the time of the interview I had been working for Dr. Schwab nearly two years as his student assistant (during my undergraduate education in Agricultural Engineering). Dr. Schwab had arranged for Mr. Edminster to interview me for the upcoming new engineering position. Schwab and Edminster had know each other for several years since they were assigned to work together on the same Agricultural Engineering textbook writing team to author the text of Soil and Water Conservation Engineering published by the Ferguson Foundation (one of the texts I used in my soil and water engineering courses in drainage and irrigation under Dr. Schwab). The Ferguson Foundation published the entire subject matter series of Agricultural Engineering textbooks used at many land-grant Universities in the U.S.

I won’t give any further details here about the interview other than to indicate the interview went very well and Mr. Edminster asked me to fill out the government employment application on SF-57 and forward it to him for processing. I began to worry as time passed whether the “processing” would be completed and a decision reached on my employment by the time I graduated with my Bachelor of Agricultural Engineering degree on Dec. 18, 1959. As it turned out the final confirmation that the engineering position was mine was received via phone about one hour before I attended the graduation ceremony at OSU that day, and also the day that Judy and I signed a lease for a new apartment near the OSU Campus. However, it still took about three more weeks for all the paperwork to be completed, but it was completed by Jan. 6, 1960, the day I was to "*report for duty with ARS*" in the Agricultural Engineering building (Ives Hall) at The Ohio State University. I was finally on the ARS payroll to begin my engineering research career.

Prior to my "*report for duty*" date, Mr. Edminster had a special assignment for me and he wanted me to attend the Winter Meeting of the American Society of Agricultural Engineers (ASAE) being held in Chicago, IL during late December 1959. The ASAE meeting was held the week following my graduation from OSU on December 18, 1959, *as I recall*, and I attended as an official ARS Collaborator (a temporary appointment arranged by Mr. Edminster so that my travel and lodging expenses could be reimbursed by ARS). The purpose for me attending the meeting was to **listen and take notes** at a special discussion session arranged by Mr. Edminster and the Beltsville office staff for all the prior ARS drainage researchers who had conducted any experiments or had field tests ongoing for evaluating the plastic-lined mole drains developed by Charles Busch at Cornell University and by the Caterpillar Tractor Co., in Peoria, IL. Some of those in attendance were planning on installing new field experiments to test the different types of plastic-lined mole drains under their regional soil and climate conditions. The planned additional installations were held up because Charles Busch had resigned his ARS engineering position.

There were a total of six ARS employees (research engineers and administrators) in attendance at the discussion meeting (*as I recall*), and they were (their locations are given within the parentheses after each person's name): T. W. Edminster (Beltsville, MD); William (Bill) Raney (Beltsville, MD); William (Bill) Donnan (Riverside, CA); Lyman Willardson (Logan, UT); Red Doering (Mandan, ND); John (Jack) Diamond (with Caterpillar Tractor Co. in Peoria, IL). Charles Busch was not in attendance as he had already transferred to his foreign assignment. During the two-day meeting I took extensive notes and filled two steno-pad notebooks.[9] Mr. Edminster opened the discussion meeting and introduced me to the group, plus he outlined the purpose for my attendance as a candidate for the project's engineering vacancy that had been relocated to Columbus, OH on The Ohio State University campus. Mr. Edminster then provided the lead-off discussion about the project and gave a summary review of the prior progress made by Charles

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[9] Over the years, and after my movements to five different offices, I have lost the notes I took so long ago at that discussion meeting in Chicago.

Busch at the Cornell University duty station. Review copies of 4 published papers on the experimental results from the earlier project phases conducted by Busch were passed out for the groups review and discussion. The earlier published research results indicated, and the group's discussions revealed, that the previous plastic mole-drain liners already field tested were not strong enough to avoid distortion of cross-sectional shape and/or partial collapse of the drainage channel. It was concluded from the earlier results that a stronger liner was needed to withstand the soil pressure exerted on the mole-drain liner under wet soil conditions, and especially in clay soils.

Each person at the meeting discussed his ideas and suggestions for improving the plastic mole-drain liners. After some lengthy back-and-forth discussions, all agreed that a circular liner would be better than an arch-shaped liner, and that the circular liner needed to have the edges of the 15-mil thickness PVC plastic sheet attached together in some manner, and not merely overlapped as was done with the Caterpillar type circular liner. Several methods to attach the edges of the plastic sheet to form the circular liner were discussed and included: taping at overlap, stapling at overlap, an overlapped rivet joint, glued overlap, or heat-bonded overlap. In the wrap-up discussions, Mr. Edminister indicated that the **assignment** for me was to develop a full-circular liner with the edges of the PVC plastic sheet attached in some manner, but it would be my decision on how to do that as the liner was placed into the mole-drain channel behind the mole-plow. The fastened full-circle liner was to be used in any future field experiments installed.

In one-on-one discussions following the group discussions, Jack Diamond (from Caterpillar Tractor Co.) indicted to me that he wouldn't want my job on the project. Jack had worked with Charles Busch during the previous few years and they cooperated on work to develop the overlapped circular mole liner installed in field experiments. Jack did add that perhaps adding a "cap" (narrow width sheet of plastic over the overlap joint at the top of the liner) may help to stabilize it in the soil. In the final wrap-up to the meeting, Mr. Edminster related to the group that I was highly recommended for the vacant engineering position by Dr. Glenn O. Schwab at The Ohio State University, who I had worked for as a student assistant for 2 years before I graduated with my Bachelor of Agricultural Engineer degree just the week before. He reminded the group that, "Dr. Schwab had early experience during his doctoral research at Iowa State University (during the 1950's) with smooth-wall polyethylene plastic pipe pulled into a mole-drain channel with a mole-plow, starting at the drain outlet." He added that Dr. Schwab would provide valuable local guidance for Jim in his new assignment." Those in attendance knew that Mr. Edminster and Dr. Schwab had known each other for several years and had worked together on the one-year assignment for the Ferguson Foundation to help write the Agricultural Engineering college textbook on "Soil and Water Conservation Engineering".

I will not cover here many details about the plastic-lined mole drain research project that I undertook following that meeting in Chicago in December 1959. I will let the two publication reprints included in Appendix-I provide those details. I will add, however, some events not covered in the publications: **(1)** I renamed the research project from the "Low Cost Subsurface Drainage" project, to the "Plastic-Lined Mole Drain" project, after I was able to convince Mr. Edminster about my reason for wanting to re-title the project.[10]; and **(2)** My engineering technician (Norman Fausey) and I completed the design goal to fasten the edges of the PVC plastic sheet, with the idea for the "Zippered" plastic-lined mole-drain, in about a 6 to 7 month time frame. We conducted the initial and preliminary field testing of the Zippered mole-drain liner and its installation equipment during the summer of 1960 on The Ohio State University research farm near the campus in Columbus; and **(3)** In September 1960 (when we were 9 months into the project), we were scheduled by Mr. Edminsterand the ARS Beltsville, MD office to travel to Northern Minnesota and North Dakota to install two ARS field projects for evaluating plastic-lined mole drains (including the new Zippered liner). Those planned projects had been delayed earlier when Dr. Charles Busch resigned from ARS leaving the project without an engineer. The projects were installed near Crookston, MN and Grand Forks, ND, and the purpose of installing them in September was in hopes of beating the arrival of winter weather and frozen ground (and snow too), and of course avoiding another delay of the projects for the local ARS agricultural engineers in charge of the projects.

After we returned to Ohio, some revisions and updating of the mole-liner equipment was

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[10] My thought was that 'Low Cost' should not the highest priority objective, a factor Yes, but not the most important objective. I felt it more important that the mole-drain liner should "WORK" rather than just Cost Less. This was something I learned in an engineering class under Prof. Richard Miller (Agr. Engr.) on how to think about objections and end goals for projects. Mr. Miller illustrated to his students that in design if we held the Penny (*the cost factor*) too close to our eye (*thus ranking it at a high priority*), it would block our view to other factors that should be considered at higher priority than cost. He stated it was OK to consider cost at a higher priority once it is determined an idea **Works**!

implemented to overcome some operational difficulties encountered in MN & ND.[11] Our own field project was installed during late November 1960 in Northwest Ohio near Castalia. We were thankful that winter weather in northern Ohio did not delay our own field project.

In the years 1961 and 1963 we installed two additional field experiments that had been tentatively planned before I took over the project in 1960. In 1961 Norm and I installed another plastic-lined mole drain project at Walkerton, IN on the Purdue University muck crop research farm; that project was for Dr. Edward Monke, an Agricultural Engineering professor at Purdue University. We returned to Walkerton, IN during the summer of 1962 to inspect the plastic mole-liners installed in the muck soil. Also during 1962 we designed and constructed the tool-bar mounted research mole-plow in the shop of the OSU Agricultural Engineering building. The new mole plow was used in late 1962 to install the second plastic-lined mole drain field project with all zippered liners at the Castalia, OH site. Then in 1963 we took the long truck trip from Columbus, OH to Logan, UT to install another of the promised field experiments for the Western Region of the ARS Soil and Water Conservation Research Division; that experiment was for Lyman S. Willardson, an ARS Agricultural Engineer stationed in the Civil Engineering Dept. at Utah State University. That installation at Logan, Utah completed the planned or promised projects before Norm and I were involved in the research. The final plastic-lined mole drain field projects were our own installed in Northern Ohio (at the Castalia, OH site) in late 1963 and in 1964.

The reprint of the 1962 ASAE published paper included in Appendix-I includes the field data we collected from the initial Northern Ohio experiment with the zippered mole-liner; the data reported in that paper was collected over the first 9 months after the drains were installed in late 1960. The reprint of the second paper in Appendix-I, the 1965 published paper presented at the first ASAE sponsor ***National Drainage Conference***, provides the final report on the plastic-lined mole drain project and the introduction of the continuing project on the use of <u>corrugated-wall</u> HDPE plastic tubing plowed-in for the subsurface drainage conduit. That 1965 ASAE paper also provided the insight for the possible future application of the small (collimated) <u>laser light-beam</u> as an off-machine grade-control reference-line for the high speed drainage plow equipment when

[11] Because of the operational difficulties encountered in MN & ND. it took a bit more than one month to complete the two field installations. I remember that month away from home well as my son was only 2 months old when we left for MN, and upon my return I had to get to know him all over again.

installing corrugated plastic drain tubing.

There is one other factor related to the Zippered plastic-lined mole drain project that was never discussed publically or published. It centered around a discussion I had with my graduate advisor, Dr. Glenn Schwab, that my evaluation after about 6 to 9 months of field testing data for the Zippered plastic-lined mole drain had lead me to **think** the Zippered mole-drain liner would not provide the deflection resistance strength for long-term structural and functional stability needed for a good subsurface drain. Dr. Schwab did not disagree with me, but reminded me that the research assignment I had been given by ARS was to develop and test a closed-circular mole-liner, and he acknowledged that the Zippered liner fulfilled part of that objective. Then Dr. Schwab continued in his response and stated that what my **thinking** was at that stage in my young research career did not count for much, because I did not have the data to prove it. He recommended that I get enough data from my field experiment to document and prove my **thinking**, and then make a report on it for publication. He added in that way I would acquire creditability in my research documentation and reporting, and in so doing any proposals I might make in the future for research, or changes in research, that needed to be undertaken in my opinion would likely be listened to and acted on by colleagues and administrators. That advice stayed with me for the rest of my research career. The 1965 ASAE paper I presented at the first National Drainage Conference (see 2nd reprint in Appendix-I) included the proof that Dr. Schwab was talking about.

I will include here one additional comment regarding the many discussions and idea sharing I had with Dr. Schwab in the first few years of the project. After we had the field research data to show that the Zippered plastic-lined mole drain was not going to be suitable for long-term use in agricultural subsurface drainage, and we adopted the corrugated-wall HDPE plastic tubing for our continued research, Dr. Schwab was very proud of the accomplishments we had made in the project. And once enough field data had been acquired to show (prove) that the corrugated-wall HDPE tubing was going to work well for the subsurface drainage conduit, and the new corrugated plastic drain manufacturing industry was rapidly expanding, Dr. Schwab said to me, "I wish that I had thought of that wrinkled-wall plastic tubing many years ago, and then I would be famous instead of you." – and we both had a good laugh about it.

# # # # #

JLFouss; 07/14/2015

APPENDIX-III

Fouss, J. L. 1973. Structural design procedure for corrugated plastic drainage tubing. USDA-ARS Technical Bul. No. 1466, July 1973. 42 pp. [*PDF file copy on CD attached in this Appendix III*]