FactSheet Extension

Ohio State University Extension Fact Sheet

Food, Agricultural and Biological Engineering

590 Woody Hayes Dr., Columbus, Ohio 43210

Trenching and Excavation: Safety Principles

AEX-391-92

Larry C. Brown
Kent L. Kramer
Thomas L. Bean
Timothy J. Lawrence

Trenching and excavation procedures are performed thousands of times a day across the United States. Unfortunately, about 60 people are killed in trenching accidents each year. Contractors and construction laborers should understand the laws and regulations applicable to trenching and excavation occupations. These statutes are in effect for the express purpose of protecting those who work in trenching and excavation situations. Although farmers are generally exempt from the state trenching and excavation statutes, they may still be held liable for accidents and loss of life resulting from trenching and excavation activities conducted under their direction.

This publication provides Ohio's construction contractors, laborers and farmers with an overview of soil mechanics relating to trench and excavation failures, and of Ohio's trenching and excavation laws. It is not intended to provide the reader a strict legal interpretation, but to increase his/her awareness of excavation and trench safety, and provide guidance on where to obtain more information.

Soil Mechanics

In trenching and excavation practices, "soil" is defined as any material removed from the ground to form a hole, trench or cavity for the purpose of working below the earth's surface. This material is most often weathered rock and humus known as clays, silts and loams, but also can be gravel, sand and rock. It is necessary to know the characteristics of the soil at the particular job site. Soils information is used by contractors and engineers who are trained to identify the proper safety protective devices or procedures needed for each situation. (The U.S. Department of Labor's Office of Occupational Safety and Health Administration, OSHA, stresses the need for a "competent person" to be in charge of all excavation and trenching activities at a job site.) Soil scientists and geotechnical specialists can be helpful in identifying and characterizing soil materials. Contact your county Soil Conservation Service office for a list of soil scientists in your area, and/or consult the telephone Yellow Pages under the heading of "engineers" with the specialty of "geotechnical" and/or "soils."

Soil is an extremely heavy material, and may weigh more than 100 pounds per cubic foot (pcf). A cubic yard of soil (3 ft x 3 ft x 3 ft), which contains 27 cubic feet of material, may weigh more than 2,700 pounds (lbs). That is nearly one and a half tons (the equivalent weight of a car) in a space less than the size of the average office desk. Furthermore, wet soil, rocky soil or rock is usually heavier. The human body cannot support such heavy loads without being injured.

From a soil mechanics point of view, one can visualize the soil as a series of multiple columns of soil blocks, with the blocks piled one on top of the other. In the soil column shown in Figure 1, each soil block measures one foot square, weighs approximately 100 lbs, and supports the weight of all of the blocks above. This means that a block sitting at a five-foot depth supports its own weight and the combined weight of the four blocks resting on it. The combined weight of this column is 500 lbs spread over a one-square-foot area; 500 pounds per square foot (psf). This five-block column constitutes a 500-pound force exerted vertically on whatever lies below.

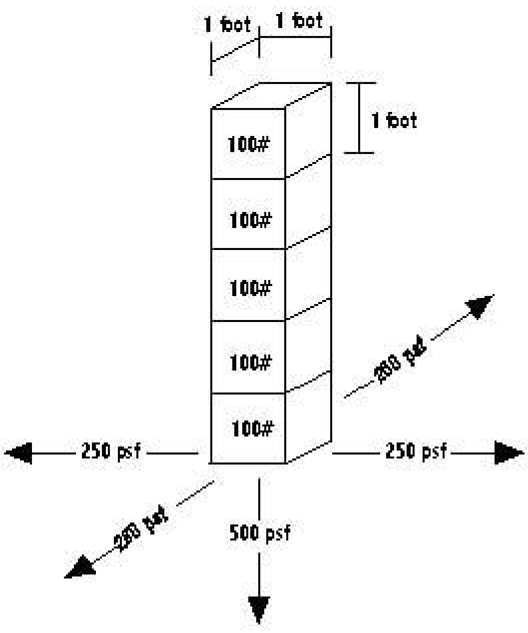

Figure 1. Forces exerted by a column of soil (abstracted from Mickle, 1991).

A column of soil exerts not only a vertical force, but also a horizontal force in all outward directions. The outward force is equal to one-half the vertical force. For example, the five-block column illustrated in Figure 1 has a downward vertical force of 500 lbs at the base of soil block number five. The horizontal force pushing out from the base of that same block is half of 500 lbs, or 250 lbs, in all outward directions. As the weight of the column increases, the soil blocks at the bottom of the column theoretically have a tendency to compress and spread outward. In undisturbed soil conditions, this process is stopped by the presence of the surrounding columns pushing back with equal pressure. These hypothetical columns press against each other, maintaining an equilibrium. Therefore, the horizontal pressures of all the columns are balanced, producing a stable relationship.

Trench Failure

When a trench is excavated, the stable relationship described in the previous section no longer exists (see Figure 2). The horizontal pressure on the soil blocks along the trench wall is no longer in equilibrium, and a block may not be able to support its weight and the weight of any blocks above. At the point where the soil can no longer withstand the pressure, the wall will shear and break away from its stable position, as indicated in Figure 2a. The first failure occurs as the bottom of the wall moves into the trench (see Figure 2b). This movement creates an undercut area at the base of the trench as soil material along the wall falls into the trench. Often there is a second movement in which more of the wall material erodes. Finally, the erosion at the base of the trench leaves the upper part of the column supported only by cohesion to the columns around it (see Figure 2c), and more soil from the column will soon fall into the excavation (see Figure 2d). Many rescue attempts are unsuccessful because rescuers attempt to save victims before the second and third failures take place, often trapping the would-be rescuers along with the first victims.

Figure 2-e summarizes the three areas of failure in the trench wall as explained in the example above. In order of occurrence, soil in Area 1 at the base of the wall moves into the trench, and then is followed by the failure of Area 2. The failure of Areas 1 and 2 leave the remaining trench wall, Area 3, unsupported. Area 3 will break the cohesion and shear off the wall under its own weight and fall into the trench. Typically, time elapses between the failure of segments. It is the uncertainty of when the next failure will occur that makes rescue or recovery extremely hazardous. Time is a major consideration. The longer the trench is unsupported, the more potential there is for further trench collapse.

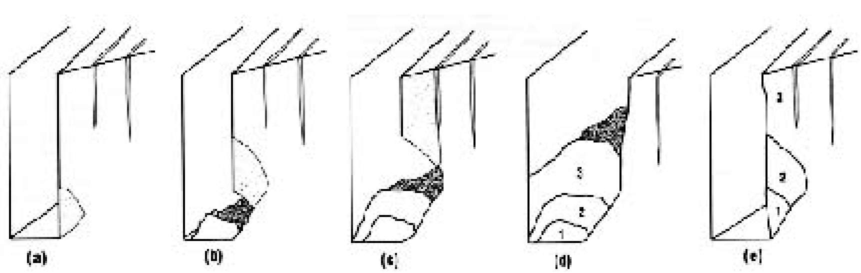

Figure 2. Mechanics of a trench failure (abstracted from Mickle, 1991).

Some employers and contractors believe that proper safety procedures waste valuable time and money, and that faster work creates larger profit margins. However, accidents that occur because safety precautions are not taken can be costly. In addition to the loss of human life, the possible financial costs of a trenching accident include: work stoppage to rescue the victim; additional time and labor to re-excavate the collapsed trench; workers compensation costs and increased insurance premiums; and additional paperwork resulting from the investigation of the accident. In some cases, fines are also imposed. For example, OSHA recently fined a contractor $232,000 after the death of a worker in a trench cave-in. Six company employees were in a 12-foot deep trench when it collapsed, killing one person and injuring another. OSHA determined that the trench was not properly supported. In another case, OSHA cited a company $580,000 for the alleged willful and serious violations of federal excavation standards. The combination of potential fines, loss of human life, personal lawsuits and poor public relations could mean the end of a successful business.

General Requirements

When performing trenching and excavation operations in Ohio, there are general precautions that should be considered before starting any work. Contact the Ohio Utility Protection Service, OUPS (1-800-362-2764), and the Oil and Gas Producers Protection Service (614-587-0486), to identify the location of any underground cables, pipes or utility installations in the area of the proposed excavation. Ohio law requires excavators to call OUPS two working days before breaking ground. Once these areas are located and marked, avoid them. When working in areas where there is a back-filled trench, or a railroad, highway, source of vibration or other unstable condition, take additional precautions to properly shore and brace the excavation. These precautions will help prevent cave-ins. Undercutting of exposed vertical faces is prohibited unless supported by one or more of the methods prescribed in the Ohio Administrative Code, Chapter 4121:1-3, for exposed faces of trenches. Place all excavated or fill materials a minimum of two feet away from the top edge of the trench. If materials need to be placed closer than two feet from the edge of the trench, install an effective barrier to prevent them from falling into the excavation.

The following is a summary of the trenching and excavation laws that apply in Ohio. (Consult the Ohio Administrative Code, Chapter 4121:1-3, directly for further details.)

Trenches

Exposed trench faces that are more than five feet high must be stabilized by either shoring, sloping the face of the wall back to a stable slope or some equivalent method to prevent cave-ins. (The definition of stable slope is based on soil properties as noted in the Ohio Administrative Code, Chapter 4121:1-3.) If the trench is excavated in hard, compact soil materials more than five feet in depth, the wall must be supported. If the walls of a trench are less than five feet deep and in soft or unstable soil materials, then trench boxes, shoring, sheeting, bracing, sloping or other equivalent methods are required to prevent the trench wall from collapsing. Trench walls above five feet in height may be sloped instead of shored.

Materials used for trench boxes, sheeting, sheet piling, bracing, shoring and underpinning should be in good condition, and should be installed so that they provide support that is effective to the bottom of the trench. Timber must be sound and free from large or loose knots. Vertical planks in the bracing system should be extended to an elevation no less than one foot above the top of the trench face.

When employees are required to be in trenches that are four feet or more in depth, an adequate means of exit, such as a ladder or steps, must be provided and located so that no more than 25 feet of lateral travel is required for a person to reach the exit structure. The trench should be braced and shored during excavation and before personnel are allowed entry. Cross braces and trench jacks should be secured in true horizontal positions and spaced vertically in order to prevent trench wall material from sliding, falling or otherwise moving into the trench. Portable trench boxes (also called sliding trench shields) or safety cages may be used to protect employees instead of shoring or bracing. When in use, these devices must be designed, constructed and maintained in a manner that will provide at least as much protection as shoring or bracing, and extended to a height of no less than six inches above the vertical face of the trench.

During the backfill operation, backfill and remove trench supports together, beginning at the bottom of the trench. Release jacks or braces slowly and, in unstable soil materials, use ropes to pull them from above after employees have left the trench.

Excavations

Excavation safety requirements are quite similar to trenching requirements. For excavations in which employees may be exposed to unstable ground, qualified personnel using practices that are compatible with standards required by a registered architect, a registered professional engineer or other duly licensed or recognized authority will design support systems such as piling, cribbing, bracing and shoring that meet accepted engineering requirements to contain the walls. Excavations with conditions such as water, silty materials, loose boulders, erosion, deep frost action or earth fracture planes require that the slope of the earth adjacent to the excavation be lessened. Scaling, benching, barricading, rock bolting, wire meshing or other equally effective means of excavation support must meet accepted engineering requirements for all sides, slopes and faces of excavations. Materials used to support excavations should be maintained in good condition.

Never excavate below the level of the base of the footing or retaining wall, except in hard rock, unless the wall is underpinned and appropriate precautions are taken to ensure the stability of adjacent walls. If it is necessary to place or operate power shovels, derricks, trucks, materials or other heavy objects on a level above and adjacent to an excavation, the side of the excavation must be sheet-piled, shored, braced or sloped as necessary to resist the additional pressure resulting from such loads. Install substantial stop logs or barricades when using mobile equipment on or near an excavation, grade away from the excavation, and provide walkways or bridges with standard guardrails for employees or equipment to cross over excavations.

Summary

This publication provides an overview of the basic soil mechanics of a trench failure, and Ohio and federal laws which regulate trenching and excavation activities. The actual laws applicable in Ohio can be found in Chapter 4121:1-3 of the Ohio Administrative Code, which can be obtained from larger public libraries, private law firms, the office of your county district attorney and OSHA offices. OSHA can provide manuals, drawings, etc., and all federal regulations and requirements. For more information, contact any of the following:
US Department of Labor-Occupational Safety and Health (OSHA) Ohio Office: Federal Building, 200 North High Street, Columbus, OH 43215 (614) 469-5582.
Region V Office: 230 South Dearborn Street, Room 3244, Chicago, IL 60624 (312) 353-2220.
Ohio Workers Compensation, Division of Safety and Hygiene, South-Central Regional Office, 6929 American Parkway, Reynoldsburg, OH 43068 (1-800-852-7464).
Ohio Land Improvement Contractors' Association (OLICA), Box 116, Dublin, OH 43017

Key Points

Identify the soil characteristics at the work site, and use this information to provide a safe work place for construction laborers.

Use prescribed methods of wall retention, piling, cribbing, sloping, shoring, trench boxing and sheeting to maintain trench and excavation walls. For each trenching or excavation situation, you should employ the proper sloping, shoring and bracing structures and measures designed specifically for the particular situation.

Trench failures often occur in multiples, starting with a movement of soil material near the bottom of the trench wall. After the failure of the base, the support of the wall will quickly erode and the wall will collapse. The collapsing soil is extremely heavy and can weigh one and a half tons per cubic yard, producing a tremendous crushing force.

Proper design, construction and placement of support structures will allow employees to work in a safe environment.

Bibliography

A Guide to Safety in Confined Spaces. 1987. DHHS (NIOSH) Publication No. 87-113. U.S. Department of Health and Human Services, Cincinnati, OH.

An Exploratory Analysis of Excavation Cave-in Fatalities. 1988. R.L. Stanevich and D.C. Middleton. Professional Safety, February, pp 24-27.

Development of Draft Construction Safety Standards for Excavation. 1983. R.L. Stanevich and F.Y. Yokel. NBS (NIOSH) Publication, NBSIR 83-2693; DHHS (NIOSH) Publication No. 83-103. U.S. Department of Commerce, Washington, DC; Department of Health and Human Services, Morgantown, WV.

Excavations. 1990 (Revised). Occupational Safety and Health Administration, U.S. Department of Labor, Washington, DC.

Occupational Safety and Health Standards-Excavations; Final Rule. October 31, 1989. Department of Labor. Federal Register, Part II. 29 CFR Part 1926.

Ohio Administrative Codes, 1991. Chapter 4121:1-3.

OSHA Up-to-Date. January 1992. [Newsletter citations]. National Safety Council, Chicago, IL 60611.

Request for Assistance in Preventing Deaths and Injuries from Excavation Cave-ins. July 1985. DHHS (NIOSH) Publication No. 85-110). U.S. Department of Health and Human Services, Cincinnati, OH.

Safety and Health Excavation and Trenching Operations. (undated) Order No. 689601. National Audio-Visual Center, National Archives and Records Administration, Capitol Heights, MD.

Sloping, Shoring and Shielding. (undated) Order No. 009863. National Audio-Visual Center, National Archives and Records Administration, Capitol Heights, MD.

Soil Classification for Construction Practice. 1979. F. Yokel. Report NBSIR 79-1945, U.S. Department of Commerce, Washington, DC.

The Mechanics of A Trench Cave-In. 1991. J.L. Mickle. Agri-book Magazine/Drainage Contractor, Vol:8-9.

Trenching. (undated) Order No. 007156. (Hazard recognition program). National Audio-Visual Center, National Archives and Records Administration, Capitol Heights, MD.

The Ohio Utilities Protection Law. 1990. T.L. Bean and L.C. Brown., AEX-316, Department of Agricultural Engineering, Cooperative Extension Service, The Ohio State University.

Acknowledgments

The authors gratefully acknowledge the assistance of Fred Galehouse, OLICA Contractor, Wayne County; Art Brate, USDA-Soil Conservation Service, Columbus; Tim St. Clair, Ohio Bureau of Workers Compensation-Division of Safety and Hygiene; Larry Trask, OLICA Executive Secretary; for the review of material in this publication. The authors also thank Michelle Wallingford, Undergraduate Assistant, Ronald Clason, Administrative Assistant, Department of Agricultural Engineering, for help in manuscript preparation, and Judy Kauffeld and Tonya Ewing, Section of Information, for graphic and editorial production.

Funding and support of this publication was provided through Grant Number U05/CCU506070-02, "Cooperative Agreement Program for Agricultural Health Promotion Systems," National Institute for Occupational Safety and Health, in cooperation with the Overholt Drainage Education and Research Program, Department of Agricultural Engineering, The Ohio State University.

Keith L. Smith, Associate Vice President for Ag. Adm. and Director, OSU Extension.

TDD No. 800-589-8292 (Ohio only) or 614-292-1868

Installation Effects on Corrugated Plastic Drain Tubing

Carroll J. W. Drablos and Walter D. Lembke

Corrugated plastic drain tubing (CPT) was first installed commercially in the United States in 1967. Its popularity has grown, and today it accounts for a majority of the material being used for subsurface drainage. As a relatively new material, CPT's durability has attracted considerable interest.

Corrugated plastic drain tubing is a flexible conduit. Part of its soil-load carrying capacity is derived from the lateral support of the surrounding soil. This lateral support (passive resistance of the soil) occurs as the sides of the drain tubing deflect outward against the soil. The amount of deflection depends on the strength of the flexible tubing, the bearing strength of the surrounding soil, the length of time the tubing has been installed, the methods used for blinding and backfilling, the amount of tubing stretch that occurs during installation, and the angle of the trench bottom groove. A small amount of deflection is necessary to obtain the lateral support from the soil. Excessive deflection, however, can lead to failure.

Extensive field evaluations of CPT have been made since 1971 (Drablos and Schwab, 1971; Drablos et al., 1976; McCandless, 1976; and Schwab and Drablos, 1977). The results of these investigations have provided the basis for many of the recommendations set forth in today's performance standards. A recent study (Fenemore et al., 1979) noted that failure is generally characterized by excessive deflection--usually 20 to 30 percent--resulting in collapse of the pipe wall.

According to field studies by Drablos and Schwab (1971), the deflection measurements of 4 inch tubing at 32 sites varied from 7.3 to 50.6 percent, with an average of 16.4 percent. A later study (Drablos et al., 1976) showed that the average deflection for 5, 6, and 8 inch tubing was 16.3, 15.7, and 10.3 percent respectively.

Watkins and Reeve (1979) stated that for practical purposes the amount of deflection of corrugated polyethylene under load is equal to the strain in the sidefill material. In other words, the vertical compression in the sidefill material governs the deflection of the tubing. Therefore, the selection and placement of the soil envelope is the means by which the performance of the combined tubing-envelope structure is controlled. The denser the envelope sidefill material, the less the compressibility, and hence, the smaller the tubing deflection.

Carroll J.W. Drablos and Walter D. Lembke are Professors of Agricultural Engineering, University of Illinois at Urbana-Champaign.

Acknowledgement: The authors wish to express their appreciation to the Corrugated Plastic Tubing Association for financial support of the project, to the land improvement contractors and farmers who cooperated and assisted in gathering field data, and to Kenneth Rippy and Janet Cherry for assistance in gathering and developing data.

Stretch that occurs during installation may cause a decrease in pipe stiffness. When perforated tubing is used, the slots may be pulled open wider than is desirable. Drablos et al. (1973) reported that the percentage of decrease in stiffness for 4 inch diameter tubing was slightly more than twice the percentage of stretch. That is, a 5 percent stretch caused an 11 percent decrease in stiffness. Schwab and Brehm (1974) reported that stretch measurements in a field study varied from zero to 4.5 percent, with the average among ten tests at 2.1 percent. The above elongations were low compared to an average of 5.3 (range 0 to 11.4 percent) for 4 inch tubing at 31 rates reported by Drablos and Schwab (1972). Another investigation (Drablos et al., 1976) at 66 sites for 5, 6, and 8 inch tubing reported the average stretch observed was 5.3 percent with a range of 0 to 14.6 percent.

Geohring et al. (1980) reported on investigations of the amount of stretch occurring in four brands of corrugated plastic tubing installed by a drain plow at three different soil sites. Measurements were taken with and without the use of a power feed device. Stretch ranged from -0.09 to 9.53 percent when the power feeder was disengaged and from -3.21 to 2.63 percent when the power feeder was operating.

Temperature is another factor that must be considered during installation. It has been reported that the pipe stiffness will decrease 57 percent if the temperature is increased from 70° F to 140° F (Drablos et al., 1973). It has been further reported that the temperature of the tubing will adapt to the temperature of the surrounding soil within a period of five minutes.

The use of proper installation techniques is a key to a successful subsurface drainage system. The purpose of this paper is to examine the effects on corrugated plastic drain tubing caused by the installation process for the drain plow and trencher. The factors observed during different phases of installation included (1) elongation, (2) temperature, and (3) deflection.

Procedure

Temperature measurements were made on tubing located in the field just prior to installation. A thermistor temperature probe was used to obtain both the air and tubing temperatures.

Field stretch evaluations were made on site. Eight contractors used drain plows, and 22 contractors used trenchers. The contractors were located in Illinois, Indiana, Iowa, and Ohio. Field stretch was determined by measuring a given length of tubing strung out on the ground and by measuring that same length after it was installed. Where on-board reels were used, the tubing was measured as it came off the reel and before it entered the trencher or plow.

Measurements for stretch were also made on a limited number of trencher installations after the tubing was in the trench. This was accomplished by measuring the length of a given number of corrugations (30 to 50) and comparing this length with the design length provided by the manufacturer. This was referred to as corrugation stretch.

Samples of the tubing were collected from 13 trencher sites and 3 drain plow sites. Laboratory measurements were made on these samples using an Instron testing machine to determine pipe stiffness.

Since the amount of deflection is an indication of the durability of the tubing, deflection measurements were made at 5 sites with the drain plow and 22 sites with a trencher. A deflectometer developed by Walker and Drablos (1976) was used to measure the amount of vertical deflection occurring for sample lengths of tubing varying from 16 feet to 48 feet.

Deflection measurements for the drain plow were made (1) immediately after installation and before any load was applied and (2) after loading on the slit. At 2 of the 5 sites, the contractor drove the plow over the top of the slit where the tubing had been installed to create the "loading on the slit" condition.

Deflection measurements were also taken for trencher installations after (1) blinding, (2) backfilling, and (3) loading on backfill area. The loading was accomplished by driving the track or wheel of the trencher directly over the newly backfilled trench.

Results

Temperature

A total of 48 air and tubing temperature measurements were taken in the field at different sites. Thirty-four of these measurements were on black tubing and 14 on white tubing. Tubing surface temperature measured during this investigation ranged from 77° F. to 137° F., and the air temperature ranged from 60° F. to 95° F. Table 1 provides average air and tubing temperatures for both black and white tubing. The average difference for air and tubing temperature is 27° F. for black tubing and 12° F. for white tubing. The difference between black and white tubing temperature was highly significant.

Table 1. Air and Tubing Temperatures Before Installation

Tubing color	Number of tests	Air temperature	Tubing temperature	Difference
			°F.	
Black	34	85	112	27
White	14	88	100	12
Difference	..	..	...	15[a]

[a]The difference between white and black tubing was significant at the 99.9 percent level.

Stretch

Stretch measurements were made for both the plow and trencher methods of installation. Measurements were made at 8 plow sites and 24 trencher sites, accounting for a total of 8,651 feet in measured length of installed corrugated plastic tubing (CPT). Two types of stretch measurements were made for the trenching method of installation, and they are referred to in this paper as (1) field and (2) corrugation. A summary of these measurements can be found in Table 2.

Table 2. Stretch Measurements for Trencher and Plow Installation

Installation method	Black tubing	White tubing	Together
		percent	
Trencher-field	2.4 (4,050 ft.)	-0.5 (600 ft.)	2.3 (4,650 ft.)
Plow-field	0.9 (3,154 ft.)	1.0 (800 ft.)	0.9 (3,954 ft.)
Trencher-corrugation	7.0 (1,860 ft.)	-0.7 (650 ft.)	4.8 (3,510 ft.)

The field stretch measurements were made for both the trencher and the plow by marking and measuring a given length of tubing after it was strung out on the ground. The marked lengths of tubing were observed during installation, and a flag was inserted in the ground at the location where each mark fed through the machine. The distance between the flags on the ground were measured and compared with the marked lengths to determine the percentage of stretch that occurred during installation.

In Table 2, it is noted that the amount of field stretch that occurred with the trencher was 2.3 percent, as compared to 0.9 percent field stretch for tubing installed with the plow. Seven of the 8 plow measurements had a power feeder, which perhaps results in less stretch. On the one plow without the power feeder, the tubing was hand fed into the plow.

The maximum field stretch with the 3,954 feet of tubing installed with the plow was 5 percent, and the maximum field stretch obtained with the 4,700 feet installed with the trencher was 6.7 percent. Only two reaches of the 32 sites investigated exceeded the American Society for Testing and Material (ASTM)-recommended standard limiting stretch for heavy duty tubing to less than 5 percent.

A comparison was also made on the difference in the amount of field stretch between black and white tubing. The 4,050 feet of black tubing installed with the trencher had an average stretch of 2.4 percent as compared to 600 feet of white tubing with an average negative field stretch. The difference in stretch for black and white tubing installed with the plow was very small.

To obtain further insight on the amount of stretch that occurred with the trenchers, the lengths of 50 corrugations were measured in the trench at 15 sites where the tubing had been installed, but before it was blinded and back-filled. Based on manufacturers'-designed number of corrugations per unit length, stretch was determined. The average stretch recorded by measuring corrugations for the 15 sites was higher than the field measurements.

Table 3. Corrugation Measurements Versus Field Measurements--Trencher

Measurement method	Average stretch, percent	Length, feet
Corrugation	4.8 (15)[a]	...
Field	1.1 (15)	2,510
Difference	3.7[b]	...

[a]Number in parentheses indicates number of sites.
[b]The difference in stretch measured by the two methods was significant at the 90 percent level.

The range of corrugation measurements was from negative stretch to 17.6 percent with an average of 4.8 percent. Five of the 15 measurements exceeded the ASTM limit of 5 percent and 3 exceeded 10 percent. The average field measurements for stretch at the same 15 sites was 1.1 percent. Since the amount of stretch recorded as the tubing fed into the machine from a strung out position was significantly less than that obtained by measuring corrugations from an installed position, there is concern on how to account for the difference. Possibilities exist that stretch occurred during the stringing process and/or when the tubing was wrapped onto a coil or reel.

Pipe Stiffness

Samples of tubing were collected from 15 sites and taken to the laboratory to determine pipe stiffness in accordance with ASTM F-405. Twelve of the samples were from trencher installations, and 3 were from drain plow installations. The pipe stiffness values ranged from 23.2 lbs./sq. in. to 44.4 lbs./sq. in. at 5 percent, with the average 35.6 lbs./sq. in. All samples except one exceeded the minimum physical test requirements for standard tubing at 5 percent deflection. Ten of the 15 samples exceeded requirements for heavy duty tubing.

Deflection

The measurement of deflection is an indication of the durability of corrugated plastic tubing. Seven deflection measurements were made on installations at 5 sites with the drain plow. Table 4 provides a summary of the data collected.

Table 4. Deflection During Installation by Drain Plows

	Deflection, pct.		Length,		Deflection length, pct.[a]	
Site	Average	Maximum	feet	Load	>5 pct.	>10 pct.
1	1.1	8.8	47	No	1.4	0
	3.5	10.5	47	Yes	16.0	0
2	0.1	10.0	37	No	0	0
3	0.1	1.2	40	No	0	0
4	0.7	5.7	31	No	0	0
5	3.0	9.0	137	No	8.7	0
	4.2	10.0	90	Yes	30.7	0
Average	2.4	8.4	429		11.2	0
Load	4.0	10.2	137		25.8	0
No-Load	1.7	7.6	292		4.3	0

[a]Deflection length is the percentage of the line length that exceeds a given percentage of deflection.

A total of 429 feet of drain plow installation was investigated. The maximum deflections ranged from 1 to 10 percent on installations without a load, with an average deflection of 1.7 percent. Two installations did have a load applied by running the track of the plow directly over the slit. The average deflection under the loaded condition increased from 1.1 to 3.5 percent and from 3.0 to 4.2 percent. The maximum deflection increased by approximately the same amount.

The average deflection for the load treatments was 4.0 percent, as compared to 1.7 percent for the no-load treatments. Perhaps the most important information in Table 4 is contained in the last two columns: the percentage of the total length of CPT found to exceed 5 and 10 percent deflection for the load/no-load treatments. Two load treatments were made. In one case, the length of pipe exceeding 5 percent deflection increased from 1.4 to 16 percent; in the other case, the increase was from 8.7 to 30.7 percent. There was no deflection in excess of 10 percent. The average length exceeding 5 percent deflection was 25.8 percent for the load treatment and 4.3 percent for the no-load treatment.

Table 5 provides a summary of the deflection that occurs for CPT installed with trenchers. Evaluations were conducted at 21 sites, and deflection measurements were made after (1) blinding only, (2) backfilling on top of the blinding, and (3) loading.

Table 5. Deflection During Installation by Trenchers

Treatment	Length, feet	Average deflection, pct.	Average maximum deflection, pct.	Deflection length, pct.[a]	
				>5%	>10%
Blinding	718	(17)[b] 1.8±0.5[c]	(17) 7.2±2.4	(17) 3.2±2.9	(18) 0.1±0.08
Backfill	796	(20) 3.2±0.8	(20) 9.0±1.9	(18) 25.4±13.0	(18) 0.4±0.4
Load	611	(14) 4.6±1.4	(14) 13.4±5.3	(14) 39.6±19.2	(14) 2.6±2.6

[a]Deflection length is the percentage of the line length that exceeds a given percentage of deflection.
[b]Measurements were made at the number of sites indicated in parentheses; successive measurements were not made at all sites.
[c]90 percent confidence limits.

The load consisted of one or 2 passes on trencher wheel or track over the new backfill. The total length of line evaluated for each of the treatments is identified in the table. The average deflection increased from 1.8 to 4.6 percent as all treatments were made. The average maximum deflection increased in a similar manner, beginning at 7.2 percent with blinding only to 13.4 percent with a load. The frequency of deflections exceeding 5 percent is not given in Table 5, but they increased somewhat when the backfill was applied and almost doubled when a load was applied.

An average of 3.2 percent of the lengths measured exceeded 5 percent deflection with only blinding. When backfill was added, approximately 25.4 percent of the measured lengths exceeded 5 percent. This increased to 39.6 percent after a load was run over the completed trench. Only a small part of the measured lengths exceeded 10 percent deflection when the load was applied.

Discussion

Previous studies have indicated that the physical characteristics of the tubing and installation techniques have an important influence on the amount of deflection that may occur with corrugated plastic drain tubing. This study evaluated (1) the amount of stretch that occurs during installation and (2) the amount of deflection that occurs after blinding, backfilling, and loading treatments. A total of 8 sites using a drain plow and 24 sites using a trencher were investigated. Samples of tubing from 15 sites were taken into the laboratory to determine pipe stiffness. All but one of the samples exceeded the minimum requirements of the ASTM F-405 standards. The strength of the tubing samples ranged from 23.2 to 44.4 lbs./sq. in. with the average of 35.6 lbs./sq. in.

Tubing and air temperature measurements were taken in the field at different sites. A total of 48 measurements was made, 34 of which were on black tubing. The difference between the tubing and air temperature was 27° F. for the black tubing and 12° F. for the white tubing. These temperature differences affect installation in that the higher temperatures may require some extra precaution during the installation process. The purpose of the precautions is to prevent direct impact of hard objects on the tubing or excessive drag as the tubing feeds through the trencher or plow. Tubing will typically reach soil temperature within a period of 5 minutes after installation and regain any of the strength lost because of higher temperatures.

Stretch measurements were made at 8 plow and 24 trencher sites. There was considerable scatter in data points when comparing stretch with tubing temperature. The scatter was due to the many variables involved in the installation process that cause stretch. There was also considerable scatter of data points when comparing field and corrugation stretch with pipe stiffness. In fact, there appears to be less stretch with lower pipe stiffness.

ASTM Standard F-449 recommends that stretch should not exceed 5 percent during installation. The average stretch observed by the field method was 0.9 percent for the plow and 2.3 percent for the trencher. The average stretch exceeded 5 percent at only 2 of the 32 trencher and plow sites where stretch was determined by field measurements. On the other hand, at the 15 sites where stretch was determined by measuring corrugations, the limit of 5 percent was exceeded 5 times, and the average stretch by the field method was 1.1 percent as compared to 4.8 percent for the corrugation method. Though the number of plow sites was limited, the amount of stretch obtained with the plow was less than 1 percent. Perhaps the main reason for low stretch was the use of the power feeder. The overall stretch obtained with the trencher exceeded 2 percent, which is within the minimum recommendations.

The amount of deflection supports the need for constant awareness on the part of machine operators during various phases of the installation process. Although the number of installations with the drain plow were limited, the average deflection for the 5 sites investigated without a load over the top was 1.7 percent. Only 4.3 percent of the length of line investigated exceeded a deflection of 5 percent. Where a load was applied over the top, the average deflection increased to 4 percent, and the length of line with 5 percent or more deflection increased to 25.8 percent.

A similar relationship was found for the tubing installed with the trencher. The amount of deflection that occurred after the blinding, backfilling, and loading treatments increased from 1.8 percent to 3.2 and 4.6 percent respectively. The average maximum deflection for each of these treatments varied from 7.2 percent for blinding only to 13.4 percent for the loading treatment. The percentage of line investigated that exceeded 5 percent deflection was 3.2 for blinding. It increased to 25.4 and 39.7 percent for backfilling and loading. The amount of tubing exceeding 10 percent deflection was small. The results indicate the impact that various treatments can have upon the amount of deflection that takes place during installation.

Even though the average and maximum deflections were well within maximum limits for CPT, it is advisable that excessive loads not be applied over the tubing for either trenching or drain plow methods of installation. It is important that the operator be familiar with the physical characteristics of CPT to insure quality installation.

Summary

Corrugated plastic drain tubing has been used as an agricultural drainage material in the United States for more than 15 years. The limits of most materials used for subsurface drainage become apparent during installation. Corrugated plastic drain tubing is no exception. Installation techniques followed by contractors in this study were within prescribed recommendations. Even where non-recommended practices were followed, such as loading directly over newly installed tubing for both the drain plow and the trencher, a tubing failure did not occur. Where quality material is used with recommended installation practices, corrugated plastic drain tubing will provide a lasting subsurface drainage system.

References

1. American Society for Testing and Materials, Standard Specification for Subsurface Installation of Corrugated Thermoplastic Tubing for Agricultural Drainage or Water Table Control, ASTM Designation: F-449, Philadelphia, Pennsylvania, 1976.

2. American Society for Testing and Materials, Standard Specification for Corrugated Polyethylene (PE) Tubing and Fittings, ASTM Designation: F-405, Philadelphia, Pennsylvania, 1977.

3. Drablos, C.J.W. et al. *Corrugated plastic drain tubing,* University of Illinois Cooperative Extension Service, Circular 1078, 1973.

4. Drablos, C.J.W., and G.O. Schwab. Field and laboratory evaluation of 4-inch corrugated plastic drain tubing, *National Drainage Symposium Proceedings,* American Society of Agricultural Engineers, St. Joseph, Michigan, pp. 20-24, December, 1971.

5. Drablos, C.J.W., and G.O. Schwab. Field and laboratory evaluation of 4-inch corrugated plastic drain tubing, *National Drainage Symposium Proceedings,* American Society of Agricultural Engineers, St. Joseph, Michigan, pp. 20-24, December, 1972.

6. Drablos, C.J.W., P.N. Walker, and J.L. Scarborough. Field evaluation of corrugated plastic drain tubing, *Third National Drainage Symposium Proceedings,* American Society of Agricultural Engineers Publication 1-77. American Society of Agricultural Engineers, St. Joseph, Michigan, December, 1976.

7. Fenemore, A.D., B.R. Bevier, and G.O. Schwab. Prediction of deflection for corrugated plastic tubing, *Transactions of the American Society for Agricultural Engineers* (ASAE), 22(6), pp. 1338-42, 1979.

8. Geohring, L.D., F.N. Swoder, and L.E. Thomas. Corrugated plastic drain tubing stretch during drain plow installations, ASAE Paper SW-558, American Society of Agricultural Engineers, St. Joseph, Michigan, 1980.

9. McCandless, D.E., Jr. Field evaluation of 102 mm (4-inch) corrugated polyethylene tubing, *Transactions of ASAE* 19(3), pp. 514-16, 1976.

10. Schwab, G.O., and C.J.W. Drablos. Deflection-stiffness characteristics of corrugated plastic tubing, *Transactions of ASAE* 20(1). pp. 1058-61, 66, 1977.

11. Schwab, G.O., and R.D. Brehm. Elongation characteristics of corrugated plastic tubing. ASAE Paper 74-2544, American Society of Agricultural Engineers, St. Joseph, Michigan, 1974.

12. Walker, P.N., and C.J.W. Drablos. Deflectometer profiles drain tubing, *Agricultural Engineering* 57(6), pp. 44-45, 1976.

13. Watkins, R.K., and R.C. Reeve. Structural performance of buried corrugated polyethylene tubing. Presented at the *Thirtieth Annual Highway Geology Symposium*, Portland, Oregon, August, 1979.

Problems Associated with Subsurface Drainage

Carroll J.W. Drablos

DRAIN PROBLEMS

Recognizing a Problem

Regular maintenance of the drainage system, including inspection of the surface of the drained area, will reduce problems to a minimum. In the spring, note the dry streaks created by each drain and check for wet spots over the drain. Look for two things:

(a) Other wet spots that remain after the rest of the field has dried off.

(b) Holes in the field caused by soil washing into the drain.

Check to see if the outlet has eroded, whether there is free discharge, and whether the rodent guard is in place. Clean any grass and debris that may have collected. Look below the outlet for signs of red iron, long green stringy organic waste, or signs of sand coming from the drain. Should any of these problems occur dig up the drain at critical points and examine it. If there is a problem, make the needed repairs as soon as possible.

Type of Problem

The failure of subsurface drains to perform as expected may be caused by:

(a) Soil physical conditions that do not permit drainage.

(b) Not accurately locating the source of the water before the drains were installed.

(c) Ochre clogging.

(d) Grade reversals in construction.

(e) Breakage, improper alignment of drain tile, or damage to plastic tubing through careless backfilling.

(f) Construction when soil was too wet.

(g) Settling sections of drain because of unstable foundations.

(h) Excessive crack widths between drain tiles, excessively large slots in plastic tubing, or perforations improperly cut--allowing soil to enter the drain pipe.

(i) Erosion of soil into the drain pipe because of loose backfill.

Carroll J.W. Drablos is Extension Agricultural Engineer, University of Illinois at Urbana-Champaign.

(j) Improper envelope material or application, that is, poor placement, tearing of envelope material, sealing of envelope with soil or ochre.

(k) Collapse of drain pipe because of excess surface load, weak pipe, or improper backfilling methods.

(l) Plugging of pipe by organic wastes and roots.

Drain problems can be confirmed through simultaneously observing the drain discharge and the height of the water table between drains. More detailed discussion of several potential problems follows below.

ORGANIC WASTES

Organic wastes cause failure in drains in a very short time with the result that the affected parts of the system must be relaid. Milkhouse wastes and washings, when permitted to enter a drain, form a live gel which very rapidly completely fills the pipe.

Catch basins and even lateral drains near feedlots and barnyards allow manure liquids and straw to enter the drain pipe. These form long, stringy, stinky, masses which fill the drain pipe. Even when large-diameter pipes are dug up, it is difficult to clean this type of material. A similar type of material is formed in the pipe when wet barnyard wastes, together with gutter washings, keep the drain wet and roots from clovers and grasses penetrate the pipe, collect the wastes, and plug the pipe.

Chemicals must never be allowed to enter the drain system as they will harm the natural environment at the outlet.

A drainage system is a major capital investment for the drainage of fields; never allow water containing any nutrients and organic wastes to enter it.

TREE ROOTS

In their search for food and water, the roots of trees and shrubs penetrate the openings of underground conduits and obstruct the flow through the conduits by the masses of growth they establish. This is particularly true in coarse-textured soils that have poor water-retaining properties. Such soils are often deficient in available moisture for the support of plant life, as compared with soils having much higher water-holding capacities. The character of the soil and its moisture-retaining capacities, in relation to annual regional rainfall, are of significance. Soils that fail to provide a continuous and ample supply of water for the trees and shrubs growing in them force the roots of such plants to seek water from other sources. Consequently, water present in drain tile, sanitary sewers, and storm drains can be a great attraction for root systems. When such conditions prevail, clogging and obstruction of conduits can be expected. How to deal economically yet effectively with root-caused obstructions in drain lines is a frequent problem.[1]

A tile line totally obstructed with tree roots must be dug up, cleaned, and relaid. This is only a temporary solution and two ways to prevent recurrence are (1) remove the trees, and (2) replace the part of the drain near the trees with pipe that has sealed joints or with a conduit that has no perforations or joints. Recommendations make in The Illinois Drainage Guide state that willow, elm, soft maple, cottonwood, and other water-loving trees that grow within approximately 100 feet of the drain should be removed and that a 50-foot clearance should be maintained between the drain and other species of trees.

If tile drains are partially obstructed but water is still able to flow through the system, it may be possible to use a chemical treatment to retard root growth. In past years the use of copper sulfate has been recommended. The roots in contact with or immersed in copper sulfate-treated liquids will absorb toxic copper. The copper is then transported upward through the root system to those parts above the water level in drain tile. Consequently, roots will be killed some distance away from their actual contact with the copper sulfate solution.

It has been recommended that periods of normal-to-low flow be chosen for the introduction of copper sulfate crystals. Both the time of contact and the concentration of solution with the root masses are thereby enhanced. A preventive dose may be repeated annually following the initial treatment. Old roots do not return, but new root infiltrations may develop.

Medium size copper sulfate crystals are preferred because, in contact with the root mass, they leach copper solution over a longer time period than the finer grade material. Thus, the treatment is prolonged and complete contact is insured.

Concern in recent years has been expressed, however, about the effect of toxicity of copper sulfate not only on trees but also on water supplies. Further study is needed to answer these questions.

OCHRE IN DRAIN LINES

The formation of ochre and associated slime clogging is a complex phenomenon. There is considerable disagreement concerning physical, chemical, and biological factors contributing to the formation of ochre. Bacteria are responsible for iron reduction in flooded soils. The reduction process requires carbon energy that can be utilized by bacteria. The amount required varies with the soil type and characteristics of the iron on the soil particle. The basic raw material of ochre, a gelatinous iron deposit in drain openings and filter envelopes, is ferrous iron flowing into the drains. Test procedures have been developed to estimate ochre potential in agricultural drains, drains in wastewater management sites, highways and landfills.[2]

There is no effective economical long-term method for controlling ochre clogging. Based upon chemical and microbiological requirements, the options are limited. Emphasis must be on living with the problem.[3]

Ochre Control

Promoting oxidation and precipitation of iron in the soil before it reaches the drain line. All measures aimed at soil aeration are acceptable. If soil type and soil moisture permit, immature soils containing high levels of ferrous iron should either be predrained with mole drains or by trench drains. This method can be used only on sites that have temporary clogging hazard and clay contents of about 30 percent. There is no assurance that iron precipitated in the soil will not become soluble again if the area should be reflooded. There are recommendations in Germany involving deep ground-breaking with suitable plows, use of a two-stage drain system with one drain on a different level than the other drain, and preliminary drainage with open trenches for 2 to 3 years.

Surface liming. Not only atmospheric oxygen, but also calcium promotes oxidation. In theory surface liming should reduce ochre by precipitating iron in the soil, but it usually is not practical. In one experimental site in Florida, liming served only to increase the formation of ochre by raising the pH from 4.2 in the drain zone to 6--a desirable range for bacterial action. To be successful, lime applications must be higher than for normal agricultural use. The lime must change the pH in the entire soil profile to drain depth and it must be a long-term project. If the pH drops and the soils become flooded from poor drainage, then the oxidized iron may become soluble and flow to the drains.

Liming of drain trenches. This procedure was evaluated in Germany and found to be unsatisfactory. Iron in combination with lime in the trench decreased permeability, which defeated the purpose of a permeable backfill in a drain trench.

In 1961, slag gravel from the production of elemental phosphorus was used as an envelope for drains in Florida. Slag precipitated iron and no ochre formed until iron entered the drains. Iron entered the drains only when the pH of the slag dropped below 7.2 and the slag was disintegrated by hydrogen sulfide in the water. The disintegrated slag formed a seal around the drain that was almost impermeable to water. A similar type of reaction occurred in Germany with the use of copper slag but because of bactericidal action of copper, the blockage from slag took about 8 years.

Synthetic drain envelopes. The use of fiberglass as an envelope or filter will fail very quickly from accumulations of ochre. The slime clogs the fibers. Most of the newer synthetic envelope materials may also, under suitable conditions, clog from the slimes of ochre. This was discovered as a result of inserting filters in controlled trickle irrigation studies. The slimes grew on the fibers and reduced the size of the openings. These tests may not have been a fair comparison since irrigation lines are not drain tubes. Field observations with drain pipes have been variable. In some cases the filter wraps were not clogged but the drain inlet openings were full of ochre.

Copper placed in filter envelopes has not been successful. The copper reacts with hydrogen sulfide, forming copper sulfide. Copper dumped directly into the end of a drain will keep the drain free of visible ochre (if the pH is less than 7.0) but the amount required causes a pollution problem and does not control ochre in the drain envelope zone.

Retarding clogging within the drain. A number of methods to retard clogging within the drains have been tried.

a. *Self-cleaning grades* have not worked in Florida. Reports from Germany claim that the grade must be at least 0.5 percent to have any effect.

b. *Both smooth bore and corrugated pipes can accumulate ochre.* Some plastics may contribute to ochre formation by complexing iron (Fe) on surfaces of the pipe but no recent tests have been conducted.

c. *Use of bactericides incorporated into the pipe during manufacture,* in theory, would be an excellent method of controlling clogging. Corrugated

PE tubing was coated with a number of bactericides including mercury, silver, and copper. There was no protection once slimes coated the surface. A slow-release material would quickly be exhausted since, to be effective, the chemical in the water would have to exceed 1 ppm whenever the drains were flowing.

d. *Large inlet holes.* Larger inlet holes are an advantage (larger than 1 mm). Ochre clogs an inlet hole by sticking to the edges and then gradually closing the hole. It must be remembered, however, that ochre can also occur in the drain envelope and in the zone abutting the drain envelope.

e. *Submerged outlets.* An old recommendation had been to let drains discharge under water if there was danger of iron clogging. There are problems with this method. The line must be completely under water *at all times,* during both drainage and subirrigation. This means very deep drainage. If the line becomes aerated for even a short period of time, ochre can form.

f. *The use of organic filtering materials.* Using pine and oak sawdust as filters has delayed ochre development in drains in Florida. It was found that if sawdust creates an anaerobic environment the iron will remain soluble as fine particulate iron sulfide until the water flows from the drain. Sawdust also contains aromatic hydroxyl compounds that can complex iron.

   Unfortunately pine sawdust disintegrates and can seal drains. Some of the longest-flowing drains in Florida were installed in cypress sawdust. Cypress does not disintegrate easily. Unfortunately, the supply of cypress sawdust has been exhausted.

g. *Iron complexes that have some bacterial inhibiting activity.* Tannins from Turkish oak and the Mimosa shrub will combine with Fe to form "ink" (iron tannate), a black colloidal material. The ink-like substance will flow from the drain. Iron bacteria are inhibited when concentrations of tannins are above 10 ppm. It is extremely difficult to control tannin concentrations since the chips containing tannin are spread throughout the factory-wrapped straw or cocofiber filter. Tannins can affect fish populations, however. The black discoloration of the ditch water has sometimes exceeds the permissible limits for tannins in water, creating pollution problems.

   The use of a complex that has bacterial inhibition is an excellent approach but, unfortunately, at present there are no materials to take the place of tannins.

h. *Ochre removal from drains.* The use of high-pressure and low-pressure water jetting has been successful in cleaning many drains clogged with ochre. It is used commercially in southern California, the Netherlands, and Germany. Sulfur dioxide (SO_2) mixed with water forms sulfurous acid. A 2-percent solution in drain lines with less than 5 percent organic matter will usually remove ochre. If the organic content is high, up to 7-percent SO_2 solution may be required because the acid does not remove the organic matrix. Some success was observed where the acid was applied through a line installed over a drain line--a method that is practical only in land-spreading of effluent sites.

Hydrochloric and sulfuric acids can also be used at 5-percent and 10-percent concentrations but the outflow after treatment must be neutralized to prevent pollution of ditches. Sulfur dioxide is a pollutant and can kill fish unless it is neutralized.

Minimizing ochre problems through installation procedures. Drains should not be installed below the water table. If possible the soil should be dry.

Drains should open into ditches rather than through collectory systems. Only a small area in a field may be potentially ochreous and the trouble thus confined to a single drain. Cleaning is also easier for single drains.

Clogging in the zone abutting the envelope of drains is more severe shortly after drain installation. The ferrous iron content is also higher during the first several years. Following drain installation, the organic matter is unstable and humates can flow into the drains. Iron problems may gradually diminish with time so that the best procedure is to jet or chemically clean the lines at least once within the first year rather than wait until the drains are severely clogged.

Shallow drains and drains that flow infrequently are not candidates for serious ochre problems. Drains in alkaline or marl soils usually have fewer problems unless these drains are deep in the soil profile.

DRAINAGE OF ORGANIC SOILS[4]

General Properties of Organic Soils

Organic soils involved in drainage problems are saturated with water for prolonged periods of time or have been artificially drained. Differences among such organic soils, commonly called peats and mucks, reflect their response to drainage. These differences, in turn, reflect variations in their characters and origins. In the classification of organic soils, efforts have been made to indicate these differences.

The classification of organic soils followed in soil surveys of the U.S. Department of Agriculture and the land grant colleges is based on a number of soil properties. Major emphasis is given to the nature, arrangement and thickness of distinctive layers in the profile, mineral content, and stage of decay. Broad classes have been distinguished according to stage of decomposition as Fibric, Hemic, or Sapric. The Fibric are the least decomposed, the Sapric most decomposed, and the Hemic are in an intermediate stage of decomposition between the Fibric and Sapric. Peats are the least decomposed and mucks the most.

Classification of the organic soils highly useful to the drainage specialist has been on the basis of mineral matter content--as ash residue from burning, and on the botanical composition.

Mineral Matter Content

In the soil survey, organic soils are distinguished from mineral soils when the surface layer in its natural state has a thickness of 16 inches or more, and has (a) 20 percent or more organic matter when the mineral fraction has little or no clay, or (b) 30 percent or more organic matter when the mineral fraction has

50 percent or more clay, or (c) an organic matter content that varies from 20 to 30 percent when the clay content of the mineral fraction ranges from 0 to 50 percent.

In land drainage, organic soils are classified by drainage specialists according to ignition loss. Peats are defined as containing 50 percent or more organic matter and mucks as containing less than 50 percent. Generally, mucks are preferred for agricultural use because they drain better, shrink less, work more easily, and need less fertilizer.

Causes of Subsidence

Surface subsidence is the result of soil shrinkage by oxidation, compaction, and direct soil loss by erosion and burning. Shrinkage is inevitable with drainage. Lowering of the water table permits entry of air into pores. Oxidation of the organic soil by action of aerobic bacteria converts such matter to carbon dioxide, which escapes into the atmosphere, and water. The removal of water by drainage causes weight of upper soil layers to compact lower layers. The operation of farming equipment in preparing and compacting seedbed consolidates surface layers by pulverizing the soil and eliminating larger soil voids.

Observation of many sites over many years in both the United States and Europe indicates an overall average subsidence of about 1 inch per year. This rate varies directly with the depth of organic material exposed above the water table. Higher initial rates of subsidence occur within the first several years after drainage. These higher rates are attributable primarily to initial compaction that may be two or three times the average subsidence occurring in later years.

Allowance for Subsidence in Design

Subsidence, with resulting drop in surface elevation, reduces the fall available for drainage into an available outlet. By the very nature of most sites where organic soils are formed, an outlet for free drainage discharge is limited in depth and grade. Unless pump drainage is provided, outlet improvements may need to be carried out long distances below the benefited area. Unequal settlement of only small areas can affect a whole field. Design of an adequate drainage system must allow for subsidence over a reasonable life expectancy of the improvement. Where no local data on subsidence rates are available, an allowance for initial subsidence of a newly developed site can be estimated as 25 to 35 percent of the designed depth of drains below the existing land level. At least 10 percent should be allowed for drains constructed or reconstructed on previously drained land.

In designing the mains and laterals, the best procedure is to first prepare a rough preliminary design without considering subsidence. Determine the approximate location, size, and depth of ditches and drains. Second, consider existing ground elevations and corresponding soil borings to take subsidence into account. Estimated subsidence should be determined along each channel, based on the channel depths and borings of the preliminary design. Third, the estimated subsidence should be subtracted from existing ground elevations to determine elevations of a subsided surface. Finally, a design hydraulic gradient should be established for the channels with respect to a point in the outlet channel well downstream and below the improvement, where subsidence should not take place. Channel sections should then be adjusted to this gradient to provide the depth and size necessary to discharge the design flow. In some situations, changes in surface elevation after subsidence may be enough to require a complete realignment or relocation of the main and laterals.

Mains and Laterals

Main and lateral ditches in organic soils should be designed to meet the general requirements of similar channels in mineral soils, with allowances for subsidence. Generally, in deep peats or moderately deep peats over open sands, mains may be spaced out as wide as 1,500 to 2,500 feet and laterals kept to possibly 500 to 600 feet. Side slopes in main and lateral ditches should not be steeper than 1-to-1. Such channels require as much width as necessary for hydraulic capacity, but bottom widths should not be less than 3 feet.

Field Ditches and Drains

Both ditches and subsurface drains can be used as field collectors in deep peat. However, installation of covered drains should not be considered in new drainage developments until 3 or more years after initial settlement has taken place, and then only after careful investigations show that a uniform bearing and an adequate outlet can be assured for the drains throughout.

Closer spacings are best where controlled drainage will be used. If there is a question, the wider spacings can be tried and supplemental lines interspaced later if necessary. Where covered drains are installed on a large block of land, some ditches should be left for surface water removal during flash floods.

The Illinois Drainage Guide recommends that subsurface drains should be 3 to 5 feet deep and spaced 80 to 120 feet apart. Since it is difficult to keep subsurface drains on grade, it is suggested that long sections of perforated pipe be used. Drainage systems that permit control of water table levels will prevent excessive subsidence of muck and peat. Open ditches work satisfactorily and can be blocked to control the water level.[5]

When the depth of organic soil to the underlying mineral soil is less than 4 feet, covered drains can still be used if they can be supported continuously in the mineral soil. Drains should not be laid with support alternating in nonyielding mineral and yielding organic soils. Backfill over a drain in clay subsoil should be pervious material.

When the depth of the organic material is 1 to 3 1/2 feet, onsite investigation is needed to determine feasibility of drainage. In such cases, ditches may be considered.

Field ditches can be dug using almost vertical side walls for fibrous peats. Side slopes of at least 1/2-to-1 should be used on the less stable woody peats. Side slopes of 1/4-to-1 are commonly used for field ditches.

The required capacities of covered drains are about twice those of mineral soils, so that coefficients should be about 1/2 to 3/4 of an inch in 24 hours for general field crops and 3/4 to 1 1/2 inches for truck crops.[4]

CONTROLLED DRAINAGE

Controlled drainage slows down subsidence and its adverse effect on the drainage system, reduces wind and fire loss, and reduces the adverse effect of a fluctuating water table on crop yields. Controlled drainage permits irrigation without hindering field operations, has low labor and maintenance cost, and usually makes use of existing drainage systems with the controls as the only added installation. Controlled drainage is obtained by designing the system so that the water table can be maintained more or less constant at more effective depths throughout the year. Where pumps are used, control is obtained by means of the pump.

The water table, when controlled, can be maintained at higher levels than under free drainage. Maximum levels should be slightly below the zone of dense rooting and usually 18 inches for most grasses and shallow-rooted vegetables, 24 inches for most vegetables, and about 30 inches for deep-rooted crops such as corn. The water table should be kept high in the spring to reduce wind erosion and lowered as the root system develops during the season. Adequate control requires continuous checks of water table levels, made through small observation wells located over various parts of the controlled area.

Adjustments in the rate of water removal can be determined with reasonable accuracy. These are based on measurement of average voids in each foot of depth. Roughly, an inch of added water may provide as much as a 1-foot rise in a 2- to 2 1/2-foot soil profile above the water table. Absorption and plant transpiration generally eliminate the effect of intermittent rainfalls of 1/2 inch or less.

Installation

Before drains are installed in newly-developed peat and muck soils, the land should be drained with open ditches for several years to secure initial subsidence. The pipe should be laid on the underlying mineral soil, provided the mineral soil is not too deep and not permeable. In peat or muck soils, 6-inch drains are often recommended as the minimum size because of differential subsidence. Perforated tile several feet in length or plastic tubing is recommended.[6]

REFERENCES

1. Hood, John W., Copper sulfate for root and fungus control in sanitary sewers and storm drains, Phelps Dodge Refining Corporation, New York, NY. 24 pp, (1949).

2. Ford, Harry W., 1982. Estimating the potential for ochre clogging before installing drains. Transactions of the ASAE 25(2) 1597-1600.

3. Ford, Harry W. Ochre and associated slimes in drain lines, University of Florida, IFAS, Agricultural Research and Education Center, Lake Alfred, FL.

4. National Engineering Handbook, Soil Conservation Service, USDA, Drainage of agricultural land, Section 16, Drainage of organic soils, Chap. 8, p 8-1 to 8-8, (1971).

5. Drablos, Carroll J.W. and Roger C. Moe, Illinois Drainage Guide, Circular 1226, Cooperative Extension Service, College of Agriculture, University of Illinois at Urbana-Champaign, 46pp, (1984).

6. Schwab, Glenn O., et al., Soil and Water Conservation Engineering, 3rd ed., John Wiley & Sons, p 353, (1981).

Pull Behind Drainage Plow

The installation of subsurface drainage for agricultural water management is an important practice for providing trafficability for farming operations and protecting crops from damage due to excess water. To provide the expected benefits, these subsurface drains need to be properly designed and installed. Recently, pull-behind drainage plows have been introduced as an option for farmer installation of subsurface drains. The plow is only one part of the equation for installing drainage pipes. Proper operation and performance of the plow depends on other components including the tractor, the grade control system, and the operator. Some of the important things that affect the proper installation and functioning of the drains are presented below.

Tractor:

- Horsepower — The minimum horsepower needs to be 190 hp. The plow load is a big unforgiving load that increases with the depth of plowing. In order to reach typical depths of 4.5 to 5 feet, you will need at least 190 hp.
- Weight — The minimum weight needs to be 26,000 lbs. Draw- bar hitch type plows require more of the weight at the front approximately 60% of tractor weight) to keep an adequate balance between front and rear when plowing. Three-point hitch mounted models transfer some of the draft force to the pulling tractor ahead of the rear axle that helps keep the front of the tractor on the ground when plowing.
- Hydraulics — The hydraulic system needs to deliver 10 gallons/minute and 2000 psi @ 1500 RPM's to the plow (NOT TRACTOR PUMP CAPABILITY) and is able to produce at least 2500 psi at higher RPM. These capacities are essential to make grade control adjustments quickly and accurately. Quick couplers can reduce hydraulic fluid delivery as much as 3 to 5 gallons/minute, so removing these will make grade control faster and more accurate. On older tractors (5 years or more), worn parts often cause hydraulic performance to be less than the rating when the system or tractor was new.
- Speed - The tractor speed at 1500 RPM must be less than 1MPH (88 feet/minute). At higher speeds, opportunities to make grade control adjustments are too far apart.
- Tires - Tractor tires must carry the extra weight and drawbar down-load. Tread on these tires should be at least 50% to minimize slippage and compaction.
- Warranty - Power train warranty may be voided when using certain plows.

Plow:

- Beam length — This is the distance between the hitch point and the plow shank. The longer the beam the smaller the effect of hitch height changes on the path of the cutting point. Plows attached to the tractor with a floating three-point hitch have a virtual hitch point and the beam length depends on the adjustment of the hitch arms. If the three-point hitch is not floating, then the beam length is very short
- Tilt stabilizers - Side to side tilting of the plow can cause errors in grade control.
- Depth adjustment — The hydraulic cylinder and control valve on the plow control the depth of the plow. The size and location of the cylinder and the type of control valve determine the rate of response of the plow to depth adjustments required for grade control. Proportional valves deliver hydraulic fluid continuously as long as a depth correction is needed, with variable flow rates depending on the amount of correction needed. Bang-Bang valves deliver fluid for a timed period on then close and must be reopened if correction is still needed. Plows can work with either type valve, but must be set up correctly.

- Supplemental hitch — When encountering deep cuts or very hard soil conditions, it will sometimes be necessary to use a second tractor to assist with pulling the plow. The second tractor needs to hitch directly to the plow by means of a cable or similar arrangement to avoid stressing the primary pulling tractor. A supplemental hitch point on the plow is recommended.
- Power feeder — Plastic draintubes are weakened significantly when stretched. A power feeder will control pipe stretch and strength.
- Pipe groove - Proper bedding of draintubes is required to maintain strength and prevent deformation and collapse. A grooving device on the plow or tubing boot is recommended to assure proper bedding of the tubing.

Grade Control System

- Is a laser grade control system necessary? YES!
- Things to consider: Training on setup and operation, operating range, how and where to set up the transmitter, how to check transmitter for accuracy.
- Tripod stability and height will affect the performance of the laser transmitter.
- Wind sensitivity of transmitter and the ability to change these settings.
- Dead band of receiver on plow to ensure accurate grade control.
- Ability to control mast up and down whether it be electric or hydraulic. Placement of mast should be in front of cutting point of the plow to give adequate correction time. Height of mast accentuates the effect of plow side to side and front to back tilting.

Operator

- The operator is the most critical part of this system. The system is complex and non traditional in terms of operator skills and experience. Because of the variability in soils and operating conditions, the learning curve will be fairly long and steep. In addition to mastering the operation of the plow and the laser grade control system, there are numerous other important factors to consider. The vendor should be willing to provide at least two days of field training for the installation system operation. The operator will need to seek other sources of training for drainage system design and maintenance issues.

Drainage System Design and Layout

- Who will survey my land
- Size, slope, spacing of laterals
- Design considerations if you want the capability to subirrigate or use controlled drainage in the future
- Minimum cover on the pipe (usually 2 feet)
- Maximum operating depth of plow and the performance of the plow at this depth

Other Installation Factors That Affect Drainage Performance

- Backhoe and its operator
- Tubing cutters to properly install connections
- Stringer cart and stringing of pipe not to stretch the pipe reducing strength and using another tractor
- Minimizing the starting and stopping while plowing to reduce error
- Training of everyone involved

Last Modified: 07/15/2004