M.Sc. AGRICULTURAL ENGINEERING

ABSTRACT

Satish Chandra Negi

AN INVESTIGATION OF LOAD-BEARING STRENGTH AND RELATED PHYSICAL PROPERTIES OF PLASTIC DRAIN TUBES.

Loaded wagons and trucks were driven over a set of plastic draintubes and clay tiles installed in a sandy clay loam soil at 2 and 3 ft. depths. Deformations up to 20 and 30 percent of tube diameters were checked with plug gauges. No damage occurred with 40 passes of a 6.23 ton tractor pulling a 7.60 ton forage wagon. Some plastic draintubes at 2 foot depth were collapsed due to repeated passes of a 26.3 ton truck after considerable displacement of soil.

A series of physical tests were carried out in the laboratory on short sample lengths from each line installed in the field. In accordance with available specifications the plastic draintubes were acceptable by crushing strength, creep, impact durability, and flexibility criteria.

This Thesis shows that there should be no difficulty with plastic draintubes installed in crop fields at depths of 2.5 feet or more with normal backfilling.

EVALUATION OF PLASTIC DRAIN TUBES

(Suggested short title)

AN INVESTIGATION OF LOAD-BEARING STRENGTH AND RELATED PHYSICAL PROPERTIES OF PLASTIC DRAIN TUBES

by

SATISH CHANDRA NEGI

A Thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Master of Science

Department of Agricultural Engineering
McGill University
Montreal

August, 1970

TABLE OF CONTENTS

Table of Contents (Cont'd) Page

ACKNOWLEDGEMENTS

The author wishes to express his sincere thanks to Professor R.S. Broughton, Chairman of Agricultural Engineering Department and director of this project for his invaluable guidance and constant encouragement throughout the course of this investigation.

Appreciation is also extended to the following:

To Professor P.J. Jutras for his help in the field work and time generously given in consultation.

To Professor R.M. Halyk for his helpful advice and assistance in the Laboratory tests.

To Messrs. G. Webb, R. Cassidy, A. Robinson, and J. Beazley for their valuable technical assistance.

To Mrs. G. Linkletter for typing the Thesis manuscript.

To the Agricultural Hydraulics Division of the Quebec Ministry of Agriculture and Colonization for assistance in the field installation of the drain tubes, and the Quebec Agricultural Research Council for financial support of some of the operating work involved in testing of the drain tubes.

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

While smooth-wall plastic water pipes have been manufactured for many years, the thinner wall corrugated plastic drain tube began to appear in Europe only about 1965 and was first manufactured in Canada in 1968. The drain tubes for the field loading tests described in this thesis were installed in November, 1968 only about 3 months after corrugated plastic drain tube was first manufactured in Canada.

This recent development of corrugated plastic tube for subsurface drainage holds prospects of reducing the cost and labour involved in subdrain installations and increasing the acreage which can be drained each year. Plastic drain tube is very light and can be loaded and transported with much less labour and trucking costs per 1,000 feet than conventional clay tile. It is flexible enough that it can be readily handled in coils of long length by a single person. Due to roll lengths of 200 to 900 feet, the number of joints required are minimized and more uniformity in installation can be achieved than with one foot long clay tiles. There have been some new developments in laying techniques for plastic drain tubes in recent years which hold real promise for improved efficiency of installation.

The resins which have been most widely used in the production of plastic drainage tubing include polyethylene (PE), polyvinylchloride (PVC), poly-styrene rubber, and acrylonitrile-butadiene-styrene (ABS). Polyethylene appears to be the most promising and economical material for use in agricultural drainage tubing. Polyethylene is a plastic which is produced in enormous quantities, and has become inexpensive. It is prepared from ethylene gas through a high-temperature, high-pressure polymerization process. It has excellent dielectric characteristics and is resistant to most chemicals. Mechanical properties of polyethylene vary with density and melt index. The plastic pipe extrusion is done by conventional equipment and most pipe is coiled for ease of handling. Extruded tubing for drainage is slotted mechanically after extrusion to provide water-entry openings.

The suitability of plastic tubes for subsurface drainage of agricultural lands depends upon many factors. One very important factor is the load-bearing strength of the tube. Drain tubes installed in field locations are often subjected to loads other than the weight of the backfill material. Such loads may consist of machinery and equipment moving or parked on the surface. Doubts have been expressed about the probability of the light plastic tubes collapsing under field loads. The load-carrying capacity, durability, ability to remain physically satisfactory under cold conditions and other aspects need to be checked out before plastic drain tubes will become an accepted product. It is the aim of this Thesis to help provide answers to some of these questions about plastic drainage tubing. Experiments were conducted to compare the strength performance of available plastic drain tubes with conventional clay tiles, both in the laboratory and the field.

The major objective of the field tests was to determine the surface loads that the plastic tubes can withstand without serious distortion and evaluate the related requirements for proper bedding and installation. The results presented will show that this objective has been met.

The laboratory tests were conducted to determine the load-bearing strength and investigate the related physical properties of plastic drain tubes and clay tiles. While the establishment of precise relationships between the laboratory and field loading conditions is beyond the scope of this Thesis, some inferences about probable field performance have been drawn from the laboratory tests.

II. REVIEW OF LITERATURE

A. THEORIES OF LOADS ON SUBDRAINS

Extensive loading research has been carried on by engineering organizations and individuals during the past half century. Serious efforts have been made toward analyzing the loads to which underground conduits are subjected in service due to the earth overburden and other load sources.

1. Classification of Subdrains

The supporting strength of a drain tube is influenced by its degree of rigidity. Consequently conduits for use in agricultural drainage are divided into two main classes: (i) Rigid conduits, such as concrete or clay tiles, fail by rupture of the walls. The inherent strength of the tile is the main source of load-bearing strength. (ii) Flexible conduits, such as corrugated metal pipes or plastic pipes, fail by excessive deflection. Their ability to support loads lies partly in the inherent strength and partly on the side support developed in the earth as passive pressure due to outward movement of the sides of the pipe.

For purposes of analyzing loads, the subdrains have been classified on the basis of construction conditions under which they are installed in the field. The two types of underground conduits are ditch conduits and projecting conduits. Ditch conduit conditions apply to drains installed in narrow trenches in relatively undisturbed soil. Projecting conduit conditions occur in trenches wider than about 2 or 3 times the outside diameter of the drain tube. Projecting conditions also apply to conduits placed under an embankment in shallow bedding with the top of the conduit projecting above the surface of the natural ground.

2. Loads due to fill materials

Prior to 1910, it was believed that the load on a drain was equal to the weight of the earth directly over it and it varied only with the height. Some believed that the load was distributed in the shape of a wedge and was more than the weight of earth over the drain; while others thought it to be less due to soil arching action. After successful application of principles of mechanics it was discovered that the load on a drain is influenced by various other factors such as settlement of soil over the drain in relation to its settlement at the sides of the drain, the width of trench, the type of bedding, compaction of the fill, etc.

In 1913, Marston and Anderson (29) were the first to develop a rational method for determining the character, direction, and magnitude of the loads on pipes in trenches due to fill materials. In 1930, Marston (28) published a complete mathematical theory of external loads on closed conduits and of the supporting strengths of pipe conduits.

For the case of rigid ditch conduits it is assumed that the density of the fill material is less than that of the original soil. As the fill material settles into the ditch there is friction between it and the sides of the ditch. These frictional forces act upward on the prism of soil within the ditch and help to support the backfill material. Consequently the load on the pipe is less than the weight of the soil directly above it. The Marston Theory (28, 29) provides a formula for the loads on pipes in narrow trenches. In its simplest form the ditch conduit load formula is

$$W_c = C_d \, w \, B_d^2 \text{ ---------------- } 1.$$

where W_c = total load on pipe in lbs. per lin. ft.,

C_d = load coefficient for ditch conduits,

w = unit weight of fill material in lbs. per cu. ft.,

and B_d = width of ditch at top of pipe in ft.

For the case of flexible pipes in narrow trenches having thoroughly compacted side fills with same degree of stiffness as the pipes, the load formula is

$$W_c = C_d \, w \, B_c \, B_d \text{ -------------- } 2.$$

where B_c = outside diameter of the pipe in ft.

In the case of rigid conduits installed in wide ditches, the backfill directly over the conduit settles less than the soil to the sides of it. The resulting frictional forces act downward on the prism of soil above the conduit and increase the effective load on the conduit. The formula for loads on pipe in wide trenches due to fill materials has been given by Marston (28) as

$$W_c = C_c \, w \, B_c^2 \text{ ---------------- } 3.$$

where C_c = load coefficient for projecting conduits.

The load coefficient C_d and C_c are functions of the height of fill above top of the pipe, the frictional coefficient of the fill material, and, respectively, the trench width or the outer diameter of the pipe. Computation diagrams were prepared by Marston (28) and Schlick (40) to facilitate the calculation of the load coefficients.

Spangler (49, 50) conducted a number of laboratory and field loading experiments on flexible pipes such as corrugated metal culverts, and reported that the pipe continues to deform for some period of time after the maximum fill load has developed. He pointed out that the vertical load and its accompanying reaction is distributed uniformly over the breadth of the pipe and bedding respectively, whereas the horizontal pressure on each side of the pipe is distributed parabolically. Spangler presented the following equation for computing the horizontal deflection of a flexible pipe:

$$\Delta x = D_1 \frac{K W_c r^3}{EI + 0.061 e r^4} \quad \text{-------------} \quad 4.$$

in which Δx is the horizontal deflection of the pipe after the load has been applied for a considerable time, K is a constant depending upon the width of bedding of the pipe, W_c is the load on the pipe per unit of length, r is the mean radius of the pipe, EI is the effective product of the moment of inertia of the pipe wall and the modulus of elasticity of the pipe material, e is the modulus of passive pressure of the sidefill material, and D_1 is the deflection lag factor.

The expression is applicable for investigation of plastic drain tube deflections under earth loads. The apparent weakness of predictions based on this equation lies in the selection of proper values for the modulus of passive resistance of the enveloping soil.

Spangler (49) established the validity of the thin-ring elastic analysis as developed by Filkins and Fort (14) for use in determining the deflections of flexible pipes under field or laboratory load systems. A close correlation was found between measured deflections and those calculated by the thin-ring elastic theory within the elastic limit of the material.

A modification of Spangler's equation was used by Klimko and Kostikov (23) for calculating the deformation of plastic drainage pipe under backfill loads. This formula reads

$$\Delta_o = \frac{\bar{\Delta} \cdot g \cdot r^3}{E\,I} \qquad \text{------------} \quad 5.$$

where Δ_o = pipe deformation in the plane of the vertical diameter,

g = equivalent of the vertical load,

r = average pipe radius, and

$\bar{\Delta}$ = a coefficient, equal to 0.016 at zero slope

E and I are the same as in the Spangler's equation.

Shafer (43, 44) stated that the flexible pipes under external loads continue to function structurally until the deflection results in a concave curvature of the top or bottom of the pipe. He recommended the safe maximum deflection as 20 per cent of the vertical diameter and using a conservative factor of safety of 4, established the design deflection at 5 per cent. According to Shafer a flexible pipe is in equilibrium when the inherent strength of the pipe, R_I, plus the lateral pressure of the soil at the sides of the pipe, W_h, is equal to the vertical load on the pipe, W_c, and its reaction. The vertical deflection of the pipe, Y_c, depends on all three factors and may be expressed in the form

$$Y_c = f\left(\frac{W_c}{R_I + W_h}\right) \qquad \text{----------- } 6.$$

The Spangler equation includes all three factors in the above expression.

It has been recognized that the deflection of flexible pipes varies directly as some power of the height of fill, H, and the diameter, D, and inversely as the wall thickness, t. Thus,

$$Y_c = K \frac{H^m D^n}{t^s} \qquad \text{-------------- } 7.$$

The values of K, m, n, and s were determined in an investigation by the A.R.E.A.(2), wherein the deflections were measured for various conduits under different fill heights.

Undoubtedly the afore mentioned theories have their utility for predicting the structural performance of flexible and rigid pipes under earth loads. The theories are supported by several actual measurements of loads on conduits determined in experimental researches, as well as by field data obtained by a good many investigations of actual conduits in use. However, they have their limitations because the coefficients involved are functions of various factors including the properties of the soil which may vary considerably in different localities and can be determined only with the use of specialized equipment.

As far as known, the first attempt to develop a nomograph that would facilitate the calculation of the loads by Marston formulas was by Miller and Wise (32). The change in installation practices affected the loading conditions and necessitated modification of Miller's nomograph. Van Schilfgaarde et al. (55) presented three nomographs, each one for a different soil. Each nomograph enables the user to determine the loads on pipes installed in both narrow and wide ditches in accordance with the ditch and projecting conduit formulas. The lower value obtained is used for the design load.

3. Surface Loads

The extraneous super-loads applied at the surface are transmitted through the filling materials to the underground conduits. Super-loads may be concentrated as in the case of truck wheel loads, or they may be distributed as in the case of piles of construction materials at the fill surface. Most farm fields are often subjected to concentrated surface loads due to tractor or truck wheels.

The greatest effect of surface loads on subdrains is measured under relatively shallow covering of earth. The effect of live loads is dissipated or spread rapidly as the depth of cover increases to 4 feet or more and is practically negligible below 6 feet (3).

According to Taylor (52), Boussinesq in 1885 obtained a general solution of the elastic equations under a point load that was applied to a semi-infinite mass. In 1934, Froehlich (17) inserted into the distributions a concentration factor that alters the distribution according to the magnitude of the factor. The concentration factor also introduced varying soil strength into the equations. Based on semi-empirical formulas derived by Froehlich, Griffith (18) reported a generalized expression for the intensity of vertical pressure in soil due to a concentrated surface load in the form:

$$P_Z = \frac{\nu}{2\pi} P_o \frac{\cos^{\nu+2}\theta}{Z^2} \text{ ------------ } 8.$$

in which P_Z is the intensity of pressure at a point in the soil mass, P_o is the concentrated load applied at a point on the surface, θ is the angle formed with the vertical by the radius vector from the point of application of the surface load to the point considered, Z is the vertical distance from the surface to the point, and ν is the dispersion or concentration factor.

Holl (20) applied equation 8 to a number of problems related to the transmission of super-loads through different soils.

Marston and Spangler (30) conducted extensive experiments on both ditch and projecting conduits and reported that the load on an underground conduit due to a concentrated surface load may be expressed as

$$W_p = \frac{1}{L} F_i \; C_t \; P_o \qquad \text{------------------} \quad 9.$$

where W_p = average load on an underground conduit due to a concentrated surface load in lbs. per lin. ft.,

P_o = Concentrated surface load in lbs.,

F_i = impact factor,

L = length of the conduit in ft., and

C_t = a coefficient for concentrated surface load.

The coefficient, C_t, may be calculated by dividing the area of the horizontal projection of the conduit into a number of small areas and summing up the pressure according to the formula:

$$C_t = a \sum \frac{3}{2\pi} \frac{H_c^3}{H_s^5} \qquad \text{------------------} \quad 10.$$

where a = area of an element in sq. ft.,

H_c = vertical height from the top of the conduit to the surface in ft., and

H_s = slant height from the center of each element to the point of application of the load in ft.

Holl as reported by Spangler (50) integrated this expression for C_t and obtained:

$$C_t = 1 - \frac{2}{\pi}\left\{\left[\sin^{-1} H_c\sqrt{\frac{\frac{L^2}{4} + \frac{B_c^2}{4} + H_c^2}{\left(\frac{L^2}{4} + H_c^2\right)\left(\frac{B_c^2}{4} + H_c^2\right)}}\right]\right.$$

$$\left. - \frac{\frac{L\,B_c\,H_c}{4}}{\sqrt{\frac{L^2}{4} + \frac{B_c^2}{4} + H_c^2}}\left(\frac{1}{\frac{L^2}{4} + H_c^2} + \frac{1}{\frac{B_c^2}{4} + H_c^2}\right)\right\} \text{---------} \quad 11.$$

Based on studies by Marston and Spangler (30), the load on pipes installed in narrow trenches due to uniformly distributed surface load may be expressed as

$$W_{us} = C_{us}\, B_d\, U_s \quad \text{-----------------} \quad 12.$$

where W_{us} = average load on an underground conduit due to a uniformly distributed surface load in lbs. per lin. ft.,

U_s = a uniformly distributed surface load in lbs. per sq. ft.,

B_d = width of ditch at top of conduit in ft., and

C_{us} = a coefficient for uniformly distributed surface load.

The load on a projecting conduit due to a uniformly distributed surface load will be the same as that due to an additional layer of fill materials weighing U_s per square foot.

The values of the calculation coefficients C_t and C_{us} can be readily obtained from a computation diagram for C_t and a computation table for C_{us} published by Marston (28). Equation 11 can be evaluated by a table published by Spangler and Hennessy (51) on the basis of studies made by Newmark (35).

4. Supporting Strength of Subdrains

The supporting strengths of subdrains can be determined by testing a representative group of specimens in the laboratory. The three-edge bearing (6) and the sand box (48) tests are recommended respectively for rigid and flexible drain pipes. The crushing strength of the pipe as determined by the laboratory test is multiplied by a load factor to predict its load-bearing strength in an actual field installation under the particular bedding condition. For pipes used in agricultural subdrainage construction, the following bedding classifications have been adopted by the A.S.A.E. Standards (3):

Bedding	Load factor
Tamped	1.9
Ordinary	1.5
Impermissible	1.1

Ordinary bedding is the one most commonly encountered in farm drainage installations. The load factors, defined as the field supporting strength of a rigid conduit divided by its three-edge bearing laboratory strength, have been determined experimentally for each bedding classification. Similar values of load factors for plastic drain pipes are not yet available.

The effect of bedding conditions on the supporting strength of draintile was investigated by Van Schilfgaarde et al. (55) and a variation in load factors from 0.9 to 2.5 was obtained for beddings made by various types of ditching machines.

B. INVESTIGATIONS OF PLASTIC TUBING FOR SUBSURFACE DRAINAGE

A modest amount of research has been done to determine loading characteristics and related physical properties of plastic pipes for use in agricultural drainage.

1. Strength and Deflection

Attempts to improve the stability of mole channels by placing a plastic liner within the drain date back to the early 1950's. Mole drains by themselves were not very satisfactory due to poor outlets and collapses of the mole channels within the first few seasons. Thus some durable liner of adequate strength was needed.

Schwab (41) investigated the feasibility of perforated plastic tubing as a method of stabilizing mole drains. On the basis of five years of research study he found that most of the deformation of polyethylene tubing occurred during the first two years after installation and tubes 1½ or 2 inches in diameter were the most practical size considering stability, capacity, and cost.

Busch (8) used a plastic arch to increase the rigidity of mole channel walls. The plastic material, a 0.015 - in. thick by 6 - in. wide rigid vinyl strip, was formed into a tight 'U' and fed down through a chute into the mole drain. The arch was used to give the effect of a roof as the mole drains were found to fail because of soil falling from the top of the channel and plugging the drain.

Fouss and Donnan (16) experimented with various types of semirigid PVC plastic liners to strengthen the mole channels.

They reported that under field conditions a completely closed circular liner had maintained its cross-sectional size and shape better than the arch or the overlap types.

The effects of surface loads on different depths of plastic-lined mole drains in a sandy loam soil were investigated by Vaigneur et al. (54). They found that the 3-in. diameter plastic liners were collapsed when the surface loads, applied through a 9-in. diameter plate, exceeded 44 psi, 34 psi, and 24 psi, respectively for drains 30-in., 24-in., and 18-in. deep. The plastic material was formed into a tubular shape and loaded by two separate devices in the laboratory. A stress of 0.30 psi on the liner resulted in a vertical deflection of 33 per cent and rendered the mole drain unserviceable.

Manley (25) conducted loading tests on plastic-lined mole drains and found that the "bridging" phenomenon of soil tends to convey internal soil pressure produced by surface loads to the sides of the mole drain. He observed that this tendency of a soil to "bridge" increases with the bulk density of the soil. He obtained a highly significant correlation coefficient between maximum load and bulk density of the soil. Since soil stability varies with bulk density, he reported that soil stability is an important factor in determining the amount of load that can be applied to the ground surface before drain failure.

The use of plastic pipe made specially for drainage has increased rapidly since its introduction in the early 1960's. Corrugated and smooth-walled plastic tubing has been widely used in the European countries since 1963, and more recently in the United States and Canada. Several investigators have conducted preliminary tests on new plastic drainage materials and its installation.

Rektorik and Myers (39, 33) using smooth semirigid polyethylene tubing in both laboratory (33) and field (39) tests, came to the conclusion that the pipe has sufficient strength to withstand earth loads up to 8-ft. depth in a trench only 10-in. wide when lateral support for the pipe is provided. They recommend that a circular arc cradle closely conforming to the outside diameter of the tube should support at least a 160-deg. section of the tube. Under field conditions polyethylene tube was found to decrease from 4-in. to 3 3/4 -in. in the initial soil settling stage of about three months and thereafter no measurable deflection took place for 18 months. The narrowness of the trench is emphasized and they suggest a 10-in. width is desirable. Another conclusion reached by these investigators was that quicksand surrounding the pipe gives support as good as where a cradle is provided.

Klimko and Kostikov (23) reported that the deformation of plastic pipe occurs only during the back-filling of trenches, when the soil is loose. They further stated that the effect of dynamic forces is small compared to the pressure of backfill. Their conclusions were based on a series of loading tests conducted in Russia on polyethylene drainage pipes. The magnitudes of surface loads and the depths of drains are not clearly specified. However, it is logical that the effect of surface loads decreases as the depth of cover increases whereas the fill load increases with depth. Therefore, surface loads are of the prime concern when a pipe is placed under shallow covers.

In the United States, Fouss (15) described the results obtained from a 17-year old field experiment initiated by Schwab (41). Polyethylene smooth-wall plastic drains installed in an Iowa silty loam soil in 1949, continued to provide adequate drainage and were found to be almost perfectly circular at the end of the 17-year test period.

2. Measuring Techniques

Various instruments have been devised to determine the load-deflection characteristics of plastic drain tubes. Busch (9) designed a "measuring mouse", which is pulled through the drain on a small wire, and has strain gages mounted on a set of spring fingers which give a measure of the cross-sectional area. Shull (45) developed a self-propelled drain-line camera system to provide information on the condition of the drains. The major limitations of the camera are that it cannot be used if the pipe diameter is smaller than 4-in., and if water in the drain is more than about ½-in. deep.

In plastic-lined mole drains inside diameter measurements have been made using various size eyebolts attached to ½-in. steel tubing and inserted from the outlet end (41). Strain gages, secured to the exterior of the pipe (33), or placed inside the pipe (23), have been employed to obtain data on strain versus pipe deformation. A "strain gage mouse", similar to the one developed by Busch (9), has been used to study the changes in shape of plastic-lined mole drains under external loads (16, 54, 25).

3. Wall Thickness

The successful use of plastic drainage tubing depends on the choice of optimum wall thickness since the cost is directly proportional to the quantity of plastic in the tube. Schwab (41) suggested that smooth-wall polyethylene tubes 1½, 2,3, and 4-in. in diameter should have corresponding wall thickness of at least 0.04, 0.05, 0.08, and 0.12-in., to prevent tube deflections in excess of 20 per cent of their original diameter. Klimko and Kostikov (23) tend to support Schwab in the recommendations for diameter and wall thickness combinations. Rektorik and Myers (39, 33) found that 4-in. smooth polyethylene tubes with a wall thickness of 0.10 -in. are satisfactory for automated handling in drainage installation as well as from the structural stability standpoint. Wall thicknesses of corrugated plastic draintubes can be reduced considerably in comparison to smooth pipe of corresponding diameter in order to have the same structural strength.

4. Perforations

Plastic drainage tubing must be perforated to permit entry of water into the tube. The number, arrangement, and size of perforations do not only determine the water intake capacity but also influence the load-bearing strength of the tubes.

Research has been conducted on various types of perforation patterns and their effect on the amount of water and silt deposition entering into the draintubes.

In Holland, Cavelaars (11) demonstrated that for slotted draintubes, the rate of inflow is largely governed by the slot length per unit length of tube. The spacing between the slots determines the concentration of the streamlines. A high concentration of streamlines increases the approach resistance in the soil near the drain and adversely affects the performance of drainage system. These findings are supported by preliminary investigations in Russia with PVC and polyethylene pipes by Klimko and Kostikov (23). They also reported that the most effective perforation for plastic drainage pipes is in the form of longitudinal slots since it lessens the danger of plugging-up of the pipe and increases the rate of inflow. They found that in fine-grained sands, the arrangement of slots and to some extent, the area of perforation did not appreciably affect the water intake capacity.

Myers et al. (33) using smooth polyethylene tubing covered with fiberglass in controlled laboratory tank tests, found more flow from tube having slot dimensions of 1/16-in. X 2-in. long, than from another with slots 1/8-in. X 1½-in. long. Their explanation for this phenomenon was that soil and water pressure forced more soil and fiberglass into the wider slot which caused a greater obstruction to flow. However, as suggested by Cavelaars, it is probable that the slot length may have also influenced the flow.

Fouss (15) proposed that total area of inlet openings could be used as a suitable criterion. He quotes a rule-of-thumb that "the cross-sectional area of the water-entry openings should represent approximately 1 percent of the pipe's outside wall circumferential area."

It has been suggested (15, 47) that in corrugated tubing, the preferred location for perforations is in the valleys of the corrugations. Such an arrangement protects the water-entry openings from clogging with soil in case the tube is subjected to longitudinal slippage during installation. This arrangement also has the least detrimental effect on tubing strength.

5. Corrugation Pattern

The strength and cost of the corrugated plastic drainage tubing is influenced by the corrugation design. Fouss (15) presented the results of a computer program developed for evaluating different patterns of corrugations. He reported that the square-wave corrugation is preferred to sine-wave corrugation design and that the tube strength is supplemented by an increase in the depth and spacing of corrugations. He concluded, "the most efficient corrugation design resulted when the maximum practical corrugation depth was used, with a correspondingly large corrugation pitch, and the thinnest possible plastic material in the corrugation ribs (e.g., 15 to 20 mils)."

6. Plastic Drain Installation

There are basically two types of machines presently used for installation of plastic drainage tubing. One of these is the conventional tile drain trenching machine modified to take advantage of the tubing's flexibility and light weight. The other incorporates refinements of mole-ploughing techniques with improved grade-control systems. The trenchless drain laying equipment tunnels a passage through the ground by means of a narrow blade of special design and causes minimal soil disturbance. The mole plough installation of plastic drain pipes coupled with the laser-beam depth-control system (15) holds promise of becoming a lower cost and more rapid method of subsurface drainage.

The search currently continues regarding optimum design for strength of corrugated plastic tubing, plastic material properties, and improvements in the mechanization of drainage installations.

C. SPECIFICATIONS AND STANDARDS FOR PLASTIC DRAINAGE TUBING

The physical properties of plastic drain tubes are governed by specifications of national agencies or industrial organizations that set standards or product standards. The commercial production of plastic drainage tubing about a decade ago necessitated development of some important guides and specifications. In 1965, the Ministry of Agriculture in England proposed tentative specifications for trench-installed plastic drain pipes up to 4-in. in diameter (38). Ede (13) reported that these specifications were developed through a 5-year field research program using smooth-walled plastic tubes of various diameter and wall thickness combinations. In 1968, Finland's Building Engineers Association published tentative standards (36) for the quality control and testing of PVC pipes used for drainage of agricultural lands. In 1969, the German Industrial Norms Agency submitted a draft of plastic drain pipe standards (56) to the public for comments and suggestions. This standard was the outcome of extensive experimental research over a period of several years on rigid PVC drainage pipes in Germany. The committee prepared one set of standards for smooth-walled and corrugated plastic pipes, since the quality requirements and test methods for both categories are essentially alike.

Herndon (19) has reviewed the present Soil Conservation Service specifications in the United States (48) for physical requirements, testing and installation of corrugated polyethylene drainage tubing. He reported that the Soil Conservation Service in collaboration with the National Bureau of Standards are developing (in late 1969) a product standard for corrugated plastic drainage tubing and fittings. Some standards on plastic tubing products, other drainage products, and methods of test have been developed by the American Society for Testing and Materials (4,5,6). Specifications for 4-in. I.D. corrugated polyethylene drainage tubing (1) were developed by the Advanced Drainage Systems, Inc. (ADS) and approved by U.S. Soil Conservation Service in 1967.

In Canada the plastic drainage tubing manufacturers organized a committee in early 1969 and prepared specifications for corrugated plastic drainage tubing. Their proposals were accepted by the Ontario Farm Drainage Association (OFDA) early in 1970 and designated as a tentative product standard (37) for a period of one year, during which time, recommendations, comments and suggestions will be entertained. Hore and Sojak (22) discussed issues that should be considered when preparing installation specifications. A similar product standard for corrugated plastic drainage tubing is under preparation in 1970 in the Province of Quebec.

The stated documents take into consideration the quality requirements for mechanized pipe laying. The drain tubes acceptable by these standards are expected to be installed by machine without impairment either in trenches or by the trenchless method of drain laying under rugged work conditions and in adverse weather, including temperatures below 0° C. These requirements are to be taken care of by the tests for impact durability, bending, and crushing strength. Methods of test for physical properties of plastic drainage tubing are described in Chapter III under section 'Laboratory Tests'.

III. MATERIALS AND METHODS

A. MATERIALS TESTED

The details relating to materials, dimensions, and structural features of plastic drain tubes used in this investigation are given in Table 1. The inside diameter of each specimen was measured with a tapered plug in accordance with the ASTM specifications for determining dimensions of thermoplastic pipe (4).

B. THE FIELD EXPERIMENT

1. The Experimental Field Layout

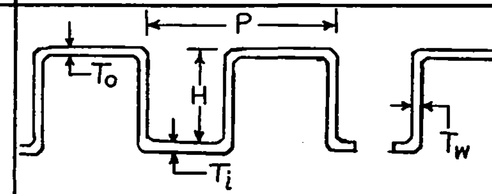
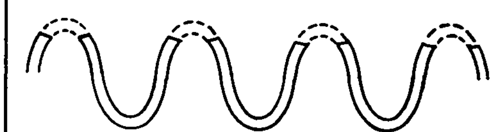
Surface load tests on drain tubes were made on a three acre plot of the Macdonald College Farm, about two furlongs north of Trans Canada Highway.

In October 1968, the area was surveyed and after a careful study of the topography a plan was prepared for drain layout. Longitudinal sections were drawn for the laterals and collectors. The grid point elevations were recorded on the plan, the design grade elevations were determined by inspection, and a land levelling plan was prepared to obtain the desired drain depths.

On November 11 and 12, 1968 plastic drain tubes and clay tiles were installed by a Buckeye Trencher and a Critchley Trenchless Drain Laying Mole Plough operated by the Division of Agricultural Hydraulics of the Quebec Ministry of Agriculture and Colonization. Fifteen lines were installed at 2 foot and 3 foot depths. Each set of laterals opened

TABLE 1

PHYSICAL DIMENSIONS OF PLASTIC DRAIN TUBES TESTED

Material and Manufacturer of Tube	Outside diameter (Inches)	Inside diameter (Inches)	Wall Thickness (Inches)			Depth of Corrugation H (Inches)	Corrugation pitch P (Inches)	Corrugation pattern and location of perforations
			Ridge T_o	Valley T_i	Web T_w			
Corrugated P.E. tubing (black) The Big "O" Drain Tile Co., Canada	4.539	4.045	0.040	0.038	0.035	0.225	0.510	 Slots in 3 rows spaced equally around the tube
Corrugated PVC tubing (yellow) Fraenkische-Isolierrohr - U. Germany	3.898	3.622	0.027	0.023	0.021	0.160	0.240	 Perforations in 3 rows spaced equally around the tube
Corrugated PVC tubing (yellow) Fraenkische-Isolierrohr - U. Germany	2.559	2.323	0.025	0.022	0.020	0.120	0.200	 Perforations in 3 rows spaced equally around the tube
Corrugated PVC tubing (grey) Origin not known	1.971	1.785	0.026	0.024	0.024	0.100	0.180	 Perforations in 8 rows around the tube
Smooth semi-rigid PVC tubing (white) Holland	1.990	1.900	0.045			Smooth Wall Tube		Slots in 4 rows spaced equally around the tube

into an access trench having a 4-in. tile collector installed and covered with crushed stone. The collectors led to an outlet for the designed drainage system. The access trenches were used for checking the deformation of the drain tubes during the field loading tests. Each line had a different drain tube material, installation method or bedding condition. The plot layout is given in Figure 1.

It has been suggested (33) that plastic drain tubes could support greater loads if placed in a groove moulded to fit the bottom 140 to 160 degrees of the tube. This would require special attachments on a drainage machine for each size of tube. In order to get some evaluation of the benefits of such a bedding groove, referred to as 'special shoe' in the plot layout, the 4-in. and 3.7-in. plastic tubes were installed in trenches with a 2.25-in. radius groove for the bottom 150 degrees. Plastic tubes were also installed in trenches with a standard 90 degree 'V' groove. The 3.7-in. plastic tube fitted closely the size of the mole whereas the 2.5-in. plastic tube was loose in the hole provided by the Critchley trenchless drain laying mole plough. Some tubes were installed by the Critchley machine with a crushed stone infill, as it has been suggested that a crushed stone or gravel infill improves the load carrying capacity as well as assisting water inflow.

The backfilled soil in the trenches was allowed to settle in the winter of 1968-69. In the following summer after ploughing and discing the field, some levelling operations

LINE	DRAIN TUBE MATERIAL	METHOD AND EQUIPMENT
1	8" Clay tile	Trencher
2	3.7" Corr. Yellow German Plastic	Trenchless plow
3	6" Clay tile	Trencher
4	2.5" Corr. Yellow German Plastic	Trenchless plow
5	4" Clay tile	Trencher
6	2" Corr. Grey Plastic	Trenchless plow
7	4" Corr. Black Canadian Plastic	Trencher
8	3.7" Corr. Yellow German Plastic	Trenchless plow, with gravel
9	3.7" Corr. Yellow German Plastic	Trencher
10	2.5" Corr. Yellow German Plastic	Trenchless plow, with gravel
11	2.5" Corr. Yellow German Plastic	Trencher
12	2" Corr. Grey Plastic	Trencher
13	4" Corr. Black Canadian Plastic	Trencher, special shoe
14	2" Semi-rigid White Dutch Plastic	Trencher
15	3.7" Corr. Yellow German Plastic	Trencher, special shoe

TO MORGAN ARBORETUM

Main 4" Tile

Access Trench & Sub Main A 4" Tile Covered with Crushed Stone

DEPTH OF DRAINS 2 FT. DEPTH OF DRAINS 3 FT.

Scale 1" = 40 Ft.

FIG. 1. PLAN OF DRAINS FOR LOADING TESTS.
INSTALLED NOVEMBER 1968 - MACDONALD COLLEGE FARM.

were carried out in order to provide the required depth of soil cover over the drain tubes in accordance with the aforementioned plan for land levelling. The desired depths were accomplished by using bulldozer, crawler loader, dump truck, and a land leveller.

2. Drain Tube Field Loading Tests

A series of field loading tests were made on the plastic drain tubes and clay tiles in the fall of 1969. The subdrains were subjected to repeated live loads consisting of a heavy tractor hitched to a loaded wagon, a 'dump' truck, and a concrete 'Ready-Mix' truck, loaded with crushed stone.

A Ford 8000 Diesel tractor was used for the field tests. The total weight of the tractor with calcium chloride solution loaded rear tires, rear wheel and front end weights was 6.23 tons with 4.20 tons on the rear axle, or 2.10 tons per rear wheel. The Ford 8000 tractor was hitched to a forage wagon loaded with maize silage. The total weight of the loaded wagon was 7.60 tons with 4.55 tons on the rear axle, or 2.275 tons per rear wheel.

The drain tubes were subjected to heavier surface loads with loaded trucks until failure of some drain tubes was reached. Firstly a single rear axle 'dump' truck loaded with crushed stone was used. The loaded truck weighed 17 tons with a 12 tons rear axle load, or 3 tons on each rear tire. Field loading tests were continued with a tandem rear axle concrete 'Ready-Mix' truck. Loaded, the truck weighed 26.3 tons. The tandem rear axle load was 20.3 tons, or 2.504 tons per rear tire.

Since the pressure distribution in soil under wheels is bulb-shaped (46), the dual rear wheels of trucks would give a greater load intensity on the drain tubes than the single wheels of the tractor or the wagon as a portion of the tube gets pressure overlap from each of the dual wheels. The load intensity on the drain tubes caused by concrete 'Ready-Mix' truck was greater because of the contribution from four wheels of the tandem rear axle.

The tractor hitched to the loaded forage wagon and the trucks made trips back and forth over the subsurface drains in accordance with a prepared loading program, and the deformations of plastic drain tubes or any damage to clay tiles were subsequently checked with plug gauges as described in the following pages.

The decrease in the vertical diameter as a result of deformation due to extraneous surface loads and earth loads is allowed within a range of 20 to 30 per cent. Such a deformation does not substantially affect the flow capacity or the cross-sectional area of the subdrain. These allowances are permitted in tentative specifications of plastic drain tubes in U.S.A., USSR, Germany, and England. Failure load was defined as the maximum load reached to produce a vertical deflection of 30 per cent.

In order to ascertain the allowable deflection, hard wooden oblong 'GO-NO GO' plugs, attached to a 50 foot length of ½-in. semi-rigid PVC plastic pipe were inserted in the drain tubes from the access trenches as shown in Figure 2.

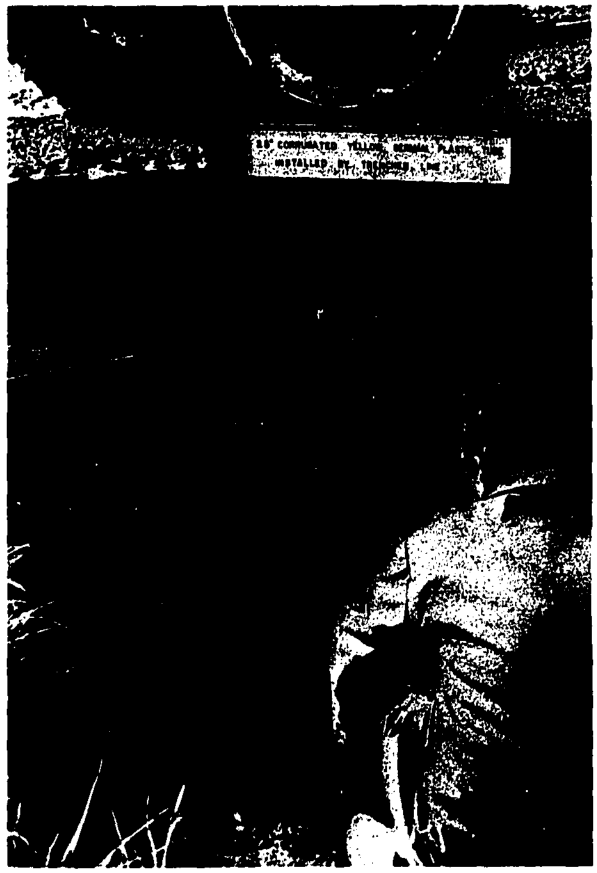


Fig. 2. Checking deformation with
plug gauge.

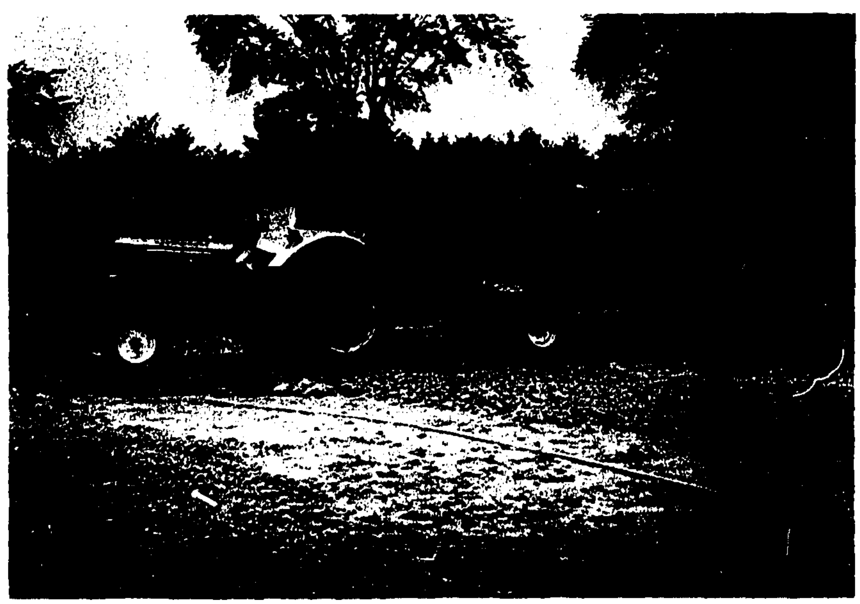


Fig. 3. Farm vehicle loads passed over drain tubes. Ford 8000 tractor (gross, 6.23 tons; rear axle 4.20 tons) hitched to a loaded forage wagon (gross, 7.60 tons; rear axle, 4.55 tons).

For deflection checks two sets of plug gauges were used. The maximum cross-sectional dimensions of the plug gauges were 0.7 and 0.8 times the diameter of the tubes, corresponding to the permitted 30 and 20 per cent deflections.

Live load tests were made on three tracks over each set of fifteen subdrains buried at 2 foot and 3 foot depths. The outer wheel tracks were located at 15, 35, and 50 feet from the observation trench. The effect of wheel loads on the drain tubes was investigated under six loading points providing six replicates per tube for each treatment of depth or soil covering.

The field loads and the number of passes along three vehicle routes over each of the fifteen subdrains are indicated in Table A.

TABLE A

Field Test No.	Surface Load	No. of passes from start after which the deformations were checked
1	Ford 8000 tractor.	10
2	Ford 8000 tractor hitched to a forage wagon loaded to one half its capacity with silage.	10 and 20
3	Ford 8000 tractor (gross, 6.23 tons; rear axle, 4.20 tons) hitched to the forage wagon with a full load of silage (gross, 7.60 tons; rear axle, 4.55 tons).	5, 10, 20, and 40
4	'Dump' truck, single rear axle, loaded with 3/4" crushed stone (gross, 17 tons; rear axle, 12 tons).	1, 5, 10, and 20
5	Concrete 'Ready-Mix' truck, tandem rear axle, loaded with crushed stone (gross, 26.3 tons; rear axle, 20.3 tons).	1, 5, 10, and 20

Surface loads encountered in farm operations are represented by Field Test Nos. 1 to 3 (Figure 3). Most farm fields which have subsurface drains installed are occasionally subjected to heavy wagon loads and to fertilizer or lime truck loads, which are represented by Field Test No. 4 and 5 (Figure 4).

At the end of the loading tests the soil above the damaged points was removed by hand shovelling to observe the degree of distortion, to replace the crushed portions, and to determine the number of points damaged. The crushed portions of the tubes obstructing the movement of plug gauges, were replaced by sleeves of new tubes. The plug gauges were then inserted further into the tubes to check the deformations of the remaining points loaded by the truck wheels.

The repeated passing of the trucks along the tracks resulted in significant displacement of soil and formation of ruts. The vehicle sinkage over the drain tubes on all the tracks was measured by determining the elevations of the tracks and the adjacent normal ground surface. At the end of each set of loading tests, the tracks on the field test area were levelled by using a cultivator and a land leveller. The operation helped to maintain a uniform soil cover over the drain tubes.

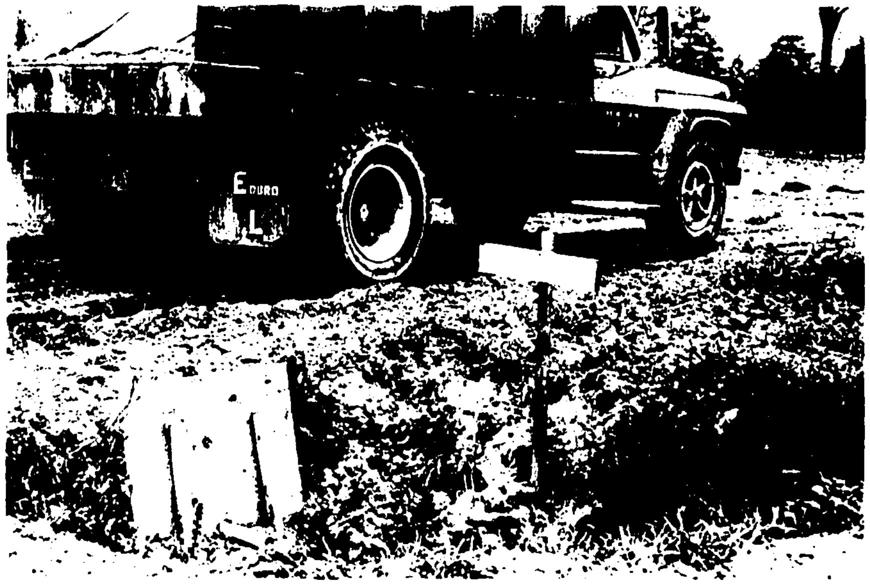
3. Physical Characteristics of Soil

The effect of surface loads on subdrains is modified by the kind and condition of soil surrounding the drain tube. To facilitate a better understanding of soil behavior,

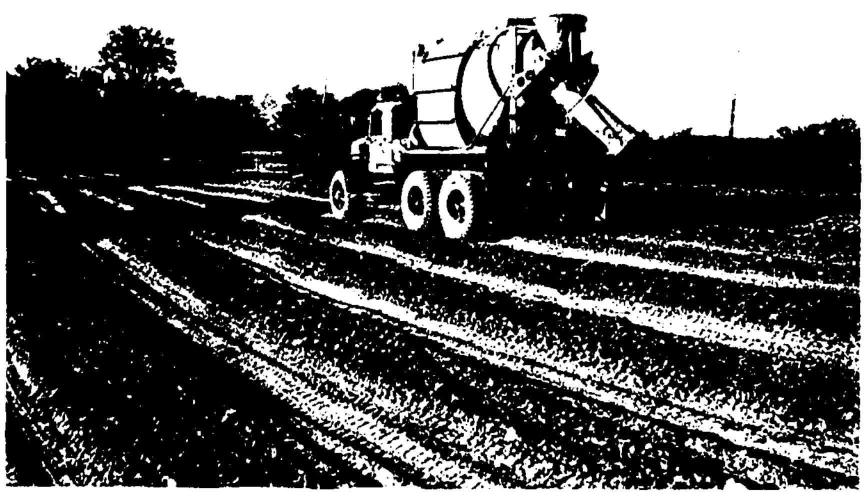
(a) Gross, 17 tons; rear axle, 12 tons.

(b) Gross, 26.3 tons; rear axle, 20.3 tons.

Fig. 4. Truck loads passed over drain tubes.



(a) Gross, 17 tons; rear axle, 12 tons.



(b) Gross, 26.3 tons; rear axle, 20.3 tons.

Fig. 4. Truck loads passed over drain tubes.

particle size distribution, bulk density, and moisture content of the field soil were obtained. Sampling sites were located about 15 feet from the observation trench on the field loading test area, over the lines 2, 8, and 14.

The results in Table B were obtained from the particle size analysis made by the hydrometer method.

Samples for bulk density were taken 6, 12, and 18-in. directly above the drain tube and at the same relative position 2 ft. to the side of the drain by using a core sampler. Samples for soil moisture measurements were taken at approximately weekly intervals during the period of field loading tests.

TABLE B. PARTICLE SIZE ANALYSIS

Depth (in.)	Clay (%)	Silt (%)	Sand (%)
(a) Location 1:	15 ft. from the observation trench, above Line No. 2.		
0 - 6	25.0	8.0	67.0
9 - 15	34.5	12.5	53.0
18 - 24	37.0	8.0	55.0
(b) Location 2:	15 ft. from the observation trench, above Line No. 8.		
0 - 6	27.5	8.5	64.0
9 - 15	37.0	10.0	53.0
18 - 24	53.0	9.5	37.5
(c) Location 3:	15 ft. from the observation trench, above Line No. 14.		
0 - 6	30.0	6.5	63.5
9 - 15	23.0	5.5	71.5
18 - 24	40.5	12.0	47.5

C. LABORATORY TESTS

A series of physical tests were carried out on short sample lengths from each line in the field. In the laboratory the crushing strength was determined by the sand box method, the three-edge bearing method, and the external loading properties of plastic drain tube by the parallel-plate loading test. A creep resistance test was carried out by application of a constant load over a period of seven days. The impact durability was checked by the drop weight test, longitudinal flexibility by the bending test, and dent resistance by applying a concentrated load for a specified period of time. Absorption tests, and freeze-thaw tests were conducted on plastic drain tube and clay tile samples. Unless otherwise specified, test specimens were made in one foot lengths. The ends of test specimens were cut square and free of burrs and jagged edges.

1. Crushing Strength by Sand Box Method

Five samples from each line in the field were tested for crushing strength by sand box method in accordance with the USDA, Soil Conservation Service specifications (48).

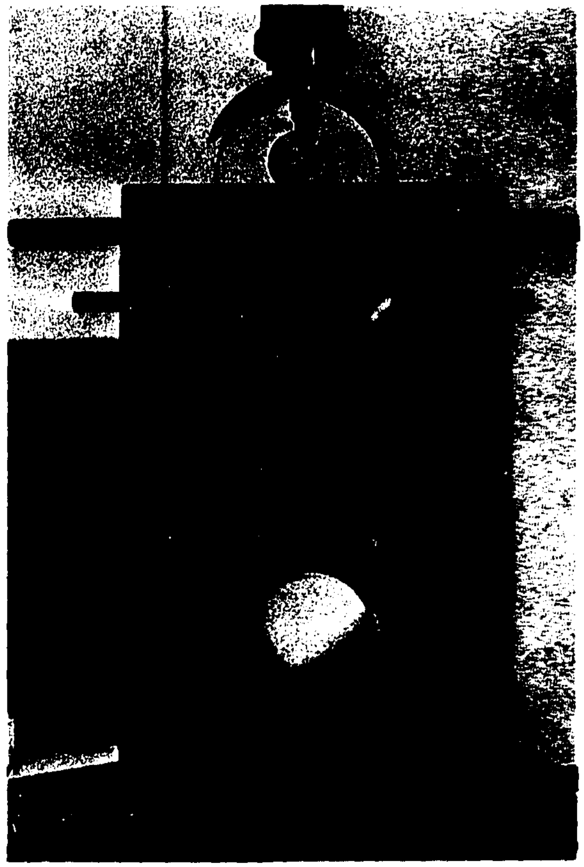
A box 13-in. X 12-in. by inside measurements and 20-in. high was fabricated. The ends were constructed of 3/4-in. thick plexiglass so the specimen could be visually observed during the test, and the sides were constructed of ½-in. steel plate. A proving ring (0 - 10,000 pounds capacity) was fixed on the top bearing plate and then fastened to the ram of the testing machine. The test specimen was placed on 3-in. deep layer of dry sand in the box with its open ends against the plexiglass ends of the box. Dry sand was then poured into the box and levelled to a depth of 6-in. over the specimen. The test apparatus is shown in Figure 5(a).

The crushing strength was defined as the maximum loading value reached before a steady decline in loading occurred. The load was applied at a uniform rate and the dial gauge reading at failure of the test specimen was recorded. The load at failure was obtained from the calibration chart for the proving ring; and the crushing strength values tabulated as pounds force per linear foot of tubing.

2. Crushing Strength by Three-Edge Bearing Method

In accordance with the ASTM standard specifications for clay drain tile (6), five samples from each line in the field were tested for crushing strength by the three-edge bearing method.

A proving ring (0 - 2000 pounds capacity) was fixed on to the upper bearing plate and fastened to the ram of the testing machine. The clay drain tile specimen and all the bearing plates were accurately centered to ensure a symmetrical distribution of loading. The test apparatus is shown in Figure 6(a). Load was applied at a uniform rate of 500 pounds per lineal foot per minute until the specimen failed. The dial gauge reading at failure was noted and the corresponding load was obtained from a calibration curve. The crushing strength values were recorded in pounds per lineal foot of tile.

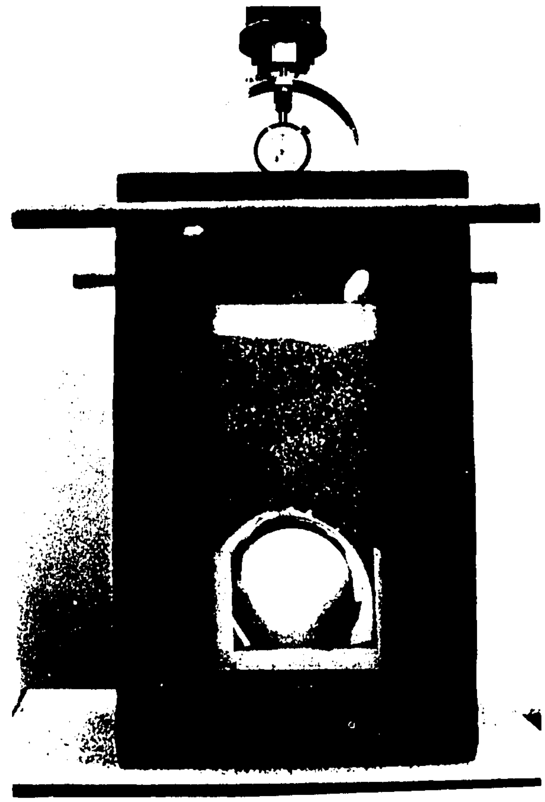


(a) Test apparatus

(b) Crushed sample of 4-in. plastic tube, Ave. ultimate load 7822 lbs. per linear foot.

(c) Broken sample of 6-in. clay tile, Ave. ultimate load 3768 lbs. per linear foot.

Fig. 5. Crushing Strength - Sand Box Method.



(a) Test apparatus

(b) Crushed sample of 4-in. plastic tube, Ave. ultimate load 7822 lbs. per linear foot.

(c) Broken sample of 6-in. clay tile, Ave. ultimate load 3768 lbs. per linear foot.

Fig. 5. Crushing Strength - Sand Box Method.

Load-deflection measurements for plastic drain tube samples were continuously recorded on the chart of the Instron testing machine with reference to relative movement of the upper and lower bearing plates. The testing device is shown in Figure 6(b).

3. Parallel-Plate Loading Test on Plastic Drain Tubes

The external loading properties of plastic drain tubes were determined by parallel-plate loading in accordance with the ASTM test procedures for plastic pipe (5).

A 6-in. long sample was placed between two rigid parallel flat steel plates. The Instron (Figure 7) was adjusted to give a constant rate of loading. The specimen was compressed at a constant (vertical) deflection rate of 0.5-in. per minute. The load-deflection curve was continuously recorded on the Instron Chart until 30 per cent deflection was reached. If no failure occurred at 30 per cent deflection, the loading was stopped. Five specimens from each line in the field were tested and each specimen between the parallel plates was oriented 35 deg. from the position of the preceeding specimen.

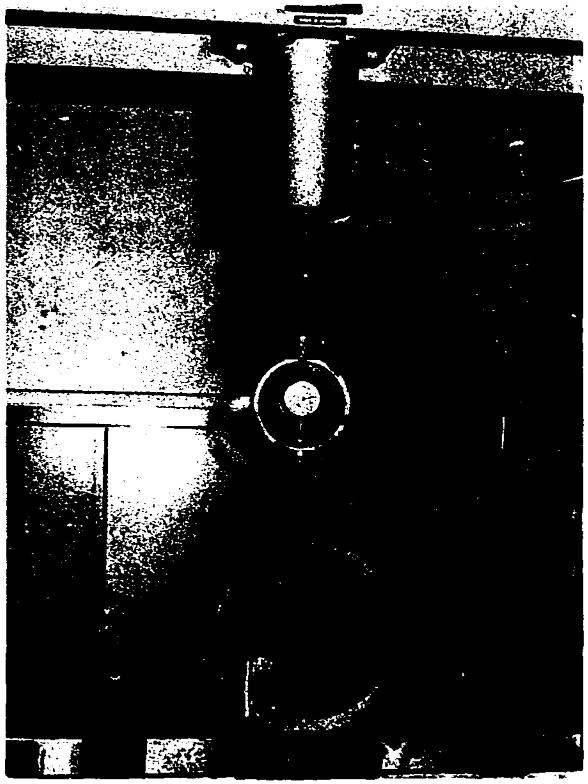
The stiffness factor (SF) at 5 and 10 per cent deflection, using load, W, interpolated from the plotted data was calculated by means of the following equation (5):

$$S\,F = \frac{0.149\ W\ r^3}{d}$$

where W = recorded load, lb/lineal in. of pipe,

r = mean radius, in. $\left(\frac{\text{avg OD} - \text{avg Wall}}{2}\right)$, and

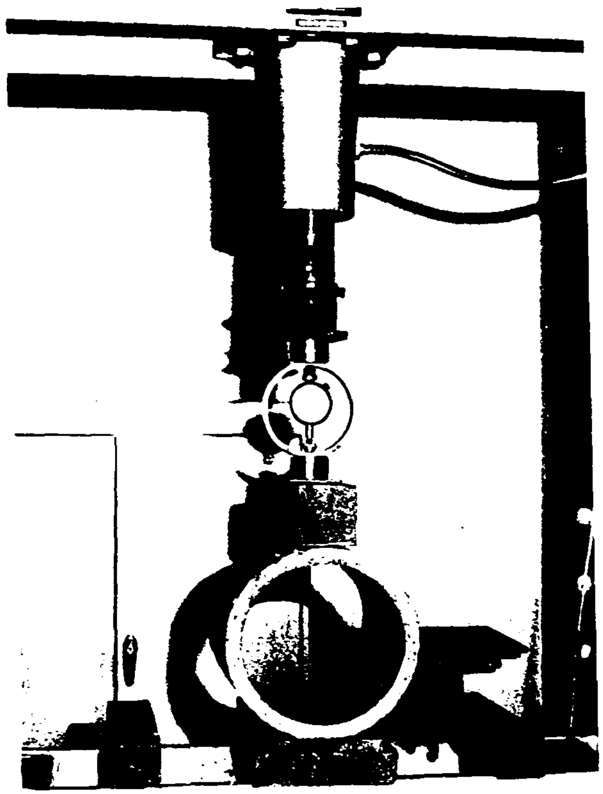
d = recorded deflection, in. (corresponding to load W).



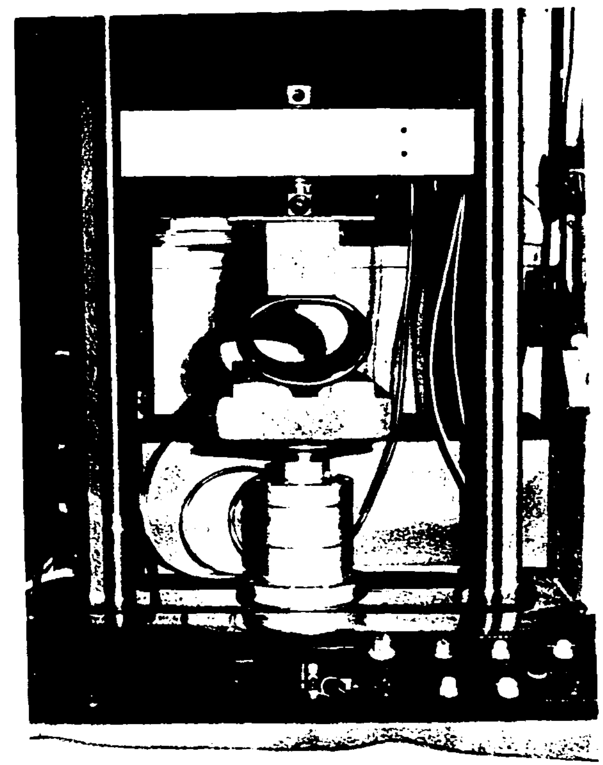
(a) Test apparatus for Clay tiles.

(b) Test apparatus for plastic tubes.

Fig. 6. Crushing Strength - Three-Edge Bearing Method.



(a) Test apparatus for Clay tiles.



(b) Test apparatus for plastic tubes.

Fig. 6. Crushing Strength - Three-Edge Bearing Method.

4. Creep Resistance

The creep resistance of one specimen from each line in the field was measured in accordance with the OFDA, tentative product standard (37). The sample was placed between parallel plates, under a constant load, and deflection of the tube was observed over a period of seven days. The magnitude of the test load in pounds per linear foot was obtained by multiplying the inside diameter of the tubing in inches by the number, 6. The change in tube diameter parallel to the direction of loading was measured with a dial gauge accurate to 0.001 inch. The deflection measurements were made at the end of 6, 24, and 168 hours from the time the test load was applied; and at the end of 6 and 24 hours upon removal of the test load. A plot on cartesian coordinates was made of the deflection (per cent decrease in diameter) versus time in hours.

5. Impact Durability (Drop Weight Test)

The impact resistance of plastic drainage tubing was tested in accordance with U.K. Standards (38). Five samples from each line in the field were kept for 24 hours in a liquid bath held at 0° C. The tests were started within 15 seconds of removal from the bath.

Samples were placed on a 'V' block of included angle 120 deg., mounted horizontally under a vertical guide which enables a weight of 0.55 pounds to fall freely onto the upper centre line of the tube resting on the 'V' block (Figure 8). The drop weight was released starting from a height of 4-in. After one blow of the drop weight, the specimen was rotated so that a new area was presented to the drop weight edge, and the height of drop increased by 4-in. The test was terminated at failure height, or at 40 inches if there was no failure, making a maximum of 10 blows per specimen. Failure was defined as the creation of perforations by shattering action. The greatest height of drop for each sample was recorded and utilized for calculating impact durability and percentage variability.

Impact durability is defined as inches average height of drop of the test weight as a percentage of 40 inches, and the variability per cent is defined by the formula:

$$\frac{\text{Mean height} - \text{Minimum height}}{\text{Mean height}} \times 100$$

6. Longitudinal Flexibility (Bending Test)

A flexibility test was conducted on 3 specimens 3 feet in length from each line in the field in accordance with the OFDA, tentative product standard (37).

Samples were stored at 0° C temperature for 24 hours. Within 15 seconds from the time of removal from the freezing chamber, the tube was bent over a cylindrical template with a radius 3 times the inside diameter of tubing and retained in place for one minute. The specimen was examined for splits or cracks while held in the bent position. The test specimen was then straightened and 24 hours later it was again inspected for failure due to splitting, cracking, or distortion of the original shape of the tubing and water inlet openings.

Fig. 7. Parallel-plate loading in Instron testing machine.

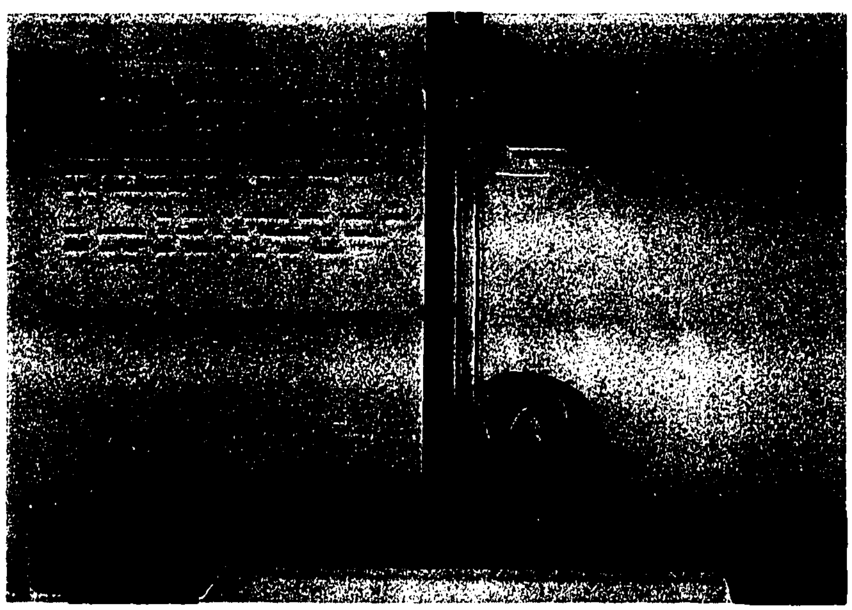


Fig. 8. Impact durability test device.

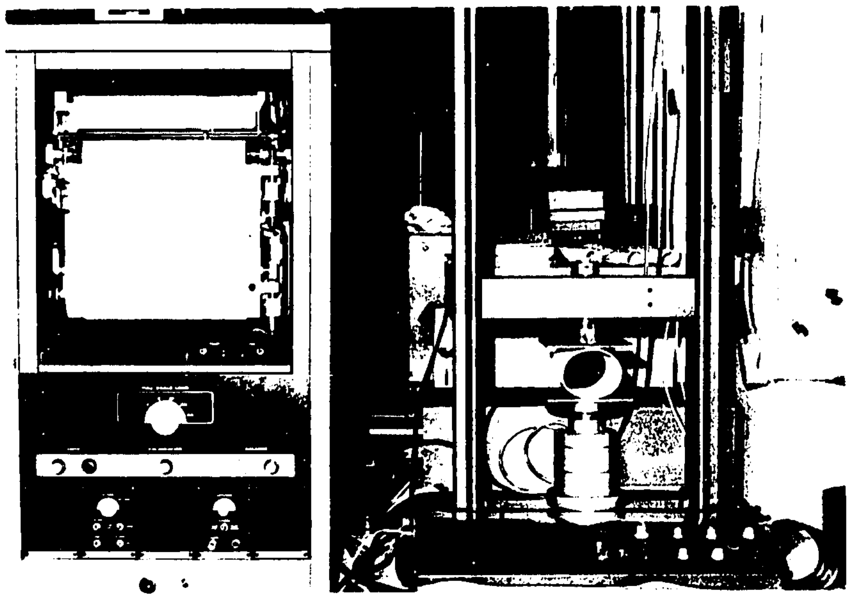


Fig. 7. Parallel-plate loading in Instron testing machine.

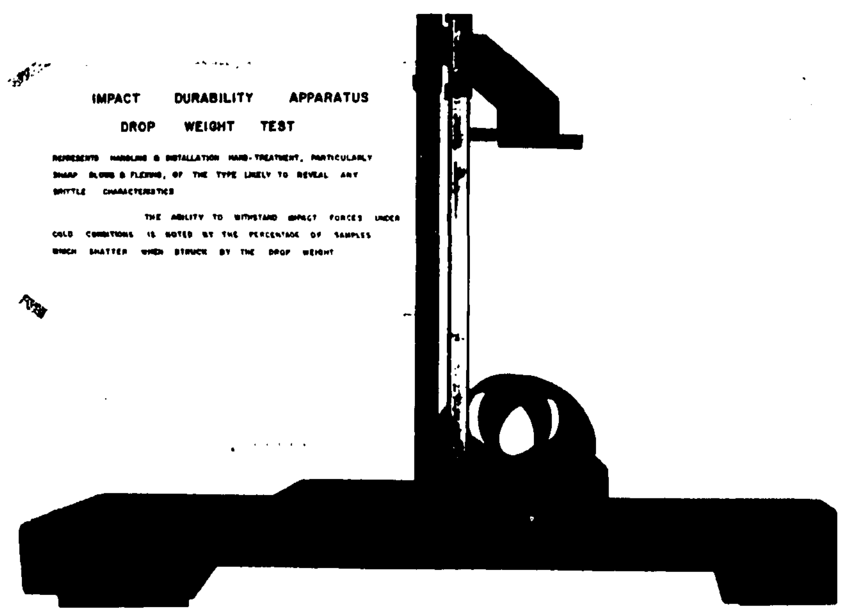


Fig. 8. Impact durability test device.

7. Dent Resistance

The dent resistance of five specimens from each line in the field was measured in accordance with a procedure proposed in an early draft of a proposed OFDA tentative product standard. The impact durability test device was modified by replacement of the drop weight with a five pound dent test loading weight terminating in a 3/8-in. diameter rounded end rod. The dent test load was applied to the top of the corrugation ridge for a period of one minute, and upon removal of the load and following a three minutes waiting period, the depression caused by the loading rod was measured with a depth gauge device. The specimen, while supported by the 'V' block, was subjected to four applications of the dent test load. The loading points were randomly selected around the specimen, but at least two applications per specimen were positioned close to a water entry slot.

8. Absorption Test on Clay Drain Tile

The test specimens selected had approximately uniform width and consisted of one full-length quarter segment taken from each of the five tile broken in the crushing strength test by the three-edge bearing method. In accordance with the ASTM, standard specifications for clay drain tile (6), the specimens were dried for 16 hours in a ventilated oven, then saturated by boiling for 5 hours in a liquid bath. The test specimens were weighed after drying and after saturation by boiling. Absorption was calculated as a percentage of initial dry weight.

9. Freezing and Thawing Test

Freezing and thawing tests were carried out as a separate project (10) in accordance with ASTM Designation : C 4 - 62 (6). One quarter segment from each of the five clay tile and plastic drain tube samples was chosen. The specimens were placed with their concave faces upward in water-tight trays. Water was adjusted to a ½-in. level in each tray. After subjection to 3 hours minimum freezing conditions, the trays were immersed in room temperature water until the ice formed during freezing had melted. The procedure was then repeated and the specimens were subjected to 36 freezing and thawing cycles.

IV. RESULTS AND DISCUSSIONS

A. FIELD LOADING TESTS

The field loading tests showed that the tractor and the loaded wagon did not produce any significant effect on the subdrains. No failure of any drain tube was detected up to 40 passes of the Ford 8000 tractor (6.23 tons) hitched to the fully loaded forage wagon (7.60 tons).

The deflection checks made with the respective plug gauges subsequent to 5 passes of the 'dump' truck (17 tons) revealed no significant deformation of the plastic drain tubes nor any damage to the clay tiles. After 10 passes of the truck it was observed that the plastic tubes in Line 8 and Line 14 at the 2 foot depths were deformed beyond 30 per cent of their original diameter. No further failure of any drain tube was detected following 20 passes of the truck.

At the end of the test, excavations were made above the damaged points to replace the crushed portions of the drain tubes so that loading tests could be continued. The 2-in. semi-rigid white Dutch plastic tube in Line 14 rebounded on removal of soil-fill pressure but the 3.7-in. corrugated yellow German plastic tube in Line 8 was distorted beyond serviceability.

The drain tube deflections did not exceed 20 per cent of the original diameter up to 5 passes of the concrete 'Ready-Mix' truck (26.3 tons). Three plastic tubes (Lines 7, 8, and 13) buried at a depth of 2 feet were deflected beyond the 30 per cent limit after 10 passes of the truck. In addition two plastic tubes (Lines 10 and 14) at the 2 foot depth, and two tubes (Lines 8 and 14) at the 3 foot depth were deformed beyond the allowable limit after 20 passes of the 'Ready-Mix' truck.

The excavations showed that four plastic tubes (Lines 7, 10, 13, and 14) at the 2 foot depth section were crushed at one or more points. The rest rebounded on removal of fill load and practically regained their original shape. The details of the drain tubes crushed during the field loading tests are reported in Table 2.

The surface soil in the installation area was classified as sandy clay loam. The soil at the drain site increased in clay content with depth and was classified as sandy clay at the trench bottoms with some pockets of clay. The bulk density of the soil in the trench area varied very little from the adjacent undisturbed soil after the surface loads were applied. At the time of loading tests, the soil moisture in the test area varied from 17 to 24 per cent (dry weight basis).

The repeated live load tests caused considerable soil compaction and rut formations. There was no measurable rebound after the loading. The surface displacement varied from 4-in. to 15-in. in Field Test No. 5 after 20 passes of the 26.3 ton truck. Deep tracks may have been caused more by plastic flow of soil under tires than by soil compaction. It is known that plastic flow occurs if the shear stresses in the soil exceed bearing strength. This strength to a great degree depends on the water content of the soil. Also the compaction and plastic flow of soil increase with increasing moisture content. There-

TABLE 2

DRAIN TUBES CRUSHED DURING FIELD LOADING TESTS

Field Line No. & Drain Tube Material	Depth to bottom of drain tube (Feet)	Field Test No.	Rear axle load (Tons)	No. of passes after which failure found	No. of points damaged from 6 loaded	Vehicle Sinkage (Inches)	Remaining Cover (Inches)
(8) - 3.7" corr. Yellow German plastic	2	(4) - 17 tons 'Dump' Truck	12	10	1	9.0	11.3
(7) - 4" corr. Black Canadian plastic	2	(5) - 26.3 tons Concrete 'Ready-Mix' Truck	20.3	10	2	11.5 10.3	8.5 9.7
(13) - 4" corr. Black Canadian plastic	2	(5) - 26.3 tons Concrete 'Ready-Mix' Truck	20.3	10	1	8.4	11.6
(10) - 2.5" corr. Yellow German plastic	2	(5) - 26.3 tons Concrete 'Ready-Mix' Truck	20.3	20	1	7.2	14.3
(14) - 2" Semi-rigid White Dutch plastic	2	(5) - 26.3 tons Concrete 'Ready-Mix' Truck	20.3	20	1	8.5	13.5

NOTE: No failure of any drain tube was found upto Field Test No. 3 - 40 passes of the Ford 8000 tractor (Gross, 6.23 tons; rear axle, 4.20 tons) hitched to a loaded forage wagon (Gross, 7.60 tons; rear axle, 4.55 tons).

fore, due to 'moist to wet' soil condition and high pressure concentration near the ground surface, the yield strength of the soil was exceeded resulting in different amounts of soil displacement and variation in original depth of drains before failure of the drain tubes was reached.

In Field Test No. 4, the failure of the 3.7-in. corrugated yellow German plastic tube (Line 8) was probably due to the soil being much softer and the vehicle sinkage greater than over the other tubes. It was not possible to obtain a uniform soil condition for the complete field test area. The sinkage over Line 8 was 9-in. after 10 passes of the 'dump' truck (17 tons). The sinkage over other lines at that stage was only about 3 inches.

Since the plastic tube itself has relatively little inherent strength and a large part of its ability to support vertical loads is derived from the passive pressure induced as the sides move outward against the earth, it is reasonable that the tube could support greater loads if placed into a firm groove formed in the bottom of the trench. Fouss (15) refers to this by stating that, "the strength requirement for the plastic drain tubes installed in a mole-drain channel is probably lower than that required for trench-installed plastic pipe, because of the excellent bedding conditions provided by the curved bottom of the mole channel."

It is noted that three out of four plastic tubes (Lines 7, 13, and 14) crushed as a result of repeated loading in Field Test No. 5 by the concrete 'Ready-Mix' truck (26.3 tons), were installed by the Buckeye Trencher. The fourth tube (Line 10) that collapsed under the truck load was loose in the hole provided by the Critchley mole plough and apparently received inadequate lateral support from the enveloping soil. Furthermore, the trench-installed plastic pipes (trench width = 18-in.) were very likely subjected to greater loads due to fill materials than those installed by the Critchley mole plough, since the overburden weight on buried pipe is a function of the square of the trench width.

Evidently the gravel envelope does not appear to improve the load carrying capacity of the subsurface drains, as both the tubes (Lines 8 and 10) installed with a crushed stone infill were collapsed during the field loading tests.

The flow capacity of partially deformed tubes would not be substantially affected as the tubes are continuous and maintain most of their flow area. However, it is possible, though not very probable, that gradual deflection over a period of years may reduce flow area and cause inadequate performance of drain tubes. It is recommended that some plastic drain tubes be rechecked over a period of 10 years.

There did not appear to be any significant benefit in using the 150 degrees circular arc groove rather than the 90 degrees 'V' groove in the trench bottom. Reference to Table 2 shows that the failures which occurred with both types of grooving were only after at least 6 passes of the 26.3 ton 'Ready-Mix' truck. The tube in the 'V' groove trench was damaged under only 2 of 6 wheel tracks, while the tube in the 150 degrees arc groove was damaged under only 1 of 6 wheel tracks. Since there were 20 passes of the 26.3 ton 'Ready-Mix' truck on each wheel track and damage occurred only on those wheel tracks nearest the observation trench where the soil was rutted the worst, it is concluded that damage differences were more likely due to soil and backfill conditions than to trench groove type.

Soehne (46) reported that the compressive stress in the soil has a tendency to concentrate around the load axis. He found that this tendency is greater when soil plasticity is increased due to higher moisture content and when cohesiveness is reduced by a higher sand content. This state was being approached in these tests since the moisture content and sand content of the field soil were relatively high. For these reasons it is evident that the field tests were conducted under adverse loading conditions. The plastic drain tubes would withstand heavier surface loads without serious distortion as the soil moisture decreased.

Nevertheless, plastic tubing for subsurface drainage in this particular soil, and similar conditions, can be expected to fail when the axle load exceeds 20 tons for drains 2 ft. deep, and 25 tons for drains 3 ft. deep. It is emphasized that plastic pipes were collapsed by surface loading only after considerable depression on the soil surface. Consequently live loads applied repeatedly may produce an detrimental effect on the subdrains.

B. LABORATORY TESTS

1. Crushing Strength

(a) Sand Box Method: The average values of the crushing strength by the sand box method for the five samples of each tube tested appear in Table 3. All samples adequately met the SCS specification requirement for crushing strength. The deformation of plastic tubes in the sand box was gradual and occurred mainly in the middle third of the sample length. This was probably due to the load being maximum at the centre and reducing to a lesser intensity towards the ends of the tube. The clay drain tiles were generally broken into four segments of approximately uniform width.

(b) Three-Edge Bearing Method: The average crushing strength values by three-edge bearing method for the five samples of each tube tested are reported in Table 4. All clay tile samples met the ASTM requirements for standard quality tile. There is no 3-edge bearing strength specification requirement for plastic drainage tubing. The load-deflection characteristics of plastic drain tubes are shown in Figure 9. Variability among crushing strength values of five samples from a line was greater than between average values from lines of same tubing material. Therefore, in Figure 9, the load-deflection characteristics of five different plastic drainage tubing installed by the trencher are plotted as representative results.

The ratio of the strength of a drain tube by sand box test to its 3-edge bearing test strength was calculated for samples

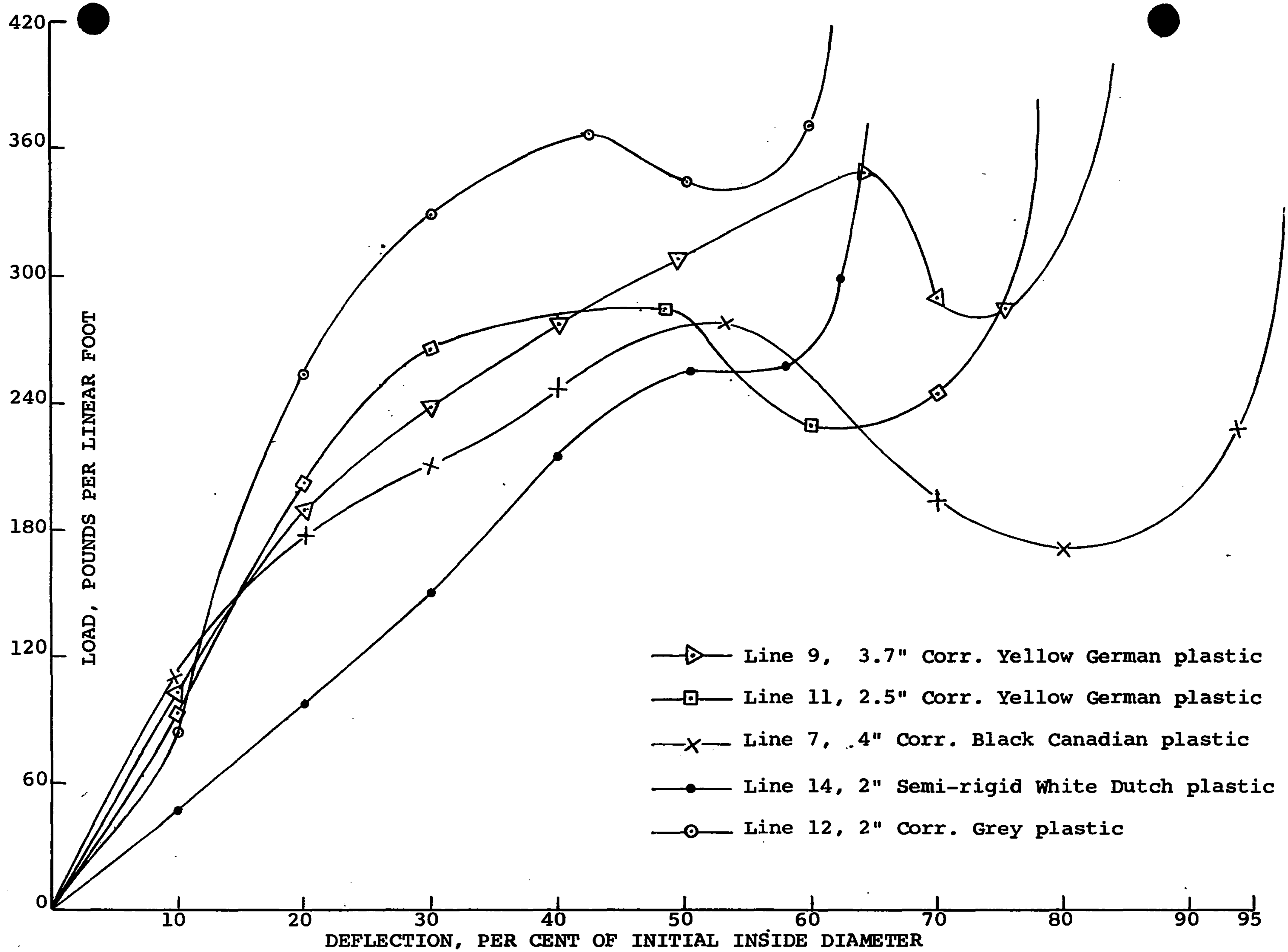


FIG. 9. LOAD-DEFLECTION CHARACTERISTICS OF PLASTIC DRAIN TUBES BY 3-EDGE BEARING METHOD

from each line in the field. A variation in strength ratios from 2.4 to 4.5 for clay tiles and from 25.0 to 39.3 for plastic tubes was obtained. The marked contrast in strength ratio values for the two classes of conduits reflects that the inherent compressive strength of clay tile is the predominant source of supporting strength whereas a large part of load supporting ability of plastic pipe is derived from the lateral pressure of the soil at the sides of the pipe.

In studying the crushing strength of plastic drain tubes by the 3-edge bearing method, it was observed that at a certain value of deflection a gradual decline in the load occurs, accompanied by considerable deformation of the plastic tube. This is followed by a sharp rise in the load-deflection curve occurring somewhat before the corrugated walls touch. At this stage in the test the load was borne entirely by the bearing plates. The first peak in the diagram was taken as the ultimate load for the tube sample.

The crushing strength and the shape of the load-deflection diagram depends noticeably on the orientation of the test specimen between the bearings. Specimens placed with a row of water-entry perforations directly below the top bearing were crushed at a relatively lower value of load. Most specimens tested were found to carry their ultimate load at a deformation of 45 to 65 per cent of the original diameter.

The 3.7-in. and 2.5-in. corrugated yellow German plastic tubes invariably folded along the rows of water-entry openings. The location of perforations on top of the consecutive corrugation ridges appears to unduly weaken the tube. Moreover, it has been suggested (15) that perforations located in the corrugation valleys are sheltered from clogging with soil in case of slippage during installation.

The sand box method for crushing strength test is preferred because of the wider distribution of the applied load and reaction, and a closer simulation of the conditions found under normal field installation.

2. External loading properties of plastic tubes by parallel-plate loading

The average values of the load in pounds per foot at 5, 10, 20, and 30 per cent deflection obtained by parallel-plate loading test are reported in Table 5. No failure of any drain tube occurred up to 30 per cent deflection. All tubes recovered from 30 per cent deflection to their original shape upon removal of the test load.

The stiffness factors, computed at 5 and 10 per cent deflection, appear in Table 5. Stiffness factor is a measure of the inherent strength of the tube and is used to investigate drain tube deflection under earth loads. An applicable expression is the equation 4 in chapter II, known as the Spangler equation for flexible pipe.

The load-deflection characteristics of five different plastic drain tubes installed by the trencher are shown in Figure 10. It is apparent from the plotted data that the load-bearing strength of 2-in. corrugated grey plastic tube (wall thickness = 0.025-in.) is 3 to 4 times greater than that of

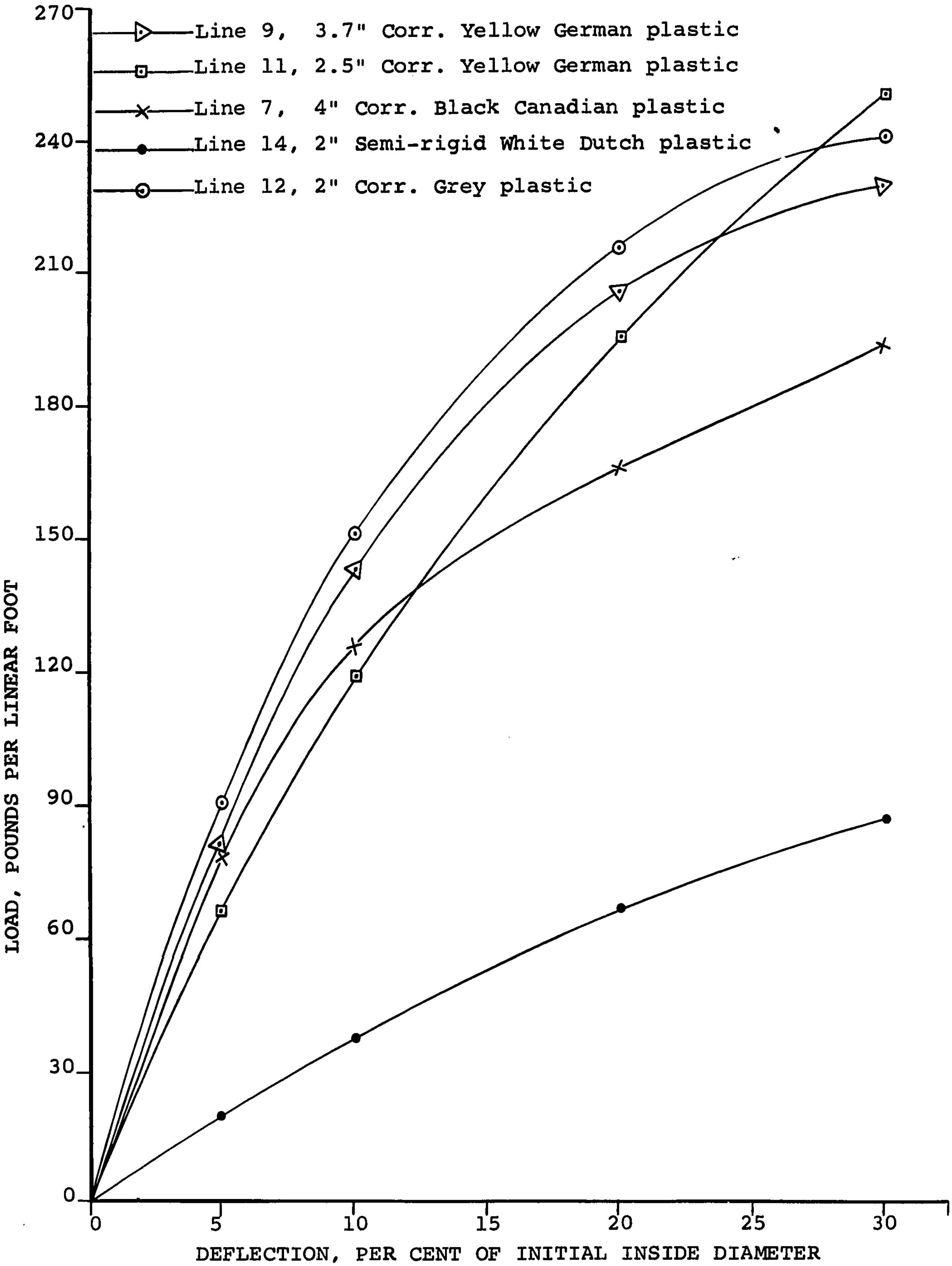


FIG. 10. LOAD-DEFLECTION CHARACTERISTICS OF PLASTIC DRAIN TUBES UNDER PARALLEL-PLATE LOADING.

2-in. smooth-walled white plastic tube (wall thickness = 0.045-in.). This demonstrates that corrugation adds considerably to the supporting strength of a pipe. Therefore, in order to have the same strength in a smooth-walled tube of a given diameter as in a corrugated-wall tube, the wall needs to be much thicker which will greatly increase the cost of the pipe. In general, all the corrugated-wall tubes carried greater loads than the smooth-walled tube at various deflections.

From a structural strength standpoint, the performance of 2-in. corrugated grey plastic tube was superior in field loading, crushing strength, and parallel-plate loading tests. This was obviously due to the efficient corrugation design and relatively small diameter of the tube.

3. Creep Resistance

In a field installation the plastic drainage tubing is subjected to long-term sustained pressures originating mainly from earth pressures. Therefore the indicated strength of short duration tests cannot alone be used as a measure of the structural performance of plastic pipes. In this regard tests were conducted to check the deformation of plastic tubes after prolonged application of a constant load. The results of creep tests appear in Table 6 and Figure 11. All samples met the specification requirements for creep resistance and practically regained their original shape within 24 hours after the load was removed.

The deformation of polyethylene drainage tubing continued

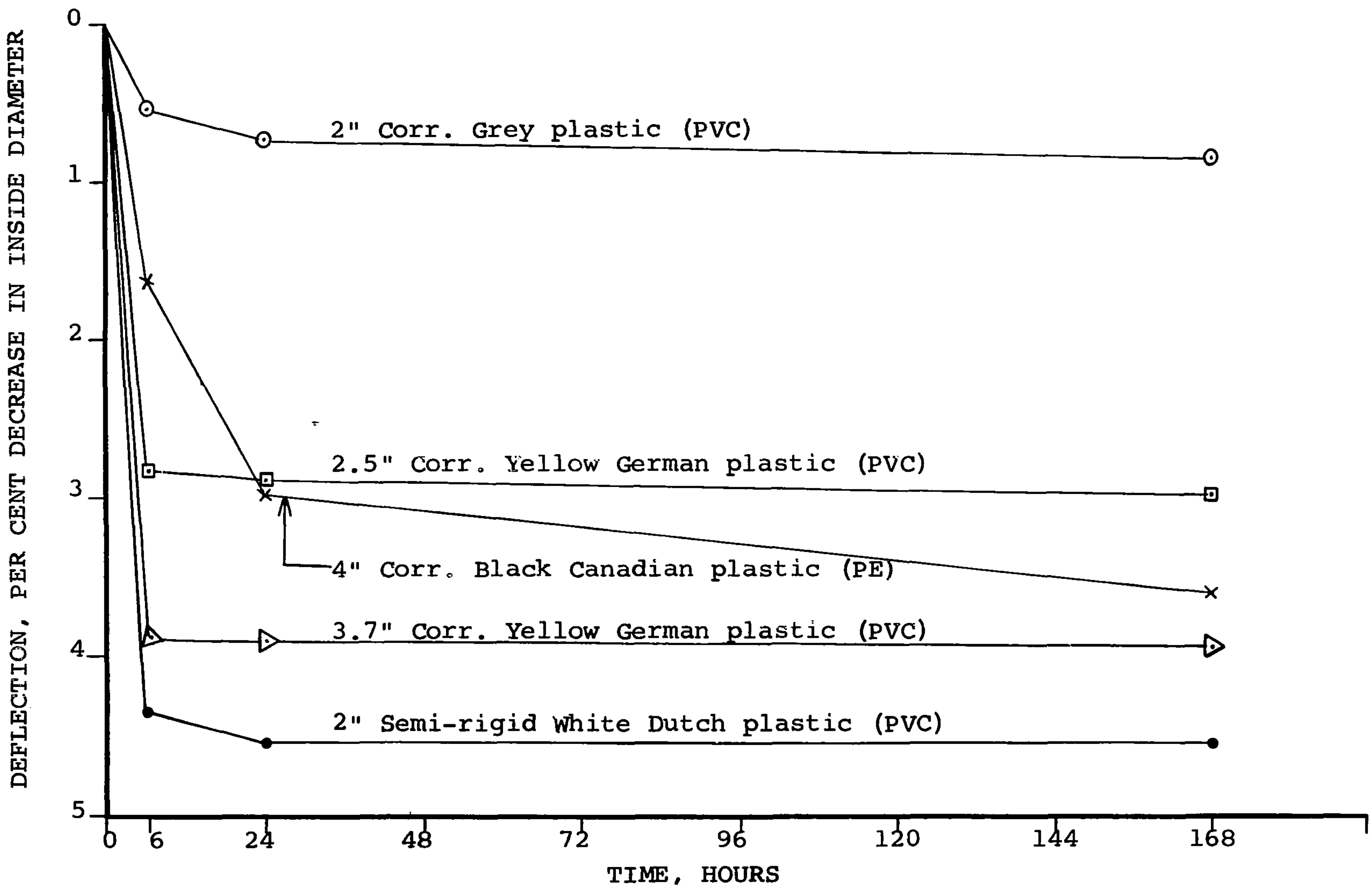


FIG. 11. CREEP TESTS ON PLASTIC DRAIN TUBES UNDER A CONSTANT LOAD (POUNDS) OF 6 TIMES THE INSIDE DIAMETER (INCHES).

throughout the length of the test, while the total deflection of PVC pipes occurred soon after the application of the load. The deformation of some PVC pipes tested for a period of 14 days under the constant load did not exceed the deflection that occurred at the end of 7 days. It is recognized that polyethylene has greater plasticity with time as compared to polyvinylchloride, and therefore, continues to deform for a longer period of time.

4. Impact Durability

For all samples tested, no splitting or cracking was observed, and the greatest height of drop recorded was 40-in. resulting in an impact durability of 100 per cent and a variability of 0 per cent. To pass the test an impact durability of 65 per cent (or 26 inches) or better is required, and the variability should not exceed 50 per cent.

The drop weight test is intended to represent handling and installation hard-treatment, particularly sharp blows and flexing, of the type likely to reveal any brittle characteristics. The ability of plastic pipe to withstand impact forces under cold conditions is not adequately checked by this method of test. After the removal of test specimen from the freezing chamber, considerable time is elapsed in making 10 blows of the drop weight and subsequent inspection of the specimen. Consequently the temperature of the specimen is increased and impact resistance at greater heights of drop is not truly indicated. In this regard the test procedure given in the OFDA, tentative product standard (37) is an improvement.

For the OFDA test each specimen is subjected to only one blow of the drop weight.

Separate testing was done to investigate the impact strength of plastic drain tubes. The specimens were conditioned prior to test at 0° C for 24 hours. The height of drop and the weight of the drop hammer was increased till failure occurred. Each test specimen was subjected to a maximum of 5 blows of the drop weight.

The energy required to damage the polyethylene tubes (4-in. corr. black plastic) was about 17 ft - lb while the values for PVC tubes ranged from 9 ft - lb (2-in. corr. grey and 2.5-in. corr. yellow plastic) to 12 ft - lb (3.7" corr. yellow plastic). The failure of polyethylene tubes was due to distortion of the original shape of the tubing and water-inlet openings. The PVC drain tubes were severely damaged. The portion of the tube struck by the drop weight edge was completely shattered. The drop weight usually passed right through the upper surface of the tube, creating a hole or sometimes the tube was even broken into 2 pieces.

The analysis of the results showed a significant inverse relationship between crushing strength and impact resistance of plastic drain tubes. This is very likely due to variation of properties of plastic materials with temperature. Evidently the PVC pipe is more subject to embrittlement at low temperatures than the polyethylene pipe. The higher impact resistance of polyethylene tube is attributed to its relatively high flexibility that allows it to deflect under load and permits absorption of more energy whereas at low temperatures the PVC pipe becomes fairly rigid and therefore is more susceptible to crushing. Nevertheless, the impact strength of the plastic drain tubes tested are far above the requirements of the available specifications. It is felt that a better impact durability test is needed. Some relation to a limit of rough handling in transportation and installation of tubing, such as experienced during backfilling, is needed.

5. Longitudinal Flexibility

The bending test was conducted to ensure that the necessary flexibility is present in the product to prevent damage or difficulty during installation operations. All the samples tested met the specification requirements. No signs of fracture or fatigue, or kinking sufficient to cause hydraulic resistance, or distortion by buckling were observed while the tube specimens were held in the bent position or 24 hours after the test.

6. Dent Resistance

No measurable depression was created on any specimen after application of the five pound test load for the specified period of one minute.

7. Absorption and Freeze-Thaw Tests

Results of the absorption tests are reported separately for each specimen, together with the average for all specimens comprising the standard sample in Table 7. All the clay drain tile samples tested failed to meet the average absorption requirements for standard drain tile. The 4-in. diameter tiles with an average absorption of 13.1 per cent might be considered to just meet the standard quality tile allowance of 13 per cent. However, all the tile samples met the individual absorption requirement of 16 per cent for standard drain tile. The analysis of the strength and absorption test results showed that the tile samples having higher absorption also usually had relatively high crushing strength. This is somewhat contradictory to the finding of Manson and Miller (27) who reported that high-absorption clay products are rarely high-strength products.

Requirements for water absorption are waived provided the other requirements in ASTM specifications (6) are fulfilled and the sample shows no disintegration or spalling when subjected to the freezing and thawing test. If the sample withstands 36 freezing and thawing cycles, it is accepted as standard quality tile, and if it withstands 48 freezing and thawing cycles, it is classified as extra-quality drain tile.

In the laboratory freeze-thaw test, the clay tiles started to flake and break up after approximately 20 freezing and thawing cycles. The tiles having high absorption had relatively low resistance to damage by freezing and thawing. There was no perceptible damage to the plastic drain tube specimens after 36 reversals of freezing and thawing.

Published information (31, 21, 12, 53) on this subject shows that there is less deterioration of tile due to frost action in a field installation than would be predicted from the laboratory freezing and thawing test. This is due to the fact that at normal drain depth in the field, the soil freezes at a very slow rate and is usually frozen for a long period, which produces lesser strains in tiles than caused by comparatively rapid freezing and thawing cycles in a laboratory test.

TABLE 3

CRUSHING STRENGTH BY SAND BOX METHOD

Drain Tube Material and Nominal Size	Field Line No.	Inside diameter (Inches)	Crushing Strength			
			Average of 5 samples		Minimum of 5 samples	
			lbs. per linear foot	lbs. per sq. inch	lbs. per linear foot	lbs. per sq. inch
8" Clay tile	1	8.010	2116	18.1*	2040	17.4
3.7" Corr. yellow German plastic	2	3.621	8560	183.1	8280	176.9
6" Clay tile	3	6.020	3768	43.1	3480	39.8
2.5" Corr. yellow German plastic	4	2.324	10124	329.9	9800	319.1
4" Clay tile	5	3.998	4460	72.2	4240	68.6
2" Corr. grey plastic	6	1.785	10688	451.6	10560	446.1
4" Corr. black Canadian plastic	7	4.033	7536	138.3	7400	135.9
3.7" Corr. yellow German plastic	8	3.623	9048	193.1	8760	187.2
3.7" Corr. yellow German plastic	9	3.622	9056	195.9	8840	188.8
2.5" Corr. yellow German plastic	10	2.323	10060	327.3	9900	322.2
2.5" Corr. yellow German plastic	11	2.323	10050	327.0	9960	324.1
2" Corr. grey plastic	12	1.778	10604	448.7	10480	442.3
4" Corr. black Canadian plastic	13	4.029	7822	143.7	7640	140.2
2" Semi-rigid white Dutch plastic	14	1.900	10140	424.8	10060	420.6
3.7" Corr. yellow German plastic	15	3.621	8872	189.9	8720	186.4

NOTE: The minimum crushing strength requirements for corrugated P.E. drainage tubing is 23.5 psi in USDA, SCS Standards (1968) and 1500 lb per lin ft. in ADS Specifications (1967).

* psi based on Total Vertical Load / Projected Area of Tube

TABLE 4

CRUSHING STRENGTH BY THREE-EDGE BEARING METHOD

Drain Tube Material and Nominal Size	Field Line No.	Inside diameter (Inches)	Crushing Strength			
			Average of 5 samples		Minimum of 5 samples	
			lbs. per linear foot	lbs. per sq. inch	lbs. per linear foot	lbs. per sq. inch
8" Clay tile	1	8.008	875	7.48	792	6.76
3.7" Corr. yellow German plastic	2	3.622	343	7.34	280	5.99
6" Clay tile	3	6.020	1041	11.89	888	10.10
2.5" Corr. yellow German plastic	4	2.323	295	9.61	268	8.74
4" Clay tile	5	4.000	982	16.00	890	14.41
2" Corr. grey plastic	6	1.784	359	15.18	337	14.25
4" Corr. black Canadian plastic	7	4.045	278	5.11	253	4.65
3.7" Corr. yellow German plastic	8	3.623	348	7.45	328	7.01
3.7" Corr. yellow German plastic	9	3.621	349	7.46	328	7.01
2.5" Corr. yellow German plastic	10	2.323	290	9.45	276	8.99
2.5" Corr. yellow German plastic	11	2.322	284	9.25	265	8.64
2" Corr. grey plastic	12	1.785	367	15.51	339	14.31
4" Corr. black Canadian plastic	13	4.051	272	5.00	259	4.76
2" Semi-rigid white Dutch plastic	14	1.900	258	10.80	224	9.38
3.7" Corr. yellow German plastic	15	3.622	345	7.37	319	6.82

NOTE: The average minimum crushing strength requirement in ASTM Designation: C4-62 for standard quality clay drain tile (4, 6, and 8-in. diameter) is 800 lb. per lin. ft. There is no 3-edge bearing strength specification requirement for plastic drain tube.

TABLE 5

LOAD - DEFLECTION MEASUREMENTS & STIFFNESS FACTOR OF PLASTIC DRAIN TUBES UNDER PARALLEL-PLATE LOADING

Drain Tube Material and Nominal Size	Field Line No.	Inside diameter (Inches)	Load, lbs. per linear foot (Ave. of 5 samples) AT				Stiffness factor, in.^{2}-lb/in. AT	
			5% Defl.	10% Defl.	20% Defl.	30% Defl.	5% Defl.	10% Defl.
3.7" Corr. yellow German plastic	2	3.622	70.50	132.08	201.10	224.00	32.05	30.00
2.5" Corr. yellow German plastic	4	2.323	44.00	116.50	191.50	223.00	8.58	11.31
2" Corr. grey plastic	6	1.785	79.40	145.36	220.13	241.00	9.12	8.34
4" Corr. black Canadian plastic	7	4.051	77.59	125.22	165.60	193.21	46.50	37.60
3.7" Corr. yellow German plastic	8	3.623	66.12	128.20	194.57	237.16	30.10	29.21
3.7" Corr. yellow German plastic	9	3,623	80.98	142.43	205.32	230.40	36.80	32.30
2.5" Corr. yellow German plastic	10	2.323	61.60	123.30	190.27	255.90	12.00	11.97
2.5" Corr. yellow German plastic	11	2.322	65.88	118.60	195.41	250.10	12.83	11.53
2" Corr. grey plastic	12	1.780	90.00	150.78	215.66	240.89	10.35	8.65
4" Corr. black Canadian plastic	13	4.060	76.99	123.10	162.96	187.33	46.18	36.84
2" Semi-rigid white Dutch plastic	14	1.900	20.10	37.50	66.73	85.40	2.42	2.26
3.7" yellow German plastic (Corr.)	15	3.620	67.85	127.68	200.67	230.00	30.86	29.07

NOTE: All samples regained their original shape following the removal of the load and no failure occurred at 30 per cent deflection.

TABLE 6

CREEP TESTS ON PLASTIC DRAIN TUBES

Field Line No. & Drain Tube Material	Inside Diameter (Inches)	Measured Deflection, Percent decrease in inside diameter				
		Time after application of load			Time after removal of load	
		6 Hours	24 Hours	168 Hours	6 Hours	24 Hours
(2) - 3.7" Corr. Yellow German Plastic	3.623	3.91	3.92	3.98	0.52	0.12
(4) - 2.5" Corr. Yellow German Plastic	2.322	2.83	2.90	2.99	0.46	0.05
(6) - 2" Corr. Grey Plastic	1.785	0.55	0.75	0.87	0.0	0.0
(7) - 4" Corr. Black Canadian Plastic	4.052	1.62	2.97	3.60	0.95	0.33
(8) - 3.7" Corr. Yellow German Plastic	3.622	3.85	3.90	3.95	0.41	0.06
(9) - 3.7" Corr. Yellow German Plastic	3.623	3.34	3.41	3.42	0.29	0.0
(10)- 2.5" Corr. Yellow German Plastic	2.323	2.95	2.97	3.00	0.31	0.02
(11)-2.5" Corr. Yellow German Plastic	2.322	2.88	2.95	2.98	0.34	0.04
(12)- 2" Corr. Grey Plastic	1.783	0.51	0.80	0.88	0.0	0.0
(13) - 4" Corr. Black Canadian Plastic	4.055	1.74	2.89	3.48	0.67	0.29
(14) - 2" Semi-rigid White Dutch Plastic	1.900	4.35	4.54	4.55	0.0	0.0
(15) - 3.7" Corr. Yellow German Plastic	3.621	4.14	4.18	4.21	0.45	0.18

NOTE: The allowable decrease in inside diameter after application of the load is 12 percent at the end of 24 hours and 125 percent of 24 hrs. deflection, at the end of 168 hours. Upon removal of the load, the deflection should decrease by at least 70 percent of 168-hour deflection within 24 hours.

TABLE 7

ABSORPTION TEST ON CLAY DRAIN TILE

Field Line No. & Drain Tube Material	Sample No.	Inside Diameter (Inches)	Weight after Drying (Grams)	Weight after Saturation (Grams)	Maximum water absorption by 5-hr. boiling (percent)	
					Individual	Average of 5 Tiles
(1) - 8" Clay Tile	1	7.968	1779.32	2047.90	15.1	
	2	7.951	1671.91	1881.50	12.5	
	3	7.956	1340.40	1514.60	13.0	14.1
	4	8.150	1570.90	1806.25	15.0	
	5	8.015	1634.90	1877.10	14.8	
(3) - 6" Clay Tile	1	6.035	1492.85	1711.50	14.6	
	2	6.012	1628.35	1874.20	15.1	
	3	6.031	924.00	1050.20	13.7	14.2
	4	6.010	1466.40	1675.20	14.2	
	5	6.012	1412.10	1600.70	13.3	
(5) - 4" Clay Tile	1	4.075	746.80	830.70	11.2	
	2	3.925	912.90	1053.20	15.4	
	3	4.093	816.82	921.00	12.8	13.1
	4	4.000	752.91	858.00	14.0	
	5	3.907	657.50	738.50	12.3	

NOTE: Requirements for standard quality tile are a maximum water absorption by 5-hr. boiling of 16% for an individual tile and 13% for the average of 5 tiles.

C. ESTIMATION OF FIELD PERFORMANCE FROM THE LABORATORY TEST

The minimum soil cover needed to prevent collapse under field conditions was estimated from the crushing strength values of the plastic drain tubes obtained by the sand box test. The minimum depth of drain required was computed by means of equation 8 in Chapter II, based on Froehlich's formulas (17). The calculations showed that a minimum of 13 inches of soil cover is required to prevent collapse under a wheel load of 3 tons. This agrees with the field loading test results since failure occurred on tubes which had cover reduced below 13 inches due to ruts. However, reference to Table 2 shows that the smaller diameter tubes in Lines 10 and 14 failed with soil covers of 14.3 and 13.5 inches respectively. It has been pointed out (15) that the increase in strength required for smaller diameter tubes is a function of the varying amount of support provided by the enveloping soil. In order to provide adequate support to the smaller diameter plastic drain tubes a larger bearing strength of the soil is required or greater soil cover is needed, and therefore the afore mentioned drain tubes were crushed at a relatively small vehicle sinkage. Using a factor of safety of 3 on the load basis, the safe drain depth of 18-in. was obtained. From the standpoint of depth to provide adequate drainage, the bottom of drain tubes should be 30 inches deep or deeper. Apparently from both structural and hydraulic aspects a trench depth of 30 inches or more appears to be desirable.

It is therefore recommended that plastic drain tubes should be installed at trench depths of 30 inches or more since displacement of soil up to 12-in. or greater may occur due to repeated passes of the heavy live loads leaving only 18-in. or lesser net cover.

Sample calculations for Line No. 7 (4-in. corrugated black Canadian plastic tube) are shown below:

The average load applied through a 8-in. X 8-in. plate to crush the drain tube sample from Line No. 7 in the sand box (Ref. Table 3) = 7536 pounds.

The intensity of pressure at a point 6-in. above the drain tube sample in the sand box = $\frac{7536}{8X8}$ = 118 psi.

The approximate intensity of pressure in the soil 6-in. directly above the top of the drain tube when failure occurred under field conditions is assumed equal to 118 psi.

The vertical distance from the surface to the point where the intensity of pressure due to wheel load of 3 tons will be 118 psi is computed from the following equation:

$$P_z = \frac{\nu}{2\pi} P_o \frac{\cos^{\nu+2}\theta}{Z^2} \quad \text{Ref. Equation 8 (17)}$$

where P_z = 118 psi, intensity of vertical pressure in the soil or the perpendicular stress,

P_o = 6000 lbs., concentrated surface load,

ν = 6, concentration factor used (46) for soft soil conditions,

θ = 0 degrees, the angle formed with the vertical by the radius vector from the point of application of load to the point considered on the load axis, and

Z = the required vertical distance in inches.

Substituting in the equation

$$118 = \frac{6}{2\pi} \times 6000 \times \frac{\cos^{6+2} 0}{Z^2}$$

$$Z^2 = 48.6$$

$$Z = 7\text{-in. (approx.)}$$

Minimum cover required to prevent failure = 6+7 = 13-in.

The curves of equal pressure shown in Figures 12(a) and 12(b) were calculated from the relationship (46):

$$P_z = P_r \cos^2\theta$$

where P_z = perpendicular stress, and

P_r = polar principal stress.

Substituting for P_z in equation 8, the principal stress is given by

$$P_r = \frac{\nu}{2\pi} P_o \frac{\cos^{\nu+2}\theta}{Z^2} \cdot \frac{1}{\cos^2\theta}$$

For the 3 ton truck wheel load, different values were assigned to P_r and θ, and the vertical distances from the surface were computed. The points of equal pressure were joined by curves. The pressure distribution under dual wheels was obtained by superposition of the stresses from two point loads spaced 12-in. apart.

The foregoing theoretical determination of the drain depth and the pressure distribution in soil under tires does not precisely model the field situation due to the following reasons: (i) Sand box test results are not directly applicable to the field loading because of differences between the sand box soil and boundary conditions and the field soil and conditions. (ii) The tractor or truck tire does not transfer its load to the soil at one point and the assumption of a point load will not truly represent the actual situation. (iii) The stress distribution in soil under wheel loads is modified by the tire inflation pressure, tire dimensions, and the moisture content and density of the soil. However, the calculated depth of drains based on sand box test strength and the pressure distribution in soil under truck wheels gives some estimate about probable field performance. The exact values of stresses in the soil cannot be obtained theoretically due to the heterogeneity of the soil.

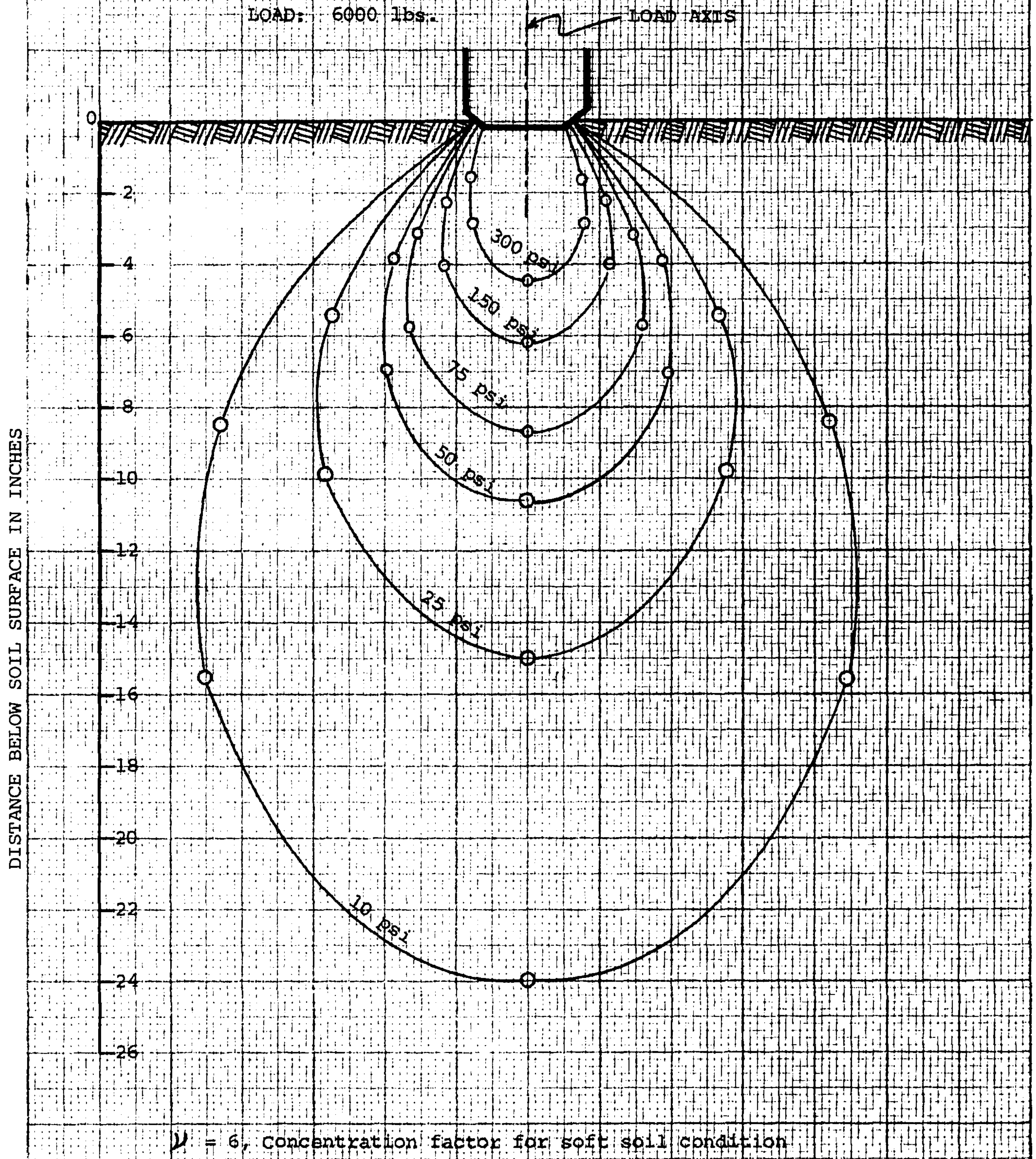


FIG. 12 (a) CALCULATED PRESSURE DISTRIBUTION IN SOIL UNDER 3 TON TRUCK WHEEL

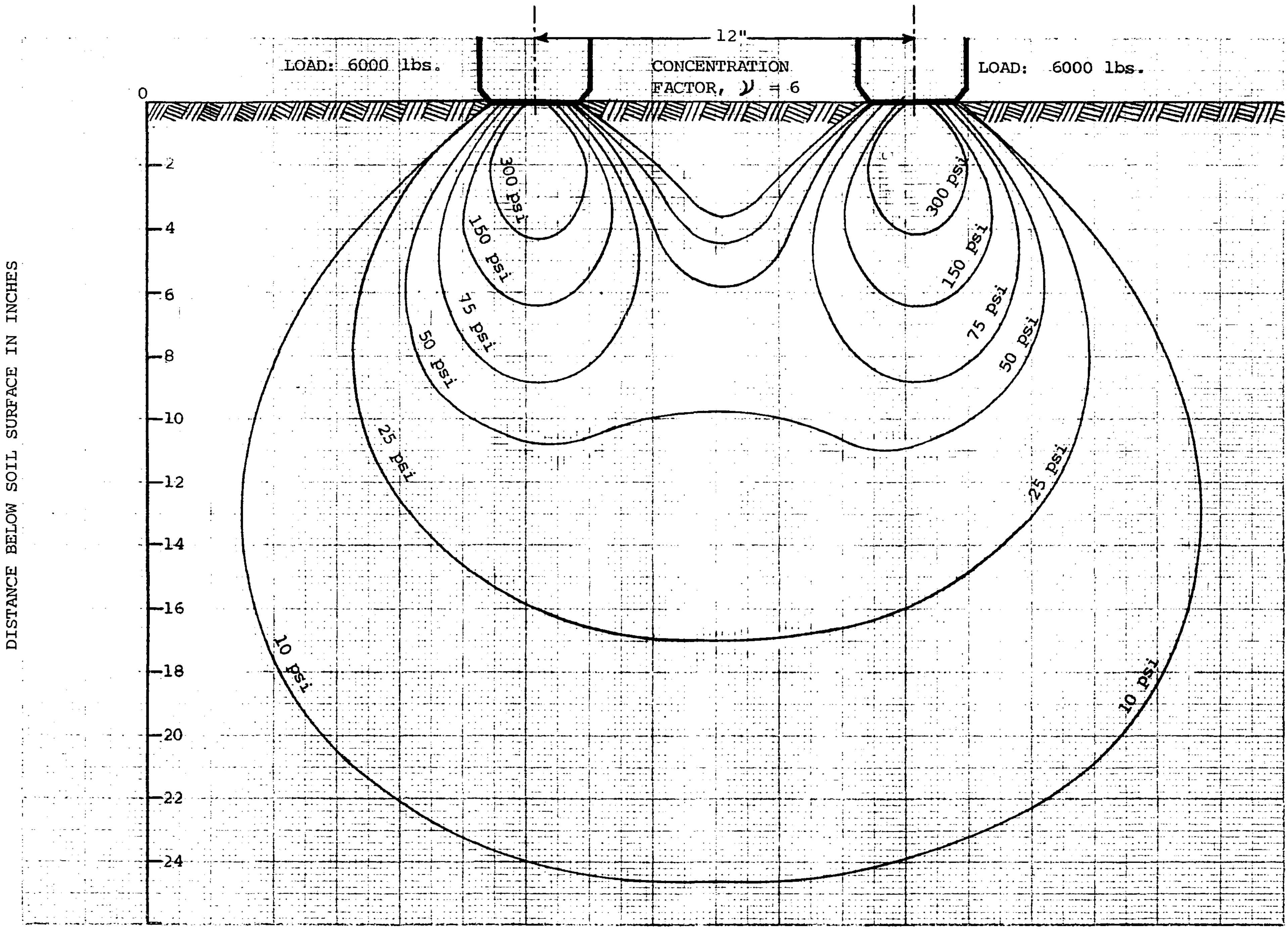


FIG. 12 (b) PRESSURE DISTRIBUTION IN SOIL UNDER DUAL TRUCK WHEELS

V. SUMMARY AND CONCLUSIONS

Newly developed corrugated plastic drain tube should make the job of subsurface drainage less laborious and more economical because of its light weight, flexibility and the attendant advantages in ease of transportation and placement. Concern has been shown regarding the probability of the light plastic tubes collapsing under field loads. In this study the structural qualities of available plastic drain tubes both in the laboratory and the field were investigated.

Fifteen lines of plastic and clay tile drains were installed at 2 and 3 ft. depths in a sandy clay loam soil and subjected to loading by farm vehicles and trucks. Deformations up to 20 and 30 per cent of diameter of the tubes were checked with two sets of plug gauges inserted from the outlet ends. Samples of the same tubes were tested for crushing strength, creep, impact durability, flexibility, absorption and resistance to freeze-thaw action in the laboratory. The physical properties of the samples were compared with the available specifications for plastic drainage tubing. Some inferences about probable field performance were drawn from the laboratory test for crushing strength by the sand box method.

During the investigation the following points were noted:

1. No damage occurred with 40 passes of the Ford 8000 tractor (Gross, 6.23 tons; rear axle, 4.20 tons) hitched to a loaded forage wagon (Gross, 7.60 tons; rear axle, 4.55 tons).
2. Some plastic drain tubes installed at 2 foot depth were

collapsed as a result of repeated passes of the 26.3 ton truck with 20.3 tons on the tandem rear axle.

3. Some plastic drains were deformed beyond 30 per cent of their original diameter but rebounded on removal of soil-fill pressure and practically regained their original shape.

4. The plastic drain tubes were crushed by surface loading only after considerable depression on the soil surface and formation of ruts.

5. There was no great advantage in using the 150 degrees circular arc cradle compared to the conventional 90 degree 'V' groove in the trench bottom. The damage differences of plastic drain tubes were attributed to soil and backfill conditions rather than to trench groove type. Careful placement of the first six inches of loose soil for blinding and subsequent backfilling of the trench was considered to be important.

6. In the field loading tests no clay tiles were broken. The plastic drains installed by the trenchless plough showed better load supporting ability than the trench-installed plastic pipes.

7. All the drain tube samples tested in the laboratory adequately met the requirements for crushing strength. Plastic tubes failed due to excessive deflection and clay tiles by rupture of the walls. In the 3-edge bearing test, most specimens carried their ultimate load at a deformation of 45 to 65 per cent of the original diameter.

Perforations located on top of the consecutive corrugation ridges in the yellow German plastic tubes were found to have adverse affect on the tube strength.

8. The ratio of the strength of a drain tube by sand box test to its 3-edge bearing test strength varied from 2.4 to 4.5 for clay tiles and from 25.0 to 39.3 for plastic tubes, indicating the extent to which the load-bearing strength of plastic pipe is enhanced when lateral support for the pipe is developed.

9. Creep in polyethylene tubes continued throughout the 168-hour test period while the deformation of PVC pipes was observed immediately after application of the load, indicating greater plasticity with time of polyethylene as compared to polyvinylchloride.

10. Polyethylene tubes have impact strength of 17 ft-lb as measured by the drop weight test at temperatures around 0° C. The failure was ductile rather than brittle, suggesting brittleness temperature is well below 0° C. PVC pipes are susceptible to embrittlement at freezing temperatures. The pipes failed due to severe brittle fracture and impact strengths varied from 9 to 12 ft-lb.

11. Majority of clay tile samples failed to meet the ASTM specifications for absorption. High-absorption clay tiles generally had relatively high-crushing strength. The clay tiles started to flake and break up after approximately 20 reversals of freezing and thawing. There was no perceptible damage to the plastic drain tube specimens after 36 cycles.

12. Based on the crushing strength values obtained by the sand box test, a minimum soil cover of 13 inches was found essential to prevent failure due to surface loads such as applied in Field Test No. 4 and 5. To provide successful drainage conduits with plastic tubing considering both structural and hydraulic aspects a depth of installation of 2.5 feet or more is recommended since ruts up to 12-in. may occur due to repeated loading by farm vehicles or trucks.

It is therefore evident that there should be no difficulty with plastic drain tubes installed at depths of 2.5 feet or more with normal backfilling, including 6-in. deep blinding with loose soil. Where drain tubes pass under laneways which carry much heavy traffic the tubes should be more than 3 feet deep or have a steel pipe section in the portion of the line under the lane.

VI. RECOMMENDATIONS FOR FURTHER RESEARCH

Some topics related to this Thesis which are seen to merit further research are given below:

1. A mathematical theory should be developed for determining the character, direction, and magnitude of the soil overburden loads on plastic drain tubes installed by the trenchless method of drain laying.
2. To study the long-term deformation of plastic drain tubes installed under field conditions, observations of the changes in shape of the tubing should be made periodically over a span of 10 to 15 years.
3. There is a need to develop an efficient simple filter for use with plastic drain tube to prevent ingress of sediment in those soils where there is a drain clogging problem.
4. Additional testing is needed to determine more specifically the best arrangement, number, and size of perforations to provide adequate water-entry openings without unduly weakening the plastic tube.
5. A better impact durability test is needed. Some relation to a limit of rough handling in transport and installation of plastic drainage tubing is needed.
6. Tests are needed to establish the hydraulic capacity of corrugated plastic drain tubes to provide better drainage system design data. It would be good if a general relation between corrugation shape parameters and friction loss characteristics could be obtained.

VII. REFERENCES

(1) Advanced Drainage Systems, Inc. Standard specification for ADS 4" I.D. corrugated polyethylene drainage tubing. 1967.

(2) American Railway Engineering Association. Culvert load determination. Bulletin No. 284. 1926.

(3) American Society of Agricultural Engineers. Design and construction of subsurface drains in humid areas. ASAE yearbook. 1969.

(4) American Society for Testing and Materials. Standard method of determining dimensions of thermoplastic pipe. ASTM Designation: D 2122-67. 1967.

(5) American Society for Testing and Materials. Standard method of test for external loading properties of plastic pipe by parallel-plate loading. ASTM Designation: D 2412-67. 1967.

(6) American Society for Testing and Materials. Standard specifications for clay drain tile. ASTM Designation: C 4-62. 1962.

(7) Armco Drainage & Metal Products, Inc. Handbook of drainage and construction products. pp 5-29. R.R. Donnelley Co. Chicago, Illinois. 1955.

(8) Busch, C.D. Low cost subsurface drainage. Agr. Eng. 39:92-93, 97, 103. 1958.

(9) Busch, C.D. Mechanical mouse aids research in subsurface drainage. Agr. Eng. 39:292-293. 1958.

(10) Butler, W.J. Freeze-thaw testing of clay, plastic, and pitch fibre drain tubes. Unpublished senior undergraduate project. Department of Agricultural Engineering. Macdonald College of McGill University. 1969.

(11) Cavelaars, J.C. Problems of water entry into plastic and other drain tubes. A.E.S. Paper No. 5/E/45, Silsoe, Bedford, England. 1967.

(12) Crabb, G.A. and Smith, J.L. Soil-temperature comparisons under varying covers. Hy. Res. Bd. Bul. 71. 1953.

(13) Ede, A.N. European standards and specifications for drainage materials. ASAE Paper No. 65-730, ASAE, St. Joseph, Mich. 49085. 1965.

(14) Filkins, C.W.L. and Fort, E.J. Stresses and deflections in circular rings under various conditions of loading. Trans. Assn. of Civil Eng. of Cornell Univ. Vol. 4, pp 99-112. 1896.

(15) Fouss, J.L. Corrugated plastic drains plowed-in automatically. Trans. of ASAE. Vol. 11, No. 6, pp 804-808. 1968.

(16) Fouss, J.L. and Donnan, W.W. Plastic-lined mole drains. Agr. Eng. 43: 512-515. 1962.

(17) Froehlich, O.K. Pressure distribution in foundation soils. (English Translation 46-11). Waterways Expt. Sta. Vicksburg, Miss. 1934.

(18) Griffith, J.H. Dynamics of earth and other macroscopic matter. Iowa Eng. Exp. Sta. Bul. 117. 1934.

(19) Herndon, L.W. Use of corrugated plastic tubing for subsurface drainage. ASAE Paper No. NA 69-406, Montreal, Canada. 1969.

(20) Holl, D.L. Stress transmission in earths. Proc. Highway Research Board. Vol. 20, pp 709. 1940.

(21) Hore, F.R. A survey of agricultural drain tile in Ontario, quality and specifications. Project No. A. Eng. 49. Department of Engineering Science. Ontario Agricultural College, Guelph. 1959.

(22) Hore, F.R. and Sojak, M. Specifications for corrugated plastic drainage tubing. CSAE Paper No. 70-409, Ottawa, Ontario. 1970.

(23) Klimko, A.I. and Kostikov, V.I. Wall thickness and perforation of plastic drainage pipe. (Translation No. 1028 of an article in Gidrotekhnika I Melioratsiia). Department of Secretary of State, Translation Bureau, Foreign Languages Division. Ottawa. 1967.

(24) Luthin, J.N. Drainage Engineering. Chapter II. Subsurface Drains. pp 187-195. John Wiley, New York. 1966.

(25) Manley, P.L. Effects of surface loads on plastic-lined mole drains. ASAE Paper No. 59-203, Ithaca, N.Y. 1959.

(26) Manson, P.W. Engineering aspects of land drainage. Chapter III, pp 315-320, in J.N. Luthin (ed.) Drainage of Agricultural Lands, Am. Soc. Agron., Madison, Wisconsin. 1957.

(27) Manson, P.W. and Miller, D.G. Practical aspects of drain tile durability. Agr. Eng. 35:717-718,725. 1954.

(28) Marston, A. The theory of external loads on closed conduits in the light of the latest experiments. Iowa Eng. Exp. Sta. Bul. 96. 1930.

(29) Marston, A. and Anderson, A.O. The theory of loads on pipes in ditches. Iowa Eng. Exp. Sta. Bul. 31. 1913.

(30) Marston, A. and Spangler, M.G. The causes of structural failures of sewers. Proc. Am. Soc. of Municipal Engrs. Vol. 38, pp 236. 1933.

(31) Miller, D.G. and Manson, P.W. Long-time performance of some clay draintile. Agr. Eng. 32: 95-97, 100, 101. 1951.

(32) Miller, D.G. and Wise, J.A. Experimental and mathematical analysis of drain tile testing and new test bearings. Minn. Agr. Exp. Sta. Bul. 52. 1928.

(33) Myers, V.I., Rektorik, R.J. and Wolfe, C.A. Deflection tests and trench conditions for plastic drain pipe. Trans. of ASAE. Vol. 10, No. 4, pp 454-457. 1967.

(34) Negi, S.C., Broughton, R.S. and Jutras, P.J. A field and laboratory evaluation of some plastic drain tubes. CSAE Paper No. 70-408, Ottawa, Ontario. 1970.

(35) Newmark, N.M. Simplified computation of vertical pressures in elastic foundations. Illinois Eng. Exp. Sta. circular No. 24. 1935.

(36) Norm Committee. Temporary norms for drain line pipes. (Translation). Finnish Building Engineers Association, Helsinki, Finland. 1968.

(37) Ontario Farm Drainage Association. Plastic Manufacturers Division. Tentative product standard for corrugated plastic drainage tubing. No. PMD-M-1169 T. 1969.

(38) Provisional specifications for trench laid plastic drain tubes of up to 4" diameter. Field Drainage Experimental Unit, Ministry of Agr., Fish., and Food, Cambridge, England. 1965.

(39) Rektorik, R.J. and Myers, V.I. Polyethylene drainage pipe installation techniques and field performance. Trans. of ASAE. Vol. 10, No. 4, pp 458-459, 461. 1967.

(40) Schlick, W.J. Loads on pipe in wide ditches. Iowa Eng. Exp. Sta. Bul. 108. 1932.

(41) Schwab, G.O. Plastic tubing for subsurface drainage. Agr. Eng. 36: 86-89, 92. 1955.

(42) Schwab, G.O., Frevert, R.K., Edminster, T.W. and Barnes, K.K. Soil And Water Conservation Engineering. Chapter 18. Installation and Maintenance of Tile Drains. pp 471-477. John Wiley, New York. 1966.

(43) Shafer, G.E. A discussion of M.G. Spangler's paper on 'Underground conduits, An appraisal of modern research'. Trans. Amer. Soc. Civil Eng. Vol. 113, pp 354-363. 1948.

(44) Shafer, G.E. Discussion of flexible-pipe culverts. Proc. Highway Research Board. Vol. 17, pp 237-239. 1937.

(45) Shull, H. Self-propelled drainage line camera. Agr. Eng. 44: 494-495. 1963.

(46) Soehne, W. Fundamentals of pressure distribution and soil compaction under tractor tires. Agr. Eng. 39: 276-281, 290. 1958.

(47) Sojak, M. Summary of preliminary test results on corrugated polyethylene drainage tubing. Ontario Department of Agriculture and Food. Agricultural Engineering Newsletter, Agdex 725-300. 1968.

(48) Soil Conservation Service. Standard specification for corrugated polyethylene drainage tubing. U.S. Dept. of Agric., Washington, D.C. 20250. 1968.

(49) Spangler, M.G. The structural design of flexible pipe culverts. Iowa Eng. Exp. Sta. Bul. 153. 1941.

(50) Spangler, M.G. Underground conduits, an appraisal of modern research. Trans. Amer. Soc. Civil Eng. Vol. 113, pp 316-345. 1948.

(51) Spangler, M.G. and Hennessy, R.L. A method of computing live loads transmitted to underground conduits. Proc. Highway Research Board. Vol. 26, pp 179. 1946.

(52) Taylor, D.W. Fundamentals of Soil Mechanics. pp 250-258. John Wiley, New York. 1948.

(53) Thomas, W.N. Experiments on freezing of certain building materials. Dept. of Scientific and Industrial Research, Great Britain. Building Research Tech. Paper No. 17, 142p. 1938.

(54) Vaigneur, H.O., Snell, A.W., Wilson, T.V. and Nunnery, S.A. Loading characteristics of plastic lined mole drains. Paper presented at the 1960 Southeast Section Meeting of ASAE, Birmingham, Alabama. 1960.

(55) Van Schilfgaarde, J., Frevert, R.K. and Schlick, W.J. Effect of present installation practices on draintile loading. Agr. Eng. 32: 371-374, 378. 1951.

(56) Work Committee III. Drain pipes of rigid PVC; dimensions; quality requirements and test methods. (Translation). Proposed (April 1969) German Industrial Norm ("DIN") No. 1187, German Norms Agency (DNA), 1 Berlin 30, 4-7 Burggrafenstrasse. 1969.