THE UNIVERSITY OF MANITOBA

ORGANIC AND SYNTHETIC ENVELOPE MATERIALS
FOR
CORRUGATED PLASTIC DRAINS

by

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"ORGANIC AND SYNTHETIC ENVELOPE MATERIALS FOR CORRUGATED PLASTIC DRAINS"

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ABSTRACT

A sand tank model was used to evaluate the performance of organic and synthetic envelope materials for 10.1-cm inner-diameter corrugated plastic drain tube (subsurface drainage). Envelopes 2.5 cm, 5.0 cm, 7.5 cm and 10.0 cm thick constructed of organic material either alone or in combination with fiberglass were tested in a medium-size sandy base material.

A linear relationship between the drainage discharge rates and the head for a narrow range of head (70.0 cm to 140.0 cm) was found for each of the tested envelopes. A 10.0-cm envelope of organic material alone or in combination with fiberglass was found adequate for inhibiting sediment entry into the drain and facilitating free flow of water into the drain. A 10.0-cm-thick envelope, made of organic material only, enabled the maximum discharge among all of the placement conditions of organic material and fiberglass tested.

Flow rate from the drains responded exponentially with respect to the size of perforations. Circular holes, 0.5 cm in diameter, in every third valley of the corrugated plastic drain tube in eight rows proved effective in improving the flow rate without any sedimentation problem. Similarly rectangular-shaped (1.0 cm x 0.25 cm) perforations, again in eight rows along the length of drain and

with two wrappings of fiberglass were found adequate with respect to discharge rates and silting of drains.

The velocity of water near the drain indicated the possibility of non-Darcy flow near the drain perforations.

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LIST OF SYMBOLS

A, $A_1 \ldots A_4$	Area of flow field in a plane perpendicular to the plane of flow net, L^2
$b_1 \ldots\ldots b_4$	Width of flow field, L
B	Constant
d	Diameter, L
de	Effective diameter
E	Energy per unit weight, m
F	Number of flow fields
$h_1 \ldots\ldots h_4$	Equipotential surfaces, L
H	Hydraulic head, L
h	Total difference in hydraulic head
I	Hydraulic gradient, $L.L^{-1}$
$I_1 \ldots\ldots I_3$	Hydraulic gradients between two successive equipotentials, $L.L^{-1}$
K	Constant
k	Hydraulic conductivity, cm. day^{-1}
$l_1 \ldots\ldots l_4$	Length of individual square fields
L	Distance along the path of flow
M	Constant
N	Number of equipotential increments
P	Pressure, Pa
q	Total flow rate in flow net, $cm^3 s^{-1} cm^{-1}$

$\Delta q, \Delta q_1 \ldots \Delta q_3$	Flow rate in individual square flow fields, $cm^3 s^{-1} cm^{-1}$
R	Regression Coefficient
V	Velocity of water, $cm\ s^{-1}$
W	Specific weight of water, $N.m^{-3}$
X	Discharge rate, $cm^3 s^{-1} m^{-1}$
X_1	Size of perforations and relative slot length
Y	Head, L
Y_1	Flow rate, $cm^3 s^{-1} m^{-1}$
Z	Elevation of a point above datum, L
α	Entrance constant of the drain tube

CHAPTER I

INTRODUCTION

Sedimentation in subsurface drains often is a cause of failure of the drainage system in noncohesive, fine sandy and silty soils. Deposition of sediment in the drain not only reduces the effectiveness of the drainage system but also shortens its life. Therefore some protective measures impeding the entrance of sediment, yet allowing water to enter into the drain freely, must be taken.

It is generally accepted that the problem of drain clogging and sedimentation can be solved by a well designed filter. Sand and gravel filters and envelopes have been used extensively in both irrigated and humid areas throughout the world. The design criteria for such filters are well established. Because of the higher cost associated with sand and gravel filters, there is an increasing need for effective and inexpensive filter and gravel materials for greater economy of drainage.

During the last decade several attempts have been made to use synthetic materials as filters for subsurface drains. Some investigations have been undertaken on the development of design criteria for fiberglass to meet the requirement of an ideal filter. Research has also been conducted to evaluate the effectiveness of various filter and envelope materials under different placement conditions and different types of soils around the drain. Studies by Rapp and Riaz (1975) and Sisson and Jones (1962) reveal that a sedimentation problem would exist, though greatly reduced, even if synthetic and organic materials were used as filters and envelopes.

Organic materials have been used for many years and for many reasons to blind conduits in subsurface drainage. However, studies made on the effect of blinding material on drainage flow and the ability of the material to retard the movement of unstable soil particles, demonstrate the potential need for more detailed study of organic materials as envelopes.

The main objectives of this study were:

1. to evaluate the relative effectiveness of different envelope thicknesses of organic material (straw) when used alone or in combination with fiberglass on discharge rate from corrugated plastic drain,
2. to evaluate quantitatively and qualitatively the relative effectiveness of envelope materials and their thickness in preventing the sediment from entering into the drain,
3. to evaluate the effect of envelope thickness on the flow pattern around the drain tube, and

4. to evaluate the effect of the size and shape of perforations on flow rates and sediment movement into the drains.

CHAPTER II

REVIEW OF LITERATURE

2.1. The Concept of Filters and Envelopes in Subsurface Drainage: The terms "filter" and "envelope" are widely and sometimes interchangably used for one another in drainage literature. However, the Soil Conservation Service of the United States Department of Agriculture (1973) defined these two terms as follows.

Filters for drains are permeable materials placed around the drains for the purpose of preventing fine-grained materials in the surrounding soils from being carried into the drain by ground water, whereas envelopes for drains are permeable materials placed around the drains for the purpose of improving flow conditions in the area immediately surrounding the drain and for improving bedding conditions.

A material may have characteristics which meet the specifications of both a filter and an envelope for a particular site condition. Well graded sand-gravel materials often have these characteristics. Peat, organic material, wood, sawdust, and fiberglass are the other materials often used as filters and envelopes around the drains.

2.2. Previous Studies on Filters and Envelopes:

2.2.1. Sand-gravel and Organic Material Envelopes:

A number of researchers have performed studies on envelopes of different materials. Brownscombe (1962) in his study of effectiveness of tile drains laid with organic materials reported that organic material successfully prevented sediment entry and facilitated water movement even 15 years after installation. He recommended an organic material envelope around the drains having a minimum thickness of 7.5 cm (after compression by backfill).

Bornestein, et al. (1967) and Bornestein and Benoit (1967) studied the characteristics of flow into subsurface drains on a sloping Cobalt silt loam soil both in the field and in the laboratory. They found that equipotential lines were identical in the field as well as in the laboratory except close to the drain tube. This was essentially due to the different hydraulic conductivity of backfill and organic material in the field study which could not be taken into consideration exactly while modelling the drainage system in the laboratory. Moreover, in both studies half of the flow took place from the bottom half of the drain joints.

Lembke and Bucks (1970) carried out a laboratory study on the performance of envelopes which lead to the following conclusions:

1. an envelope of 7.5 cm was adequate in restricting sediment entrance into the drain yet allowed water to move into the drain freely.
2. there was very little difference in tile outflow rate for a 7.5-cm envelope compared with a 15.0-cm envelope.
3. a circular envelope cross-section was more stable than a rectangular envelope cross-section.
4. from flow net analysis, it was found that potential drop in the bottom half of the drain was more than that of the top half of the drain.

Palmer and Johnson (1962) did a field evaluation of flow through blind inlets. They found that the discharge was approximately proportional to the applied head when the drain outlet was not running full.

Sisson and Jones (1962) studied seven filter and blinding materials to compare their relative effectiveness with respect to drain clogging and flow of water into the drain in a uniform medium sand. The filter materials studied were corncobs, sawdust, organic material, topsoil, gravel, fiberglass over the top three fourths and vinyl sheet under the bottom one fourth of the drain. They concluded that:

1. fiberglass with plastic, organic material and sawdust, in that order, provided the best protection against sediment movement. Gravel, a 270-degree wrap of fiberglass and topsoil ranked fourth, fifth and sixth respectively.

2. none of the filter materials impeded water movement into the drain.
3. negative pressure within filter materials during ponded water flow tended to favour a low rate of soil movement.
4. for the no-filter condition, soil moved into the drain along the surface of seepage but entered first at the bottom.

Dierickx, et al. (1975) conducted a study on silting of drainage pipes as influenced by the different locations of the perforation lines on the drain perimeter. They used a 5.0-cm corrugated plastic drain tube with six perforation lines (106 perforations per meter length) in a sandy soil. In order to determine the extent and rate of silting and water flow through the different perforation lines of corrugated drain tubes without any filter material, they carried out the following tests:

1. a normal drain tube with six perforation lines was embedded in the backfill of sandy soil,
2. a drain tube with two open perforation lines on the top was embedded in the backfill of sandy soil--the other four perforation lines were sealed,
3. a drain tube with two open perforation lines at one side was embedded in the backfill of sandy soil--the other four perforation lines were sealed,

4. a drain tube with two open perforation lines at the bottom was embedded in the backfill of sandy soil--the other four perforation lines were sealed.

Also they conducted a comparative study between this sand model tank and a conductive paper model and checked the theoretical solution of Kirkham (1949). They concluded that:

1. drain discharges for the normal drain, the drain with a perforated top, the drain with a perforated side and the drain with a perforated bottom were 53.5, 33.9, 32.2 and 28.2 $dm^3 s^{-1} m^{-1}$ respectively,
2. sediment yields for the normal drain, the drain with the perforated top, the drain with the perforated side, and the drain with the perforated bottom were 1372.2, 1296.4, 1501.2 and 1112.1 gm^{-1} respectively,
3. a negative relation existed between the sand discharge and time. During the first 10 minutes, the rate of sand discharge declined when using the normal drain with six perforations and the drain tubes with a perforated top and with a perforated bottom. The decline continued until it reached a constant negligible value at the end of the experiment. The decrease in the sedimentation rate for the normal drain with the perforated perimeter, and the drain with a perforated top was very sharp during the first five minutes.

4. the cohesionless sand entering the drain tube had the same particle-size distribution as the original sand around the drain tube.
5. the first period of drainage after the installation is very critical from the point of view of silting of the drain.
6. in the sand tank, a drain partly filled with sand gave a water discharge value less by 16.8 percent than the discharge values of both the theoretical solution of Kirkham (1949) and the conductive paper model.

The difference in discharge can be attributed to theoretical assumptions such as the drain running full and the assumption of no back pressure on flow in Kirkham's (1949) analytical solution to seepage of ponded water in a drain overlying an impervious layer.

Bishay, et al. (1975) carried out a study to investigate the relative effectiveness of conditioned sandy soil as an envelope material to prevent the silting of 5-cm diameter corrugated plastic drains in a sand tank under ponded water conditions. A 1.0-cm thick envelope of organic material was also used for comparison purposes. De Boodt[1] (1970) reported that soil conditioners, such as the bituminous emulsion and polymerized acrylamide PAM have the ability to change a structureless soil or a soil with

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[1] Cited by Bishay, et al. (1975).

weak aggregates into a soil with a distinct aggregation pattern which resists breakdown when put in contact with water. Soil conditioning, as it is conceived these days, aims at creating a stable soil structure with inter- and intra-aggregate voids. The non-conditioned sand has loose structure as there is no binding agent to link the individual quartz particles together. The procedure for developing an artificially structured and aggregated soil by means of the soil conditioner bitumen emulsion and PAM as used in the study is described below:

1. the sandy soil, brought to a moisture content of 20 percent on a weight basis, was subsequently sprayed with a 50 percent bituminous emulsion; 15 cm^3 of bitumen emulsion was applied for 1 kg soil giving a 0.75 percent bitumen/soil ratio. Spraying and mixing of the soil with the bitumen were done simultaneously. The aggregates thus formed were allowed to become air-dry and their size distribution was determined. For one metre of drain tube, 22 kg of stabilized soil were needed for an envelope of 4-cm thickness around the tube;
2. the sandy soil, brought initially to a moisture content of 20 percent on a weight basis, was subsequently sprayed with a 2-percent PAM solution so that 100 cm^3 of a 2-percent PAM solution was used for 1 kg of soil giving a 0.2-percent ratio. The pH was brought to 8.5 and a cross linker was added. Spraying and mixing of

the soil with PAM were done simultaneously. The aggregates thus formed were allowed to become air-dry and their size distribution was determined. For one metre of a drain tube, 22 kg of stabilized soil was needed to make an envelope of 4-cm thickness around the tube. They concluded that:

1. the amount of sand discharged from the drain during the first five minutes from the start of the drainage accounted for a major portion of the total sediment load during a test run of 24 hours.
2. soil treated either by bitumen emulsion or PAM solution facilitated a flow rate 1.3 times greater than did a non-treated soil. The difference in flow rates for the two types of conditioned envelopes was negligible.
3. the highest water discharge values were obtained for a 1.0-cm thickness of organic material envelope around the drain.

Bishay, et al. (1975) also evaluated the hydrological performance (the capacity of the drain tube in taking up water from the soil and the effect of a filter material on it) of conditioned sandy envelopes in terms of "effective diameter" by applying the formula of Boumans[1] (1965) as described below:

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[1] Cited by Bishay, et al. (1975).

$$d_e = \frac{d}{e^{2\pi\alpha_e}} \quad \text{.......................} \quad 2.1$$

where:

d_e = effective diameter, mm

d = real diameter of the drain tube, mm

α_e = entrance constant of drain tube (dimensionless)

The effective diameters were 28.2 mm, 50.0 mm, 68.0 mm, 76.6.0 mm and 117.6 mm for a real drain without a filter, the ideal drain (drain with a zero entrance constant), the drain surrounded by a soil envelope conditioned with PAM, the drain surrounded by a soil envelope conditioned with bitumen, and the drain surrounded by the organic material respectively. It is evident that a considerable increase in effective diameter of the drain tube takes place when using organic material as a filter. Also a drain tube enveloped with a conditioned soil either treated with bitumen or PAM gives an increase in effective diameter of the drain tube which is important compared with the effective diameter of the drain tube without any filter material.

4. the artificially conditioned filter can be applied to all kinds of sensitive soils, i.e. sand, silt, or any other cohesionless materials.

Bishay, et al. (1975) and Dierickx, et al. (1975) agree that the first period of drainage after the installation of a drainage system is critical from the point of view of silting. They also agree that sediment and flow of water from the drain vary inversely with respect to time at the start of the test.

De Boer, et al. (1971) conducted field and laboratory studies to evaluate the effectiveness of three envelopes in a coarse silt base material. The three envelopes used were a 15.0-cm all-gravel envelope, a 7.5-cm all-gravel envelope and a combination 7.5-cm gravel and fiberglass material envelope. They concluded that:

1. envelope materials will be required for the installation of subsurface drainage systems in an unstable non-cohesive soil.
2. a 7.5-cm gravel envelope performed as satisfactorily as a 15.0-cm gravel envelope.
3. a 7.5-cm gravel envelope in combination with a 1.25-cm fiberglass envelope also worked satisfactorily.
4. heavy sedimentation was noticed for a no-envelope test.

Davis, et al. (1971) investigated drain envelope performance in a sandy soil following drain clogging and sedimentation in the Coachella Valley in California. Their experiments included three types of pipes: a butt-joint 30.5-cm section of clay drain tile, a 60-cm section of tongue-and-groove concrete pipe and corrugated plastic tubing. The envelope material used was pea gravel, an oasis pit-run material and an oasis pit-run material with fines less than 0.15 mm removed. In addition to the above a plastic drain protected with a plastic sheet for entry velocity control was also used. Their findings are summarized as follows:

1. for the range of conditions tested, any envelope material around the drains will perform successfully if installed carefully.
2. the drains with minimum discharge were those installed without an envelope material or with velocity control protection. The computations made for the drain with velocity control protection indicated that it had only one two hundredth of the required area for satisfactory operation according to specifications and therefore could be expected to fail.
3. mica particles were observed being transported by the water through the gravel envelope. However, indications of reduced discharge due to the deposition of soil particles were not observed.
4. observation lines installed without an envelope failed.

Hwang, et al. (1974) studied the effect of backfill on drainage discharge in layered soils. They concluded that:

1. hydraulic conductivity of backfill material has a significant effect on the rate of water table drawdown in layered soils.

2. backfilling the drain trench with permeable soil can more than double the flow into the drain if the drain is located below the interface in a two-layered soil where the top layer is more permeable than the bottom layer.

Sommerfeldt (1975) conducted an investigation on outflow from various subsurface drainage materials. In lysimeters, he evaluated the performance of 55-mm, 65-mm and 105-mm inner-diameter plastic drains and 105-mm clay tile drains with and without gravel and gravel or fiberglass envelopes in two types of clay loam and fine sandy loam soil over a period of three years. He concluded that:

1. the discharge from the 55-mm rigid plastic drain with an envelope was comparable to that from the 105-mm tile drain but without the envelope the discharge from 55-mm rigid plastic drain was substantially less than no envelope condition for 105-mm tile drain.
2. initial discharge from the 65-mm flexible plastic drain always exceeded that from clay tile (105 mm inner diameter) but as the experiment progressed, the rate of flow from each drain changed and at the end discharge from the 65-mm drain was frequently less than that from the tile.
3. the discharge from the 105-mm plastic drain varied often between that from the 65-mm plastic drain and from the 105-mm tile and approached that from the tile with time.

4. for drains installed in fine sandy loam soil, the discharge from the 65-mm and 105-mm plastic drains without envelopes was more than double that from clay tile.

Experiments at the University of California at Davis[1] showed that drain diameter has significant effect on the flow into the drain. This is not in agreement with the findings of Sommerfeldt (1975).

Willardson, et al. (1975) studied the performance of two types of envelope materials, pit-run gravel and pit-run gravel with five percent of field soil added, in Coachella fine sand. They used a 7.5-cm thick envelope around a 12.5-cm inner diameter tile drain with a particle-size distribution in accordance with the specifications of the Soil Conservation Service, United States Department of Agriculture. They reported that as little as five percent of field soil in the envelope material seriously reduces drain envelope performance. Fine particles either naturally occurring or added during installation cause the hydraulic conductivity of the drain envelope to decrease drastically. Furthermore, conditions are created which result in a discharge rate decreasing with time.

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[1] Annual Report, 1970, U.S.D.A. Western Regional Research Project W-51, Dynamics of Flow into Drainage Facilities.

Lembke and Buck (1970), Sisson and Jones (1962), De Boer, et al. (1971), Davis, et al. (1971), Hwang, et al. (1974), Sommerfeldt (1975), Willardson, et al. (1975), Dierickx, et al. (1975) and Bishay, et al. (1975) all agree about the necessity of envelope material in fine sandy and silty soils which eventually enhances the drainage discharge rate and at the same time inhibits sediment entry into the drain. Also the studies of Lembke and Buck (1970) and De Boer, et al. (1971) reveal that a 7.5-cm gravel envelope performs as satisfactorily as a 15-cm gravel envelope. It is also evident from the studies of Lembke and Buck (1970), Bornestein, et al. (1967), Bornestein and Benoit (1967) and Hwang, et al. (1974) that half or more than half of the flow into the drain is contributed from the bottom half of the drain. Hwang, et al. (1974) however, reported that the contribution to the drainage flow from the bottom half of the drain is as high as 75 percent of the total drainage rate. Hwang, et al. (1974) found this result when the drain tile was placed below the interface in a two-layered soil where the top layer was more permeable than the bottom layer. Studies at Oregon[1] agree with the findings of Hwang, et al. (1974).

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[1] Annual Report, 4 October, 1971, U.S.D.A. Western Regional Research Project W-51, Dynamics of Flow into Drainage Facilities.

Luthin[1] reported results similar to those of Lembke and Bucks (1970), Bornestein, et al. (1967), Bornestein and Benoit (1967), Hwang, et al. (1974) and the studies at Oregon.[2] Moreover, he added that conditions of high exit gradient can cause the soil material to become unstable which may lead to the entry of such materials into the drain. Further, he reported that gravel envelopes are not successful in retaining fine particles if the gravel is of uniform size.

Factors influencing soil transport near drain lines and the rate of soil transport in plugging tile lines were investigated at Riverside, California.[3] This study developed test gravel envelopes having 5, 10, 15 and 20 percent particles by weight finer than 250 micron. The hydraulic head loss (measured across the envelope thickness) increased linearly with flow rates for each test envelope and was greatest for the envelope containing 20 percent fines. After all trials, the percentages of fine material remaining in the envelope were 4, 8, 12 and 15 percent

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[1]Joint Drainage Workshop, 13 September 1972, U.S.D.A., Western Regional Research Project W-51, Dynamics of Flow into Drainage Facilities and W-107 Management of Salt Load in Irrigated Agriculture.

[2]Annual Report, 4 October, 1971, U.S.D.A., Western Regional Research Project W-51, Dynamics of Flow into Drainage Facilities.

[3]Minutes, Committee Meeting, 7 November, 1974, U.S.D.A., Drainage Design Research WRCC-19, Salt Lake City, Utah.

compared to 5, 10, 15 and 20 percent initially. Thus the quantity of fine materials removed by drainage was greatest for envelope materials having the larger initial percentage of fines and was lowest for envelope material having the lower initial percentage fines. It was also found that drain openings were not plugged with soil particles, but rather the fine particles were trapped within the envelope thereby reducing effective pore sizes and eventually increasing hydraulic resistance to flow.

Willardson (1975) reported that non-Darcy flow occurs very near drain openings which results in excessive head loss. He added that for normal ranges of flow, turbulent flow can develop near the drain.

Studies of Lembke and Bucks (1970) and Sisson and Jones (1962) are in agreement as far as improved hydraulic conditions around the drain are concerned, but differ in their evaluation of the effectiveness against sediment entry. Lembke and Bucks (1970) reported no measurable amount of sediment in tile outflow whereas Sisson and Jones (1962) reported a sedimentation rate of 0.81 g per hour from a length of 15.0 cm. This is probably due to a different gradation of the soils. Brownscombe (1962) reported sediment in tiles which was due to the displacement of the organic material envelope from the drain.

Unlike the well established design criteria for sand-gravel filters, no accepted design criteria for organic filters are available. However, the Soil Conservation Service of the United States Department of

Agriculture (1973) has recommended a 15-cm to 30.0-cm envelope in the absence of suitable design criteria.

While studies of envelope performance by Sisson and Jones (1962), Brownscombe (1962) and Palmer and Johnson (1962) and Bishay, et al. (1975) provide some information for establishing badly needed design criteria, this information is inadequate and does not specify the gradation of organic material and the effect of different thicknesses of organic material on protection against sediment and on facilitating water entry into the drain.

Willardson, et al. (1968) recommended a velocity-control device for preventing sediment entry into the drain. The essential element for effective sediment prevention is an entrance flow channel for controlling both the direction and magnitude of the inflow velocity. They introduced a layer of impermeable material on the top half of the conduit such that a flow channel between the top surface of the drain and the impermeable layer was formed. The distance between the top surface of the drain and impermeable layer could be increased as desired. Sediment control was achieved by causing the water to flow in an upward direction through the channel against gravity. By adjusting the width of the channel and the shape of the impermeable layer at the point of water entry into the flow channel, the velocity of entry of water into the drain was kept less than the critical limiting velocity which would dislodge and lift soil particles. Willardson, et al. (1968) reported that the width of the channel should be such that the average velocity in the channel is less than the 10 percent of the terminal velocity of the finest particle size in the base material.

Gulati, et al. (1970) in their study of the control of sediment flow into subsurface drains evaluated the method of preventing sedimentation developed by Willardson, et al. (1968), and demonstrated the possibility of such a device. They concluded that:

1. with vertically upward flow, critical velocities required to set sand and glass bead particles in motion were about 1.0 percent of Stoke's settling velocity. For glass beads 0.028 mm to 0.425 mm in diameter, average critical velocities were 0.0011 cm s^{-1} to 0.132 cm s^{-1} respectively. The average critical velocity for fine silica sand with an average diameter of 0.213 mm was 0.041 cm.s^{-1}.
2. non-uniform distribution of velocities may result in piping or sediment movement.
3. the average critical velocity in the upflow channel increased with a decrease in interface width. This effect was more pronounced for silica sand than for spherical glass beads.

The values of average critical velocities reported by Gulati, et al. (1970) were 10 percent less than the velocities reported by Willardson, et al. (1968) for the safe functioning of the drainage system. The higher critical velocities obtained in the study of Willardson, et al. (1968) may be due to mechanical bridging of the sand particles in the narrow upflow channel. Further studies by Davis, et al. (1971) on entry velocity control revealed that flow rates from the drain were exceptionally less than the flow rates from drains with gravel envelopes.

2.2.2. Synthetic (Fiberglass) Filters: In Ontario, Hore and Tiwari (1962) studied the performance of cover-materials (Tileguard and Duramat), used singly and in combination, as filters for tile drains. Tileguard above and below the tile provided the best protection against sediment movement and facilitated the highest discharge for all treatments. Mechanical analysis of soil which moved into the tile revealed that the percentage of 10-to 100-micron soil particles increased significantly as compared to the original soil.

Nelson (1960) tested the filtering characteristics of fiberglass sheets with longitudinal and random re-inforcing fibers. He reported that fiberglass with random reinforcement of fibers works satisfactorily in most un-stable soils. He also developed a soil filtration curve relating the percentage of soil particles by weight that would pass through the sheet under agitation by a jet of water to the particle size. The suitability of a fiber-glass sheet as a drainage system filter in a particular soil was established by comparing the gradation curve of that soil and the soil filtration curve of the fiberglass sheet.

Overholt (1959) studied the suitability of fiberglass material for filters in tile drains. He found that the flow rate from tile drains with a fiberglass sheet filter increased with time. The flow rate from the tile drains with no filter, on the other hand, decreased with time over the same period of time. He also noticed heavy silting of drains with no filter.

Shull (1964) studied the hydraulic characteristics of fiberglass materials. He found that the lateral hydraulic conductivity of synthetic materials was significantly greater than the transverse hydraulic conductivity. He described the term transverse hydraulic conductivity for flow in a direction normal to the surface of the mat. On the other hand, lateral hydraulic conductivity was used to describe the conductivity characteristics of the mat for flow in a direction parallel to the surface of the mat. In either case a dramatic decrease in conductivity took place when the thickness of synthetic material was reduced by compaction from 0.97 cm to 0.25 cm. In spite of the reduced hydraulic conductivity fiberglass materials met the requirement of an improved hydraulic condition surrounding the drain.

Shull (1967) performed a study on soil filtering properties of three fiberglass mats. He determined the amount of soil retained by a fiberglass mat as a function of soil particle size. He reported that soil particles larger than a very fine sand do not easily move through fiberglass mats. He evaluated the procedure by conducting a soil filtering test with a fiberglass sheet and compared it with the results of Nelson (1960). The nature of the curves by the two methods was similar. However, the amount of soil retained on the fiberglass sheet by the Nelson (1960) method was smaller. This difference in the retention of soil particles on the fiberglass sheet can be attributed to the fact that Nelson (1960) used a forced jet of water on the fiberglass sheet and, therefore, a smaller amount of soil particles was retained on the fiberglass sheet. Shull (1967) used gravity flow where the effective forces were relatively smaller and, therefore, a larger amount of soil particles remained on the sheet. For actual field conditions it is safer to use the results of Nelson (1960) which embody a higher factor of safety against silting.

Lembke (1967) in an investigation of observed and predicted tile flow on a lake plain soil, reported that the discharge begins at an initially high rate of 991 dm^3 per day and decreases to a lower constant rate of 538 dm^3 per day for each 30.5 cm length of drain following a flow period of one day one year after the construction of the drainage system. This was due to the filling of the pores of the filter by the finer particles in the base material.

Allen and Myers (1969) carried out laboratory and field studies in a drainage area underlain by a highly permeable shallow sand aquifer by employing 15-cm and

20-cm inner-diameter concrete drains at a depth of 244 cm. The envelope material used was fiberglass mat. They reported that:

1. seventy-five percent of the flow predicted by an analogue solution comes up from beneath the tile whereas all flow comes from above the drain when a barrier condition between the drain tile and aquifer is created.
2. equipotential lines for the field condition indicate significant upward movement of water from beneath the drain.

The findings of Allen and Myers (1969) agree with the findings of Lembke and Buck (1970), Bornestein, et al. (1967), Bornestein and Benoit (1967), Hwang, et al. (1974) and Luthin.[1]

Sommerfeldt (1975) conducted an investigation on outflow from various subsurface drainage materials. For field conditions, he reported that with fiberglass envelopes, the volume of discharge from a 65-mm plastic drain was greater than that from a 105-mm tile drain during the first year but later fluctuated about that from the tile. On the average its discharge was about the same as that from the tile.

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[1] Joint Drainage Workshop, 13 September, 1972, U.S.D.A., Western Regional Research Project W-51, Dynamics of Flow into Drainage Facilities and W-107, Management of Salt Load in Irrigated Agriculture.

Rapp and Riaz (1975) studied the relative effectiveness of seven different filter materials on the flow of sediment and water into plastic drain tubes. They concluded that:

1. a fiberglass mat with fiberglass felt, Tileguard with fiberglass felt and a fiberglass mat with a polyethylene sheet underlay are most effective against sediment entry.
2. all the fiberglass materials provided better protection against sediment than a gravel filter.
3. the amount of water discharged was the highest for the gravel filter followed by Tileguard with fiberglass felt, and a fiberglass mat with fiberglass felt.
4. discharge for the no-filter condition was minimum while the sediment moving into the drain was maximum.

Research by Nelson (1960) and Shull (1964, 1967) provides information on filtering characteristics and hydraulic conductivity of synthetic materials but does not describe what thickness of filter materials should be used around the drains. Similarly the findings of Hore and Tiwari (1962), Overholt (1959), Allen and Myers (1969), Lembke (1967), Sommerfeldt (1975) and Rapp and Riaz (1975) confirm the effectiveness of fiberglass filters over the no-filter condition around the drain but caution that these filters are still inadequate for complete protection of the drain from siltation.

2.3. Effect of Perforations on Flow and Sediment Movement: Cavellaars (1967) studied the problem of water entry into corrugated plastic drain tube, clay tiles, and smooth polyvinyl-chloride pipes. He concluded that:

1. the flow of ground water into drain pipes is determined to a greater extent by the conditions of soils in the immediate vicinity of drain than by the type of drain pipe and filter material used.
2. for slotted pipes, the relative slot length (total slot length per unit length of drain) appears to be a good indication of their water intake capacity. Both slot width and pipe diameter have much less influence.

Rektorik and Myers (1967) used two rows of rectangular slots (5.0 cmx0.16 cm) with six slots for each 30.5-cm length of 10.0-cm diameter Polyethylene drain pipe. Placement of the drain at a 244-cm depth did not reveal any failure of the drain except at one point the drain diameter was reduced to 9.0 cm.

Tests on soil movement into drains at Riverside, California[1] were conducted with slot widths of 0.081 cm. Particles smaller than the slot moved through it leaving a filter near the slot which prevented particle movement. Although the average velocity was about 34.5 cm s^{-1} at

[1]Annual Report, 4 October, 1972, U.S.D.A., Western Regional Research Project W-51, Dynamics of Flow into Drainage Facilities.

the outer edge of the slot, angularity of gravels used in this study would probably restrict movement of particles greater than 0.05-mm diameter.

In Brawley, California[1] tests were conducted to determine the amount of dry envelope material which would pass through simulated drain openings of various sizes. Five circular openings (0.156 to 0.938 cm) and a slot 0.32 cm x 3.13 cm were tested. It was found that for size ranges such that some material passed through the opening, bridging was effective after a short time and stopped further movement through the opening. The effective size of the slot was approximately three times larger than its narrowest dimension. It was found that bridging will occur for a narrow range of material gradings if the particles are one third the size of the opening or larger.

Kirkham and Schwab (1951) and Schwab and Kirkham (1951) performed a study on the effect of circular perforations on flow into subsurface drains by an electric analogue method. They concluded that:

1. for four or less holes for each 30.5 cm of drain conduit, the flow is roughly proportional to the number of holes per unit length.
2. above four holes for each 30.5 cm, additional holes do not result in a proportionate increase in flow;

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[1]Annual Report, 4 October, 1972, U.S.D.A., Western Regional Research Project W-51, Dynamics of Flow into Drainage Facilities.

however, flow is rapid up to 10 holes for each 30.5 cm of drain conduit.

3. doubling the diameter of perforations does not double the flow but does result in an appreciable increase in flow.

In Alberta, Rapp and Riaz (1975) studied two types of 10.0-cm inner - diameter corrugated plastic drains with reference to sediment and water movement into the drains. The two types of drains were identical in shape and relative slot length but had different sizes of perforations. They reported no significant effect of perforations on flow rate and sedimentation.

Two studies, one at Riverside, California[1] and the other at Brawley, California,[2] agree that bridging will occur after washing out of some finer particles into the drain for the size of perforations on drains and the material selected in their study. However, they do not describe the effect of bridging on flow rates. Kirkham and Schwab (1951) and Schwab and Kirkham (1951) on the other hand, thoroughly describe the effect of circular perforations on drainage discharge. They do not describe the effect of perforations on silting of drains. However,

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[1]Annual Report, U.S.D.A., Western Regional Research Project W-51, Dynamics of Flow Through Drainage Facilities.

[2]Ibid.

Schwab, et al. (1957) predicted that perforations having a maximum diameter of 0.63 cm should be safe without a silting problem. Since the present day conduits have perforations other than circular section, a potential need of further investigation into the effect of different shapes and sizes of perforations on flow rate and sedimentation exists.

CHAPTER III

EXPERIMENTAL EQUIPMENT

Special experimental equipment was constructed for the evaluation of the performance of envelopes constructed using organic and synthetic materials in the laboratory. The description of the equipment is divided into three sections: the vertical soil chamber, water chamber with water supply system and the manometer system.

3.1. The Vertical Soil Chamber: The vertical soil chamber was 112 cm deep with a 66-cm x 66-cm square bottom. It was constructed of 1.90-cm (3/4-in) plywood with the exception of the front wall which was made of 1.56-cm (5/8-in) plexiglass. The drain tubes with their envelopes were placed in the main soil chamber with the drain axis 17 cm above the bottom of the chamber in the tank's vertical plane of symmetry perpendicular to the front (plexiglass) wall. A 10.0-cm diameter plywood disc 1.90 cm thick was fixed on the wall opposite the plexiglass wall to secure the blind end of the drain tube. The open end of the drain tube protruded through a tight-fit (sealed) hole in the front plexiglass wall 20 cm out of the box where drainage water and sediment were collected and measured in a container.

3.2. Water Supply and Water Chamber: Two water chambers each 112 cm deep and having a 66-cm x 5.5-cm horizontal section were constructed and attached to the two opposite side walls of the main soil chamber. The partitions between the soil and water chambers were perforated to a depth of 56 cm from the upper edge with 0.63-cm diameter holes drilled in a 2 cm x 2 cm grid. Small plastic tubings (with 0.63-cm outer diameter, 0.32-cm inner diameter and 1.90-cm length) were inserted into the drilled holes to prevent the plywood from soaking water. The walls were painted several times in order to seal completely all cavities between the outer wall of tubing and the plywood. A single layer of fiberglass was pasted on the inner side of the perforated walls to prevent the entry of sand from the main chamber into the two water chambers.

Water was supplied into the two water chambers through a branching flexible 1.60-cm diamter hose equipped with a flow meter (Neptune-5/8-Trident-8, Model No. 22328918, with the smallest division equivalent to 0.454 dm^3), pressure regulator (Patent No. 3,139,901, Serial No. 5474, 0 to 344 kPa) and a main shut-off valve.

3.3. Manometer Board: Two plywood sheets, 120.0 cm x 86.0 cm x 1.0 cm in size were obtained. A good quality metric graph paper was pasted on one side of each of the two sheets. The smallest division of the graph paper was 0.1 cm. These two graduated boards were placed parallel to the water chamber at a distance of 20 cm from the outer wall of the tank one on each side. These boards were connected with the main body of the sand tank by means of flat angle iron pieces 126 cm x 2.0 cm x 0.3 cm in size bent into a u-shape and clamped with nuts and bolts. The four such u-shaped angle iron pieces kept the two manometer boards vertical and parallel to the outer wall of the tank. The bottom of the board rested on the floor.

A set of eighteen manometer tubes (1.2-cm outer diameter) of different lengths was clamped on one of the manometer boards. Similarly a second set of fifteen manometer tubes was clamped on another manometer board. The arrangement of the two sets of manometer tubes on the two manometer boards is shown in Figures 3.3 and 3.5. Centre-to-centre spacings of vertical axes of the manometer tubes were 6.0 cm. Pressure tubes extending from the interior of the tank at various locations were connected with the bottom of the manometer tubes. The location and arrangement of the pressure tubes in the vertical soil chamber are shown in Figures 3.1 and 3.2. With this arrangement direct measurement of pressure head at strategic points in the soil chamber was accomplished. A detailed view of the entire experimental set up is shown in Figures 3.3 to 3.6.

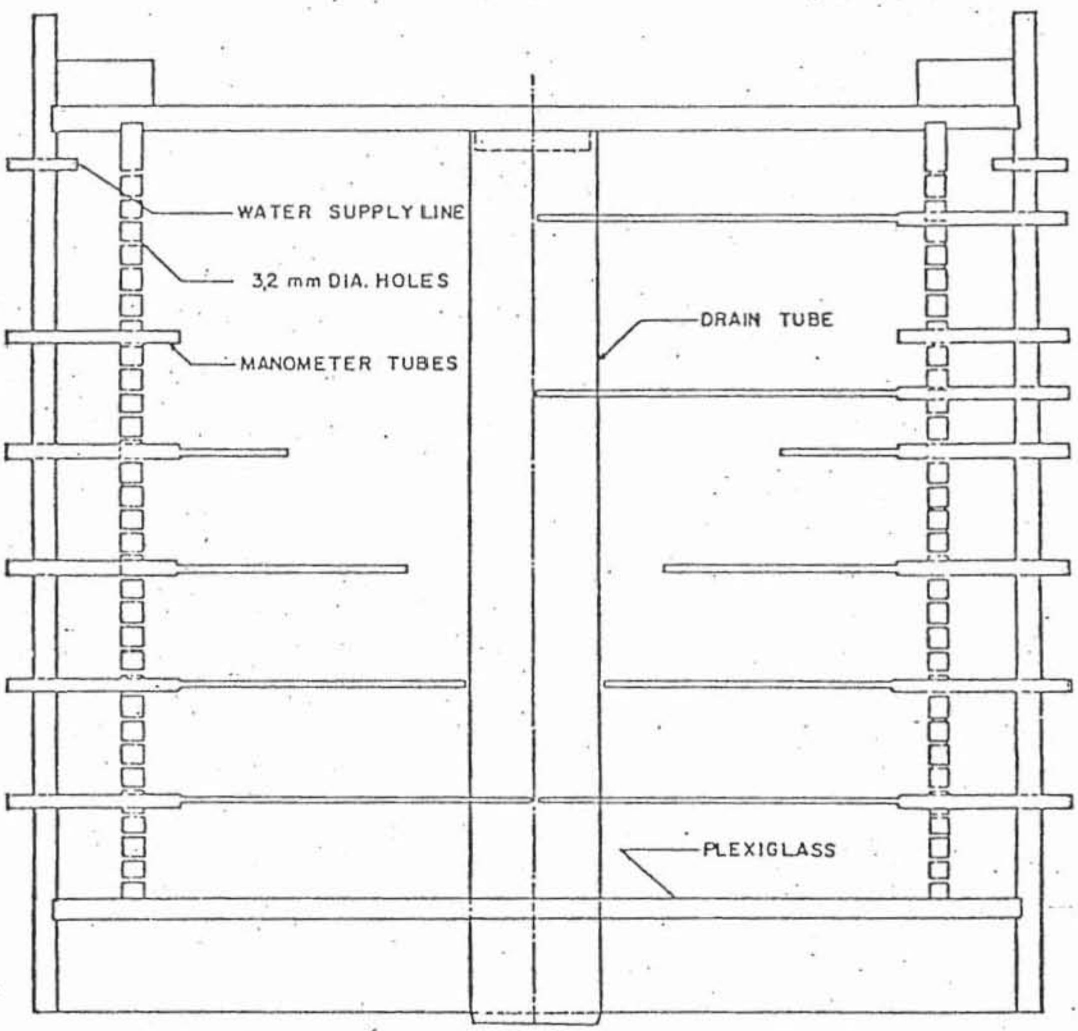

Figure 3.1 Top view of experimental tank.

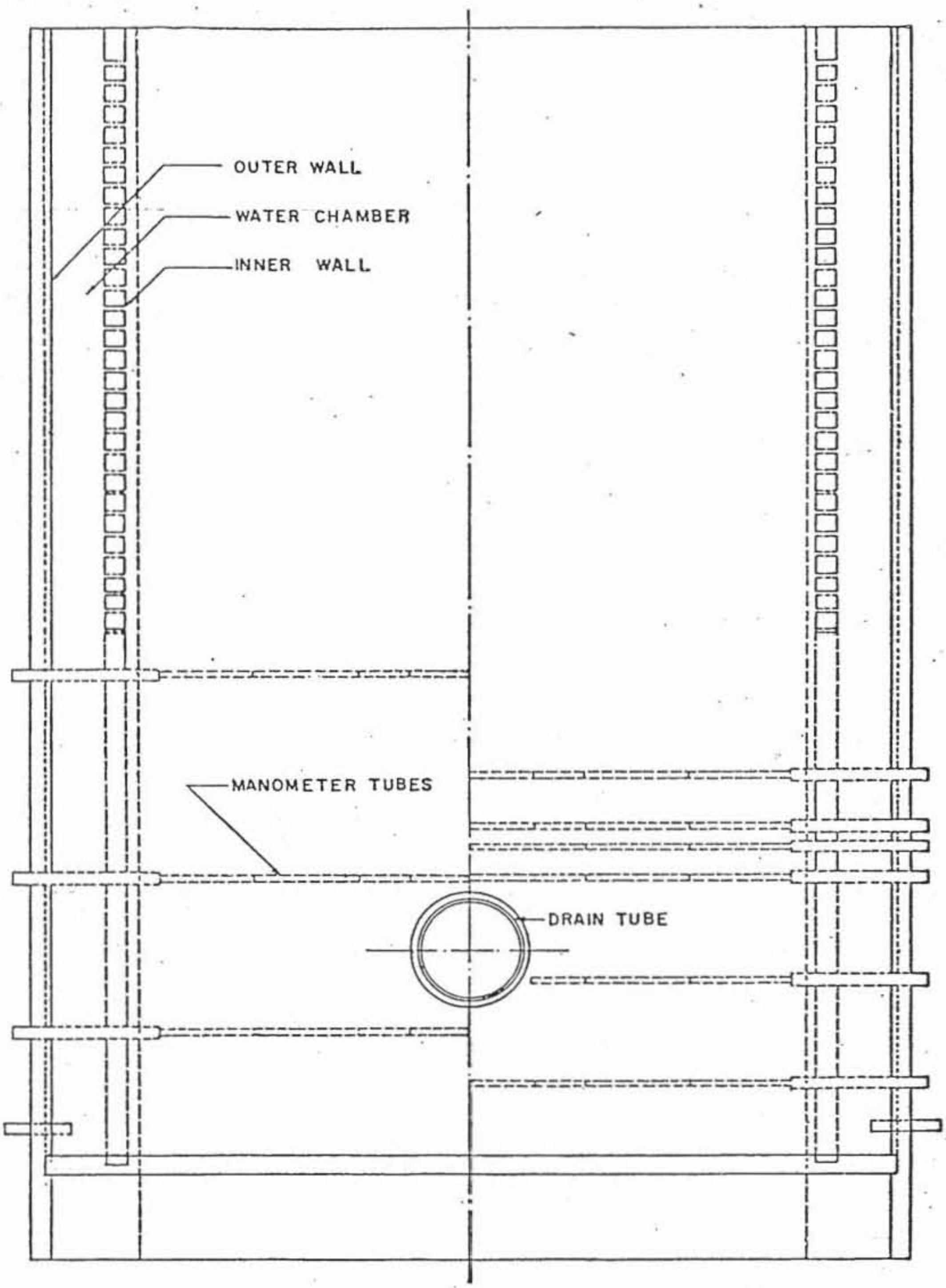

Figure 3.2 Front view of experimental tank.

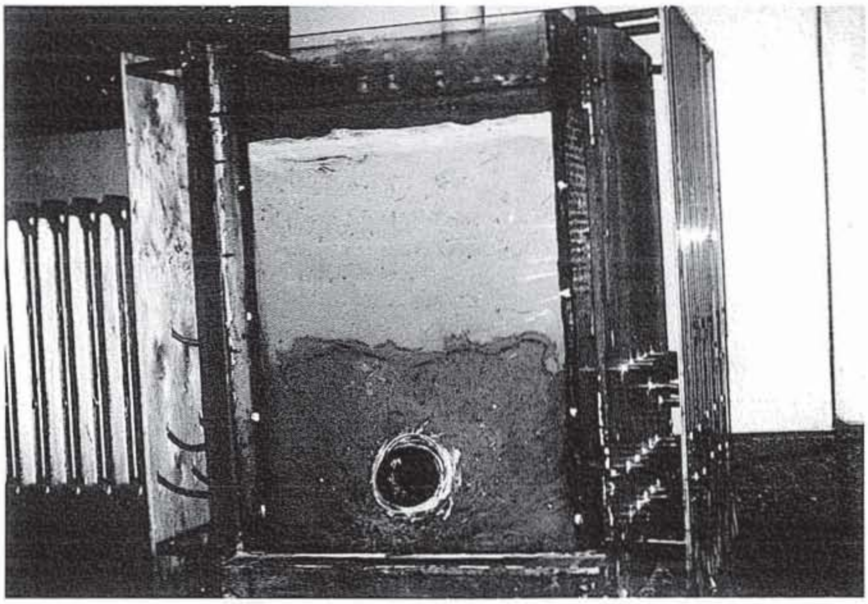

Figure 3.3 Experimental tank.

Figure 3.4 Flowmeter and pressure regulator in experimental set up.

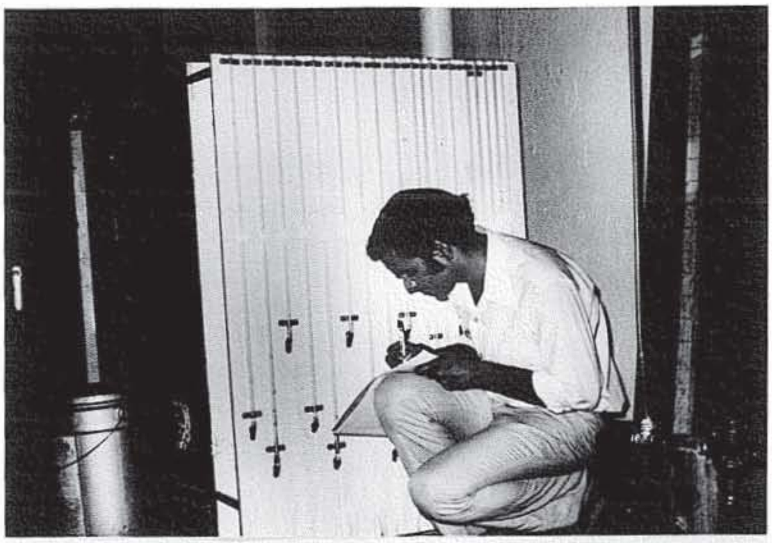

Figure 3.5 Manometer tubes and measurement of pressure head at various locations in the vertical soil chamber.

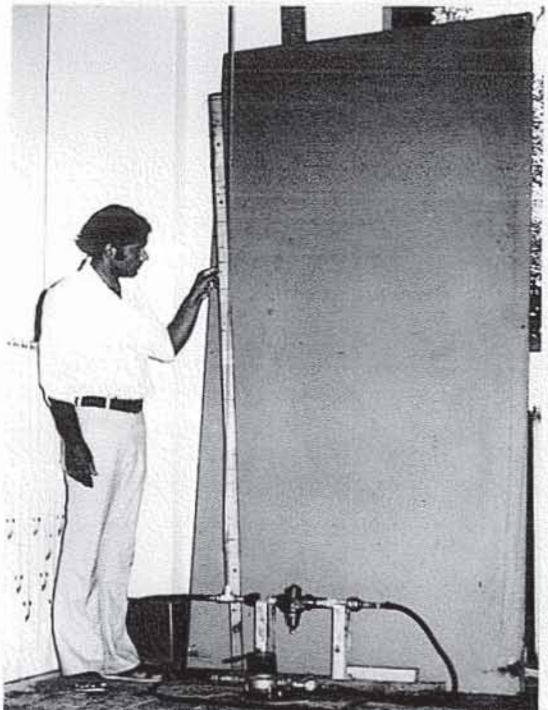

Figure 3.6 Measurement of pressure head.

3.4. Mechanical Analysis of Sand: A mechanical sieve shaker was used to determine the particle-size distribution of the base-material (sand for loading the tank) and of the sediment washed out into the drain and the container. A set of Canadian Standard Sieve Series (Nos. 35, 50, 60, 70, 80 and 100) was used for the mechanical analysis of sand.

The mass of the samples varied from 100.0 g to 1000.0 g depending upon the amount of sediment washed out. Each sample was shaken for five minutes and then the sand retained on each sieve was collected on an aluminum plate by means of a fine brush. The mass of sand on every sieve was determined with a precision of 0.01 g.

CHAPTER IV

PROCEDURES

4.1. Selection and Preparation of Test Materials: A base material commercially known as Selkirk Silica Sand was selected for the study. The gradation curve of this sand is shown in Figure 4.1. It consists of particle sizes ranging between 0.5 mm and slightly less than 0.15 mm. The particles of this range have been reported by Dunn (1959) to be most unstable. Low values of critical tractive force are required to move these soil particles. The particle size and critical tractive force relationship after Dunn (1959) is shown in Figure 4.2. Since the above study was performed in cohesive channels, the application of this criterion in subsurface drainage should describe the movement of such unstable particles with a higher factor of safety.

The tested envelope materials were straw and fiber-glass. Since the straw is easily available and cheap and has been reported to be effective [Brownscombe (1962)] in controlling sedimentation of drains and facilitating water entry into the drains, a closer study of its performance was considered desirable. The gradation curve of straw is shown in Figure 4.3. The abscissa of the graph is different from the particle-size graph of Figure 4.3

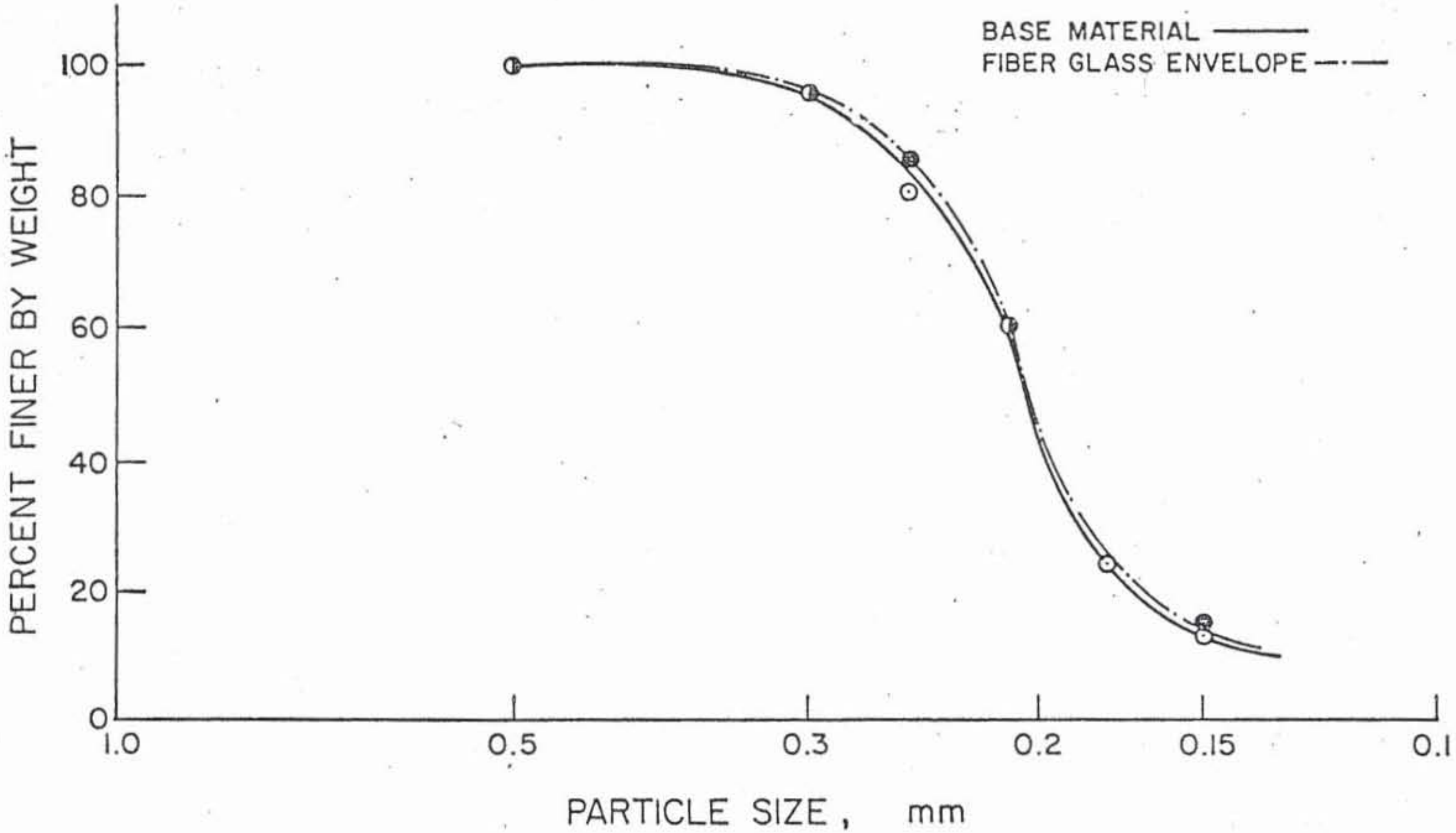

Figure 4.1 Gradation curves of base-material and sediment moved into the slotted drain with a circumferential envelope of fiberglass.

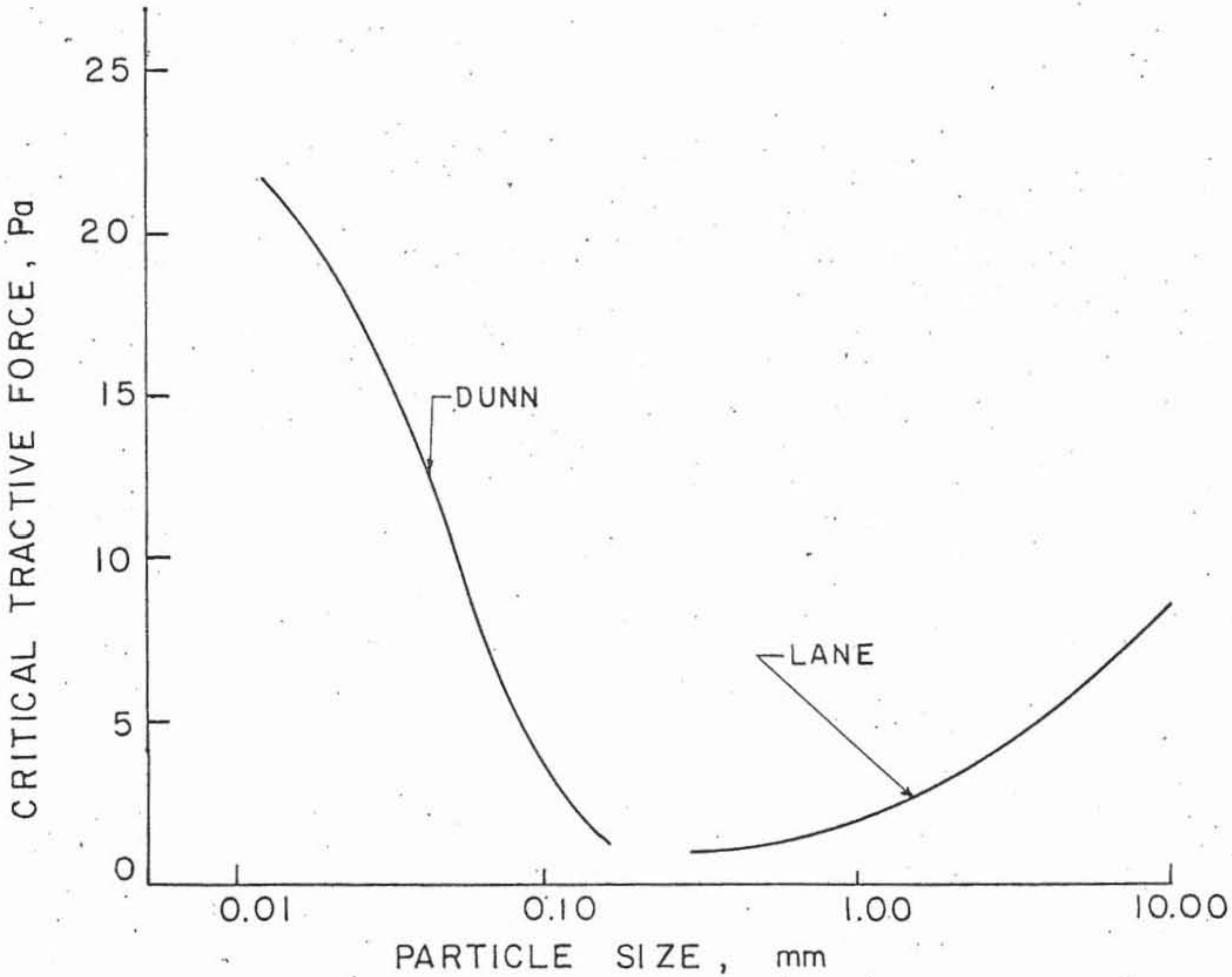

Figure 4.2 Critical tractive force and particle-size relationship in cohesive channels (after Dunn and Lane)

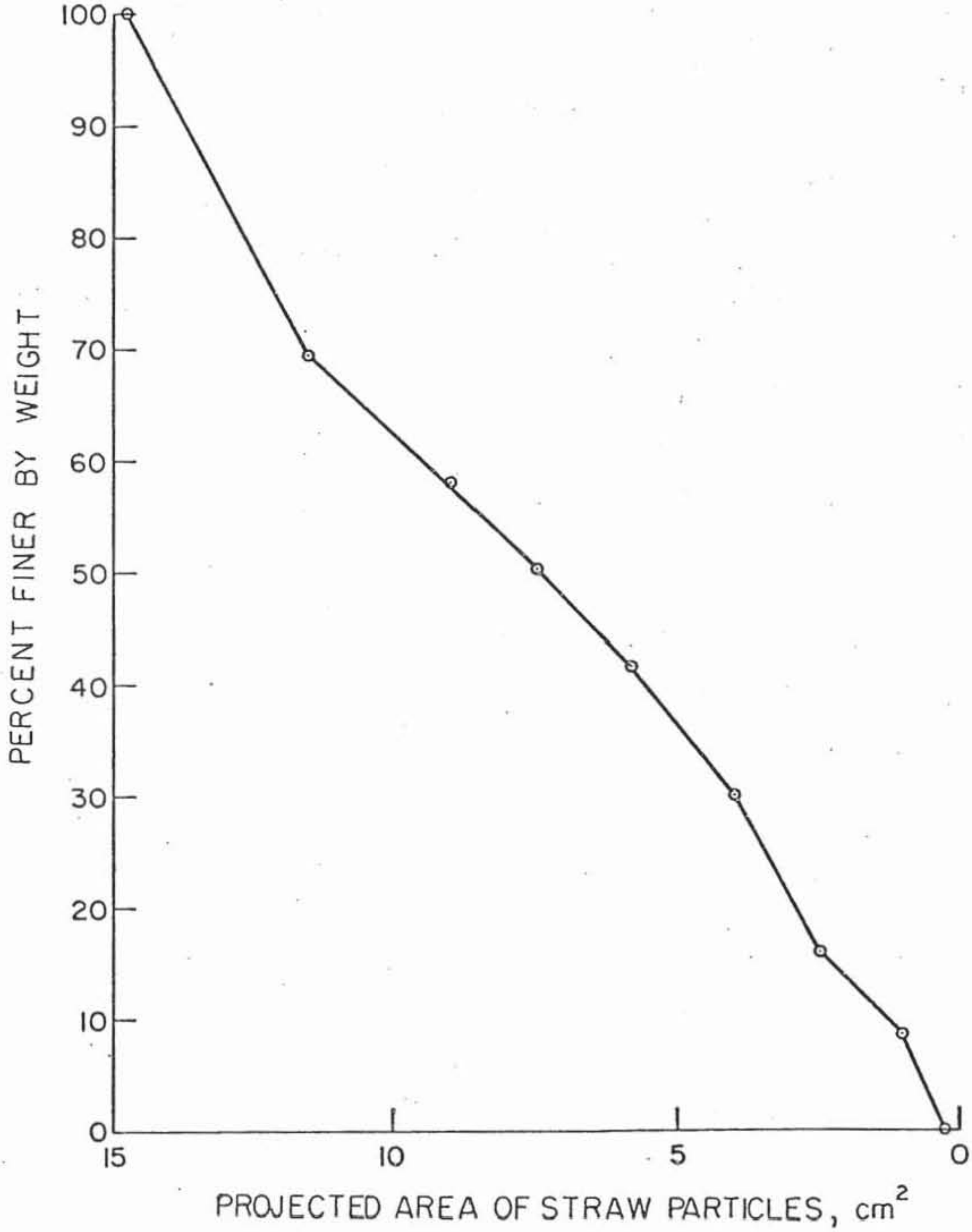

Figure 4.3 Particle-size distribution of organic-material (straw) measured in terms of projected area of straw particles.

and refers to the projected or compressed area of the straw particles. An effort was made to maintain the bulk density of straw in the envelope at 1.0 g cm^{-3} before it was placed in the tank. Since gravity, viscous, and surface tension forces are involved near the drain, the model was constructed on a full-scale basis.

The fiberglass material used in the experiment was Globe Glass Saturaters Limited PG-90 Tileguard felt with uniform porosity. It is supplied in 30.5-cm (12-in) wide rolls.

Two types of 10.1-cm (4-in) diameter corrugated plastic drain tubing, one with spiral corrugations and eight rows of precision-cut blister holes (Daymond Flexi-pipe), the other with ring corrugations and three slotted perforations in every third valley (supplied by the Big 'O' Drainage Company) were used. Non-standard (adjusted) type of tubing was added later to the experiment. The size of the perforations for the spirally-corrugated drain tube was increased by means of a knife to a predetermined length. The circular perforations on the non-standard type of 10.0-cm diameter tubing were made by drilling 0.975-cm diameter holes in the drain tube.

4.2. Experimental Methods: Filters 2.5 cm, 5.0 cm, 7.5 cm and 10.0 cm thick were constructed using: straw wrapped around the circumference of the drain tube, straw with an inner layer of fiberlass wrapped around the circumference of the drain tube (S.I.F.), and straw wrapped around the drain tube with an outer layer of fiberglass around the straw (S.O.F.), were tested in this study in the experimental tank. Each of the above 12 combinations were used on two types of 10.1-cm corrugated plastic drain described earlier.

The envelope material was wrapped around the drain tube which was then placed in the tank. The maximum thickness of envelope, limited somewhat by the dimensions of the tank, was 10.0 cm.

The experiment tank was loaded and unloaded with the base material for each of the 14 combinations for the two types of ring and spiral corrugated 10.1-cm diameter tubes. The depth of sand column was always maintained at 88.0 cm in all treatments.

At the start of each test run water was allowed to enter into the water chamber as described earlier. When the height of the water column exceeded the level of the perforations, water started seeping into the sand. The outlet of the drain tube was closed at this stage to prevent the leakage of water at the start of the run.

Water was allowed to enter into the sand until a ponded layer 10.0 cm deep was attained on the surface of the sand. The water supply was discontinued at this stage. This was done to make sure that the air entrapped near the drain escaped. When all the manometers indicated the same level of water, the plug closing the drain outlet was removed and water was allowed to drain from the tank until the ponded water on the sand surface disappeared. The water supply was restored first at a pressure head of 75.0 cm by adjusting the pressure regulator and the main valve. The discharge rate was then determined by collecting water in a container. Similarly water input rate to the tank was measured by means of a stopwatch and a flowmeter installed in the supply line. When the two flow rates were equal for a period of time, steady state was assumed to be achieved, and readings of the manometer were taken. The same procedure was repeated with different pressure heads. A maximum head of 140 cm was used during the test as further increase of head was not possible because of the limiting discharge rate of the drain tube and the size (depth) of the tank. It took about 12 hours to complete each run.

At the end of each run, the sediment in the container and in the drain tube was collected, oven-dried at 105° C for 24 hours and weighed. Mechanical analysis of the sediment (washed out) was then performed. This sediment was later mixed with the base material. When a series of runs with different heads was completed with each particular type of envelope, the tank was unloaded and refilled with new drain and envelope combinations. The procedure was repeated for each envelope thickness and combination in a random sequence. The measurements made and recorded for each run were: 1. rate of water flow through the drain, 2. pressure head at which water was supplied, 3. manometer readings, and 4. sediment discharged during the entire test.

4.3. Derivation of Flow Equations: Statistical analysis using simple and exponential regression techniques was employed in computing the flow equations. For each envelope of synthetic and organic materials pressure heads were correlated as independent variables with flow rates as dependent variable.

Three main equations have been developed: the prediction equation for flow at different heads and the prediction equations of flow per unit length of drain for rectangular and circular perforations on plastic conduits.

4.3.1. Model of Flow Equations: An exponential regression model of the type expressed by Equation 4.1 was employed for predicting the relationship between the flow rate and the size of perforations.

$$Y = K + B \exp(Mx) \qquad 4.1$$

where:

x = the size of perforations,

Y = the flow rate,

K, B and M = constants.

For each of the two perforation shapes, two models were developed, one for a head of 84.0 cm and the other for a head of 110 cm of water.

Simple linear regression analysis was used for predicting the flow equations for different envelope thickness of organic and synthetic materials.

4.3.2. Computation of Equations: The linear and exponential regression analysis was performed by using Manitoba Statistical Package (MANSTAT) numbers 14 and 26 at the University of Manitoba Computer Centre.

CHAPTER V

RESULTS AND DISCUSSION

5.1. Head-Discharge Relationship for Different Envelope Thickness: The head-discharge relationship for 2.5-cm, 5.0-cm, 7.5-cm and 10.0-cm thick envelopes of organic material alone and in two different combinations with fiberglass is shown in Figures 5.1 to 5.3. The relationship between head and discharge was considered to be linear for each envelope thickness; the correlation coefficients were in the range of 0.94 to 1.00. Palmer and Johnson (1962) reported an approximately proportional relationship between drainage flow and head of water. A relatively narrower range of head of water (70-cm to 140-cm) in the present study on one hand and different conditions in the field in the study of Palmer and Johnson (1962) on the other hand may explain the variations in the two sets of results.

A 2.5-cm envelope of organic material at a head of 120.0 cm increased the flow rate by 11.0 percent as compared to the envelope of fiberglass only. Comparing the four envelopes of organic material alone at the same head (Figure 5.1), the 5.0-cm, 7.5-cm and 10.0-cm envelopes enhanced the flow rate by only 5.5 percent over that of the fourth 2.5-cm envelope. The simple regression curves for

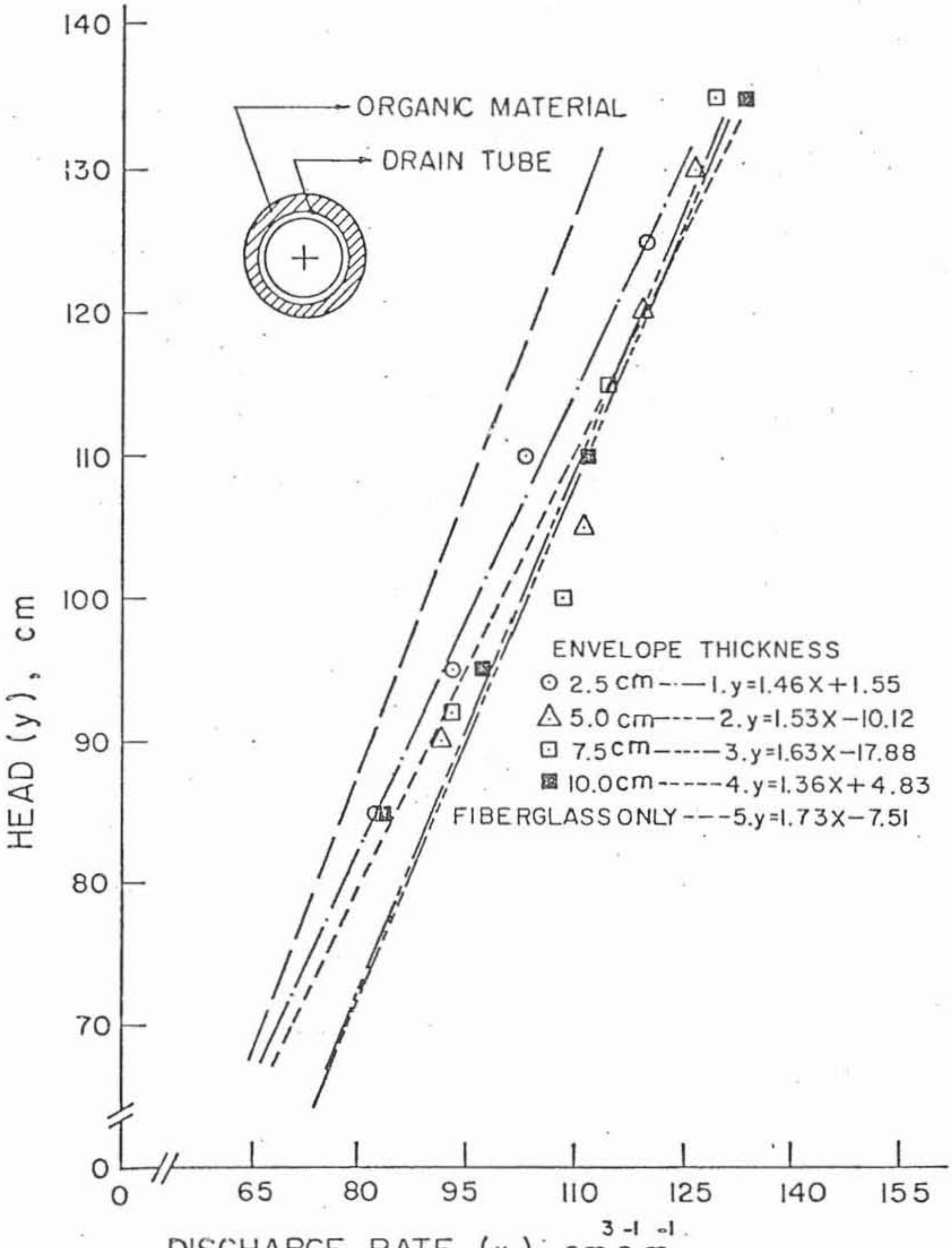

Figure 5.1 Head-discharge relationship for a slotted 10.1-cm inner-diameter drain tube with a circumferential envelope of organic material of different thickness and, for comparison, a circumferential envelope of fiberglass.

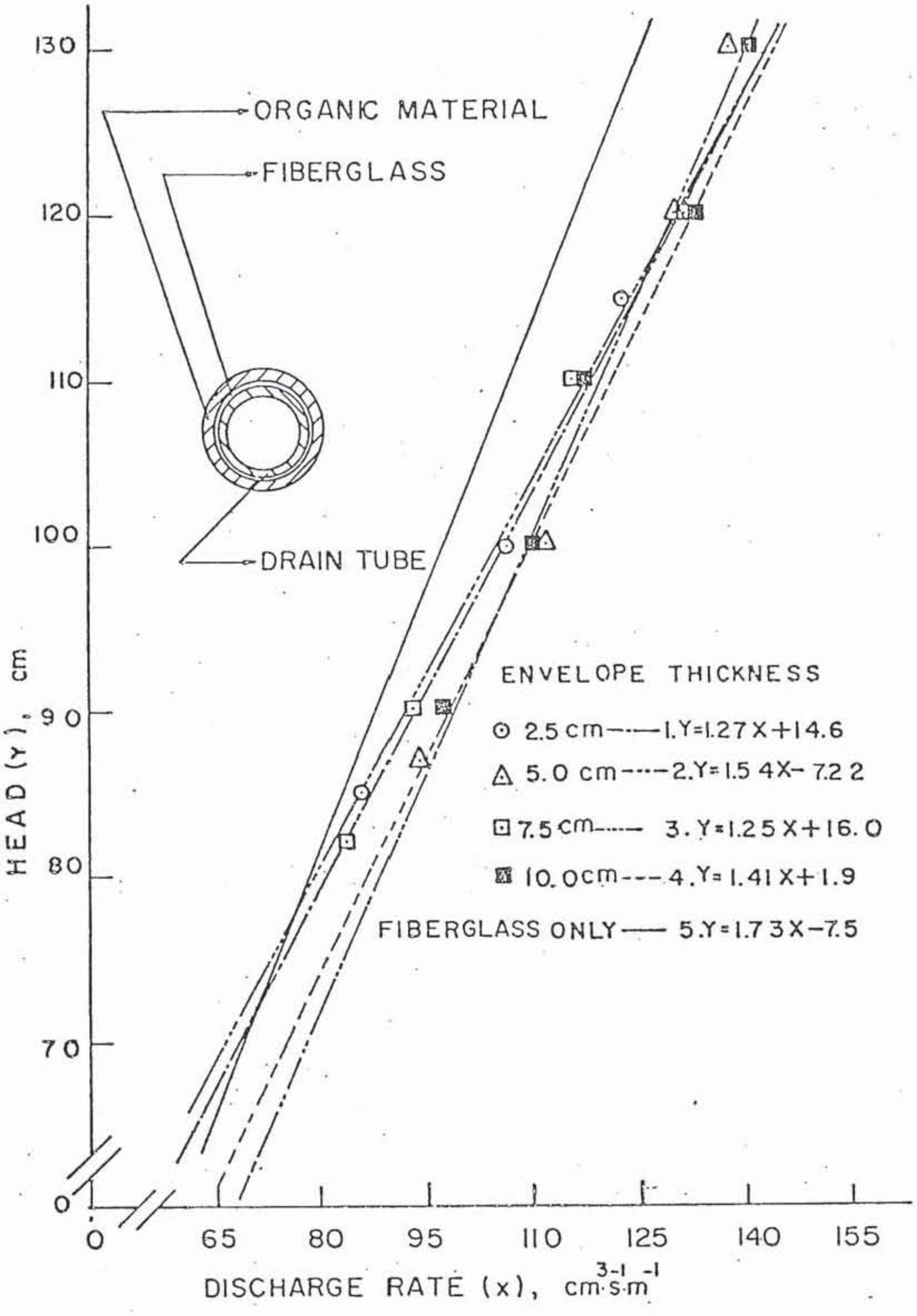

Figure 5.2 Head-discharge relationship for a slotted 10.1-cm inner-diameter drain tube with a circumferential envelope of fiberglass in the inner position and organic material of different thickness in the outer position (S.I.F. treatment).

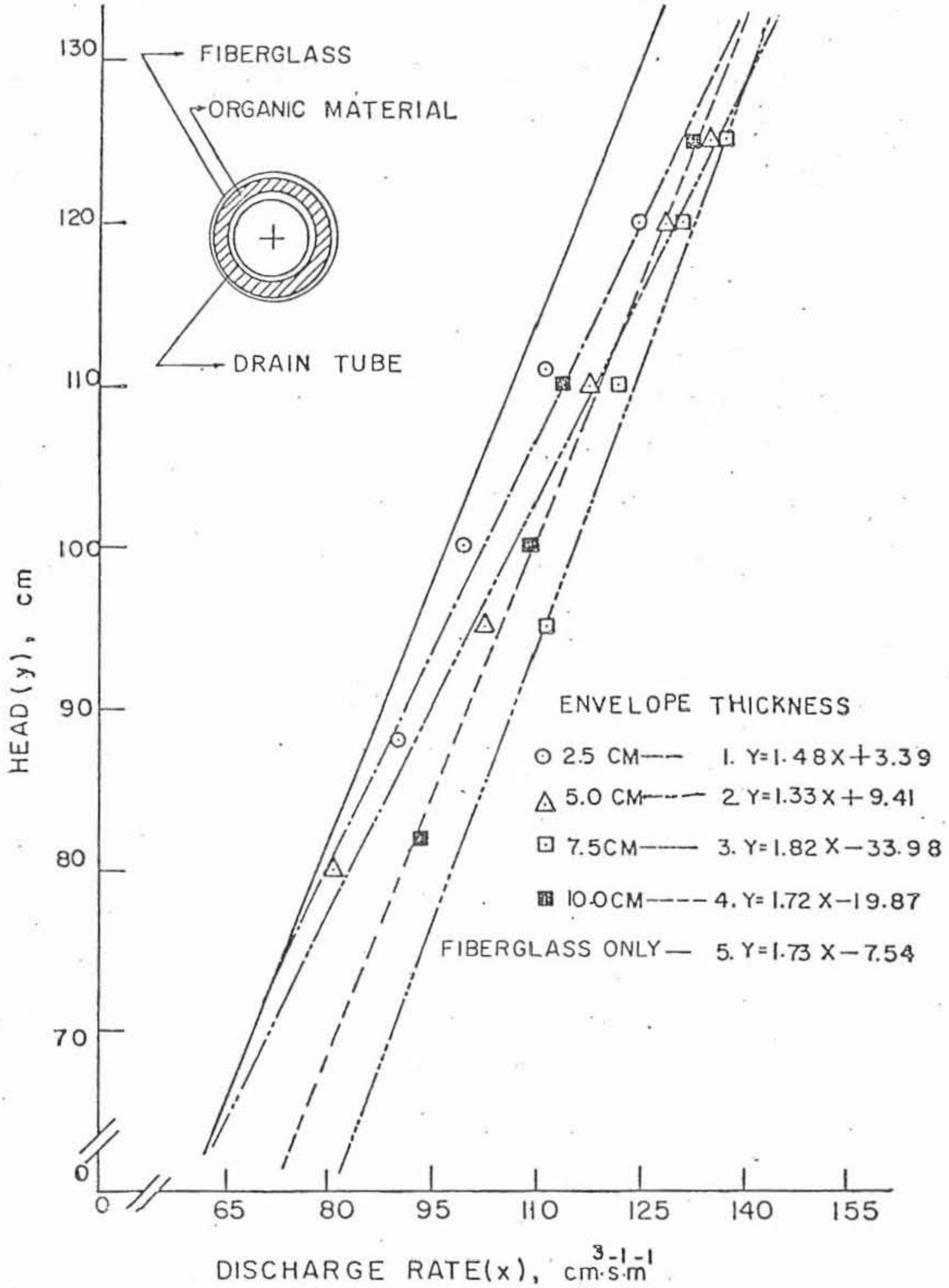

Figure 5.3 Head-discharge relationship for a slotted 10.1-cm inner-diameter drain tube with a circumferential envelope of fiberglass in the outer position and straw of different thickness in the inner position (S.O.F. treatment).

the organic material envelopes had smaller slopes compared to the curves for a wrapping of fiberglass over the drain. This indicates that flow rates from drains with organic material envelopes are more responsive to head change as compared to fiberglass. Therefore, improving the permeability conditions around the drain by increasing the envelope thickness (organic material) enhances the flow rate.

The head-discharge relationship at a head of 120 cm for all four envelopes for the S.I.F. arrangement (Figure 5.2) demonstrated a flow rate increased by 13.5 percent over that for fiberglass only. However, there was no appreciable difference in flow rates among the 2.5-cm, 5.0-cm, 7.5-cm and 10.0-cm organic material envelopes at heads higher than 100.0 cm. Also at lower heads the values of flow rates for each of the four envelopes are scattered and they are closer to the flow rates for fiberglass only.

The head-discharge curves at a head of 120 cm for all four envelopes for the S.O.F. arrangement (Figure 5.3) indicated a similar pattern to that described for the above two placement conditions.

Keeping in mind the scattered values of flow rates for different thicknesses of envelopes under all three placement conditions of organic material and fiberglass, it is unlikely that a relationship between flow rates and envelope thickness can be established. However, it is evident that placement of organic material alone or in combination with fiberglass around the drain improves the flow characteristics of the drain.

For gravel envelopes Lembke and Buck (1970) and De Boer, et al. (1971) reported that increasing envelope thickness from 7.5 cm to 15.0 cm increased the discharge by merely 3.0 percent which, along with the results of the organic material envelopes, establishes that the effect of higher envelope thickness on flow rate is not significant. However, the need of an envelope is strongly indicated in fine sandy, silty and noncohesive soils. Research by Hwang et al. (1974), Sommerfeldt (1975), Rapp and Riaz (1975), Sisson and Jones (1962), Brownscombe (1962), Willardson, et al. (1975), Bornestein and Benoit (1967), Bornestein, et al. (1967), Davis, et al. (1971), Allen and Myers (1969), Hore and Tiwari (1962), Bishay, et al. (1975), and Dierickx, et al. (1975) are in agreement with the results of the present study.

Since there was no appreciable difference in flow rates among the 2.5-cm, 5.0-cm, 7.5-cm and 10.0-cm thick envelopes and no replications were made to establish statistically the observed variations in flow rates with different envelope thicknesses, the effect of various envelope thicknesses on discharge was assumed negligible. With this assumption, a single curve combining the four thicknesses for each of three placements (organic material alone, the S.I.F. arrangement and the S.O.F. arrangement) was developed to study the relative effectiveness of these placements on drainage discharge. Figure 5.4 compares these curves with the curve representing the flow for a wrapping of fiberglass only. The maximum discharge rates were observed in the case of organic material envelopes followed closely by the S.I.F. envelope and the S.O.F. envelope. Fiberglass alone ranked a distant fourth. The difference in flow rates for the S.I.F. envelope and the S.O.F. envelope was not significant. In both cases combinations of organic material and fiberglass reduced the flow as compared to organic material alone. This is because of the higher conductivity of organic material alone; which closely agrees with the findings of Hwang, et al. (1974) and Willardson, et al. (1975) who say that hydraulic conductivity of backfill material plays a vital role in drainage discharge.

The studies of Sommerfeldt (1975) in a fine sandy loam demonstrated the significant effect of envelope material on drainage discharge. However, there was no appreciable difference in flow rates for different type of envelope materials around the drain. The flow rates without an envelope, and with a gravel envelope and a fiberglass envelope were 70, 112 and 122 $cm^3 s^{-1} m^{-1}$ respectively. It is evident that a fiberglass envelope around the drain enabled a higher discharge than a gravel envelope. This is contrary to the findings of Rapp and Riaz (1975), Sisson and Jones (1962) and De Boer, et al. (1971). In the

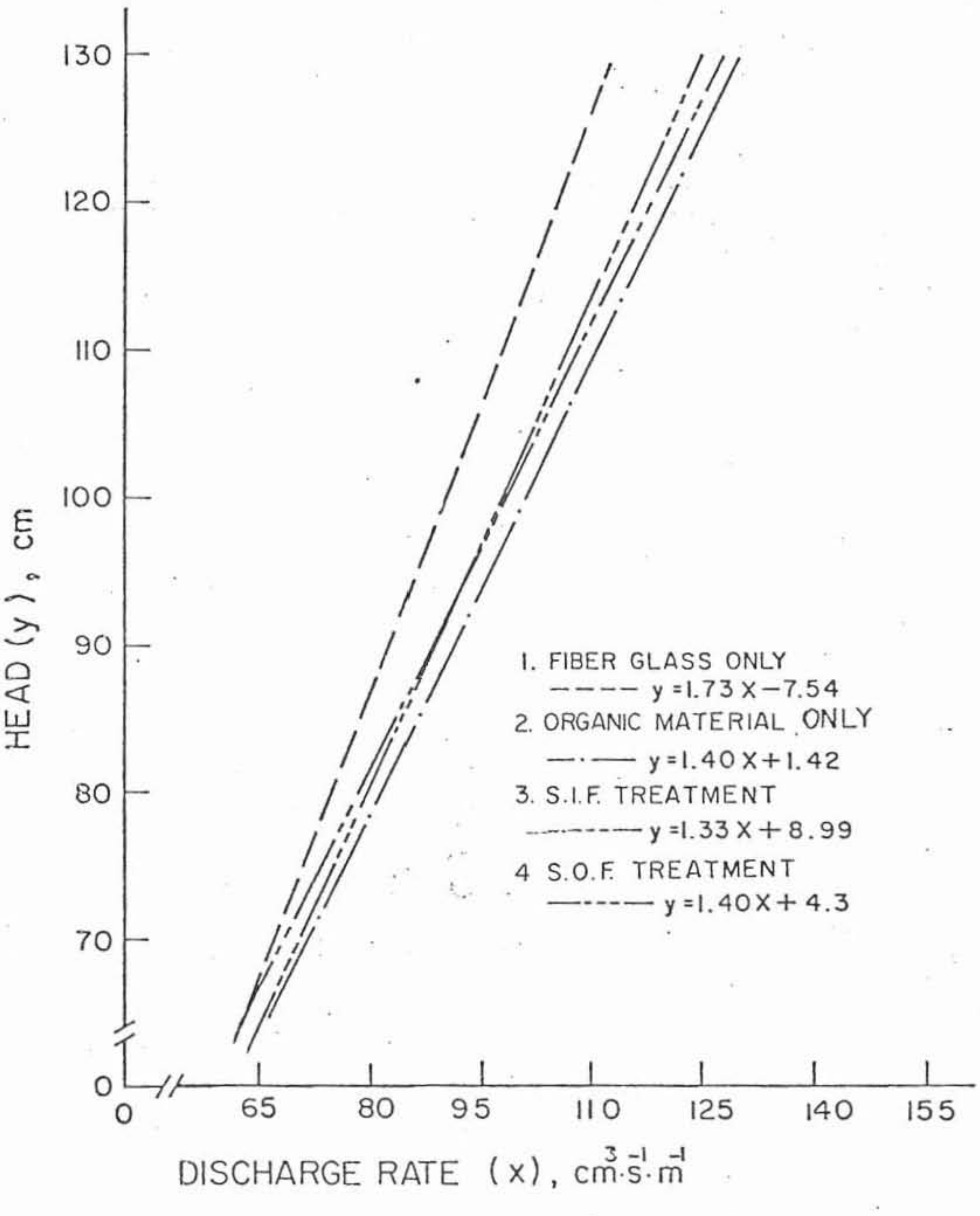

Figure. 5.4 Average head-discharge relationship for a 10.1-cm inner-diameter slotted drain tube for different placement conditions of organic material and fiberglass.

present study flow rates from drains with fiberglass and organic material envelopes were 101 and 117 $cm^3 s^{-1} m^{-1}$ (at 105 cm head, Figure 5.4) respectively. Obviously there exists a difference in observed flow rates for fiberglass envelopes at a given pressure head between the present study and that of Sommerfeldt (1975). This difference can be attributed to the time-dependent flow rates of the drainage systems. Sommerfeldt (1975) found that flow from a drain with a fiberglass envelope initially increases with time, remains relatively constant for some time and then decreases. The value of the flow rates (101 $cm^3 s^{-1} m^{-1}$) was obtained in the beginning of the trend of increasing flow with time. Overholt (1959) reported results indicating an increase of flow with time for the first period agreeing with Sommerfeldt (1975). A study by Lembke (1967) also agrees with the findings of Sommerfeldt (1975).

A test was also performed on a drain with no envelope and the flow rate was the lowest of all. The head-discharge relationship could not be developed because of extremely heavy sedimentation.

The above procedures were repeated for a corrugated drain tube with blister-like holes. The relationship between the head and the flow rates is shown in Figures 5.5 to 5.8. The trends in head-discharge rate relationships for this tube for each envelope type and thickness were similar to the results for the ring-corrugated drain tube

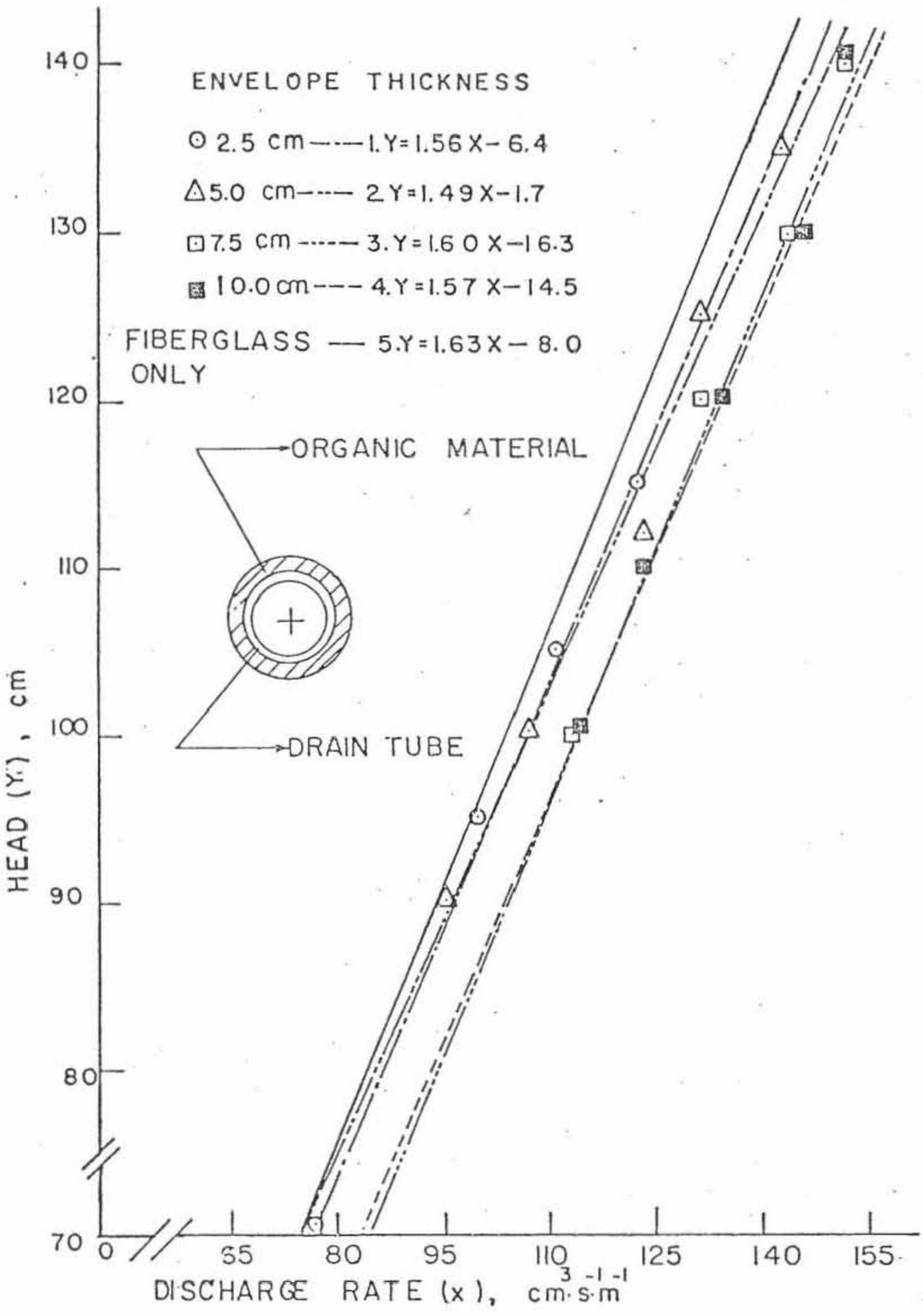

Figure 5.5 Head-discharge relationship for a 10.1-cm inner-diameter blister-hole drain tube with a circumferential envelope of organic material of different thickness.

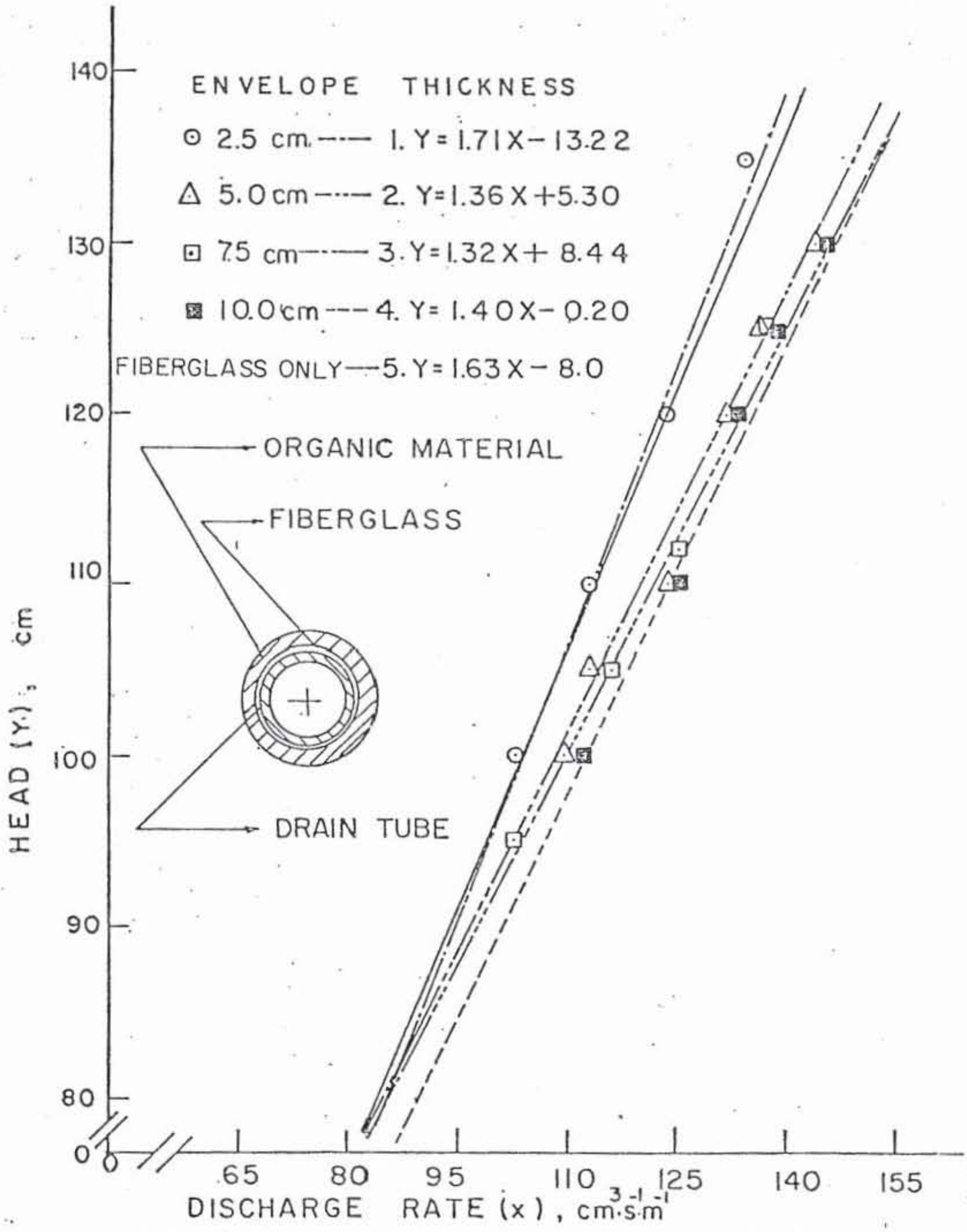

Figure 5.6 Head-discharge relationship for a 10.1-cm inner-diameter blister-hole drain tube with a circumferential envelope of fiberglass in the inner position and organic material of different thickness in the outer position (S.I.F. treatment).

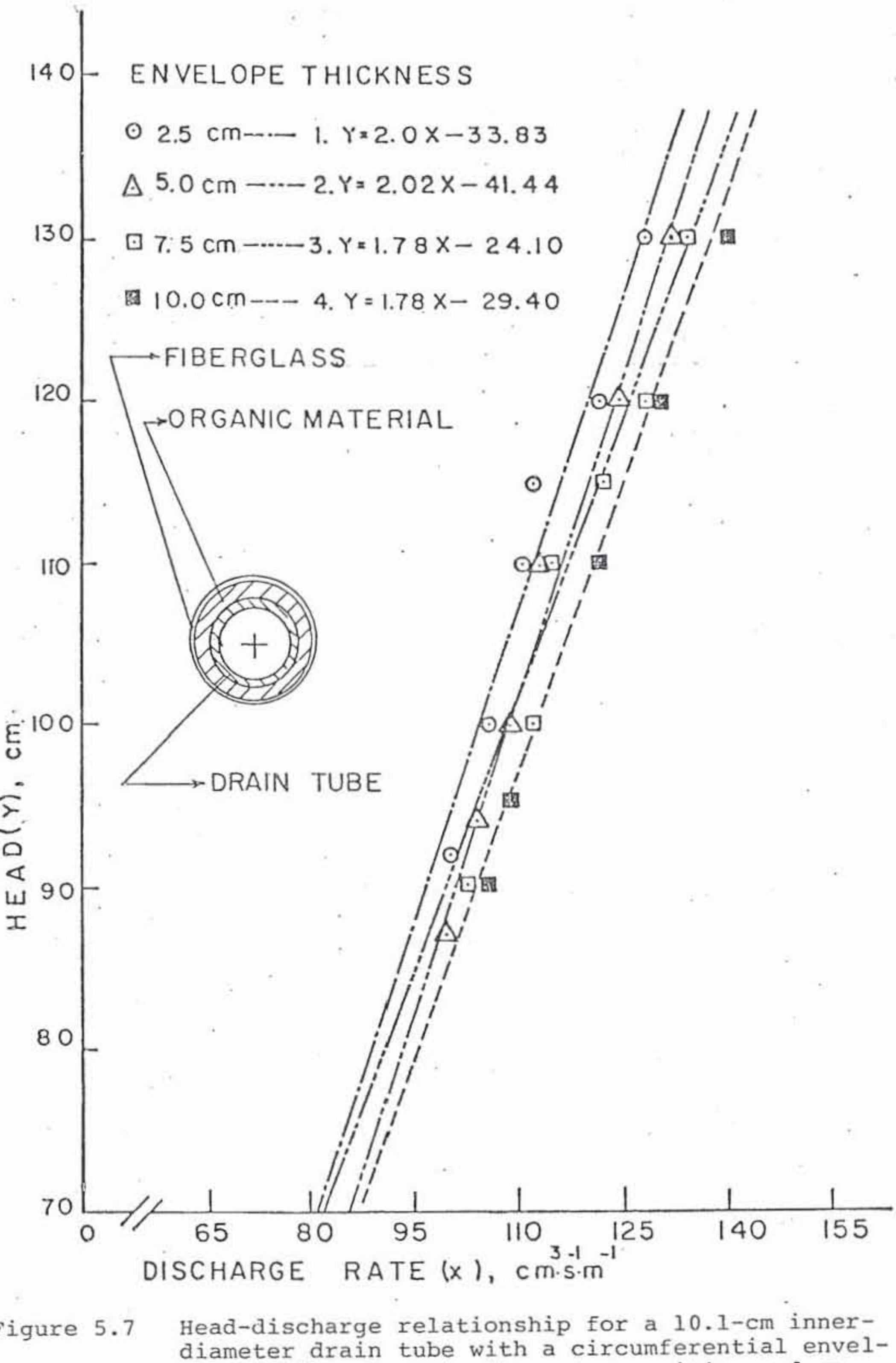

Figure 5.7 Head-discharge relationship for a 10.1-cm inner-diameter drain tube with a circumferential envelope of fiberglass in the outer position and organic material of different thickness in the inner position (S.O.F. treatment).

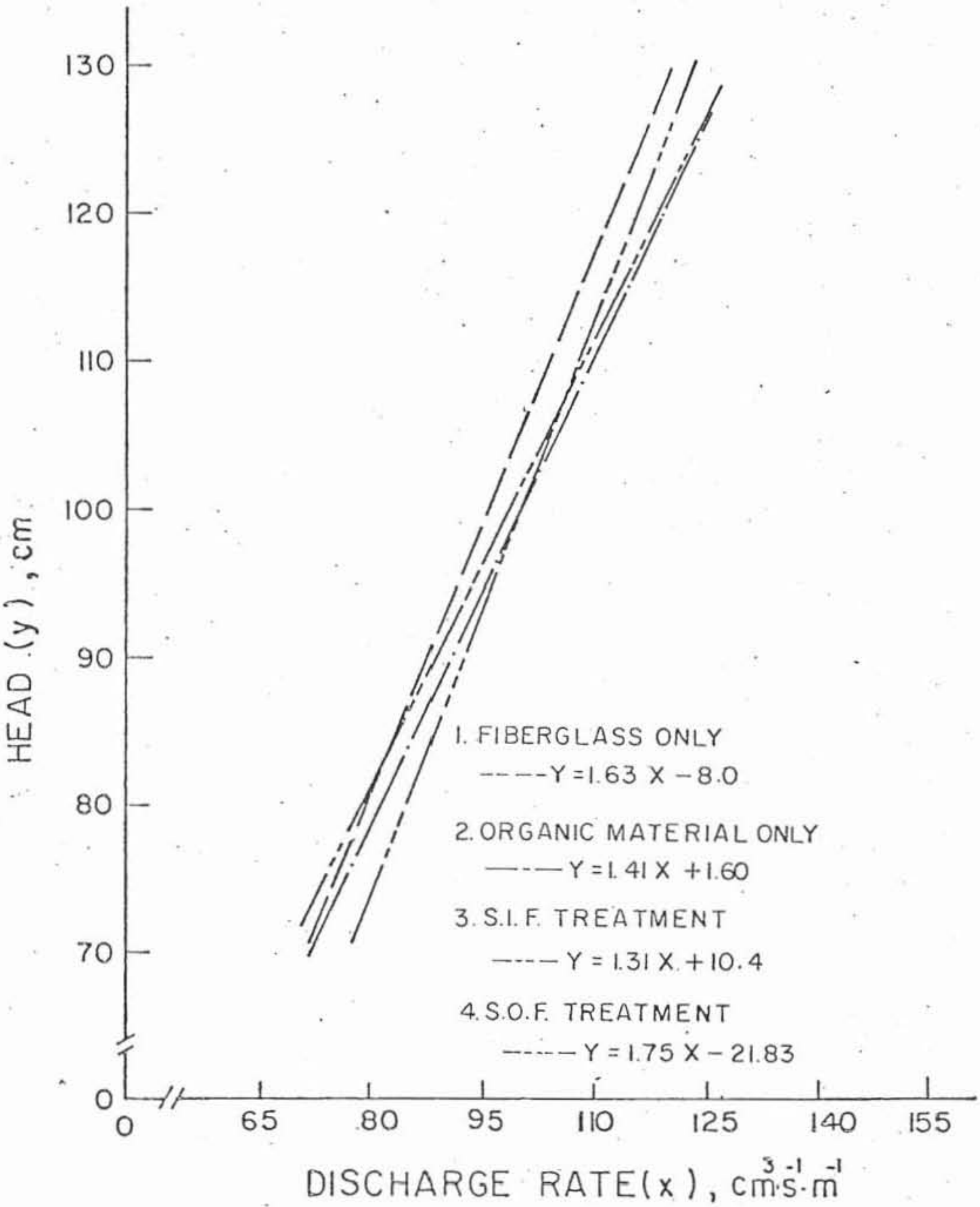

Figure 5.8 Average head discharge relationship for a 10.1-cm inner-diameter blister-hole drain tube for different placement conditions of organic material and fiberglass.

with slots (large rectangular perforations). Moreover, the effect of different thicknesses of envelopes on flow from the drain was more pronounced throughout the head range of 70.0-cm to 140-cm.

Comparing Figures 5.1 to 5.4 and 5.5 to 5.8, it is evident that the margin between the maximum and minimum flow rates at a constant head is relatively reduced in the case of spiral corrugated drain tubes with blister holes, as compared with the ring corrugated drain tubes with slots. In either case the maximum flow rate at a head of 120 cm of water remains at 132 $cm^3 s^{-1} m^{-1}$. The minimum values of flow rates however, are 116 $cm^3 s^{-1} m^{-1}$ and 123 $cm^3 s^{-1} m^{-1}$ for the two types of drain. Improved hydraulic conditions around the drain tube which are achieved by envelopes of organic and synthetic material suppressed the effect of perforations on flow and made the maximum flow rate equal for the two drains. In the absence of an organic material envelope, size of perforations affected the flow.

5.2. Sediment Movement:

5.2.1. Quantitative Evaluation of Sedimentation: A comparison of the average quantity of sediment moved into the drains for each treatment is shown in Figure 5.9. Increase of envelope thickness under each of the three placement conditions of fiberglass and organic material reduced the amount of sediment moved into the drain. There

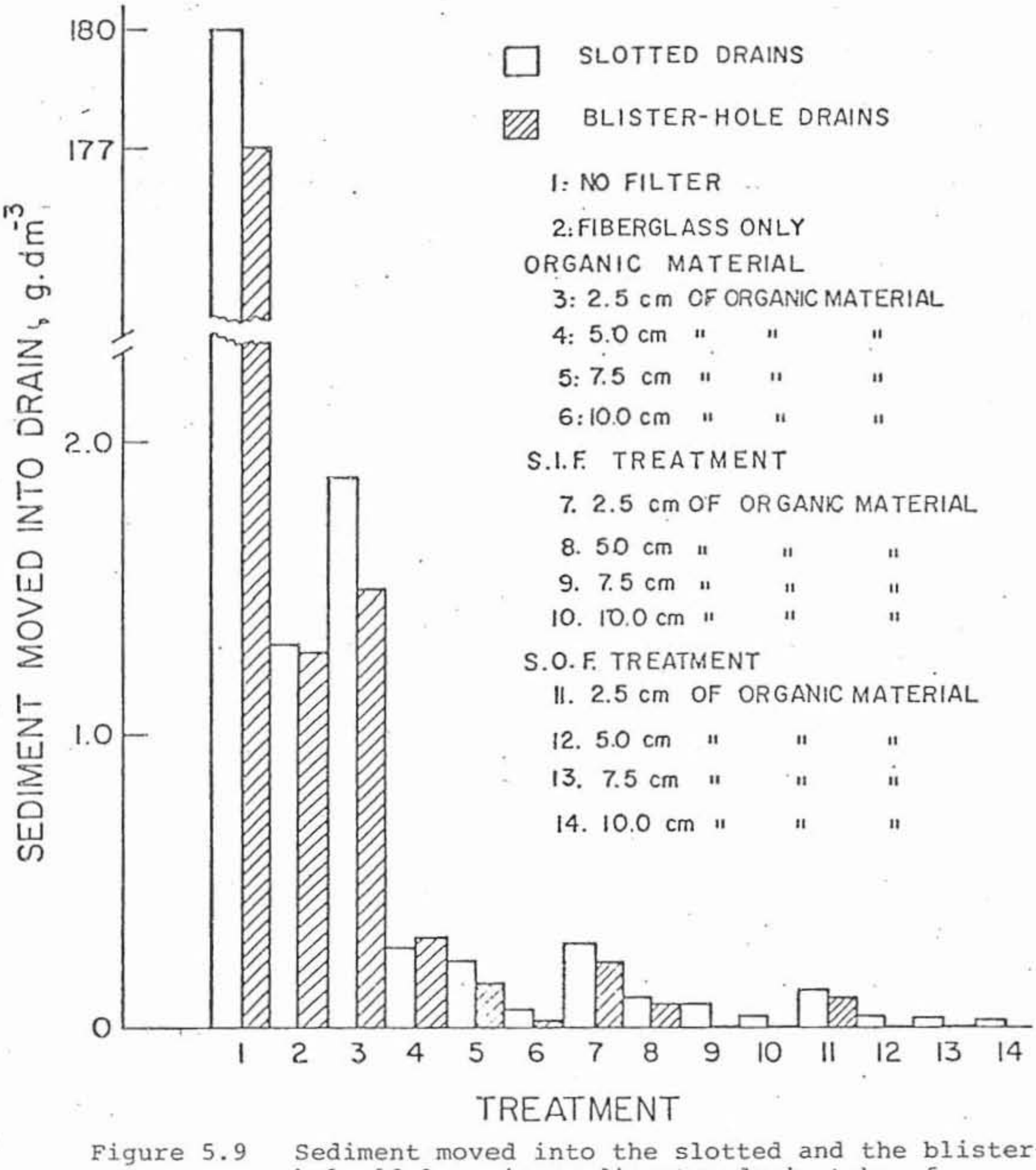

Figure 5.9 Sediment moved into the slotted and the blister-hole 10.1-cm inner-diameter drain tubes for various treatments.

was a sharp decrease in sediment moved into the drain from 1.90 g dm^{-3} to 0.28 g dm^{-3} as the envelope of organic material was increased from 2.5 cm to 5.0 cm. Further increase in envelope thickness to 7.5 cm and 10.0 cm diminished the sediment entrance into the drain but at a slower rate. The other two placement conditions employing S.I.F. and S.O.F. combinations exhibited similar results. Sediment entry for the 2.5-cm thick envelope of S.I.F. and S.O.F. were 0.28 g dm^{-3} and 0.13 g dm^{-3}, respectively, which is significantly less than the 1.90 g dm^{-3} of sediment moved into the drain when organic material alone of 2.5 cm thickness was used. Evidently, protection against sediment entrance is much better for the combination of organic material and fiberglass compared to fiberglass alone. A 5.0-cm envelope of organic material and a 2.5-cm envelope of organic material in combination with fiberglass gave comparable protection against sediment movement into the drain. A 7.5-cm and 10.0-cm thick envelope reduced the sediment entrance into the drain to zero. A test was also performed for a drain having no envelope. The sedimentation rate was 180 g dm^{-3}. Rapp and Riaz (1975) and Overholt (1959) reported similar results. All 10.0-cm envelopes under each treatment proved most effective in inhibiting the silting of the drains. The Soil Conservation Service of United States Department of Agriculture (1973) recommended thicknesses of organic filters from 15 cm to 30 cm. These recommended thicknesses are high, probably because of the wide range of organic materials considered--from organic soils to sawdust and wood chips. However, a filter of organic material (straw) of 10.0 cm proved effective in preventing the silting of drains and yet allowed water to move into the drain freely. This result is in agreement with the results of Sisson and Jones (1962) who reported that organic material provided better protection than gravel filters. Studies at Riverside, California[1] and by Davis, et al. (1971) indicated that fine particles smaller than 250 micron manage to move into the drain through a gravel envelope. However, these fine particles do not hinder the movement of water.

5.2.2. Qualitative Evaluation of Sediment: Mechanical analysis of the sediment which moved into the drain for each treatment was performed (Figure 4.1 and Figures 5.10 to 5.15). The gradation curve (Figure 4.1) of the sediment which moved into the drain through the fiberglass wrapping was identical to the gradation curve of the base material. The poor filtering property of longitudinally reinforced fibers observed in this study is in close agreement with the findings of Nelson (1960), Shull (1967) and Hore and Tiwari (1962). The gradation curves of washed-out sediment (Figures 5.10 to 5.12) indicate that organic material whether used alone or in combination in the S.I.F. arrangement was effective in restricting the entrance of sediment particles of base material into the drain.

[1]Minutes, Committee Meeting, 7 November, 1974, U.S.D.A. Drainage Design Research WRCC-19, Salt Lake City, Utah.

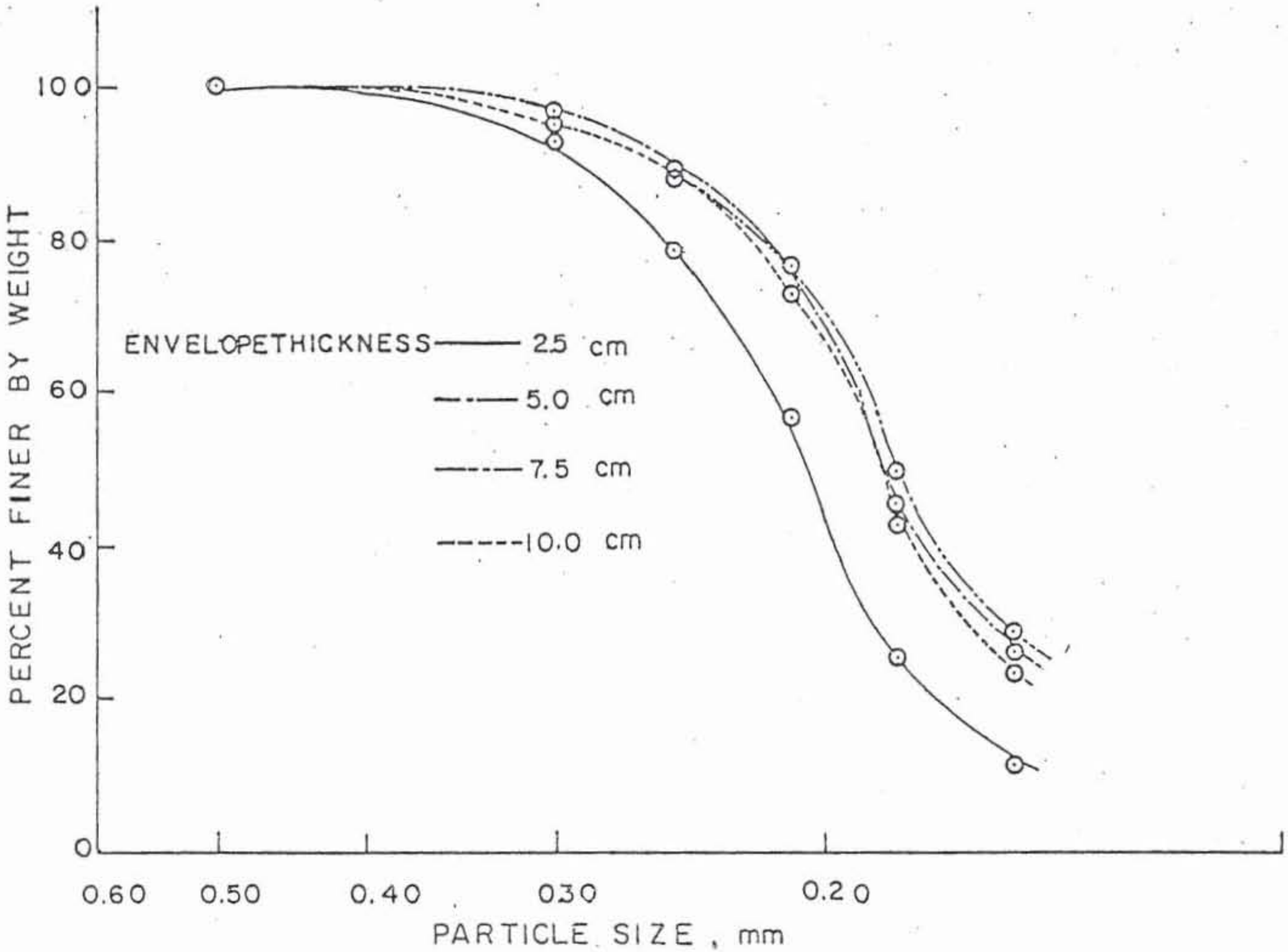

Figure 5.10 Gradation curves of sediment moved into the slotted drain with a circumferential envelope of organic material of different thickness.

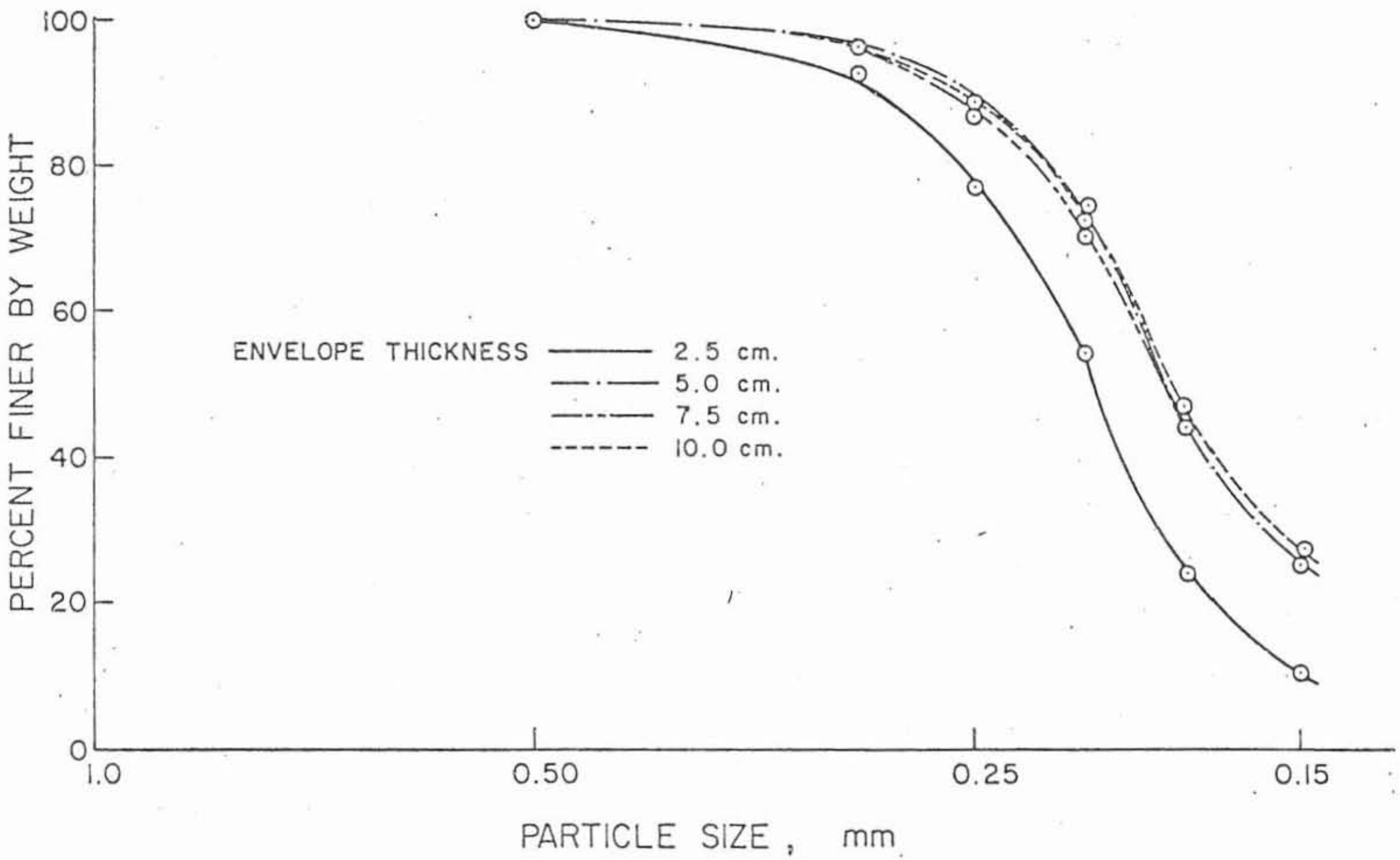

Figure 5.11. Gradation curves of sediment moved into the slotted drain tube with a circumferential envelope of fiberglass in the inner position and organic material of different thickness in the outer position (S.I.F. treatment).

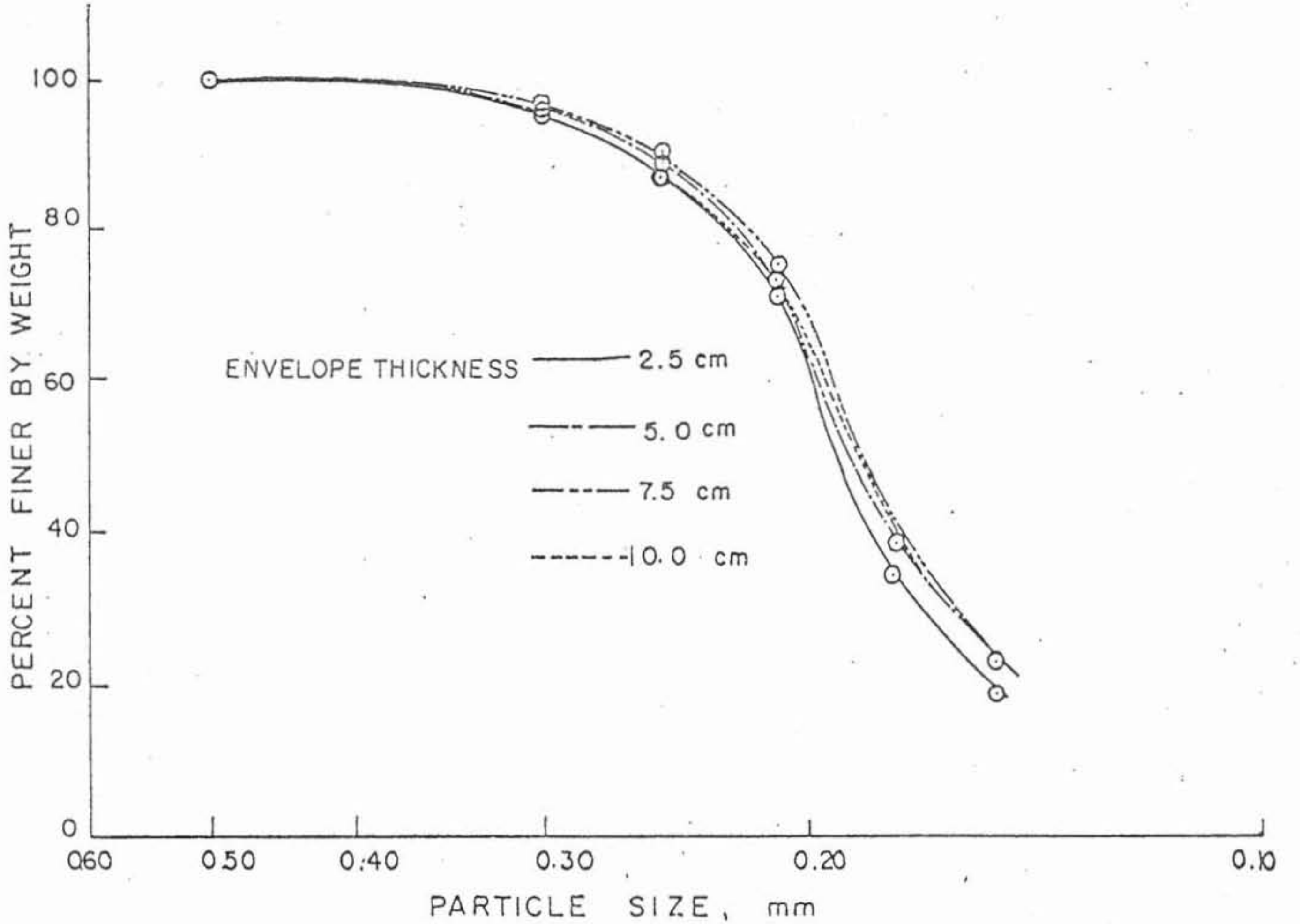

Figure 5.12 Gradation curves of sediment moved into the slotted drain tube with a circumferential envelope of fiberglass in the outer position and organic material of different thickness in the inner position (S.O.F. treatment).

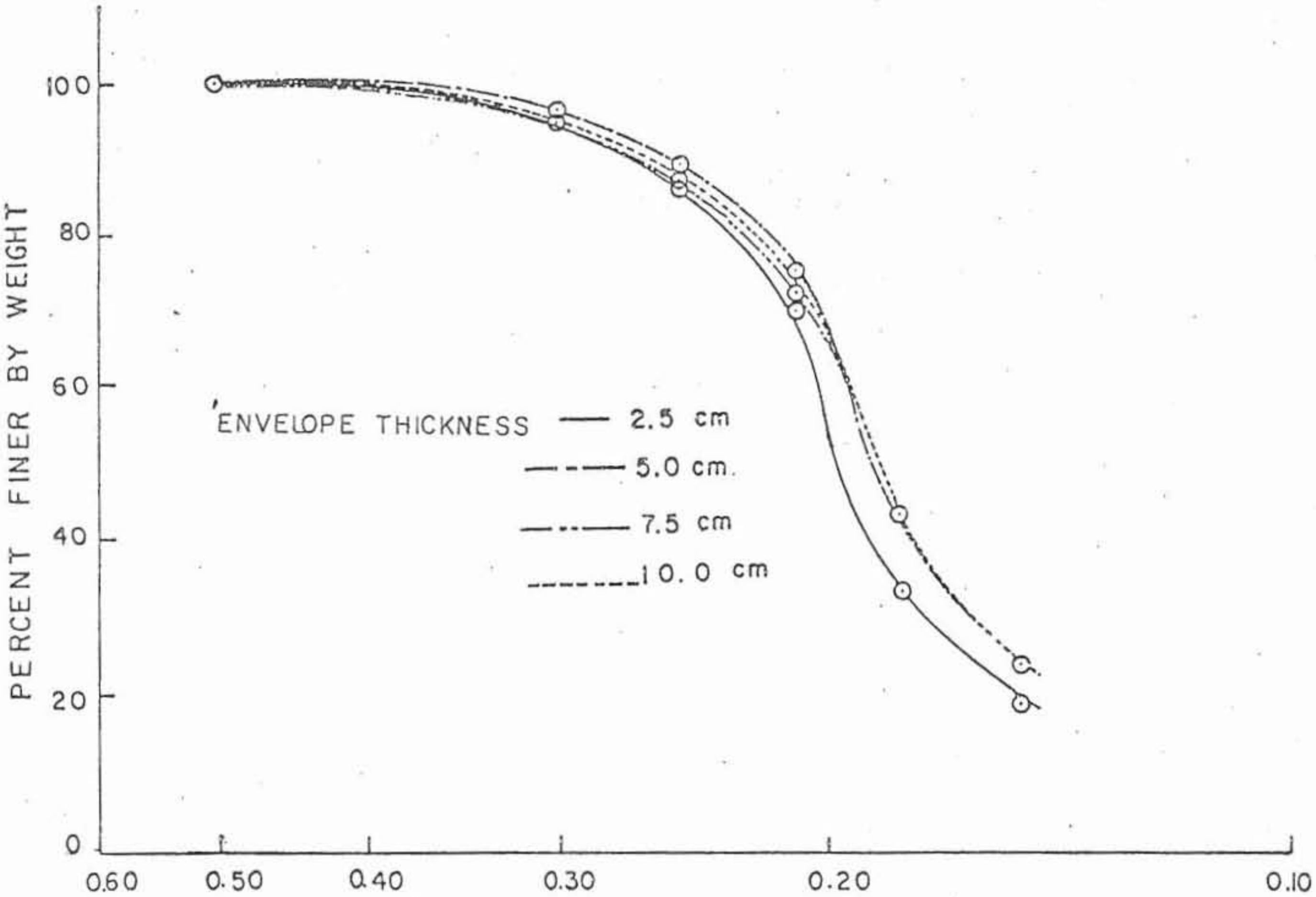

Figure 5.13 Gradation curves of sediment moved into the blister-hole drain tube with a circumferential envelope of organic material of different thickness.

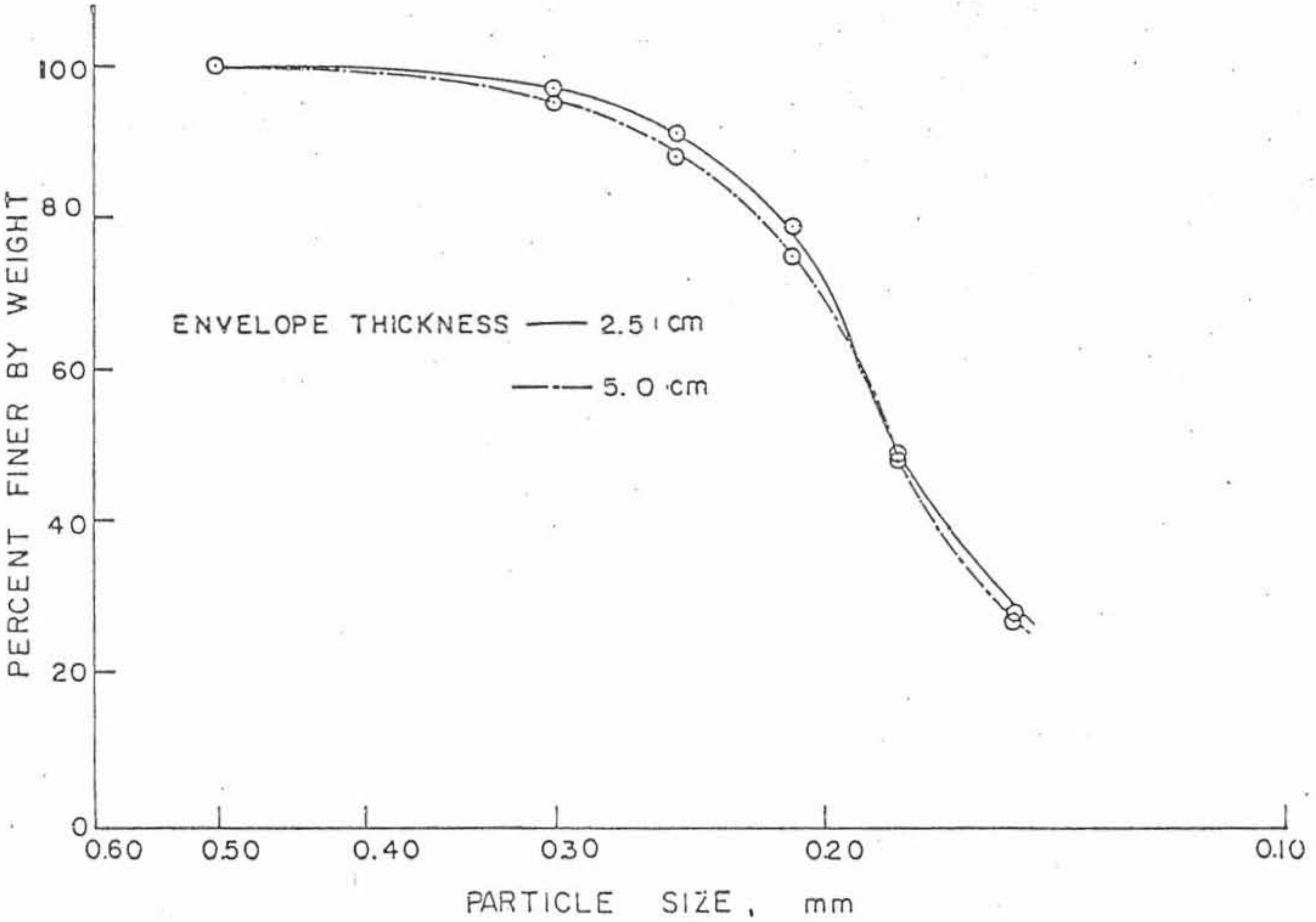

Figure 5.14 Gradation curves of sediment moved into the blister-hole drain tube with a circumferential envelope of fiberglass in the inner position and organic material of different thickness in the outer position (S.I.F. treatment).

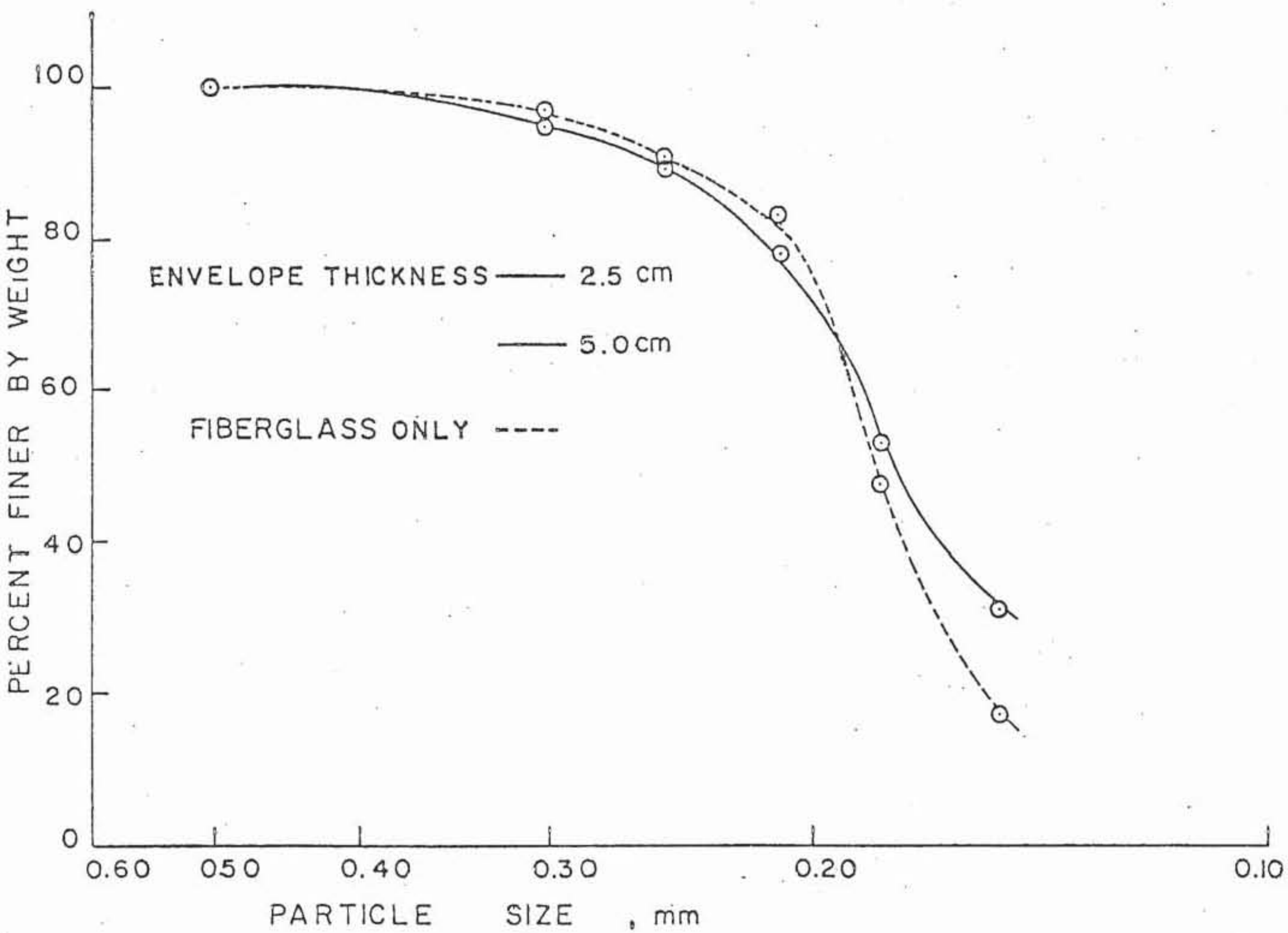

Figure 5.15 Gradation curves of sediment moved into the blister-hole drain tube with a circumferential envelope of fiberglass in the outer position and organic material of different thickness in the inner position (S.O.F. treatment).

However, the percentage of particles finer than 0.15 mm increased by 15 percent as the organic material envelope thickness was increased from 2.5 cm to 5.0 cm. Little changes in sediment was noted for further increase in thickness of the organic material envelope to 7.5 cm and 10.0 cm. The effect of organic material envelope thickness on the percentage of fine particles was less, however, for the S.O.F. envelope (Figure 5.12), than for the S.I.F. envelope. Probably for the 2.5-cm S.O.F. envelope (Figure 5.12), some sediment moved into the drain either due to displacement of fiberglass from its position or due to tearing of fiberglass at some places by organic material, thereby allowing the base material to move into the drain.

Envelopes of 7.5-cm and 10.0-cm thickness for each treatment proved effective against sedimentation but some particles still managed to move into the drain. This is contrary to the findings of Dunn (1959) because, according to him, finer particles are supposed to be more stable. Had they been more stable, the percentage of particles finer than 0.15 mm would not have increased. This difference in behaviour may be explained by the cohesive nature of the sediment in his study.

Particle-size distribution curves of the sediment which was washed through the blister hole drain tube were similar to those for the slotted drain tube (Figures 5.13 to 5.15). However, for the drain tube with holes, a 7.5-cm and a 10.0-cm envelope of organic material in combination with fiberglass completely prevented the sediment from entering the drain. No curves for thos combinations are shown, therefore, in the graphs.

5.3. Flow Pattern Near the Drain: Two flow nets were constructed (detail in Appendix A) for ponded water 1.0 cm above the surface of the sand (Figures 5.16 and 5.17). The depth of sand was 88.0 cm and the envelopes were 2.5 cm and 7.5 cm thick respectively. In drawing the flow net the effect of the different hydraulic conductivity of organic material was not taken into consideration. Drain tube with holes was used. An attempt was made to find the pressure head at different locations inside the envelope and it was noticed that the manometers were dry in the close vicinity of the periphery of drain. This reveals that, very close to drain tube in the envelope, the pressure is either atmospheric or negative. This is in agreement with the findings of Sisson and Jones (1962). For the 2.5-cm envelope, about 57 percent of the total flow took place from the bottom half of the drain whereas 68 percent of the flow took place from the bottom half for a 7.5-cm envelope. Similar results were reported by Lembke and Buck (1970), Bornestein, et al. (1967), Bornestein and Benoit (1967), Hwang, et al. (1974) and Allen and Myers (1969).

Since the bottom half of the drain in each of the two flow nets contributed more than half of the flow into the drain, there exists a possibility of higher resistance to flow in the top half of the drain as compared to the

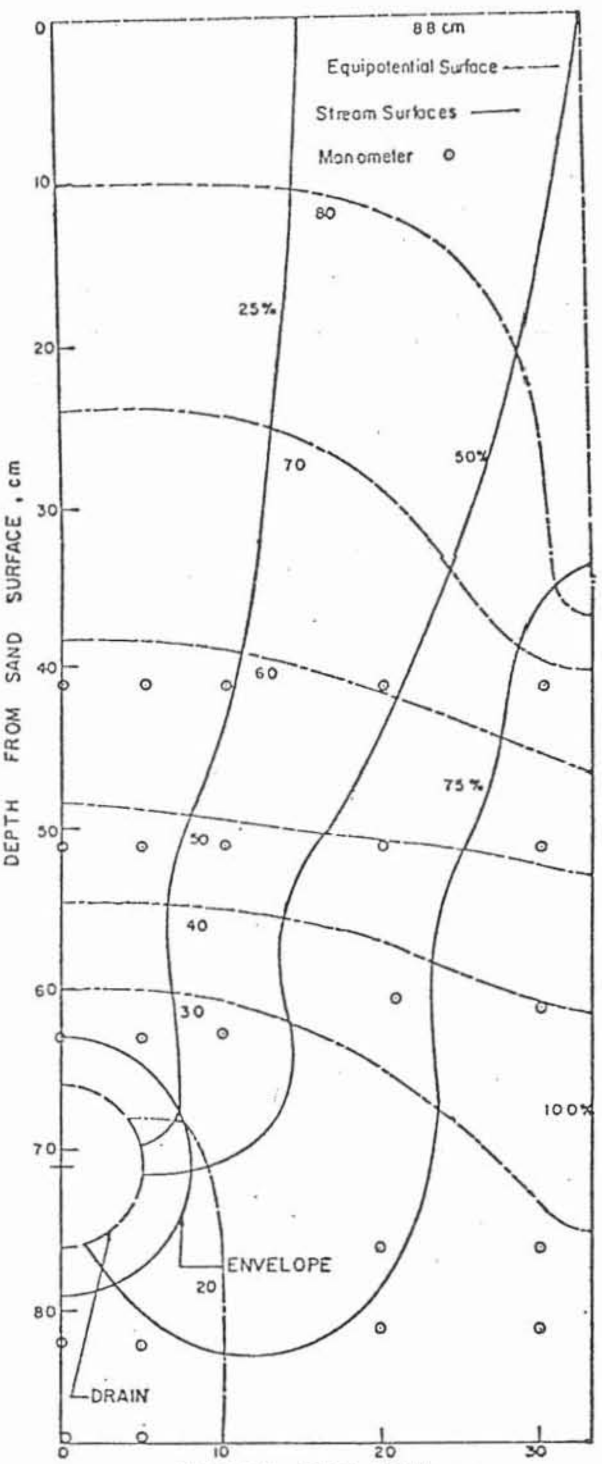

Figure 5.16 Flow net for a 2.5-cm circumferential envelope around the blister-hole drain.

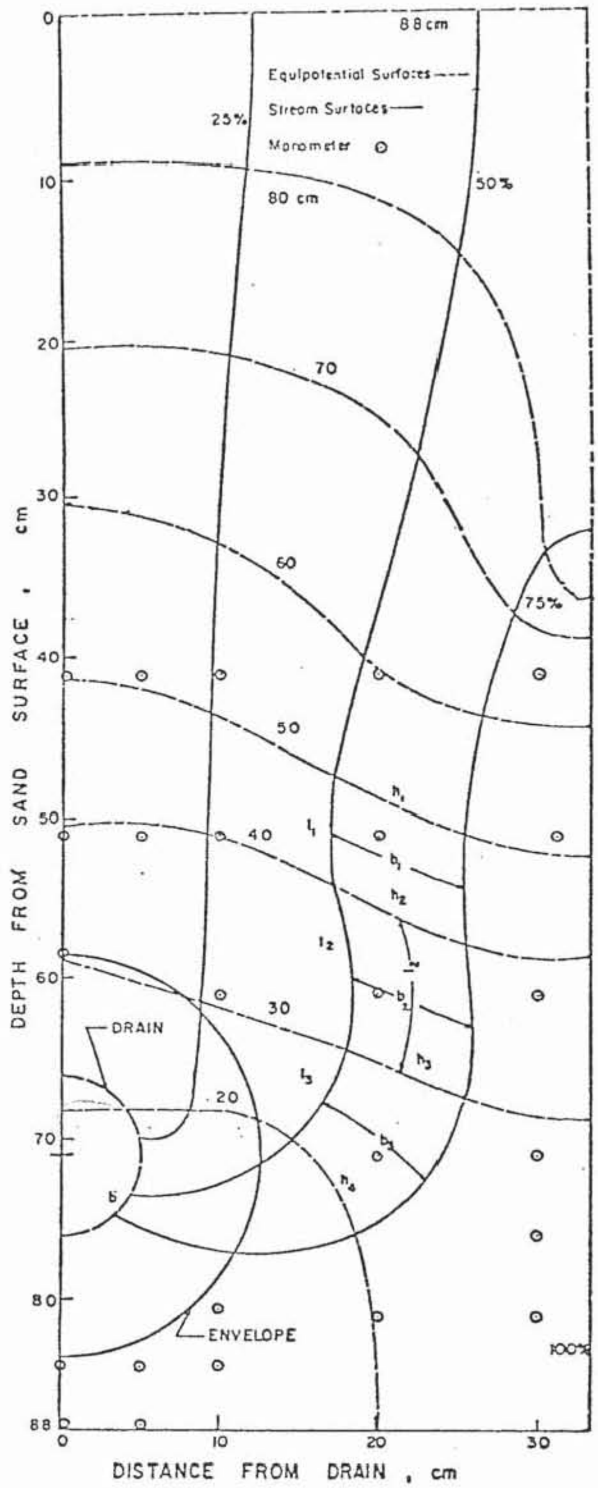

Figure 5.17 Flow net for a 7.5-cm circumferential envelope around the blister-hole drain.

bottom half. This can be attributed either to compression of organic material or penetration of sediment into the envelope, thereby causing more resistance to flow and, therefore, less contribution to flow from the top half of the drain. The penetration of sand particles into the envelope might have taken place either because of high flow velocity in response to a high value of hydraulic gradient or because of the entrance of sand into the envelope at the time of loading of the tank. During the test fine particles of sand washed into the envelope with water and coarser particles and organic material bridged the pores and did not allow further entry of fine sand particles into the drain. A similar bridging phenomenon was observed in the study at Riverside, California.[1]

Flow of water from the bottom half of the drain tube is against the force of gravity. An approximate evaluation of the maximum velocity in the bottom half of a 7.5-cm envelope of organic material was done. For a discharge rate of 113.0 $cm^3 s^{-1} m^{-1}$, the velocity (detail in Appendix A) was found to be 0.047 $cm\ s^{-1}$ which is much less than the terminal velocity of 2.05 $cm\ s^{-1}$ of a 150-micron

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[1]Annual Report, 4 October, 1972, U.S.D.A., Western Regional Research Project W-51, Dynamics of Flow into Drainage Facilities.

size particle. Ten percent of this terminal velocity as recommended by Willardson, et al. (1968) is still 4.3 times higher than the computed velocity. Gulati, et al. (1970), however, brought down the limit of maximum safe velocity to one percent of the Stokes velocity. Considering this figure of one percent of the Stokes velocity as the upper limit of velocity of entry of water, it is apparent that the velocity of 0.047 cm s^{-1} is nearly two times higher than the maximum allowable velocity of water near the drain; and therefore particles as fine as 150 microns would continue to move into the drain. Recent studies by Willardson (1975) indicated that a non-Darcy flow occurs very near the drain openings and, therefore, turbulent flow can develop in the flow regime near the drain tube. Also the studies conducted at Riverside, California[1] on soil movement into the drain with a slot width of 0.081 cm, revealed that the maximum velocity of water at the outer edge of the slot is 34.5 cm s^{-1}. This magnitude of velocity of water indicates the possibility of the existence of non-Darcy flow near the drain at the perforations. The magnitude of the velocity of water at the perforations will be higher than 0.047 cm s^{-1}.

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[1]Annual Report, 4 October, 1972, U.S.D.A., Western Regional Research Project W-51, Dynamics of Flow into Drainage Facilities.

The model was not elaborate enough to explain precisely the exact location of sediment entry into the drain and to evaluate the exact velocity of water at the perforations.

5.4. Effect of Perforations on Flow Rate: A study was carried out of the effect on flow rate of rectangular and circular perforations in plastic drain tubing. For the rectangular shape of perforations the study included a comparison of the spirally corrugated blister-hole drain tubing having eight rows of short slots and the ring-corrugated slotted drain tubing having three rows of longer slots. The study also included, for the rectangular shape, an investigation of the effect of relative slot length using spirally-corrugated blister-hole drain tubing. For the circular shape, the study utilized a spirally corrugated drain tubing in which the blister holes had not been previously corrugated but in which circular perforations were drilled at the locations of the eight rows of blisters. The effect on flow rate of different diameter of circular perforations was observed.

5.4.1. Rectangular Perforations in Slotted and Blister-hole Drain Tube: The size of the rectangular perforations on spirally corrugated drain tubing having eight rows of short slots and the ring corrugated drain tube having three rows of longer slots were 0.85 cm x 0.25 cm and 3.6 cm x 0.25 cm respectively. A comparison of the head-discharge relationship (Figure 5.18) for these two sizes

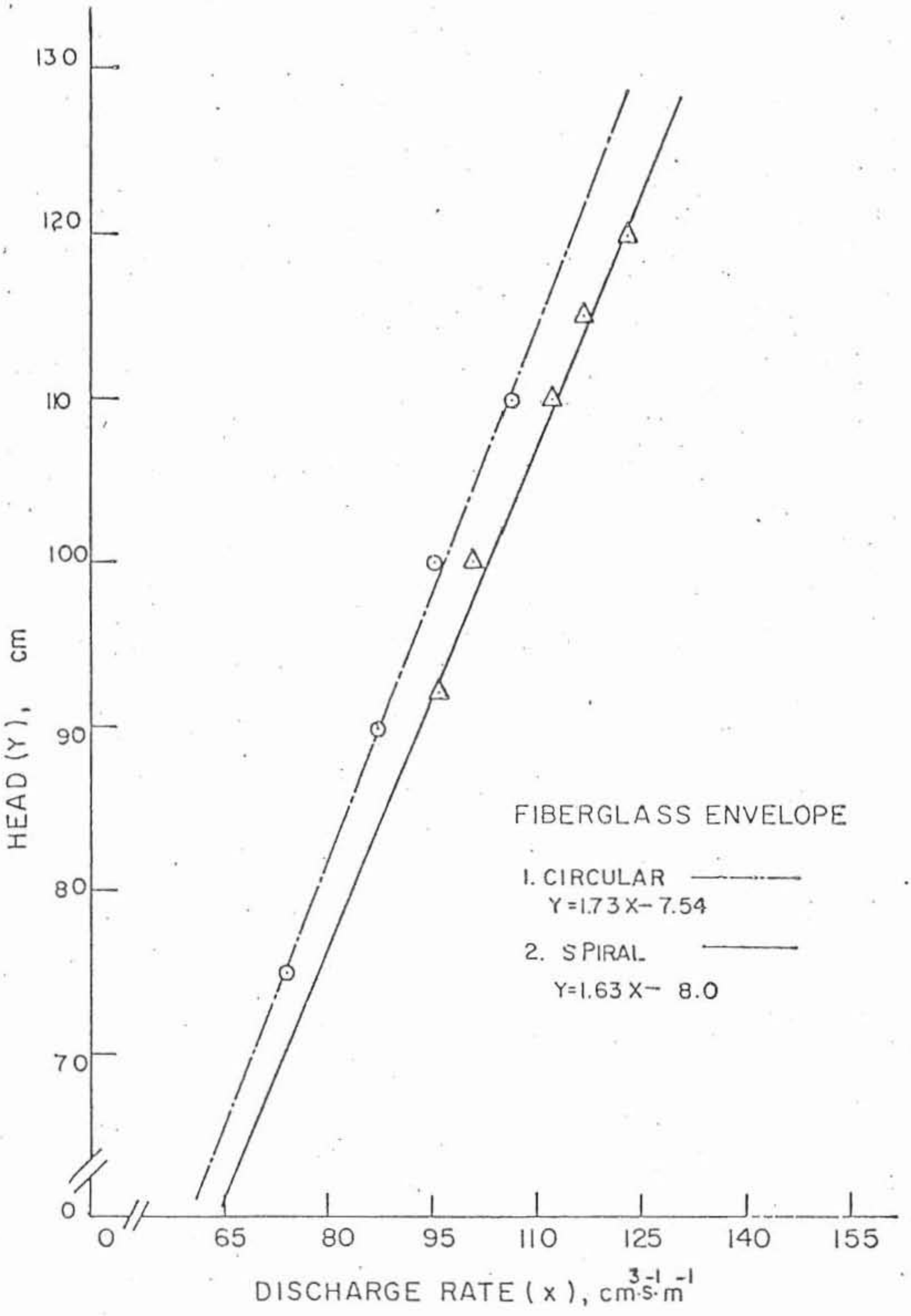

Figure 5.18 Head-discharge relationship for slotted and blister-hole perforations on 10.1-cm inner-diameter ring and spirally corrugated drain tube.

of rectangular perforations resulted in a 6.4 percent higher discharge rate for the spirally corrugated blister-hole drain tubing with short slots than for the ring-corrugated drain tubing with longer slots, at a head of 100.0 cm of water. This is because the drain tube with short slots had a higher relative slot length (2.90) than the drain tube with large slots (2.70). This reveals that, at least in the range studied, relative slot length affects the flow from the conduit. This result closely agrees with the findings of Cavellaars (1967), Also for small number of rows and large slot length, the concentration of stream lines in the proximity of drains increases, thereby resulting in a higher resistance to flow.

5.4.2. Rectangular Perforations with Different Relative Slot Lengths: A study on the effect of different relative slot length in the flow rate was performed for a spirally corrugated blister-hole drain tube with eight rows of perforations. A maximum relative slot length of 5.95 was studied. Flow rate and relative slot length relationships for an 84-cm depth of soil column at 84.0 cm and 110.0 cm head of water (Figure 5.19) was observed to be exponential. There was a sharp increase in flow rate per unit length of drain as the relative slot length increased from 0 to 1.42. An increase of relative slot length from 1.42 to 3.14 increased the flow only slightly. Further increase of relative slot length affected the flow

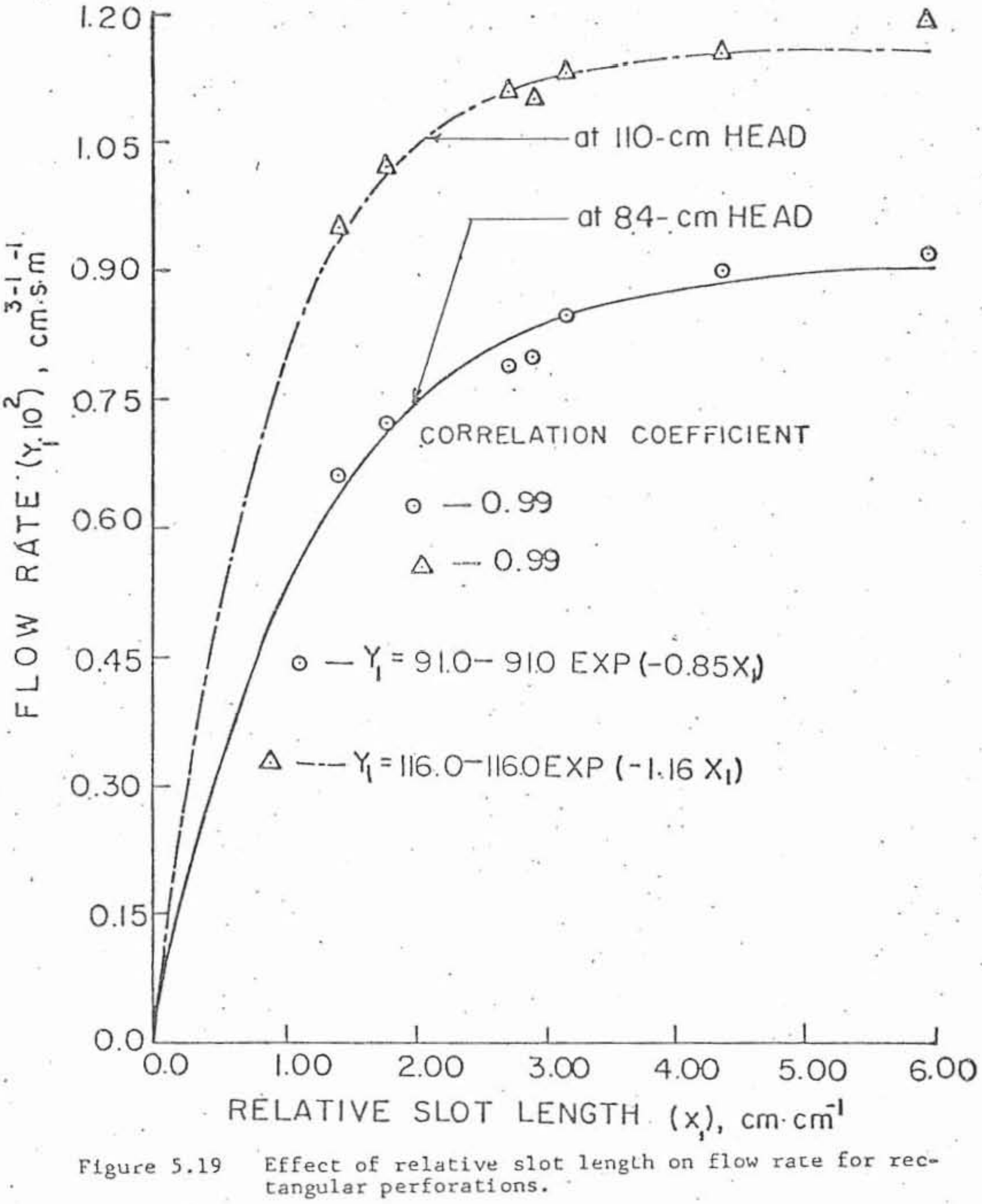

Figure 5.19 Effect of relative slot length on flow rate for rectangular perforations.

rate very little. A head of 26 cm of water over the soil surface increased the flow by 25 percent for relative slot length equal or greater than 3.14 as compared to the condition of no head of water on the soil surface. This curve too resembles in nature the previous curve. Both curves attained their maximum value for a relative slot length of 3.14 or higher. From this point onwards no noticeable increase in flow occurred because flow under this situation is not governed by the size of perforations, but instead it is governed by the physical properties of sand (at a constant head of water). Therefore a relative slot length of 3.14 with a corresponding slot size of 1.0 cm x 0.25 cm and eight rows of perforations is adequate for maximum flow rate without endangering the strength of the drain tube needlessly. If a smaller number of rows (four) is to be selected, a slot size of 3.14 cm x 0.25 cm should give equally good results.

5.4.3. Circular Perforations with Different Diameter: A blister-hole drain tube having no previous corrugations was employed, and the effect of circular perforations on flow rate studied. An exponential relationship of the form described in Figure 5.19 for rectangular perforations, also existed for circular perforations. The curves for circular perforations up to 0.97 cm in diameter are shown in Figure 5.20. For diameters below 0.30 cm the flow rate increased sharply. Flow rate increased at a slower rate

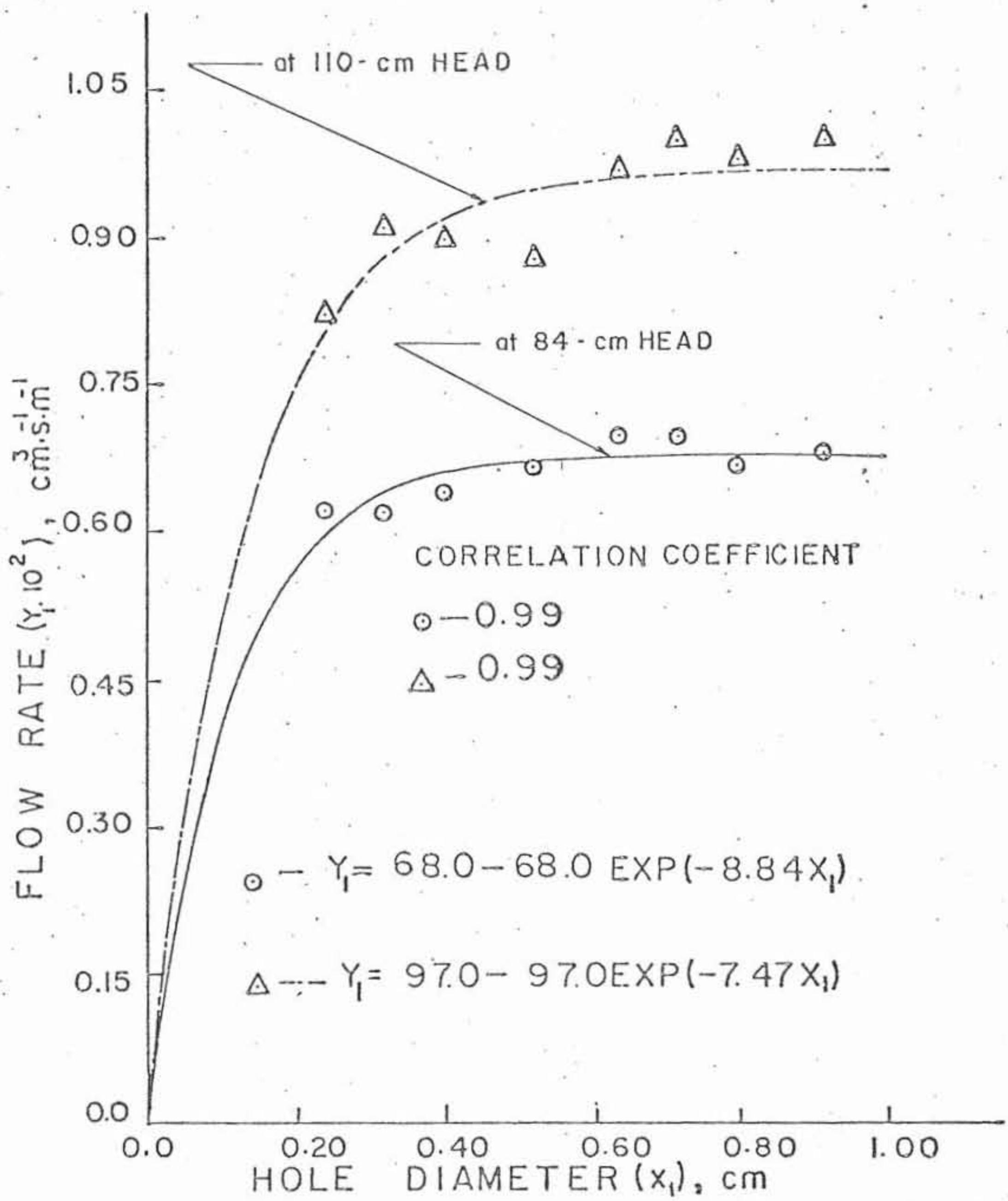

Figure 5.20 Effect of circular perforations on flow rate.

for a diameter range of 0.30 cm to 0.50 cm. Further increase in diameter did not improve the flow rate. Schwab and Kirkham (1951) and Kirkham and Schwab (1951) also reported similar results.

For circular perforations, the flow rate increased by 33.0 percent for a head of 26 cm of water over the surface of the sand as compared to the condition of no head of water over the sand surface. The maximum discharge for the circular holes was 68.0 $cm^3 s^{-1} m^{-1}$ of drain length at a head of 84 cm of water. The corresponding diameter is 0.50 cm and is suitable if eight rows of circular perforations are used for a 10.1-cm inner-diameter drain tube.

5.5. Effect of Perforations on Sediment Movement: A study on the effect of two types of perforations (rectangular and circular) for the same number of rows and on sedimentation was made for a non-standard type of drain.

5.5.1. Effect of Rectangular Perforations on Silting: Double wrapping of fiberglass was used to study the effect of perforations on silting of the drains. No silting of the drains took place for relative slot lengths of less than 4.37 (1.4 cm x 0.25 cm and eight rows). For a relative slot length of 5.95 (slot size 1.90 cm x 0.25 cm and eight rows), 85 g of sediment was found in the drain. The corresponding volume of water that flowed through the drain was 318.51 dm^3. It will be safe, however, to use a relative slot length of 3.14 (slot size 1.0 cm x 0.25 cm) which prevents silt from entering into the drain and at the same time allows water to move into the drain freely. Tests at Riverside, California[1] with a slot width of 0.081 cm allowed particles finer than 0.081 cm to enter the drain in the beginning but resulted in the formation of a filter over the slot which was free from fine particles. Therefore, movement of finer particles was restricted. Also, studies at Brawley, California[1] evaluating the amount of dry envelope material which would pass through a simulated slot size of 3.13 cm x 0.32 cm revealed that movement of fine dry envelope particles into the drain stopped after some time on account of the bridging action by coarser particles. The probable reason for the variation in the results of the present study and in the studies at Riverside, California[1] and at Brawley, California[1] is that the particles in their study could have possessed some cohesiveness, which would have prevented the movement of particles from entering into the drain. The second reason which applies only to the results at Brawley, California[1] might be the absence in the Brawley[1] study of seepage forces which did not dislodge the sand particles.

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[1]Annual Report, 4 October, 1972, U.S.D.A., Western Regional Research Project W-51, Dynamics of Flow into Drainage Facilities.

5.5.2. Effect of Circular Perforations on Silting: Hole diameters of 0.238 cm to 01975 cm were used to study the effect of perforation diameter on silt movement with a double wrapping of fiberglass over a non-standard drain tube. No siltation of the drain took place for the above-mentioned range of hole diameters. Further increase in diameter could not be made because of the fixed width of corrugated valleys. Schwab, et. al. (1957) reported that the maximum diameter of perforations for preventing the inflow of soil should be about 0.62 cm. In the present study, even a 30-percent larger diameter would have prevented the inflow of soil. Recent studies at Brawley, California[1] revealed that for circular openings (0.156 cm to 0.938 cm), finer envelope material will pass through the perforations but after some time bridging action will take place and entry of finer particles into the drain will be checked. The difference in the results can be attributed to the lack of seepage force in the study at Brawley, California.[1] However, a diameter of 0.975 cm is not the upper limit of maximum perforation size with respect to soil particle movement.

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[1] Annual Report, 4 October, 1972, U.S.D.A., Western Regional Research Project W-51, Dynamics of Flow into Drainage Facilities.

CHAPTER VI

CONCLUSIONS

The conclusions which can be drawn from this study are as follows:

1. In terms of discharge rates, the different placement conditions of organic material and fiberglass envelope materials rated in descending order as follows:
   a. organic material
   b. organic material with fiberglass wrapped either inside or outside the organic material
   c. fiberglass.
2. Flow rate from the drain did not significantly increase with respect to thickness of envelopes made of organic material either alone or in combination with fiberglass.
3. Protection against sediment movement increased with envelope thickness. Envelopes of 10.0 cm thickness for all treatments proved to be the most effective and sediment entry was nearly zero.
4. Ten-cm envelope for organic material allowed maximum flow and restricted the entry of sediment.
5. Two wrappings of fiberglass around the drain restricted the entry of sediment for relative slot length of less than 4.37 (slot size 1.40 cm x 0.25 cm and eight rows).

6. A relative slot length of 3.14 (slot size 1.0 cm x 0.25 cm and eight rows) with a double wrapping of fiberglass around the drain was sufficient for maximum flow without any sedimentation.
7. Circular perforations of 0.5 cm diameter in every third valley with eight rows were suitable with a double wrapping of fiberglass around the drain if circular perforations were to be used.
8. No sedimentation of the drain tube (10.1 cm inner diameter) took place for hole diameters as great as 0.975 cm (in eight rows and one hole in every third valley) for a double wrapping of fiberglass around the drain.
9. Flow from the bottom half of the drain was greater for larger envelope thicknesses.
10. Velocity of water close to the drain tube before entering the perforations was 0.047 cm s^{-1} which is 2.2-times higher than the safe velocity of water near the drain. A velocity of this order may create drain sedimentation.

CHAPTER VII

RECOMMENDATIONS

Recommendations for further study are as follows:

1. Results of this study were based on one-year-old organic material and tests were conducted in the laboratory. A field study of the organic material envelope should be conducted to evaluate the effect of material aging on drainage discharge and silting of drains.
2. An evaluation of the exact entry velocity of water at the perforations should be made for an effective check against sedimentation.
3. A study should be made to determine the location at which sediment enters into the drain.
4. An evaluation of strength of the drain tube for the perforations as reported in the conclusion should be made.

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APPENDIX A

PRINCIPLES OF FLOW IN SATURATED MEDIA

Flow of water in the saturated zone involves mechanical, chemical and thermal energy and molecular attraction. Mechanical forces tending to move water through soils are described below:

HYDRAULIC HEAD: In saturated flow through soils, as in open channel flow, the total energy per unit weight (E) of the water is the sum of the kinetic, pressure and gravity components as expressed in Bernoulli's equation.

E = kinetic energy + pressure energy + elevation energy 1

Velocities in ground water flow are almost always low making the kinetic energy term negligible. Essentially, then the energy causing the flow is the sum of two potential energy items, pressure and elevation. This potential for flow is called hydraulic head. Hydraulic head is also designated as hydraulic potential. Hydraulic head is conveniently expressed as energy content per unit weight of water. If P is the pressure at a point referenced to the atmosphere (Pascal), W = specific weight of water ($N.m^{-3}$) and Z = elevation of the point above a datum in m, then hydraulic head H, in m, at the point is:

$$H = \frac{P}{W} + Z \quad \ldots\ldots 2$$

Piezometers convert pressure at a point to a physical pressure head, the height of water column in the piezometer. This height is not hydraulic head since it represents only the term P/W in the equation. To find the hydraulic head, the elevation Z of the point above the datum must be added to the pressure head.

HYDRAULIC GRADIENT: Ground water flow results from the force available to move water through the soil due to difference in energy, i.e. difference in hydraulic head. Hydraulic gradient is the difference in hydraulic head at two points divided by the distance between the points measured along the path of flow. If H_1 and H_2 are the hydraulic head at two points and L be the distance along the path of flow, then the hydraulic gradient I is:

$$= \frac{H_1 - H_2}{L}$$

$$= \frac{\left(\frac{P_1}{W} + Z_1\right) - \left(\frac{P_2}{W} + Z_2\right)}{L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3$$

PATHS OF FLOW (STREAM LINES): The force due to hydraulic potential tends to move water along the line of force normal to equipotential surfaces provided the medium is isotropic. Stream lines represent the path followed by percolating water through a saturated soil medium under laminar conditions.

EQUIPOTENTIAL LINES: An equipotential line is a line passing through points of equal hydraulic potential.

FLOW NET: The graphical representation of Laplace's equation is given by two sets of curves intersecting at right angles. The two sets of curves, known as streamlines and equipotentials respectively, constitute a flow net for a system or a part of a system.

Many flow systems common in soil drainage may be studied in two dimensions rather than three because of uniformity in the third dimension. The construction of a flow net is described below.

GRAPHICAL CONSTRUCTION OF A FLOW NET: In many drainage problems the boundary conditions are often so complex that the solution cannot be obtained analytically. The graphical method of flow net construction is based on trial sketching. Before starting the trial construction of a flow net, it is essential to examine the hydraulic boundary conditions of the problem and to ascertain their effect on the general shape of flow lines and equipotentials. The boundary conditions are meant to define the boundary or limiting flow lines and equipotential lines of a flow net. These boundary conditions may vary from problem to problem but in most cases, can be easily established by inspection of the geometry of the hydraulic structure.

In the present study the top and bottom of the sand surface represents the boundary equipotential lines, the top surface being at 100 percent potential. Sketching may now be started by drawing an equipotential line by guess next to the boundary line. This way approximate equipotentials are drawn until the last equipotential line in the bottom boundary is drawn. Stream lines are then drawn keeping in mind that streamlines intersect equipotentials at 90 degrees, and that the mean length and width of all fields are approximately equal. If the first trial line has been correctly chosen, the last flow line must be consistent with the lower boundary condition. Otherwise the nature of change required in the first flow line is ascertained by visually examining the entire flow net backward. The first flow line is redrawn and the whole construction is repeated. Thus by trial and error the correct flow net is established.

COMPUTATION OF VELOCITY: Considering a series of squares between two stream lines, it is evident that no flow of water can take place across any stream line and therefore, for any flow field between two stream lines

$$\Delta q_1 = \Delta q_2 = \Delta q_3 = \Delta q \qquad (4)$$

where Δq_1, Δq_2, Δq_3 are the flow from the individual square fields which is equal to another constant Δq.

For an isotropic material, k is the same in all directions and therefore flow is equal to kIA, where A is the area of cross section perpendicular to flow. It follows that:

$$kI_1A_1 = kI_2A_2 = kI_3A_3$$

where I_1, I_2 and I_3 are average hydraulic gradients between the equipotentials h_1 and h_2, h_2 and h_3 , and h_3 and h_4, respectively.

For a unit depth of the flow field in a plane perpendicular to the plane of the flow net,

$$A_1 = 1.b_1$$
$$A_2 = 1.b_2$$
$$A_3 = 1.b_3$$

where b_1, b_2 and b_3 are the average widths of the square fields.

Hence,

$$k \frac{h_1 - h_2}{l_1} b_1 = k \frac{h_2 - h_3}{l_2} b_2 = k \frac{h_3 - h_4}{l_3} b_3$$

where l_1, l_2 and l_3 are the lengths of square fields parallel to the stream surface.

For squares, $\frac{b_1}{l_1} = \frac{b_2}{l_2} = \frac{b_3}{l_3} = 1.0$

Consequently, $h_1 - h_2 = h_2 - h_3 = h_3 - h_4 = \Delta h = \frac{h}{N}$...5

Where Δh is the difference in hydraulic head between individual equipotentials and h is the total difference in hydraulic head. N designates the number of equipotential increments.

From equation 5 it is evident that the drop in head is the same between any two successive equipotential lines and the rate of flow Δq between any two adjacent flow lines is also a constant. Therefore, the total rate of flow q in the flow net is

$$q = F \cdot \Delta q$$

$$= F \cdot k \cdot \frac{\Delta h}{l} \cdot b$$

$$= k \cdot \frac{F}{N} \cdot h \cdot \frac{b}{l}$$

Since $\frac{b}{l} = 1.0$

$$= k. \frac{F}{N} \cdot h \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 6$$

where F represents the number of flow lanes.

The rate of flow Δq is the same in all flow fields, but the velocity varies inversely with the width of the flow field as given by

$$V = \frac{\Delta q}{b}$$

$$= \frac{q}{F} \cdot \frac{1}{b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 7$$

In the present study in the flow net F and q were 4 and 0.565 $cm^3 s^{-1} cm^{-1}$ respectively. The value of b close to the drain was 3.0 cm. Substituting these values in equation 7,

$$V = \frac{0.565}{4 \times 3}$$

$$= 0.047 \text{ cm s}^{-1}$$

This velocity is computed on the assumption that when water moves close to the drain at perimeter, the wall of the drain does not obstruct the flow.

APPENDIX B

FLOW EQUATIONS AND REGRESSION COEFFICIENTS

Serial Number	Type of Envelope	Spirally Corrugated Drain Tube		Ring Corrugated Drain Tube	
		Prediction Equation	Correlation Coefficient	Prediction Equation	Correlation Coefficient
1	Fiberglass	$y = 1.63x - 8.0$	1.00	$y = 1.73x - 7.54$	1.00
2	Straw				
	2.5 cm	$y = 1.56x - 6.38$	1.00	$y = 1.46x + 1.55$	0.99
	5.0 cm	$y = 1.49x - 1.75$	0.99	$y = 1.53x - 10.12$	0.98
	7.5 cm	$y = 1.60x - 1.63$	1.00	$y = 1.63x - 17.88$	0.97
	10.0 cm	$y = 1.57x - 14.50$	0.99	$y = 1.36x + 4.83$	1.00
3	S.I.F. Treatment				
	2.5 cm	$y = 1.71x - 13.20$	0.99	$y = 1.27x + 14.58$	1.00
	5.0 cm	$y = 1.36x + 5.30$	0.99	$y = 1.54x - 7.22$	0.99
	7.5 cm	$y = 1.32x + 8.40$	0.99	$y = 1.25x + 15.90$	1.00
	10.0 cm	$y = 1.40x - 0.22$	0.99	$y = 1.41x + 1.89$	1.00
4	S.O.F. Treatment				
	2.5 cm	$y = 2.00x - 33.80$	0.98	$y = 1.48x + 3.39$	0.99
	5.0 cm	$y = 2.02x - 41.40$	0.99	$y = 1.33x + 9.41$	1.00
	7.5 cm	$y = 1.77x - 24.00$	0.98	$y = 1.82x - 19.87$	0.99
	10.0 cm	$y = 1.78x - 29.40$	1.00	$y = 1.72x - 19.87$	0.99

(Continued)

Appendix B (Continued)

Serial Number	Type of Envelope	Spirally Corrugated Drain Tube		Ring Corrugated Drain Tube	
		Prediction Equation	Correlation Coefficient	Prediction Equation	Correlation Coefficient
5	Average				
	Organic Material only	y = 1.41x - 1.60	0.99	y = 1.39x + 2.41	0.97
	S.I.F. treatment	y = 1.31x + 10.40	0.94	y = 1.33x + 8.99	0.99
	S.O.F. treatment	y = 1.75x - 21.83	0.94	y = 1.40x + 4.30	1.00

APPENDIX C

PARTICLE-SIZE DISTRIBUTION OF ORGANIC
MATERIAL (STRAW)

Weight of Sample = 259.62 g

Sample No.	Length Range cm	Average Length cm	Weight each group g	Percent Weight of each group	Percentage Cumulative Weight	Percent Finer	Average Width cm	Projected area of straw Particles cm^2
1	Above 45	45.0	0	0	0	100		14.80
2	30 - 45	37.5	78.05	30.063	30.063	69.937	0.33	11.5
3	25 - 30	27.5	29.63	11.412	41.476	58.524		9.05
4	20 - 25	22.5	21.60	8.090	49.564	50.436		7.45
5	15 - 20	17.5	22.10	8.512	58.078	41.924		5.78
6	10 - 15	12.5	29.70	11.440	69.517	30.483		4.14
7	5 - 10	7.5	34.24	13.188	82.705	17.295		2.48
8	2 - 5	3.5	21.45	8.262	90.967	9.033		1.12
9	0 - 2	1.0	23.27	9.032	100.000	0.000		0.33