

# Experiments With Filter Materials for Subdrains

ARTHUR F. PILLSBURY, Institute of Transportation and Traffic Engineering,  
University of California, Los Angeles

This report deals with work with agricultural tile drainage systems; their requirements differ in many respects from the requirements for highway subdrains. There are also environmental differences: agricultural tile drains are required predominantly in basin lands, and in valley (flood plain) lands where there is considerable stratification. Tile drains are required rather infrequently in uplands and terrace lands. Major highways now largely avoid basin lands, and their shift more to the terraces and uplands would be beneficial to man's environment. Some subdrains for highways might be required on the terraces, but the main need should be with unstable upland slopes.

•THIS work was undertaken from the viewpoint of improving the effectiveness and efficiency of agricultural tile drainage systems. The environment under which such drains are placed, and the criteria for placement design, are normally quite different than subdrainage as required for highways. Nevertheless, the findings of one discipline can well prove useful to another discipline, and it is hoped that some cross-fertilization might develop in this instance.

## AGRICULTURAL SUBDRAINS

### Purpose

Agricultural tile drains in all climates serve the function of: (a) improving the bearing power of the soil surface to permit tillage, planting, harvesting and other essential traffic with a minimum of compaction; and (b) providing aeration of the plant rootzone. Plants, for optimum growth, require a soil of low bulk density and, for most plants, a well-aerated rootzone from somewhere between 18 in. to at least 5 ft in depth. In arid and semiarid regions, where irrigation is regularly required, there is a third and often dominant function—to provide a rootzone low in salts. Soil waters and irrigation waters always contain some salts, and the plant rootzone is the concentration zone of those salts. Evapotranspiration (evaporation from soil and water surfaces, and transpiration from the leaves of plants) removes pure water and leaves salts behind. Maintenance of a low-salt rootzone implies the periodic application of sufficient water to accomplish some leaching of salts downward in excess of the water required to replenish the rootzone, and a water table (normally fluctuating) whose mean depth is sufficient to minimize the total upward capillary movement of moisture. The required mean depth of the water table usually ranges from about 4 to 6 ft in arid regions, depending on soil, crop, and tile spacing. The depth of the tile lines themselves is usually 1 to 2 ft greater than the mean water table depth.

### Environment

The type of land where agricultural subdrains are required can be explained in accordance with the characteristics imparted to that land by its position on the landscape,

as usually found in the southwestern United States. The upland soils are the primary or residual soils formed by the weathering of the underlying rock materials. They have varying amounts of profile development (a subsoil differing to some degree in texture and structure from the topsoil), depending on climate and relative rates of erosion. Most erosion occurs during major floods, and the sediments are carried downstream to the floodplain where deposition takes place. As flows emerge from the canyons, velocity decreases with a drop in gradient and floodwaters spread out over the floodplain. Although there is much textural mixing, increasing with an increase in density of the sediments in the suspension, the soils deposited in the valleys are normally of loamy medium texture, and of fine texture in the basins (largely clays, clays being defined as soils where the effective diameter of the particles is less than 2 microns). Slopes are so flat in the basins that drainage is impeded, and there is at least temporary ponding of the floodwaters, permitting finer sediments to settle out.

The floodplain soils—valley and basin—are called alluviums. They are usually called recent alluviums because deposition during floods has been rapid enough to prevent any "maturing" or development of a profile. Their relative uniformity to a considerable depth makes them invaluable as agricultural lands. These lands have good groundwater aquifers, and pumping the groundwater for a water supply normally keeps the water table well below levels that would call for subdrains. However, as the distance towards the basin lands increases, and as aridity, which is related to more stratification, increases, groundwater pumping ceases to be an effective water level lowering mechanism. It is in the basin and basin rimlands where subdrains are required.

Terrace lands are floodplain alluvium that, through geologic change, are no longer subject to deposition and are on a flat enough slope to avoid appreciable erosion. They have therefore matured to a variable extent—often having developed marked differences between topsoil and subsoil. In the southwestern climates, terrace subsoils commonly have much lower hydraulic conductivity than topsoils. After prolonged rain, water infiltrating the topsoil has wet up that topsoil and begins to develop a temporary perched water table which moves off laterally. These, and some upland soils with similar profile development, are far from being prime agricultural lands, but, because of night air drainage, they may be prized for certain agricultural specialty crops requiring relative freedom from frost. Subdrains at a depth to intercept the lateral flows may sometimes be required in the interests of soil aeration.

There are some agricultural subdrains required in upland and terrace lands. However, the dominant need is in basin lands, and in valley lands when there is considerable stratification. This is flat land and subdrains are usually on a grade of about 0.001, with pumps lifting the effluent several feet from sumps if a low enough outlet cannot be obtained. In many respects, there is lack of uniformity in such lands, but there is a great deal of uniformity in the type of land requiring agricultural subdrains. Relatively large areas are usually involved, all in the same environment requiring much the same treatment.

## HIGHWAY SUBDRAINS

### Environment

There are distinct advantages in getting highways and population concentrations out of the valleys and basins and onto the terraces and uplands. This relates to atmospheric pollution (1), avoidance of the flood hazard, and preservation of prime agricultural lands. In addition, terrace lands and rolling uplands provide, aesthetically, a much better environment for urban development. Sacramento, for example, was originally planned as a natural transportation hub, and no visible effort has been made to alter this. There would be marked advantages if the state would start planning its new capitol buildings for the terrace lands to the east. Planning for new highways tends to follow traditional patterns, yet the effects on urban trends when highways take a new route are readily apparent.

There should be a concerted effort, with all major highways, to avoid basin lands and to get out of the valleys as much as possible. As a rule, major highways can avoid basin lands and those parts of valleys requiring agricultural subdrains. Secondary

highways on such lands, with compacted subgrade and surface seal, will continue to require parallel ditches or subdrains to intercept lateral flows. On terraces and uplands with soils having profile development, it is presumed that topsoil will be removed, or mixed with the subsoil and compacted. Therefore, subsurface drainage will be attained with interceptor drains parallel to the upstream side of the highway. Since these will be relatively shallow, they will most often be ditches rather than covered drains.

The major needs for highway subdrains would seem to be in upland areas of unstable slopes; unstable because of geologic conditions. The greatest hazards of landslides would seem to be in sedimentary formations where downsloping beds of shale or clay might be involved. Water seeps above the strata interfaces can provide lubrication, particularly where hydrostatic pressure exists. Any cuts and fills often adversely affect stability, and interception of seeps can improve stability.

In summary, most highway subdrains should require individual investigation, and not be susceptible to the rather uniform treatment that marks the agricultural drains. Furthermore, there can be significant differences in design for the two types.

### ENVELOPES AND FILTERS

Almost all agricultural "tile lines" are made either of vitrified clay or of concrete<sup>1</sup> with water entering at the unsealed joints. Perforated and slotted plastic tile and perforated bituminized fiber pipe have been used, but these are all still experimental. One company is considering experiments with a highly porous plastic pipe having adequate structural strength to resist crushing. Porous concrete drainage pipe has been manufactured, but the writer does not recommend its use.

Most of such tile drainage lines are installed with nothing surrounding them but soil. In the humid regions, it is sometimes customary to select topsoil for the initial backfill in immediate contact with the pipe because it will have higher hydraulic conductivity than subsoil. However, in more recent years, it has often been found advantageous, in promoting inflow into the tile lines of humid regions, to surround the pipe with some type of "blinding material" or envelope. Use of such material allows the streamlines of flow to be normal to the pipe instead of converging at the joints. Further, the large pores in the material permit the water to move up to the tile at low velocity so that soil material is not disturbed or carried in the water.

The term "blinding material" generally refers to some type of vegetative residue such as tule trash or a crop residue. Engineers in Holland report that they have been successful with heather trash, and that peat has also been used. The Oxnard Plain in southern California seems to be the first area to use pea gravel extensively as an envelope material. Farmers in that former swampland originally had trouble with the tile lines silting up, but their solution was to connect the upper end of each tile line with an irrigation hydrant. By opening a slide gate on the side of a hydrant, any tile line could be flushed out from time to time. This system has functioned quite satisfactorily.

Tile drainage developed later in the Imperial Valley of California. Irrigation was by open ditch, making it impractical to do anything but plug each tile line at its upper end. At the same time, there was the problem of lines being plugged with soil material. It was probably in this valley more than anywhere else that the concept of a filter developed. Pits were located that seemed to provide a reasonable filter of sand material. Actually, it was used as is, i.e., a "pit run" material, because the cost of washing or sizing would be prohibitive. By and large, it did a reasonable job. However, texture

<sup>1</sup>Clay tile is made in accordance with ASTM Designation C4, latest revision, "Standard Specifications for Vitrified Clay Drain Tile" and concrete drain tile in accordance with ASTM Designation C412, latest revision, "Standard Specifications for Concrete Drain Tile." In the western United States, concrete drain tile is made in accordance with ASTM Designation C118, latest revision, "Tentative Specifications for Concrete Pipe for Irrigation or Drainage." In the arid to semiarid regions where lines are 6 to 8 ft in depth, heavy duty pipe, as provided in C4 and C118, is specified. Where sulfates can be a problem, type II or type V cement is specified for C118 pipe.

was quite variable and some lines were found to silt up over a period of years. The writer made textural analyses of the filters used on such lines and of the material found on the inside of the lines. This material was very fine sand or a mixture of very fine sand and coarse silt. (Effective diameter of 50 percent of the material "finer than" ranged from 0.066 to 0.12 mm.) It was suggested that material conforming to the grading requirements of standard concrete sand (2) would make a satisfactory filter.

The soils of the valleys of southern California are badly stratified, and thin lenses or strata of a cohesionless material in the textural range of very fine sand to very fine sand and coarse silt are commonly encountered. There are, of course, both finer and coarser strata, but it is assumed that finer material, which contains clay, has enough cohesion to resist erosion, or is carried on through the tile lines. It is assumed that joint openings, as occasioned by irregularities, are too narrow to admit coarser material. Therefore, concern is simply for a rather narrow range of material, and there is no need to adjust the grading of the filter to the texture of the soil in which the tile is placed.

There is some evidence in the Imperial Valley, and considerable evidence in the Coachella Valley, of a gradual degradation in the effectiveness of tile lines. A pit run material somewhat similar to that used in Imperial is used in Coachella. It is known to contain fines, including a considerable amount of micaceous material. Gradual sealing apparently occurs in the joints. Laboratory studies were undertaken using Coachella soil and Coachella filter sand. The following are conclusions from that study:

1. Over a period of several months, and with a constant head of water on the soil surface, rate of flow from the tile does deteriorate with time. Prime deterioration is in the first one or two weeks.
2. Washing of the filter sand before placement resulted in considerably increased flow, but deterioration with time continued.
3. Surging of the laboratory tile was quite effective in improving flow, but did not eliminate the deterioration with time. Surging was a mild application of the way wells are developed, but done so as not to displace the filter.

Surging was then tried on two tile lines in the Coachella Valley. There was marked and immediate improvement in performance, but in about a week the tile lines were back down to the poor level of performance that existed before surging. The marked deterioration in performance may be limited to the Coachella Valley. No evidence of it has been observed in the San Joaquin Valley where filters are also used. Incidentally, there is no firm evidence as yet that filters are required in the San Joaquin Valley, although there is evidence that envelopes are beneficial.

#### Design Criteria for Sand Filters

For sand to function as a satisfactory filter, it appears desirable to filter out cohesionless material in the  $D_{50}$  range of 0.06 to 0.12 mm, based on findings in the Imperial Valley. Employing the well-known F/A ratio (3, 4, 5, 6)

$$F/A = \frac{D_{50} \text{ of filter}}{D_{50} \text{ of aquifer}}$$

and the given range of  $D_{50}$  for cohesionless soil material, provides a basis for beginning the filter design. Qazi (7) and des Bouvrie (8) suggest the use of the standard deviation as an index of the range in gradation of the filter. They state: "Dixon and Massey (9) show that in a large normally distributed sample, the area enclosed by the ordinates through points at a distance of 1.645 (where  $\sigma$  is the standard deviation of the sample) on each side of the mean  $\sigma$  contains 90 percent of the total variates in the sample. Therefore, the standard deviation ( $\sigma$ ) can be found from an accumulation grain size distribution plot on logarithmic probability paper (on which a normal distribution plots as a straight line), by dividing the interval between the 95 percent and the 5 percent size by  $2 \times 1.645 = 3.29$ ."

Qazi and des Bouvrie present a chart (Fig. 1) showing minimum suggested values of the F/A -  $\sigma$  relationship to provide a satisfactory filter. Further, des Bouvrie (8) suggests the following minimum filter thicknesses with successful F/A -  $\sigma$  combinations:

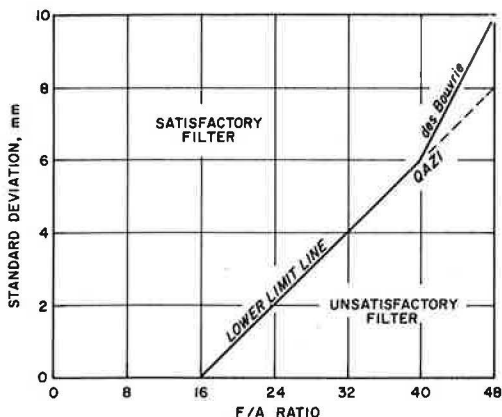


Figure 1. Lower limit line, as suggested by Qazi and modified by des Bouvrie, for a satisfactory filter.

1. 0.5 to 1.0 in. for  $F/A \leq 12$ ;
2. 3 in. for  $F/A = 12$  to 24;
3. 6 in. for  $F/A = 24$  to 28; and
4. 9 in. for  $F/A = 28$  to 40, and so on.

For reasonable economy, the minimum filter thickness should not exceed 3 in., although this may be more important with agricultural tile drains than with highway subdrains.

Referring again to standard concrete sand (2), by adhering to the customary grading restrictions and the given criteria,  $F/A$  can range from 4 to 20 and  $\sigma$  from 0.54 to 1.41 mm. Some concrete sand might therefore be unsatisfactory. Costs to satisfy the needs of highway subdrains would be less of a factor, and complete success can be assured with the additional

restrictions that  $D_{50} \leq 1.0$  mm and  $\sigma \geq 1.0$  mm, or a specially graded filter could be designed and specified in accordance with the restrictions. This might well be preferred with highway subdrains. In the writer's experience and laboratory trials, material adhering to these criteria have been quite satisfactory. All of the Imperial Valley material that failed as a filter did not adhere.

#### Glass Fiber Mat Filters

A commercial organization was installing perforated bituminized fiber pipe in Imperial Valley with a 1-in. thick by 12-in. wide fiber glass mat placed over the top of the pipe. Perforations were on both sides of the top of the pipe,  $2\frac{1}{2}$  in. from the vertical. Good results were claimed. The glass fiber blankets are made and sold in quantity for insulation purposes, and therefore inexpensive. Further, the USDA Agricultural Research Laboratory in Brawley was experimenting with the same filter material, including the amount the material compressed when subjected to compression in place. The writer then initiated comparative laboratory experiments with the following relative results (on the basis of flow from treatment No. 1 being 100):

Treatment No. 1—A continuous blanket (strip 12 in. wide) under the tile, and a blanket over the tile wide enough to go around the tile and lap over the bottom blanket, flow 100.

Treatment No. 2—Doughnut. A ring of fiberglass mat placed in the tongue and groove joint of the tile. Best doughnut used, flow 11.

Treatment No. 3—A collar of a different type of glass fiber material designed as a sleeve collar over each joint. Best collar used, flow 16.

Treatment No. 4—An envelope of Coachella filter sand around joints, flow 40.

On the basis of this laboratory performance, a replicated cooperative field experiment was initiated on the Hugh Bennett property near Firebaugh in the San Joaquin Valley. The treatments are as follows:

Treatment No. 1—Six-in. concrete drain tile with sand filter. San Joaquin Valley pit run sand, 18 tons per 100 lineal feet.

Treatment No. 2—Perforated (4 in.) bituminized fiber pipe, with perforations 45 deg apart, placed up, and covered with a continuous glass fiber blanket 1 in. thick by 12 in. wide.

Treatment No. 3—Six-in. concrete drain tile with 1-in. thick glass fiber rings (doughnuts) inserted in the joints and a 2-ft wide by 1-in. thick continuous glass fiber mat placed over the top.

Treatment No. 4—Six-in. concrete drain tile placed on top of a continuous glass fiber blanket 4 ft wide and 1 in. thick which went across the bottom and up one side of the trench. A continuous blanket 2 ft wide and 1 in. thick was tacked to the other side of the trench, then a 2-ft wide blanket 1 in. thick was placed over the tile.

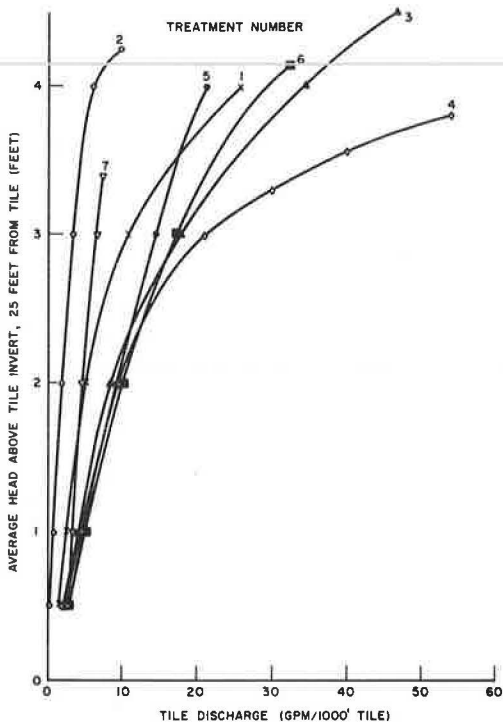


Figure 2. Relationship between tile discharge and average head above tile invert for the seven treatments.

A small amount of soil material was found in the perforated tile lines (treatments 2 and 5). Also, small cores of mat and soil were found in the tile with perforations down (treatment 5). No cores were found in the tile line with perforations up, but very little water had flowed into this line.

The glass fiber material appeared never to have been wet above about the centerline of the tile lines (above the elevation of the perforations for treatment 2). Below this level, the material was compressed to a thin sheet and was mushy and without resilience. The soluble binder had been leached away. The failure of this material may be the reason why significant differences between treatments were not observed. There is some thought that possibly a glass fiber material with very coarse strands of borosilicate glass and an insoluble binder might be suitable, but the material manufactured for insulation purposes is not. One reason for differences between field and laboratory tests might have been that the field trials were in a highly saline sodic soil; the laboratory work was not.

### PROTECTION FROM BACKFILL

The usual practice is to backfill the trench immediately behind the tile-laying machine. The loose material is mounded over the trench and then a furrow is constructed along its length. This furrow is then filled with water and ponded to "sub in" the backfill. Many experienced installers believe that it is during the subbing-in that much damage can occur. There is the belief that the trench is then a trough filled with water and loose soil, and that the resultant soupy soil, here and there, pipes through the filters or envelope. This could have been the case at the Bennett plots but not in Imperial Valley where the soil must have entered gradually over a period of years. Following subbing-in, most soil dries and achieves considerable structure—particles binding

Treatment No. 5—Perforated 4-in. bituminized fiber drainage pipe spirally wrapped with a glass fiber mat 1 in. thick. Perforations were the same as in treatment No. 2, but the perforations were placed down.

Treatment No. 6—Six-in. concrete drain tile with a 2-ft wide by 1-in. thick glass fiber mat placed over the tile only.

Treatment No. 7—Six-in. concrete drain tile with 2-ft wide by 1-in. thick glass fiber mats under and over the tile.

Treatments 4 and 7 were installed by hand. All other treatments were installed by machine. The machine used for treatments 1, 3 and 6 had a device for placing the tile, as it was shoved into position, under moderate longitudinal compression.

Yield of effluent from these tile lines has been in accordance with Figure 2. Treatment No. 2 is significantly lower than the other treatments, but within the other treatments differences are not significant. In June 1964, arrangements were made to dig down to one tile line of each treatment. The results showed that there were obviously wider joint openings with hand-placed tile because considerable fine sand and silt was found in both treatments 4 and 7, and not in the machine placed concrete lines. This could have entered the pipe during "subbing-in."

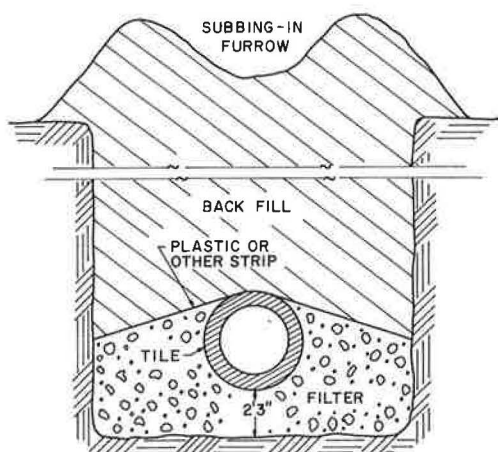


Figure 3. Profile of a tile installation with filter, demonstrating flow towards the tile when the filter above the water table is unsaturated and the interface between soil and filter acts as a barrier. This condition is normal, even when the soil is saturated above the tile.

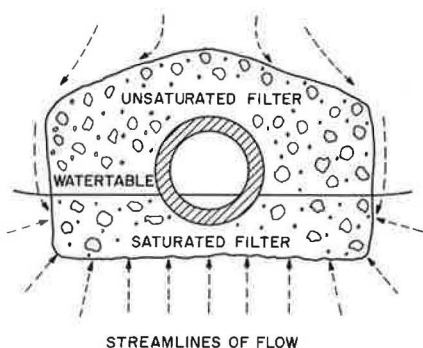


Figure 4. Profile of suggested installation technique, showing tile, filter, plastic or other type protective strip, and "subbing-in" furrow for compacting backfill.

start percolating downward through soil, and will move around the envelope through soil to the water table. The water table will rise, increasing flow, but above the water table the envelope remains unsaturated and the boundary between the soil and the gravel remains an interface, blocking flow through it. The boundary between the soil and the gravel remains an effective interface until the pipe is flowing full and the water is under sufficient pressure to raise the water table to the top of the gravel. The tile would then not be functioning as a drain. Design criteria are such that the pipe should never run full.

Any function of envelope or filter material over the tile is to prevent the piping of flow directly to a joint or other opening, primarily during the subbing-in period and while the soil structure of the backfill is becoming stabilized. There is no objection to a barrier here being impervious, and it should have structural strength to span any joints or other openings into the pipe without failure. Asphalt roofing paper, strips of plastic sheeting, or other materials that adhere to these criteria can be used. The

together—and stability. The writer has simulated subbing-in in the laboratory, and has found that it can entrap considerable air which discharges into the tile in a pulsating manner with considerable disturbance and displacement of the filter. This verifies the theory of damage during subbing-in.

Where envelopes or filters are used, it is usual practice to place the material all around the pipe. If not, it is placed only on top, possibly because that is the easiest and cheapest place to put it. Theory would indicate the area above the tile contributes little or nothing to flow into the tile. The lack of wetting of the glass fiber mat above about the centerline of the tile at the Bennett plots confirms this theory. Movement of water in soil below a water table is said to be saturated flow, and the water table represents the elevation of zero atmospheric pressure. Above a water table, soil water is under a negative pressure. It moves in response to hydraulic gradient, but it is sucked along due to the affinity of soil for water. With an abrupt change from a fine to a coarse textured material in the direction of movement, there is an effective break in the hydraulic gradient. This is because water moves through the fine capillaries of the fine textured soils at higher suction values than through the relatively extremely large capillaries of the coarse textured soil, and those capillaries are few and far between with the coarse textured soil.

This concept is shown in Figure 3, the cross section of a tile line with a gravel envelope. Presume that it is just before irrigation and there has been recession of the water table so that flow is low. The water table in the tile and essentially in the envelope is the surface of the water in the tile. The envelope above this is unsaturated. With irrigation, water will

material should be wide enough to cover the exposed top of the pipe and the envelope to prevent piping around the edge (Fig. 4).

### CONCLUSIONS

This has been intended as a summary of experiments with tile filters, or "subdrain filters" in highway engineer's terminology. Actually, it has gone beyond this in the hopes of developing a broader viewpoint as to the environment in which such facilities might be required, and information on what is required.

As to subdrain filters, a graded sand is the most satisfactory material that has been reasonably proven. The glass fiber mat material produced for insulation purposes is not satisfactory. There may be other types of glass fiber mat that are satisfactory, but this is not yet proven.

### REFERENCES

1. Bush, A. F. Urban Atmospheric Pollution. Civil Engineering, pp. 66-68, May 1965.
2. Standard Specifications for Concrete Aggregates. ASTM Designation C33-64.
3. Terzaghi, K., and Peck, R. B. Soil Mechanics in Engineering Practice. John Wiley & Sons, New York, 1948.
4. Investigation of Filter Materials for Underdrains. U. S. Army Engineer Waterways Experiment Station, Tech. Memo. 183-1, Vicksburg, Miss., 1941.
5. Leatherwood, F. N., and Peterson, D. F., Jr. Hydraulic Head Loss at the Interface Between Uniform Sands of Different Sizes. Trans. Amer. Geophysical Union, Vol. 35, pp. 588-594, Aug. 1954.
6. Karpoff, K. B. The Use of Laboratory Tests to Develop Design Criteria for Protective Filters. Earth Laboratory Branch, Engineering Laboratories Division, Bureau of Reclamation, USDL Paper presented at the 58th Annual Meeting of ASTM, Atlantic City, New Jersey, June 27, 1955.
7. Qazi, A. R. Design Criteria for Tile Drain Filters. Master's Thesis, Colorado State Univ., 1961. 90 pp.
8. des Bouverie, C. Design Criteria for Drain Tile Filters. Master's Thesis, Colorado State Univ., 1962. 132 pp.
9. Dixon, W. J., and Massey, F. J. Introduction to Statistical Analysis, 2nd Ed. McGraw-Hill, New York, 1957.