LABORATORY TEST FOR A DRAIN WITH GRAVEL ENVELOPE

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ABSTRACT

A field-size drain was installed in a laboratory tank with dimensions of 0.8 by 2.4 by 2.7 m. The drain was 100-mm-diameter corrugated plastic tubing and had a circular gravel envelope 100 mm thick, surrounded by a 2.2-m-diameter circle of sand base material. During pretesting operation with high heads, base material entered the drain. Tests were made with heads up to 0.6 m. Test results were the discharge-head loss relationship for the system, water table location in the base material, and hydraulics of the system - indicated by equipotentials and flow streaklines. The gravel envelope efficiently conveyed water from the surrounding base material into the drain tubing.

INTRODUCTION

When installing subsurface agricultural drains, the Service requires a layer of gravel (called the gravel envelope) to surround the drain tubing. The gravel envelope (1) conveys water from the surrounding base soil into tubing perforations with minimal head loss, thus, improving drain efficiency; (2) provides bedding for the drain tubing; and (3) prevents excessive entry of problem soils into the drain. Gravel is an appreciable cost item of drain installation, and possibly different envelope shapes or an envelope substitute could reduce this cost. A large sand tank was constructed at the Engineering & Research Center in Denver, Colorado, for studying different envelope shapes or substitutes and to obtain some measure of envelope efficiency. This paper presents observations and data obtained during sand tank operation and hydraulic conditions related to a Service-designed gravel envelope.

THE SAND TANK

The sand tank was 9 ft (2.7 m) long, 8 ft (2.4 m) deep, and 2.5 ft (0.8 m) wide with an acrylic plastic face, figure 1. As shown in the photograph, the drain was centrally located and had a gravel envelope, which in turn was surrounded by a large circle of base material. Other pertinent facts were: (1) drain - corrugated plastic tubing, 4-in (100-mm) diameter, and parallel with the 2.5-ft box width; (2) envelope - circular-shaped, 4-in (100-mm) thick, with gravel gradation conforming to Service design criteria and gravel hydraulic

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conductivity of 0.01 ft/s (3 mm/s) obtained from another study; and (3) base material - a fine uniform sand with D_{60} particle size of 0.25 mm, placed in a 7.2-ft (2.2-m) diameter circle, and sand hydraulic conductivity of 0.00055 ft/s (0.17 mm/s) (obtained from another study). Placement of the sand and gravel was designed to simulate flow conditions around a field drain located well above an impermeable barrier. Gravel surrounded the base material and allowed uniform water entry to the entire circumference of the base material. Waterflow converged toward the drain. Piezometer taps were located in the tank ~~base~~ face to measure piezometric heads. The base material contained 115 taps placed in a polar grid; and the gravel envelope had 20 taps placed in radial lines extending outward from perforations in the drain tubing. Water was pumped from a storage box into the tank and returned to the storage box.

SAND SETTING OPERATIONS

The gravel and sand were placed in the box up to the bottom of the drain tubing. Water was brought into the bottom of the box, ponded above the sand, and drained to settle the sand. The upper half of the box was then filled with sand and gravel. Both ends of the drain were plugged and the upper half of the box subjected to ponding. During this process, some base material moved into the upper half of the gravel envelope, as seen at the face of the tank. The plugs in the drain were removed and the box drained. The sand was further stabilized by passing a continuous waterflow through the sand and into the drain. Water levels were progressively increased in the outer gravel until the entire circular base material was submerged. After 1 day, a dark coloration area was noted at the outer edge of the base material (more extensive at the bottom). During the second day the dark coloration had moved radially inward. The dark coloration indicated complete saturation, and the lighter areas indicated presence of minute air bubbles in the sand. Numerous air bubbles were also present in the gravel envelope. Operation of the tank with a high head was planned until all the sand appeared completely saturated. However, after 3 days of operation, base material was observed in the drain discharge, and at the front of the box some sand had entered the lower half of the gravel envelope. Settling operations were stopped and the box partially drained. Sand was observed in the drain tubing along 1 ft (0.3 m) of the drain at the back of the box. This sand was removed before testing.

Head loss-discharge data of the sand settling operations are given in figure 2. Head loss was the difference between the water surface elevation at the edge of the base material and the water surface elevation inside the drain. Higher heads than normal for field conditions were imposed on the base material and envelope system.

THE TESTS

All tests were made with a flow depth of 1 in (25 mm) in the drain tubing, simulating a drain flowing 25 percent full. For each test, a water surface elevation was set and held constant at the outer edge of through the base material and into the drain. Measurements were made of

the base material. The water level produced a head acting on the system, and hereafter will be designated the head. Water flowed by gravity drain discharge, head loss, and piezometric head. Flow streaklines were induced in the base material by injecting blue dye through chosen piezometer taps, and sketches were made of the streaklines.

Two different test series were performed. The first test series was done immediately after the sand settling operations and the second test series was done after indications that sand hydraulic conductivity had changed. In the first test series, heads were progressively increased (fig. 2). For conditions resulting in data point A (fig. 2), sand was observed in the drain. For point B, sand flowed from the drain. Thus, the first test series was ended. To stop sand from entering the drain, the head was lowered to that of point C. Sand was removed from the tubing and tank operation continued with the constant head. Drain discharge increased over a 2-week period. For the next 2 weeks, heads were gradually increased to that of point D. Close observations were made to ensure that sand was not entering the tubing. Drain discharge increased to that of point D over the next 4 weeks. The sand tank operated another 3 weeks, and the head loss-discharge remained constant. Thus, hydraulic conductivity of the sand had stabilized and a second test series was made, points D through E of figure 2.

For each test of series 1 and 2, the piezometric head data were converted to potentials. The datum of zero potential was assigned to the water surface elevation in the drain. Potentials are given in table 1 for conditions of point D of test series 2, and equipotentials and streaklines are shown on figure 3. Equipotential lines were drawn for 0.2-ft (0.06-m) increments of head. Also, location of the water table (atmospheric pressure line) was determined from the piezometric head data. Pressures at piezometer taps approximately up to 0.8 ft (0.25 m) above the water table were negative, thus showing the presence of a capillary fringe zone above the water table.

Test results show the hydraulic conditions in the gravel envelope and surrounding base material. Beneath the drain, water converged in direct radial lines toward the envelope (fig. 3). Proceeding counterclockwise around the envelope, convergence became curvilinear. The greatest curvature for streaklines was in the capillary fringe above the water table. The streaklines indicated that flow lines crossed the water table. Other tests did in fact show streaklines crossing the water table. Water entered the capillary fringe from below the water table, showing the water table was not a flow line as commonly assumed in classical treatment of ground-water flow. Note in figure 3 the proximity of equipotentials to the edge of the gravel envelope. About 70 percent of the head loss occurred within one-half the radial distance from the envelope edge to the outer base material edge, 50 percent within one-fourth distance, and about 30 percent within one-tenth distance. A proportionately high head loss occurred in the base material relatively close to the envelope.

Flow characteristics of the gravel envelope are also shown in figure 3. At the tank face a water level was present in the envelope. Above the water level, flow entered the envelope through a "surface of seepage." Blue-dyed water was observed trickling down surfaces of the gravel particles. Piezometric head measurements were unable to detect a head loss for waterflow through the gravel envelope. The gravel envelope efficiently conveyed water from the base material to the drain tubing. Water levels in the gravel envelope varied slightly with discharge. For figure 3 (maximum test discharge), the water level in the gravel envelope was 0.018 ft (5 mm) higher than the water level inside the drain. A 0.018-ft (5-mm) head loss occurred as water flowed through the tubing perforations. For point E (fig. 2), the difference in water levels was 0.002 ft (1 mm).

Hydraulic gradients acting across the base material-envelope interface were desired, but could not be obtained. The irregular surface of adjoining gravel particles made it difficult to precisely locate the interface. Thus, hydraulic gradients were obtained for a location in the base material at a 0.01-ft (3-mm) distance from the intended edge of the envelope. The location was that of the innermost ring of piezometer taps. Hydraulic gradients, acting radially inward, were computed from the piezometric head data. The maximum gradients occurred along a 30° to 60° arc beneath the envelope. For test series 1, point B, the gradient was 3.5 and for test series 2, point D, the gradient was 1.5.

The head loss-discharge relationship was considerably different between test series 1 and 2 (fig. 2). A comparison of potential fields between the two test series indicated hydraulic conductivity of the sand had increased for test series 2. This increase was attributed to removal of air from the sand; air was apparently dissolved by the flowing water. Eight weeks were required for the hydraulic conductivity of the sand to reach equilibrium (change between points B and D of figure 2). The lower hydraulic conductivity, resulting from the entrapped air, contributed to the higher hydraulic gradients of test series 1.

As shown at the face of the tank in figures 4a and 4b, sand penetrated into the gravel envelope; most of this penetration occurred during the settling operations. When the sand and gravel were removed from the box, penetration was found throughout the 2.5-ft (0.8-m) envelope length. On the top and sides of the envelope, penetration varied from 0.5 to 2.0 in (10 to 50 mm). The most extensive penetration was beneath the drain, figures 4c, 4d, and 4e. Penetration varied from 2 in (50 mm) to the entire envelope thickness. Most penetration probably occurred during the settling operation when the maximum head of 4 ft (1.22 m) acted on the system.

CONCLUSIONS

The envelope efficiently conveyed water from the surrounding base material into the drain tubing. For a drain inflow of 2.10 x 10^{-3} ft^3/s per foot (0.195 L/s per meter), the head loss was 0.018 ft (5 mm) for flow from the envelope edge into the tubing perforations. Sand penetrated into the gravel envelope during pretesting operation of the sand tank with high hydraulic heads. Test data indicated a maximum hydraulic gradient of 3.5 acted near the envelope when a head of 2 ft (0.6 m) was imposed on the system. Greater hydraulic gradients undoubtedly occurred during the pretesting operation with a 4-ft (1.2-m) head. The intent of the sand tank tests was to measure the hydraulics of a gravel envelope and the surrounding base material. Because of the difficulty in changing envelopes in the large tank, different shapes or materials for envelopes have not yet been compared. However, the present results provide a base for comparing future test results with basic Service design.

ACKNOWLEDGMENTS

This research study on drain envelopes was inititated by Dr. Lyman Willardson, formerly of the ARS (Agricultural Research Service) 1/ and Ray Winger, Chief of the Drainage and Groundwater Branch (now retired), Water and Power Resources Service. The ARS helped fund the design and construction of the large sand tank.

Table 1. - Potentials of the test of point D of test series 2
Potentials are given in feet of head.

Radial line	Circumferential arc								
	C1	C2	C3	C4	C5	C6	C7	C8	C9
R1	0.042	0.234	0.437	0.594	0.732	0.854		*1.248	*1.406
R2	0.032	0.222	0.433	0.594	0.735	0.880	*1.129	1.248	1.409
R3	0.033	0.213	0.420	0.579	0.736	0.883	*0.978	1.249	1.410
R4	0.038	0.214	0.409	0.579	0.728	0.892	1.058	*1.347	
R5	0.046	0.215	0.414	0.578	0.743	0.897	1.055	*1.189	*1.347
R6	0.058	0.238	0.414	0.591	0.751	0.913	1.074	*1.253	1.417
R7	0.178	0.317	0.466	0.609	0.753	0.914	1.077	*1.241	*1.419
R8	0.268	0.377	0.500	0.614	0.745	0.902	1.072	*1.276	1.423
R9	0.316	0.408	0.504	0.606	0.729	0.872	1.043	*1.174	1.364
R10	0.355	0.418	0.497	0.586	0.682				
R11	0.371	0.424	0.486	0.555	0.627				
R12	0.388	0.428	0.481	0.535					
R13	0.398	0.447	0.482	0.496					
Radius	0.54	0.68	0.86	1.08	1.37	1.73	2.18	2.75	3.47

Radial lines and circumferential arcs are nomenclature for the polar coordinate grid of piezometer taps at the tank face. The radial lines were spaced at 15° intervals, R1 extended vertically downward from the drain centerline, R13 vertically upward. Radii in feet for the circumferential arcs are given by "Radius" row in the table.

* Denotes points off polar grid because of structural members.

1/ ARS has been redesignated as the Science and Education Administration - Federal Research.

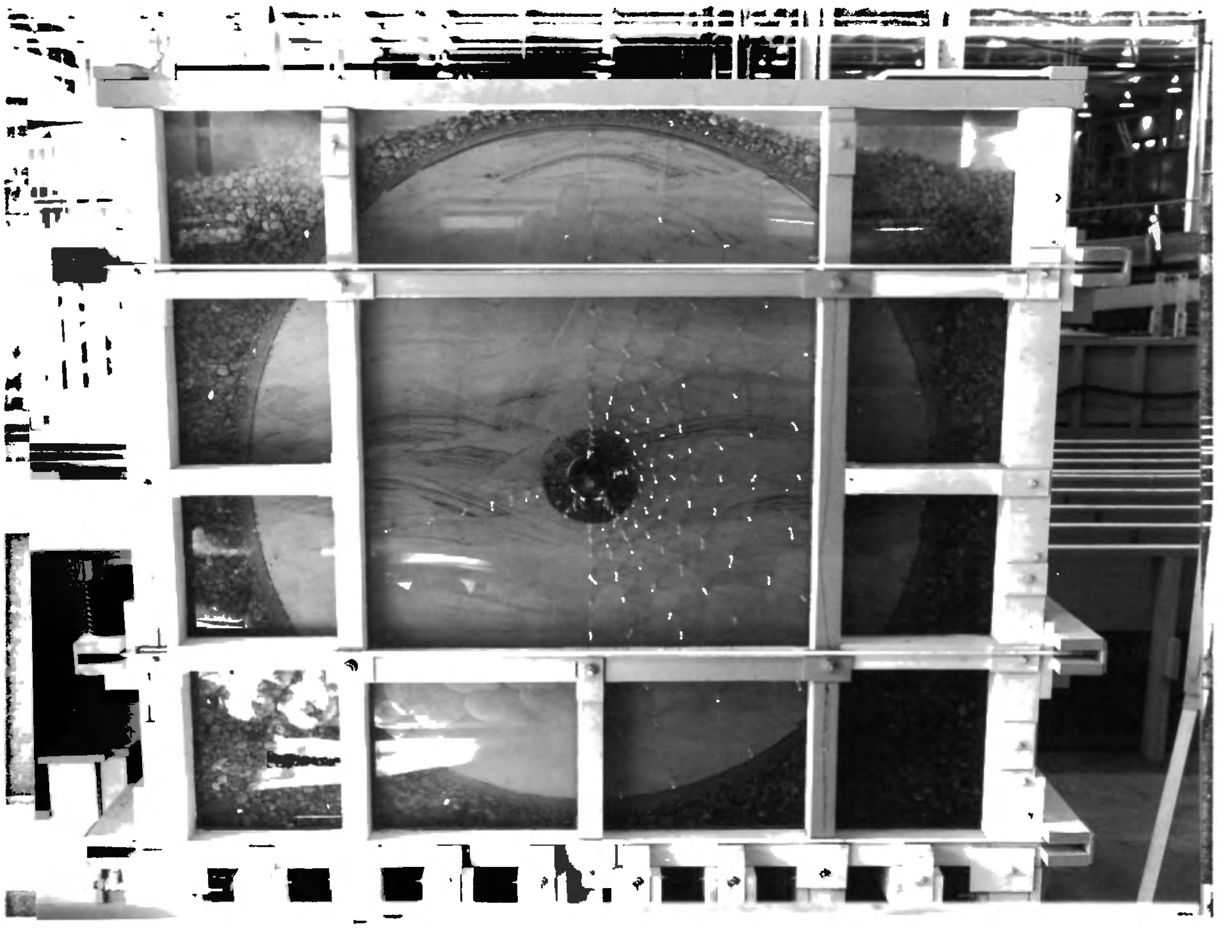


Figure 1. - The sand tank with drain tubing, envelope, and base material.

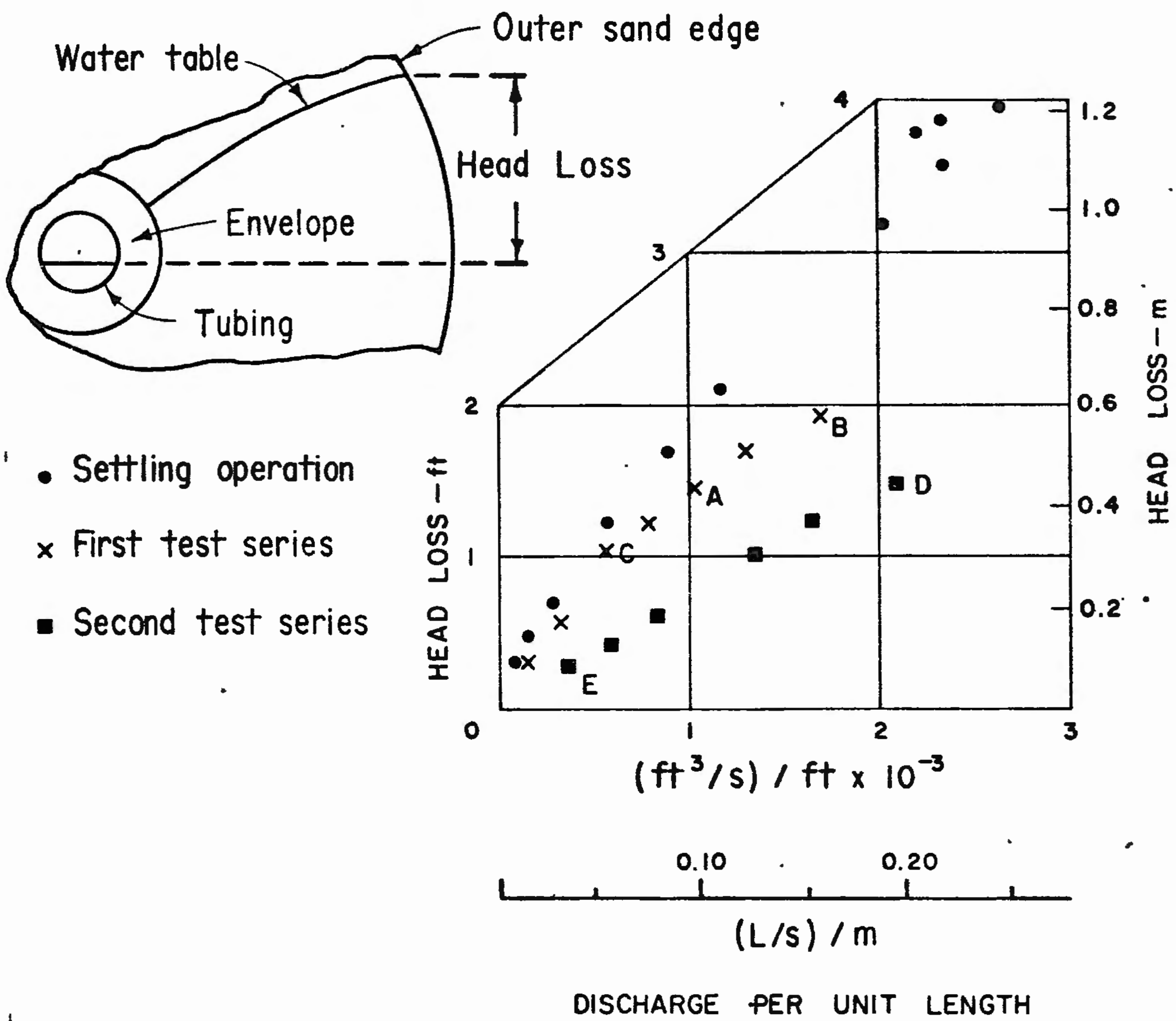


Figure 2. - Head loss-drain discharge.

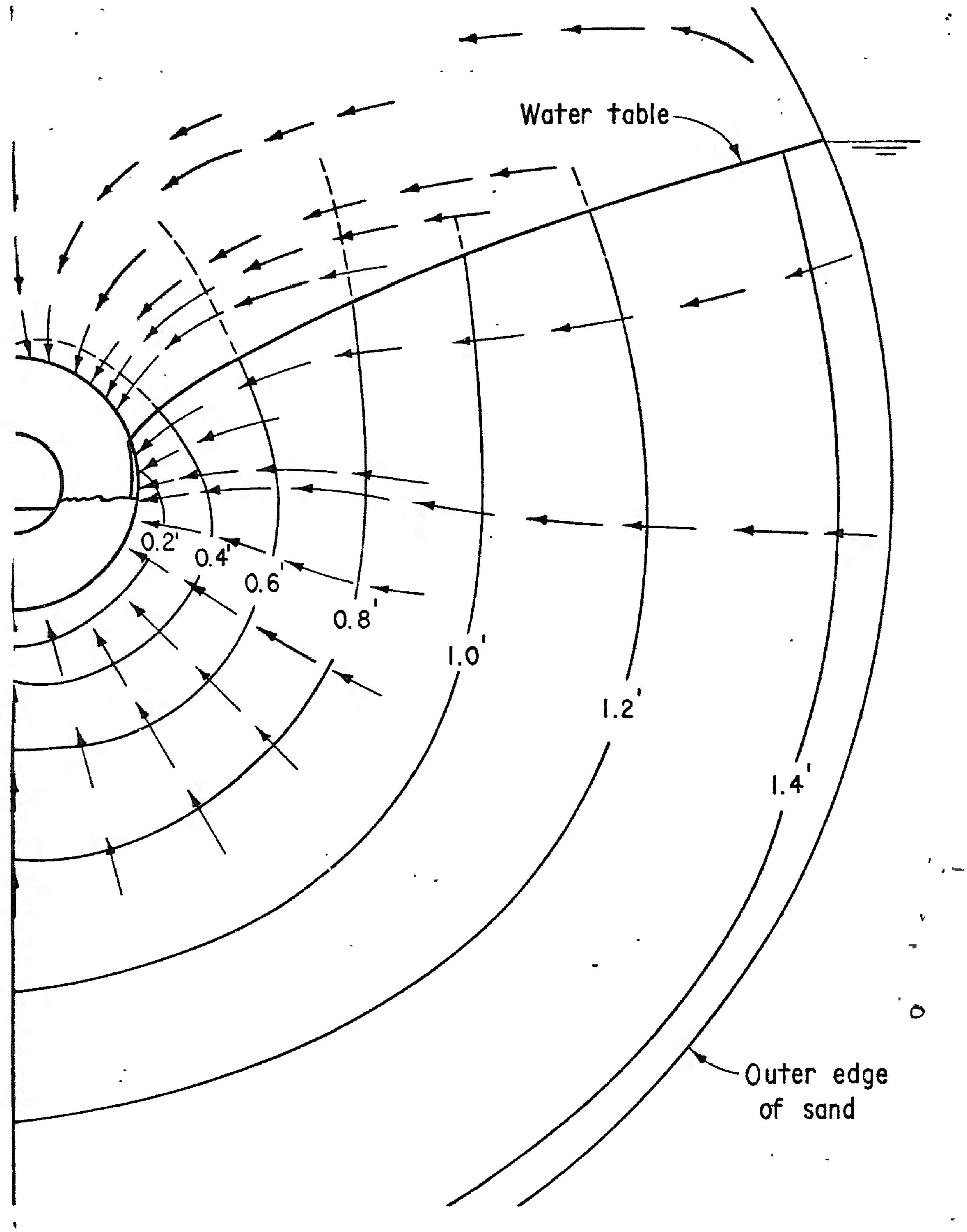
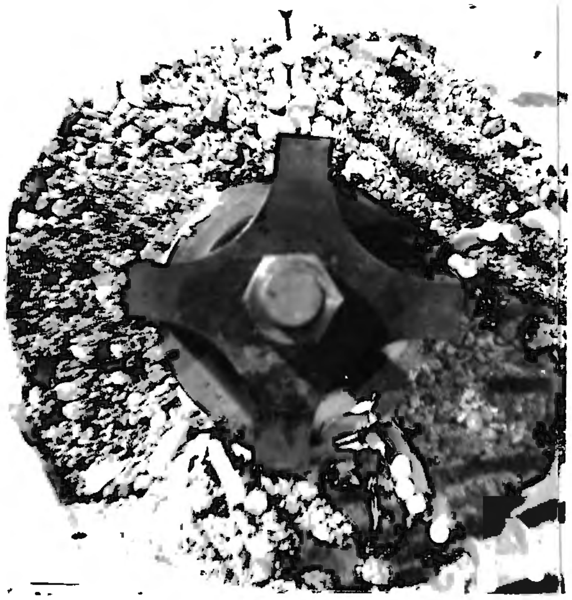


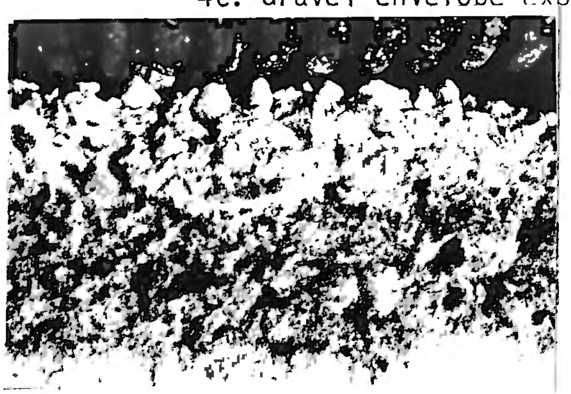
Figure 3. - Sketch of the potential and flow field for for test condition of data point D in figure 2.



4a. Before operation.

4b. After testing and before removing sand.

4c. Gravel envelope exposed beneath the tubing.



4d. Sand penetration to tubing.

4e. Sand penetration almost to tubing.

Figure 4. - Sand penetration into the gravel envelope.

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KEYWORDS: drainage/ subsurface drains/ plastic tubing/ ground-water flow/ flow nets/ water table/ unsaturated flow