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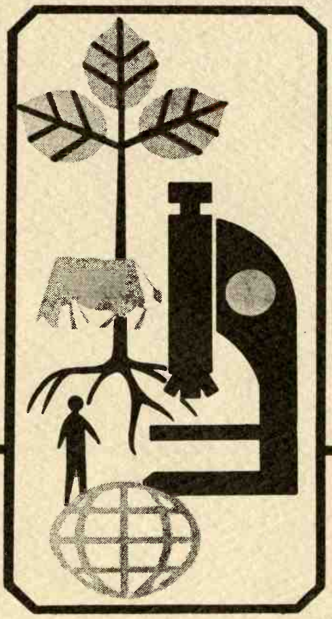
I-Pai Wu and D. D. Fangmeier

The Agricultural Experiment Station • University of Arizona • Tucson, Arizona



Produced in cooperation with Anjac Plastics Incorporated, El Monte, California

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Introduction

Twin chamber tubing is a special tubing developed for trickle irrigation. It consists of a main chamber and a secondary chamber as shown in Figure 1. Water is discharged from orifices in the wall of the main chamber into the secondary chamber, which discharges water for irrigation. The ratio of numbers of orifices in the main to the secondary chamber controls the pressure differences between the two chambers. The orifice discharge from the secondary chamber is relatively small because it is released under a lower pressure than the main chamber pressure. The main advantages of the twin-chamber tubing are that larger orifices can be used without increasing discharge and longer lengths of tubing can be used with a more uniform orifice discharge than with single-chamber tubing.

The design of trickle irrigation laterals is dependent upon the energy relations of flow in the laterals. The pressure distribution along the lateral, which controls the orifice discharge, is a function of the diameter of lateral, input or operating pressure, size and spacing of orifices and lateral line slopes. Recent studies by Myers and Bucks (1) and Wu and Gitlin (2) showed that uniform irrigation can be obtained by using different sizes of orifices or adjusting the size and spacings of orifices according to a known pressure distribution along a lateral line. If a specified degree of non-uniformity is accepted, the length of a lateral line for a given type of trickle system and operating pressure can be selected as reported by Wu and Gitlin (3) for single-chamber tubing.

The purposes of this study were:

1. to develop a simple model for computer simulation of twin-chamber tubing, and
2. to develop design curves from the computed data.

Anjac Bi-Wall was selected and used as an example. The results also apply to Anjac Lay-flat type B tubing.

Flow in Twin-Chamber Tubing

In twin-chamber tubing the main chamber serves as the water supply tube and the secondary chamber serves as a water distribution tube. For purposes of analysis, it was assumed that no net longitudinal flow occurs in the secondary chamber. This is a reasonable assumption if the secondary chamber has a small flow area and the tubing slope is not large.

The hydraulic characteristics of twin-chamber tubing have been studied by Wilke and Wendt (4), Bui (5) and the Engineering Department of the Hawaiian Sugar Planters' Association (HSPA) (6) using laboratory and field studies. The pressure ratios between main and secondary chambers were studied by Bui (5) and HSPA (6) for Chapin Twin-wall and Anjac Bi-Wall, respectively. Bui's laboratory experiments (5) showed an average pressure ratio between main and secondary chambers of about 12 for Chapin twin-wall 18″/72″ (18″/72″ indicates an 18-inch orifice spacing in the secondary chamber and a 72-inch orifice spacing in the main chamber). The HSPA data (6) showed an average pressure ratio of about 10 between the main and secondary chambers for Anjac Bi-Wall 18″/72″. If the pressure ratio between main and secondary chambers is considered constant as indicated (5, 6), then

$$\frac{h}{h'} = C_1 \tag{1}$$

where h is the pressure in the main chamber, h′ is the pressure in the secondary chamber and C_1 is the constant. The main chamber orifice discharges will be

$$q = C_2 a\sqrt{2g\,(h-h')} \tag{2}$$

where q is the orifice discharge from the main chamber, C_2 is the discharge coefficient and a is the area of the orifice in the main chamber. When Equation 1 is substituted into Equation 2 and the constants C_1, C_2, g and are combined, q can be expressed by the pressure in the main chamber only

$$q = C\sqrt{h} \tag{3}$$

The sums of the flow from four adjacent secondary chamber orifices for Anjac Bi-Wall 18″/72″, 24″/96″ and 36″/144″ tubings obtained from HSPA (6) data were plotted as shown in Fig. 2. A single equation was obtained in the form of Equation 3 with C = 0.000012. Thus

$$q = 0.000012\sqrt{h} \tag{4}$$

where q is the main chamber orifice discharge in cfs, and h is pressure head in feet. This demonstrates that the relation in Equation 1 is true and the orifice flow from the main chamber can be determined by the pressure in the main chamber.

The authors are: Associate Professor, Agricultural Engineering Department, University of Hawaii, Honolulu, Hawaii; and Professor, Department of Soils, Water and Engineering, The University of Arizona, Tucson, Arizona, respectively.

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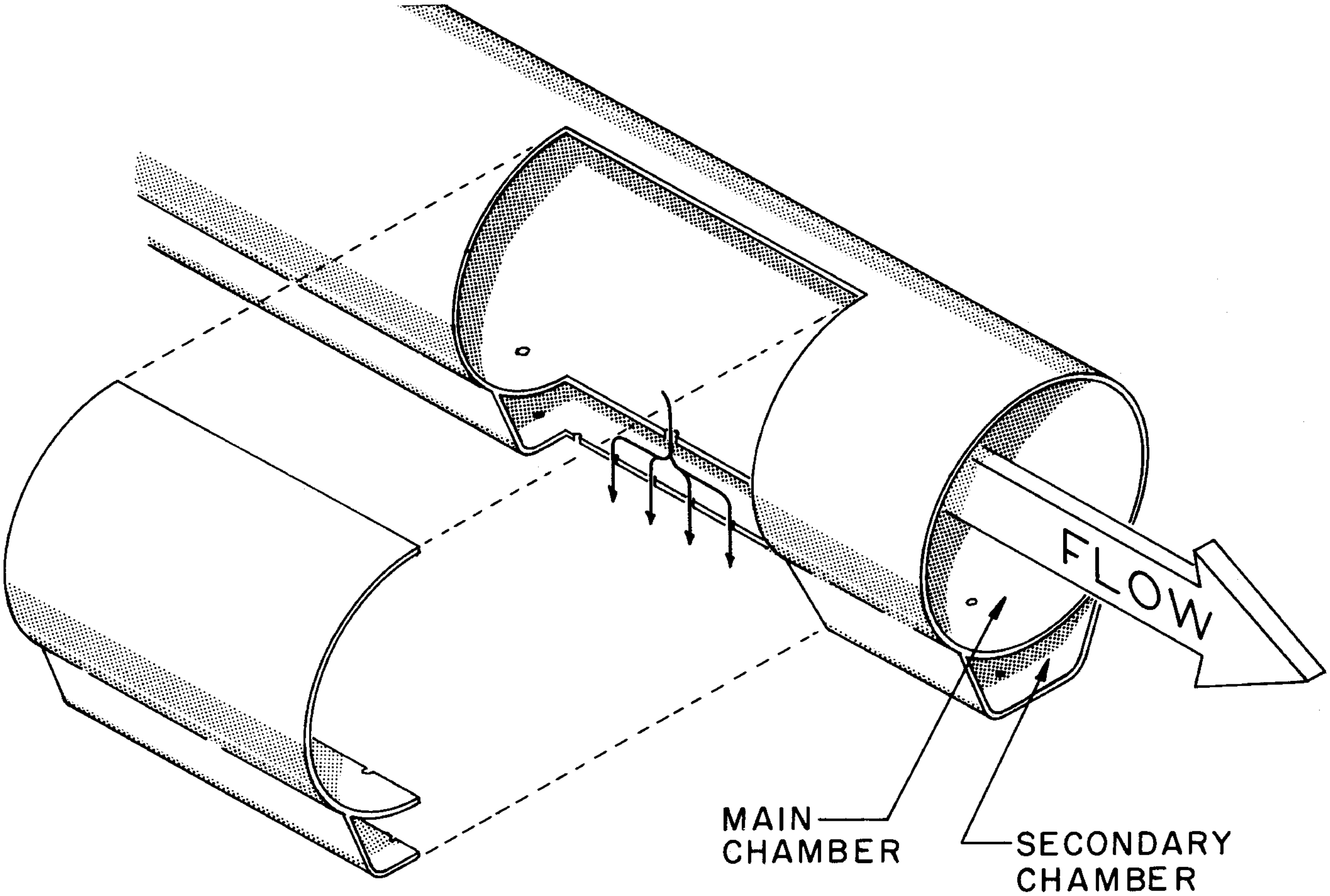

Figure 1. A general sketch of a twin chamber irrigation tubing.

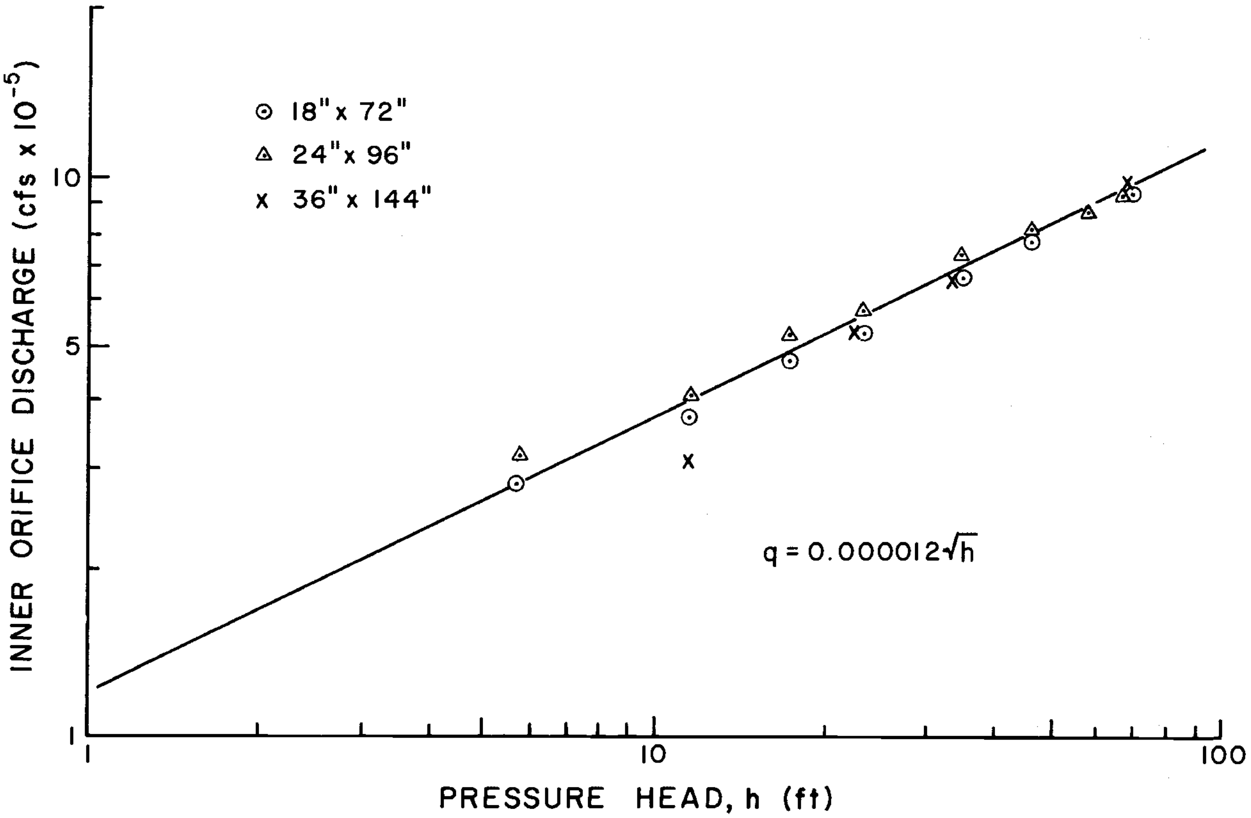

Figure 2. The relationship between pressure head and orifice discharge of the orifices along the main chamber (Anjac Bi-Wall).

Spatially Varied Flow in a Smooth Pipe

Since the main chamber is considered as a water supply tube, the hydraulic analysis of a single chamber can be applied. The flow is steady, spatially varied, and decreasing with respect to the length. The total energy at any section of a trickle line can be expressed by

$$H = z + h + \frac{V^2}{2g} \tag{5}$$

where H is the total energy expressed in feet, z is the potential head or elevation in feet, h is the pressure head in feet, and $V^2/2g$ is the velocity head in feet.

A simple model for computer simulation of the flow was obtained by applying Equation 5 across an orifice and one orifice spacing in the main chamber. Thus

$$z_1 + h_1 + \frac{V_1^2}{2g} = z_2 + h_2 + \frac{V_2^2}{2g} + h_L \tag{6}$$

where h_L is the energy loss due to friction in feet and the subscript 2 denotes the first orifice downstream from an orifice at 1. Rearranging, substituting $V = Q/A$ and $z_2 - z_1 = S_0 \Delta L$ yields

$$h_1 = h_2 + S_0 \Delta L + h_L - \frac{Q_1^2 - Q_2^2}{2g\,A^2} \tag{7}$$

where S_0 is the slope of the tubing, ΔL is the distance between orifices 1 and 2 in feet, Q is the flow in the tubing in cubic feet per second and A is the flow area of the main chamber. Factoring the last term substituting $Q_1 - Q_2 = q$ and rearranging gives

$$h_1 = h_2 + S_0 \Delta L + h_L - \frac{Q_1 q}{gA^2} + \frac{q^2}{2gA^2} \tag{8}$$

The head lost by friction can be evaluated from the Darcy-Weisbach equation

$$h_L = f \frac{L}{D} \frac{V^2}{2g} \tag{9}$$

where D is the diameter of the main chamber. The friction coefficient f can be evaluated for the three types of flow conditions; laminar, transition and turbulent,

$$f = \frac{64}{N_r} \qquad \text{for } N_r < 2000 \tag{10}$$

$$f = 3.42 \times 10^{-5} N_r^{0.85} \qquad \text{for } 2000 < N_r < 4000 \tag{11}$$

$$f = \frac{0.316}{N_r^{0.25}} \qquad \text{for } N_r > 4000 \tag{12}$$

where N_r is Reynold's number based on main chamber diameter and Equation 12 is the Blasius equation for turbulent flow in a smooth pipe.

Computer Simulation and Laboratory Results

A Fortran computer program was developed to evaluate pressure and orifice discharge along the main water supply line. The program was designed to calculate pressure and discharge distribution from the downstream end toward the upstream. The required inputs were main chamber diameter, orifice spacing, pressure (at downstream end), slope, and orifice discharge-pressure relationship (Equation 4). An example is given to show the application of the computer program and the validity of the simulation model by using an Anjac Bi-Wall trickle irrigation tubing. The main chamber diameter of this tubing is 0.61 inches and the orifices are 0.020 inches in diameter.

Equations 4 and 8 were used in the computer simulation program and results obtained for different downstream pressures, h (5′ to 80′) and different slopes, S_0 (+ 5% to −5%). The computer simulated results can be plotted as in Figure 3 which shows the input pressure, length of laterals and total head loss for Anjac Bi-Wall 18″/72″ at a zero slope. Figure 3 was obtained by plotting many computed and measured (6) data points which were used to draw curves representing selected values of head loss. Similar charts can be plotted for different slopes (plus and minus) and for different orifice spacings such as 24″/96″ and 36″/144″.

Simulated results were also plotted in Figures 4 and 5 for comparison with measured data (6). Figure 4 shows the comparison of total discharges for different tubing lengths at zero slope at an input pressure of 10 psi. The comparison shows the variations between measured and calculated discharges for 18″/72″, 24″/96″ and 36″/144″ tubings. The agreement is satisfactory except for long lengths of tubing. The agreement is not as good for up and down slope laterals (Figure 5). However, for short laterals it was still very satisfactory. Based on the comparisons in Figures 3, 4 and 5, it is concluded that the computer simulation model could be used to estimate pressure and discharge distributions along twin chamber trickle irrigation laterals.

Design Criteria

Design criteria for a trickle irrigation system are not well defined. Myers and Bucks (1) have reported that a 100% uniform irrigation can be achieved. If some non-uniform distribution is allowed, trickle irrigation laterals can be designed for a given degree of non-uniformity of the orifice discharge. Since the trickle tubing irrigates discrete points, it might be reasonable to use the variations of orifice discharge as a design criterion. Howell and Hiler (7) proposed to maintain the emitter flow ratio above 0.90, which is equal to a 10% emitter discharge variation. In this study a 10% orifice discharge variation is used,

$$\frac{q_{max} - q_{min}}{q_{max}} 100 = 10\% \tag{13}$$

or

$$\frac{q_{min}}{q_{max}} 100 = 90\% \tag{14}$$

where q_{max} and q_{min} are maximum and minimum orifice discharge, respectively.

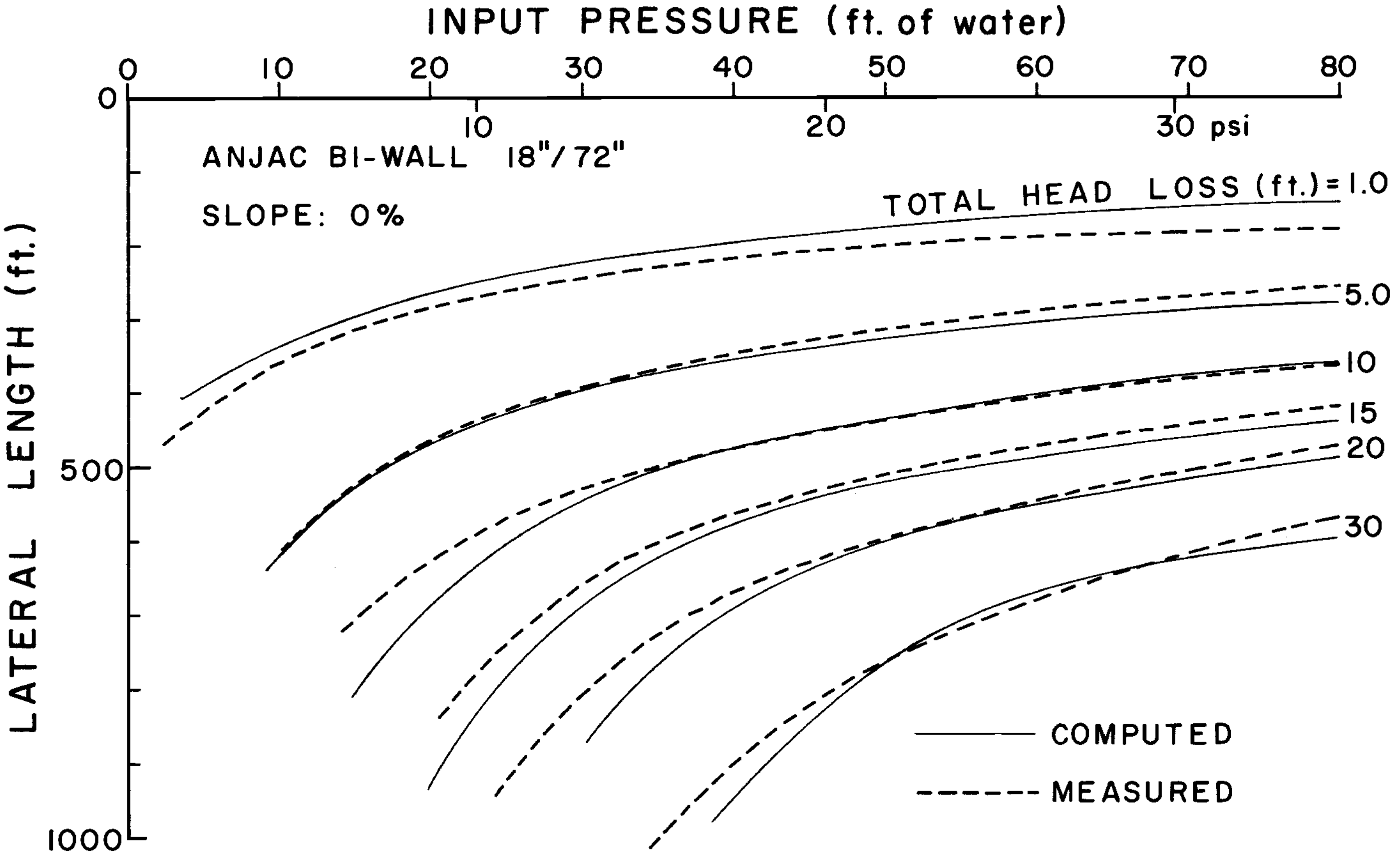

Figure 3. The total head loss for various input pressures and lateral lengths of 18"/72" Anjac Bi-Wall tubing on zero slope.

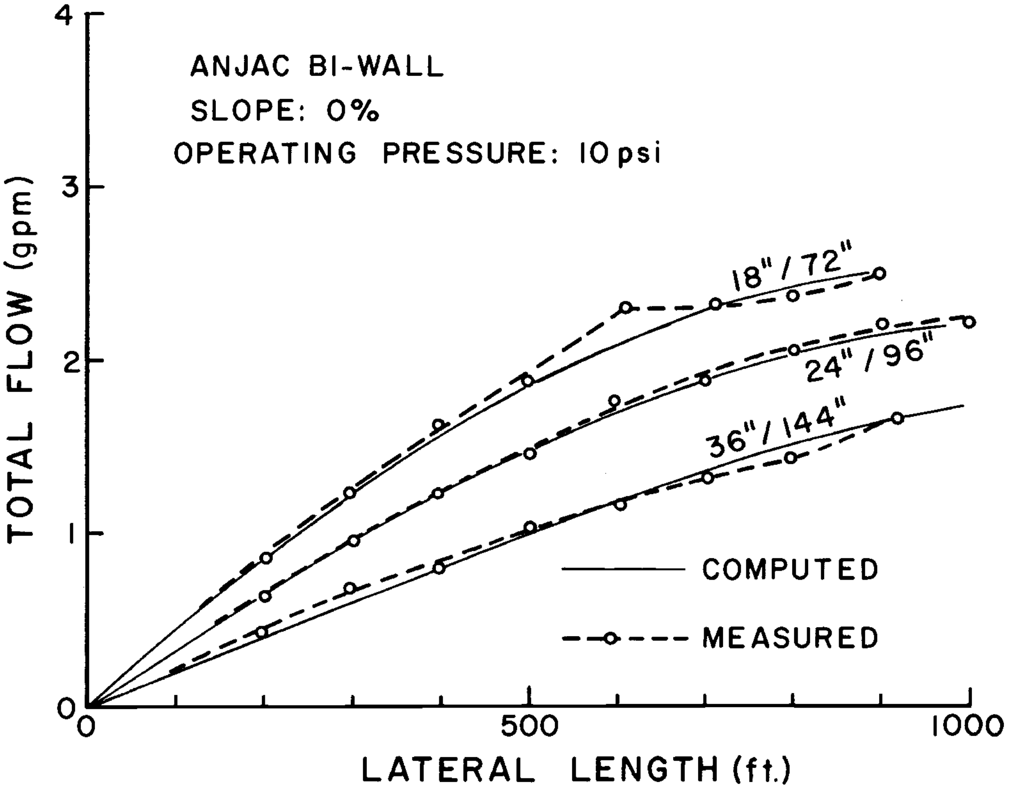

Figure 4. A comparison of computed and measured total flow for different lateral lengths of Anjac Bi-Wall on zero slope.

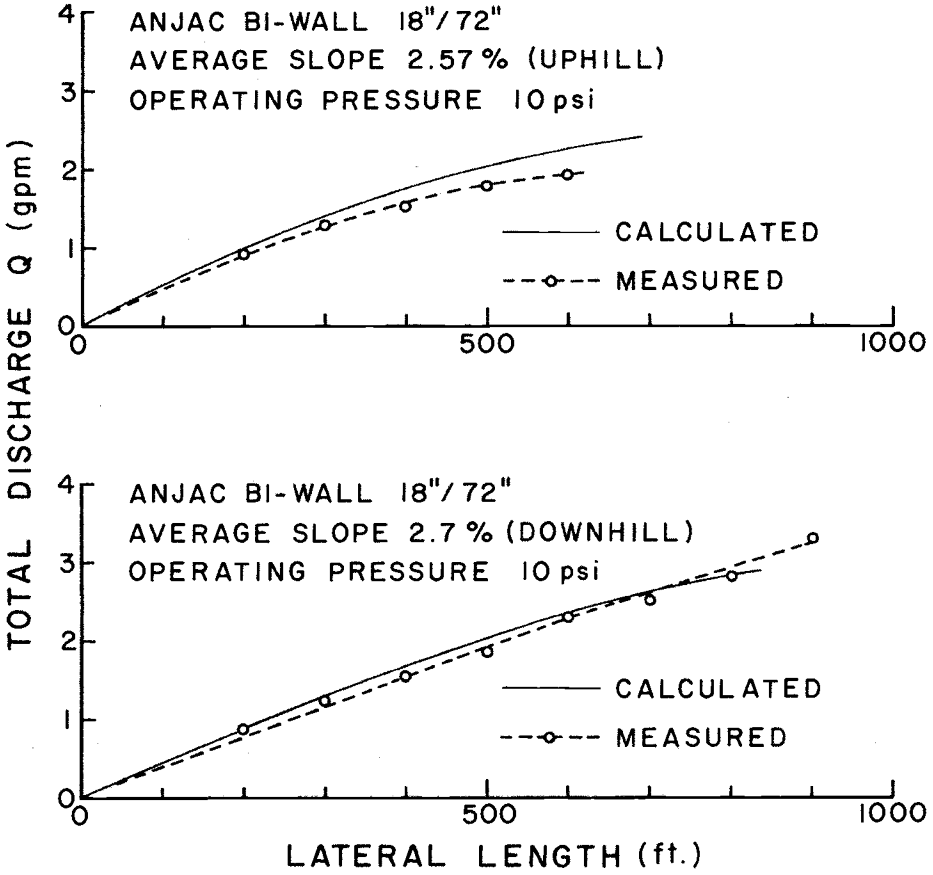

Figure 5. A comparison of computed and measured total discharge for Anjac Bi-Wall 18"/72" tubing laid on two different slopes.

Orifice Discharge Distribution and Total Discharge

The profile or orifice discharge along a lateral will be similar to the pressure distribution since orifice discharge is a function of the water pressure as expressed by Equation 4. Three general types of orifice discharge profiles occur as shown in Figure 6. These profiles occur because of the restrictions of Equations 13 or 14, hydraulic losses in the tubing, change of velocity head, and gain or loss of head by slopes. The three general profiles are explained as follows:

Type 1—Orifice discharge decreases with respect to the lateral length. This type occurs when the lateral line is laid on zero or uphill slopes. In this condition q_{max} is determined by the input (operating) pressure.

Type 2—Orifice discharge decreases with respect to the lateral length and reaches a minimum discharge point and then increases with respect to the length of lateral line. This is caused by the situation that a gain of energy by slopes at downstream points is larger than the energy drop by friction. This type usually occurs when the lateral line is laid on small downhill slopes. In this condition q_{max} is determined by the input pressure.

Type 3—Orifice discharge increases with respect to the lateral length. This is caused by the steep slopes where the energy gain is larger than hydraulic losses for all sections along the lateral line. In this condition q_{min} is determined by the input pressure.

The total discharge can be estimated by using mean orifice discharge with little error. The mean orifice discharge can be estimated by

$$q_{mean} = \frac{q_{max} + q_{min}}{2} \qquad (15)$$

The total discharge can then be calculated by

$$Q = Nq_{mean} \qquad (16)$$

where N is the total number of orifices. The total discharge for each discharge profile (as shown in Figure 6) can be determined as follows:

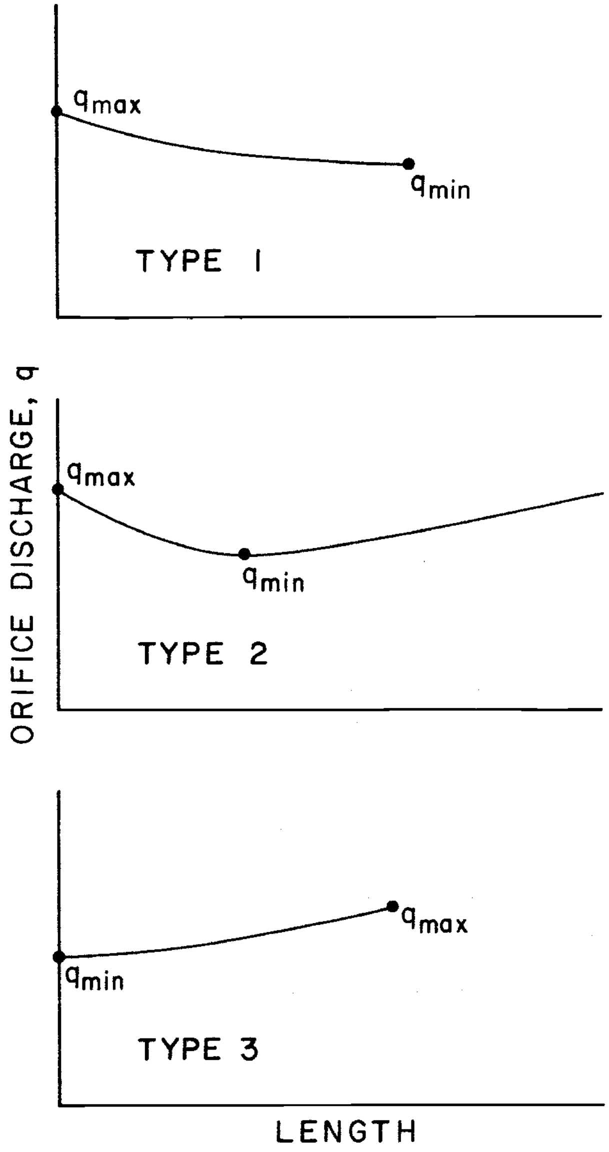

Figure 6. Three types of orifice discharge distribution profiles with respect to lateral length.

1. **Type 1**—The total discharge is calculated by Equation 16. Substituting Equations 14 and 15 into Equation 16 and considering that q_{max} is the orifice discharge q_0 caused by the input or operating pressure, the total discharge for 10% discharge variation will be

$$Q = 0.95N\, q_0 \qquad (17)$$

2. **Type 2**—Since q_{max} is the orifice discharge, q^o, caused by input pressure, the same relation shown in Equation 17 can be used.
3. **Type 3**—In this type, q_{min} is the orifice discharge q_0 caused by input pressure, the total discharge for 10% discharge variation will be

$$Q = 1.055\, N\, q_0 \qquad (18)$$

The effectiveness of using Equation 15 to estimate mean orifice discharge and Equations 17 and 18 to calculate the total discharge is shown in Figure 7. It was found that the calculated total discharge using Equations 17 and 18 will cause only a 2% overestimation of experimental data.

Design Charts

Simulation results from the computer model provided the discharge and pressure distribution along a lateral line for different combinations of input pressure, length and slope. These simulated results were used to develop design charts for a maximum orifice discharge variation of 10%. These charts are shown in Figures 8 to 13 for Anjac Bi-Wall 18″/72″, 24″/96″ and 36″/144″ tubings. Figures 8 to 10 show curves for zero and several downhill slopes and Figures 11 to 13 show curves for zero and several uphill slopes. The zero and uphill slope curves are smooth. The downhill curves are not smooth because either Type 2 or 3 orifice discharge distribution profiles may occur. This causes a discontinuity to occur at the transition from Type 2 to Type 3 profiles.

Although the design charts were developed to obtain answers for specific conditions, they show some interesting trends. First for uphill slopes and Type 3 profiles on downhill slopes, increasing the pressure will improve the discharge uniformity. Second, for long lengths on downhill slopes there is a slight improvement in uniformity if the pressure is decreased as long as the discharge pattern fits the Type 2 profile. Third, the zero slope curves provide an estimate for the maximum lateral lengths on downhill slopes.

The design charts may be used with a given slope to determine either the maximum lateral length for a given input pressure or the minimum input pressure for a given length. As an example on chart use, assume an input pressure of 20 feet, a 1% uphill slope and 24″/96″ tubing. In Figure 12 read vertically from 20 feet of pressure to the 1% slope curve, then horizontally to the length axis. The maximum length is 280 feet. A shorter length will have a more uniform discharge. If a 1% downhill slope (Figure 9) and a length of 600 feet are assumed, two input pressures are obtained, 31 feet and 21 feet. This means either pressure or anything in between will satisfy the design criteria of 10% or less discharge variation. The minimum pressure would reduce costs and should be selected.

A design chart was developed for determining discharge per 100 ft. Q_{100}, as shown in Figure 14. The discharge Q_{100} is calculated using q_0 and number of orifices per 100 feet

$$Q_{100} = q_0 \times \frac{100}{\Delta L} \qquad (19)$$

where ΔL is the orifice spacing in the main chamber in feet. Figure 14 shows the discharge for Anjac Bi-Wall, 18″/72″, 24″/96″ and 36″/144″ with input pressures up to 30 psi. The total discharge (design discharge) can be determined depending on the discharge profile types as follows:

1. **Type 1**—The total discharge can be determined from Equations 17 and 19

$$Q = 0.95\, Q_{100} \left(\frac{\text{Length}}{100}\right) \qquad (20)$$

2. **Type 2**—The total discharge can be determined by using the same equation, Equation 20, as used in Type 1.
3. **Type 3**—The total discharge can be determined by

$$Q = 1.055\, Q_{100} \left(\frac{\text{Length}}{100}\right) \qquad (21)$$

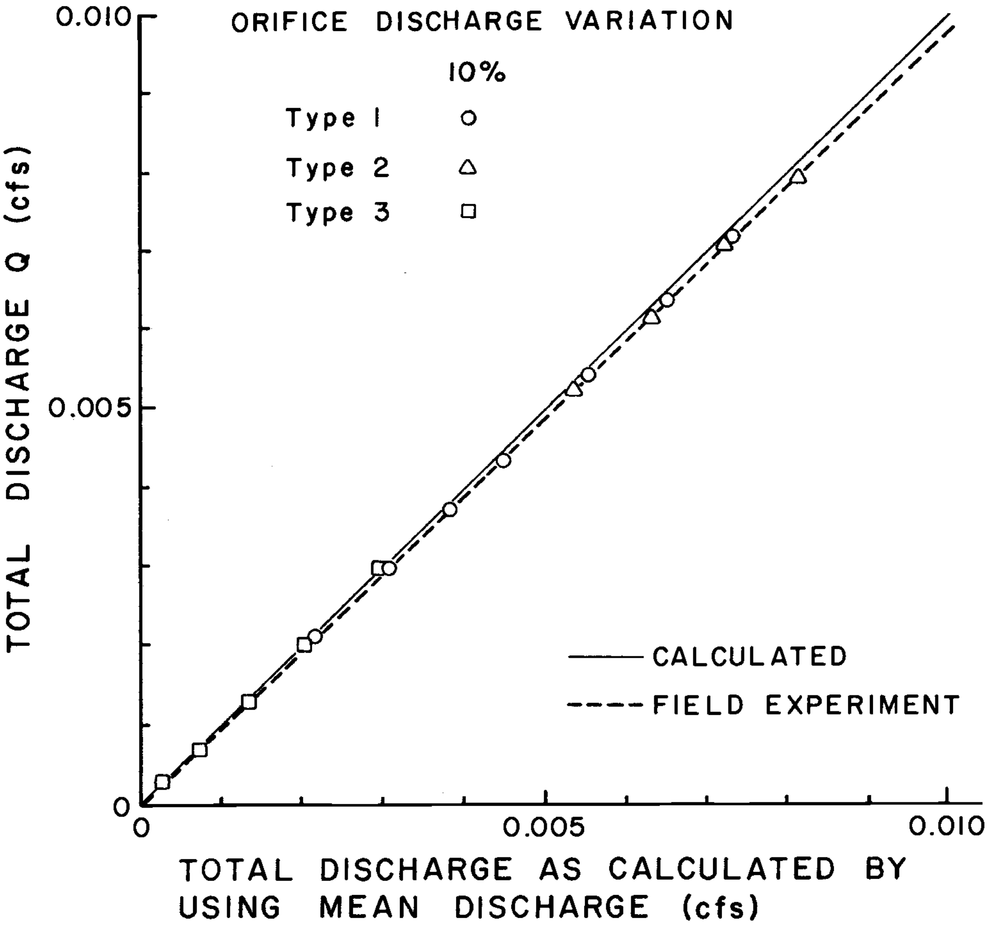

Figure 7. The relationship between total discharge and the estimated total discharge by using mean discharge.

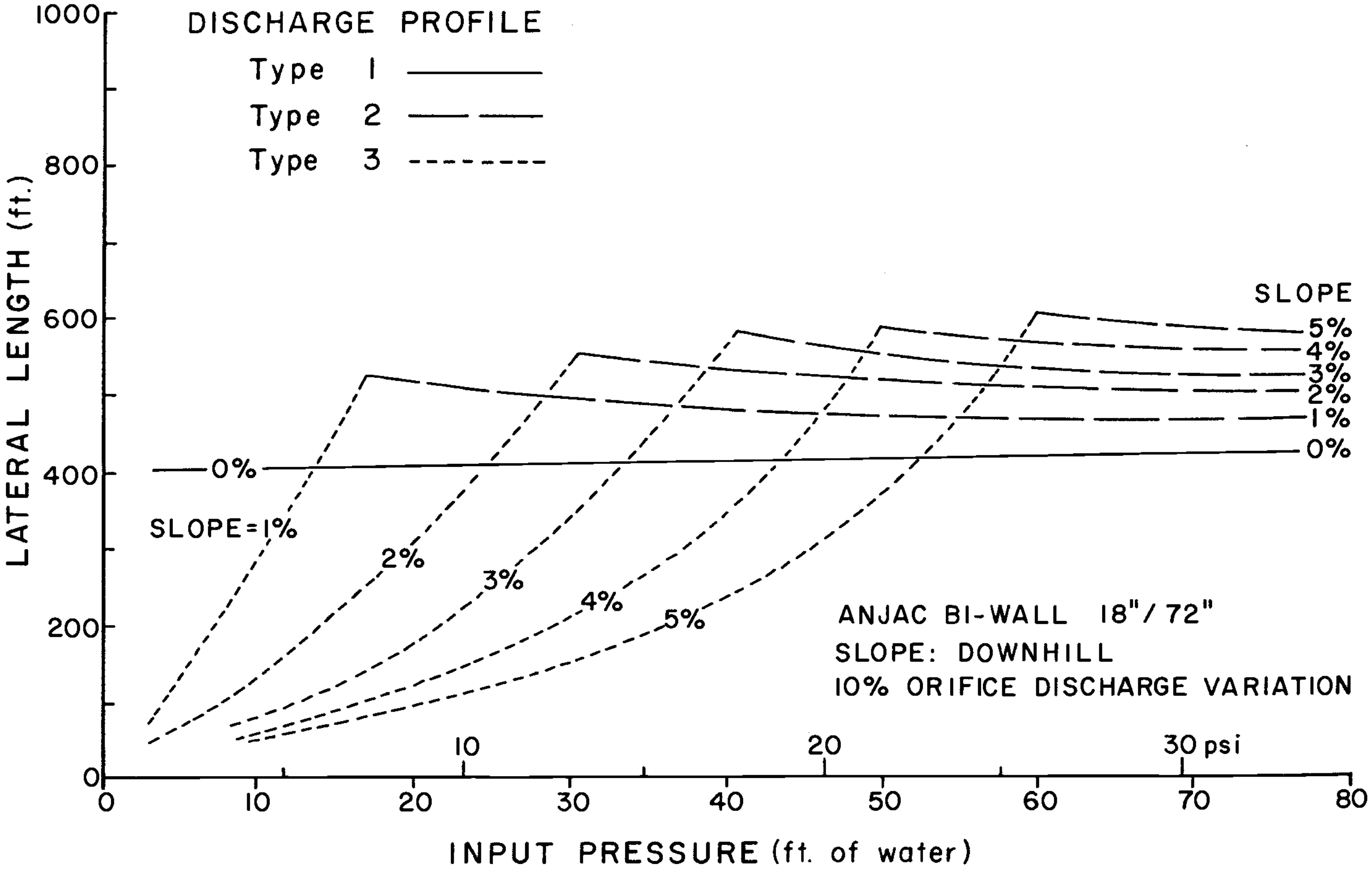

Figure 8. Design chart for Anjac Bi-Wall 18"/72" laid on downhill slopes.

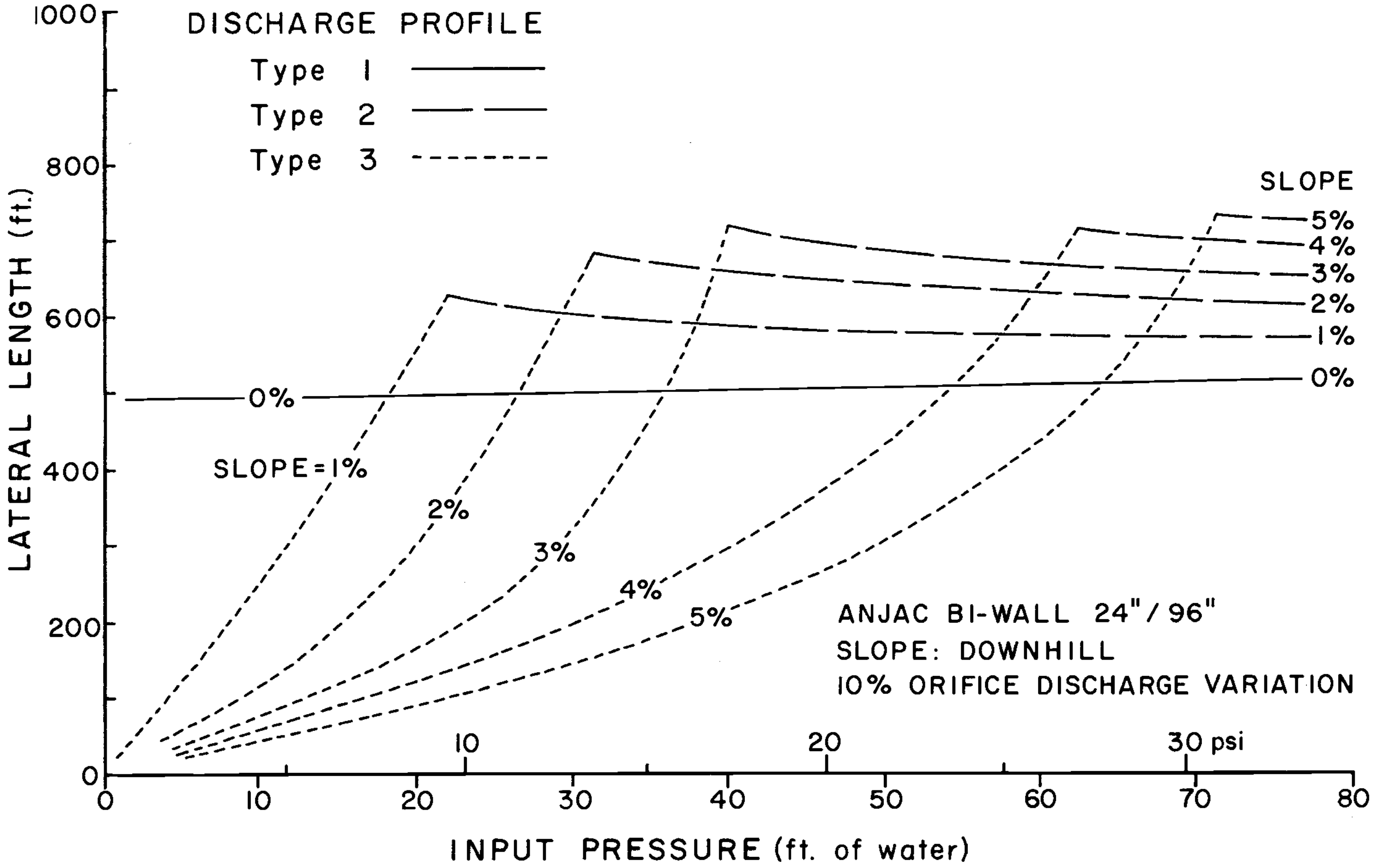

Figure 9. Design chart for Anjac Bi-Wall 24"/96" laid on downhill slopes.

Engineering Application

Figures 8 to 14 can be used for determining lateral lengths or input pressures and the total discharge. An example is given as follows to show the engineering application and design procedures.

a. Given information

Lateral length = 500 ft
Slope (downhill) = 1%
Trickle irrigation tubing selected: Anjac Bi-Wall 18"/72"
Maximum orifice discharge variation: 10%

b. Design operating pressure

From Figure 8, the operating pressure is found to be 7 psi. A line denoting 500 feet of lateral also intersects the Type 2 curve at 12 psi. Thus, any pressure between 7 and 12 psi can be used. The lower pressure will decrease the operating costs.

c. Design total discharge Q

From Figure 14, the discharge per 100 feet for 12 psi is

$Q_{100} = 0.48$ gpm.

The total discharge can be determined from Equation 20.

$$Q = 0.95 \times 0.48 \times 5.0$$
$$= 2.28 \text{ gpm}$$

For 7 psi the discharge per 100 feet is

$Q_{100} = 0.34$ gpm

Total discharge is determined from Equation 21.

$$Q = 1.055 \times 0.34 \times 5.0$$
$$= 1.79 \text{ gpm}$$

The input or operating pressure selection may also be based on the desired lateral discharge which ranges between 1.79 and 2.28 gpm.

If a lateral 300 feet long is laid on a 1% uphill slope, the design chart in Figure 11 will be used and similar procedures used to determine the pressure and total discharge. The input pressure is 27 feet and the discharge is 1.34 gpm.

Summary and Discussion

The hydraulic analysis of a twin-chamber irrigation tubing can be made by considering the main chamber as the supply tube and the secondary chamber as the distribution tube. By doing so, the hydraulic analysis of a single chamber trickle irrigation tube can be used to determine both the pressure and discharge distribution along a twin-chamber irrigation tube.

A computer program was developed to calculate pressure and discharge distribution along a twin-chamber trickle irrigation lateral line. The program uses the Darcy-Weisbach equation for hydraulic loss in the main or supply chamber. The friction coefficient is obtained using separate equations for laminar, transitional and turbulent flow. The computer program calculated the pressure and orifice discharge distribution along a line up to 1,000 feet in length under input pressures ranging from 5 to 30 psi with slopes ranging from plus to minus 5 percent. The validity of the computer program was checked by comparing results with data from laboratory and field experiments.

Design charts were developed for 18"/72", 24"/96" and 36"/144" orifice spacings to determine maximum lateral length or input pressure and the total discharge. Anjac Bi-Wall with 18"/72" spacings was selected as an example to show the development of design charts and the procedures of engineering application. Similar design charts can be developed for other spacings of Anjac Bi-Wall or other types of twin-chamber trickle irrigation tubes. The same technique can also be used to develop design charts for single chamber irrigation tubes.

Acknowledgments

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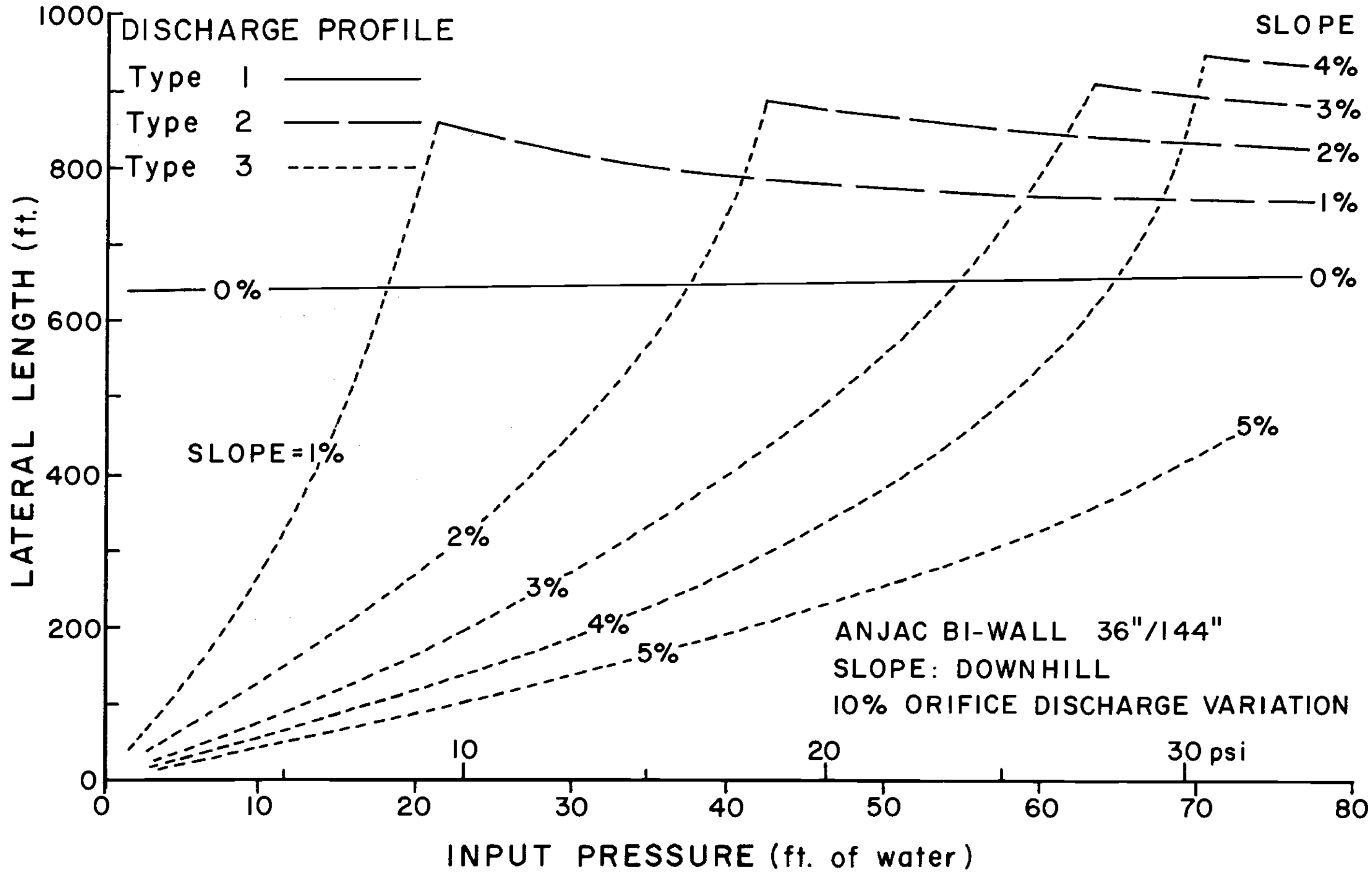

Figure 10. Design chart for Anjac Bi-Wall 36"/144" laid on downhill slopes.

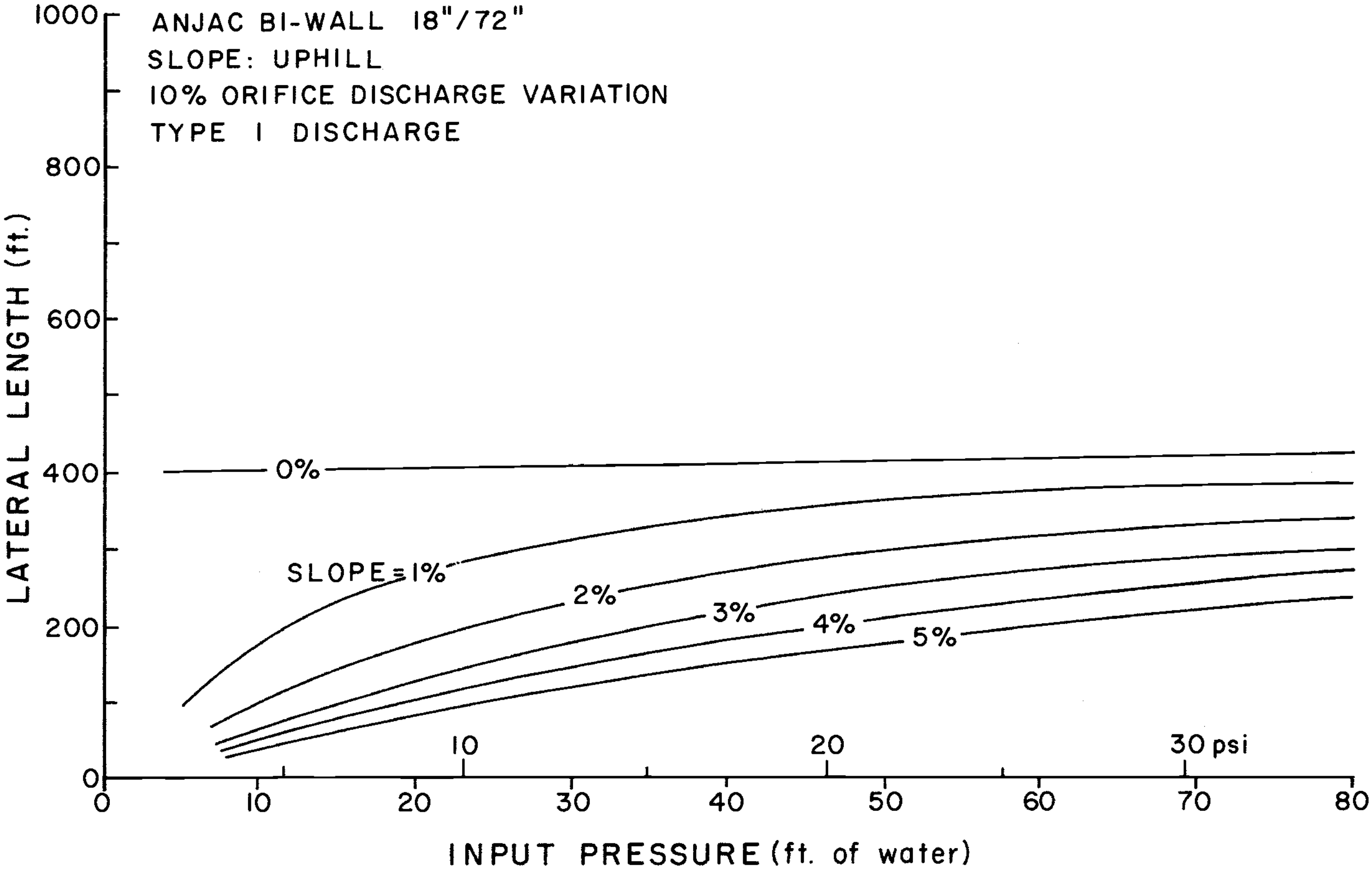

Figure 11. Design chart for Anjac Bi-Wall 18"/72 laid on uphill slopes.

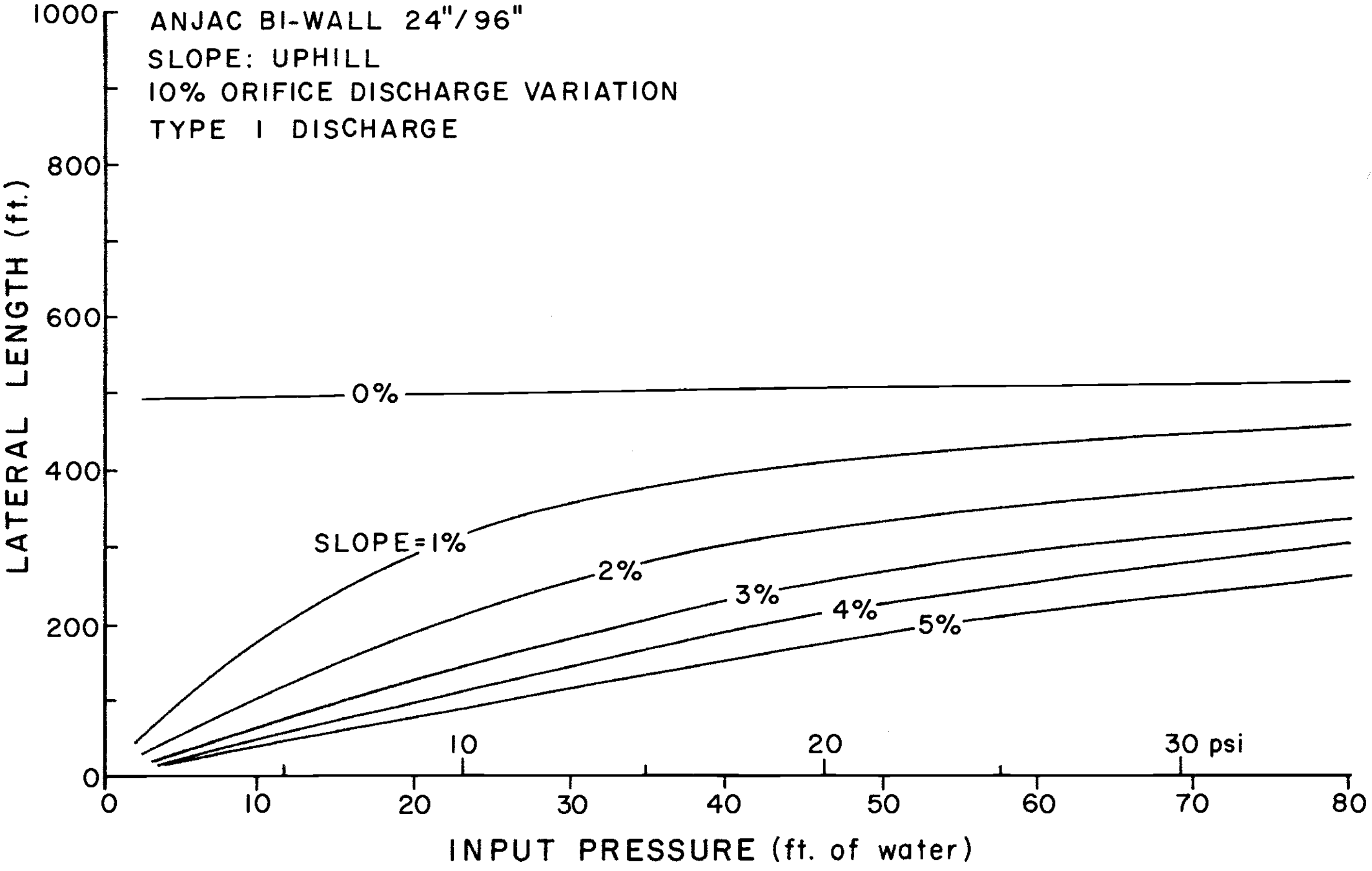

Figure 12. Design chart for Anjac Bi-Wall 24"/96" laid on uphill slopes.

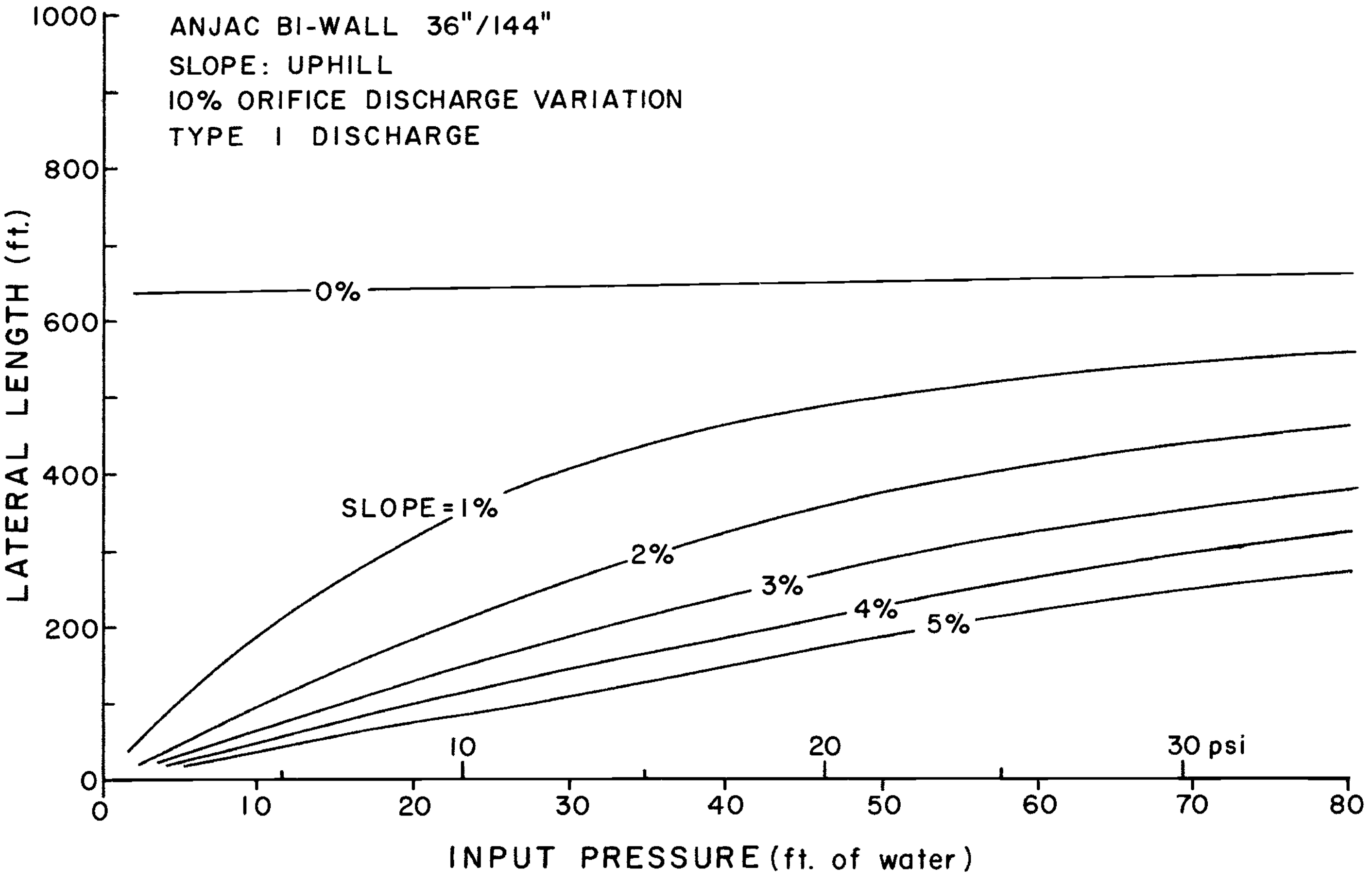

Figure 13. Design chart for Anjac Bi-Wall 36"/144" laid on uphill slopes.

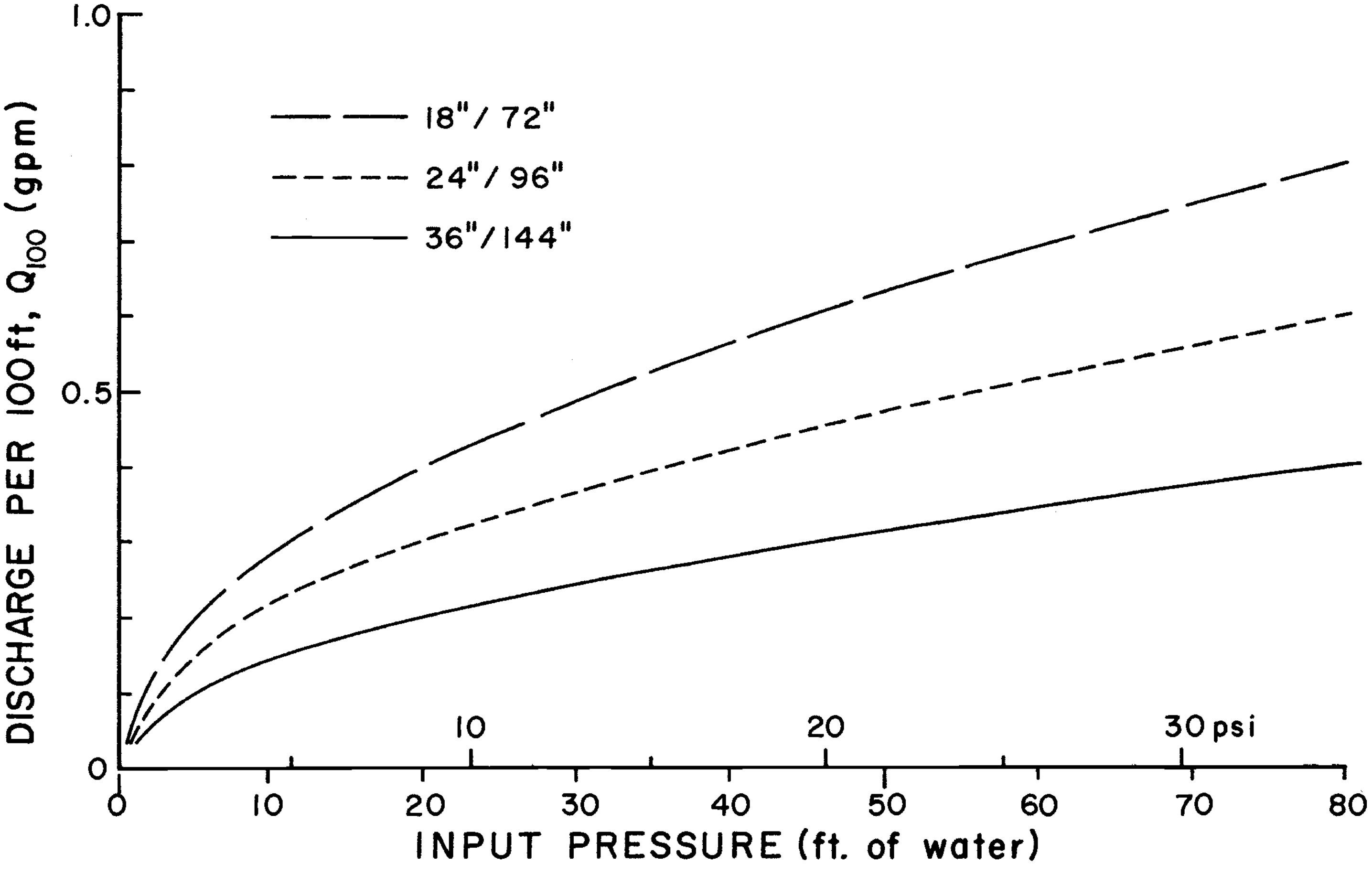

Figure 14. Determination of discharge per 100 ft., Q_{100} for Anjac 18"/72", 24"/96", 36"/144" tubings.