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16. ABSTRACT

Three selected sump grates were tested to evaluate their hydraulic and debris handling performance in a sump condition. The grates were selected based on the results of a previous study - Bicycle-safe Grate Inlets Study - Volume 1 - Hydraulic and Safety Characteristics of Selected Grate Inlets on Continuous Grades. The major objective of the initial study was to identify, develop, and analyze selected grate inlets which maximize hydraulic efficiency and bicycle safety.

Six sizes of each sump grate design were tested on a 1:2 scale model representing a sump condition at the bottom of a vertical sag. The grates were tested using a longitudinal slope of 0.2 percent and roadway cross slopes of 1/48, 1/24, and 1/16 with gutter flows represented up to 30 ft^3/s (0.85 m^3/s). Numerous design curves are provided to aid the hydraulic design engineer with sump grate selection.

17. KEY WORDS AND DOCUMENT ANALYSIS

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b. *IDENTIFIERS*-- / sump grates/ vertical sag

c. *COSATI Field/Group* COWRR:

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2. Drafting - Joseph Santillana
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The contract was monitored by Dr. D. C. Woo, Contract Manager, Environmental Design and Control Division, Federal Highway Administration.

NOTATION

A = cross sectional flow area, ft^2 (m^2)

A_o = cross sectional area of curb opening

A_g = cross sectional area of clear opening of grate

C_o = orifice discharge coefficient

C_w = weir discharge coefficient

g = gravitational acceleration

h = height of curb opening

L = length of sump grate or curb opening

n = Manning's coefficient of roughness

Q_T = gutter flow

S_O = longitudinal slope

S_X = cross slope = 1/Z

W = width of grate

y = depth of flow at curb

y' = depth of flow at outside edge of grate

CHAPTER 1

INTRODUCTION

This volume presents the results of hydraulic and debris tests conducted on three selected grates slightly modified for use in a sump condition (low point of a vertical curve). The three grate designs were identified in volume 1 (1)* as hydraulically efficient and bicycle safe. The objective of the original study was to identify, develop, and analyze selected grate inlets which maximize hydraulic efficiency and bicycle safety. As a result of the original study, three of the eight grates tested were identified as superior in performance, using the criteria of bicycle safety, hydraulic efficiency, and debris handling ability. The three grates included:

1. Parallel bar grate with 3/4 in (19 mm) spacers (smaller than the 7/8 in (22 mm) narrowest bicycle tires), designated the P - 1-1/8, because the center-to-center spacing of the parallel bars was 1-1/8 in (28.6 mm)

2. Parallel bar grate with a 1-7/8 in (47.6 mm) center-to-center spacing of the parallel bars, and transverse rods spaced 4 in (102 mm) on centers designated P - 1-7/8 - 4

3. Curved vane grate, designated CV - 3-1/4 - 4-1/4, because the longitudinal bars were spaced 3-1/4 in (82.6 mm) center-to-center and the transverse curved vane members were spaced at a nominal 4-1/4 in (108 mm).

In order to provide extra protection against debris accumulation in a sump condition, a 4-1/4 in (108 mm) high curb opening was added along the entire length of each grate. The combination of the grate and the curb opening is defined as the sump grate in this report.

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* Numbers in parentheses refer to references at the end of the chapter.

REFERENCES

1. Burgi, P. H., and Gober, D. E., "Bicycle-Safe Grate Inlets Study, Vol. 1, Hydraulic and Safety Characteristics of Selected Grate Inlets on Continuous Grades," Federal Highway Administration, Report No. FHWA-RD-77-24, June 1977.

CHAPTER 2

TEST FACILITY AND EXPERIMENTAL APPROACH

Test Facility

To properly study the performance of the selected sump grate designs, the test facility as shown in figures 5-1 and 5-2 of volume 1 was modified for a curb opening as illustrated in figure 2-1. The facility was further modified to accommodate the following field conditions:

1. Longitudinal slope S_0 = 0.2 percent
2. Cross slope 1/Z = 1/48 to 1/16
3. Maximum flow depth (full scale) y = 10 in (254 mm)
4. Manning roughness factor n = 0.016 to 0.017
5. Grate inlet sizes:

   3 ft by 4 ft (0.91 m by 1.22 m)
   3 ft by 2 ft (0.91 m by 0.61 m)
   2 ft by 4 ft (0.61 m by 1.22 m)
   2 ft by 2 ft (0.61 m by 0.61 m)
   1.25 ft by 2.67 ft (0.38 m by 0.81 m)
   1.25 ft by 2 ft (0.38 m by 0.61 m)

6. Grates tested:

   P - 1-1/8
   P - 1-7/8 - 4
   CV - 3-1/4 - 4-1/4

For each grate tested, a 4-1/4 in (108 mm) high curb opening was added along the entire length of the grate for this study.

To test the maximum size grate with a flow depth of 10 in (254 mm) would require a larger discharge than available on the facility (5.5 ft^3/s (0.16 m^3/s)). Therefore, the sump tests were conducted at a 1:2 scale ratio, which would permit representing a maximum discharge of 31 ft^3/s (0.88 m^3/s).

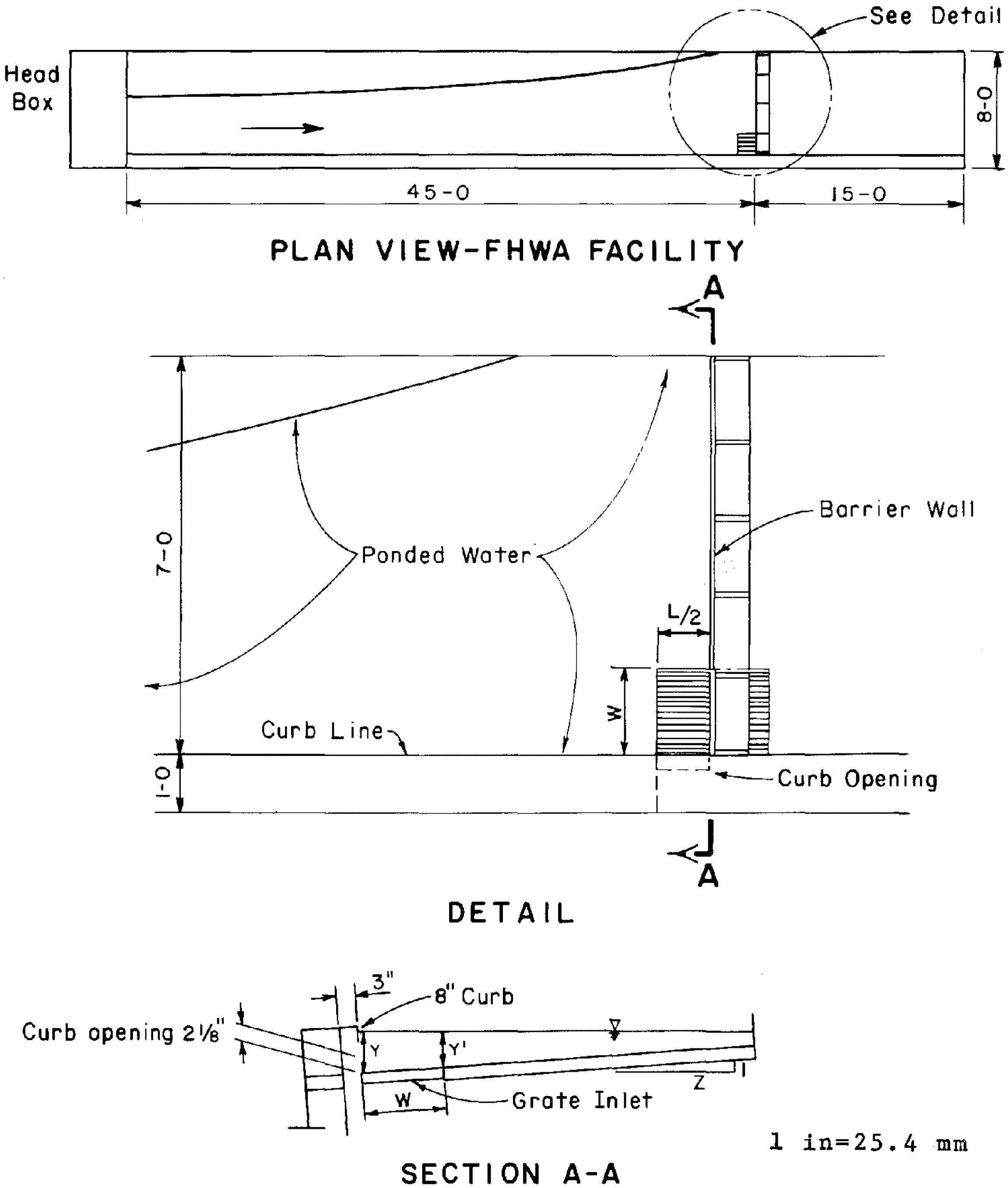


Figure 2-1. - Detail of sump condition.

To simulate a 40 ft (12 m) approach to a sump grate inlet at the bottom of a vertical curve on a highway, an average longitudinal slope of 0.2 percent was used in this study. Assuming a symmetrical vertical curve, the roadway was blocked off half-way across the grate inlet being tested, figure 2-2. Unlike the continuous grade test, there was no bypass flow for the sump test. A curb opening 2-1/8 in (54 mm) high representing 4-1/4 in (108 mm) on a roadway was used for all the sump tests. The upstream face of the wood block which extended across the roadway was placed across the center of the grate and sealed, figure 2-3. Vertical spacers were placed between the parallel bars of the P - 1-1/8 and P - 1-7/8 - 4 test grates at the midspan to insure symmetry. The curved vane grates were also adjusted to insure symmetry. Since the test grates were of different lengths, the wood block as well as the block extension into the curb opening could be moved along the roadway and sealed at the midspan of each grate size. For all tests, the length of curb opening matched the length of grate inlet tested.

Test Procedures

Except for the minor modifications mentioned, the test facility was the same as that described in chapter 5, volume 1.

Hydraulic Tests. - The hydraulic test facility was designed to be operated by one person. Since the facility was easily operated, an inlet size was selected and then each of the three sump grate designs was tested over a range of cross slopes, 1/Z, and gutter flow conditions, Q_T. For each cross slope condition, 1/Z, five gutter flows, Q_T, were tested.

The maximum gutter flow was governed by the depth of flow at the curb, y, normally 5 in to 6 in (127 mm to 152 mm) on the test facility representing 10 in to 12 in (254 mm to 304 mm) curb height. The five data points obtained were sufficient to develop curves relating depth of flow, y, to gutter flow, Q_T, for each cross slope, grate size, and design.

Gutter flows were measured using a combination orifice-Venturi meter described in chapter 5 of volume 1. Water surface elevations were measured at three locations and averaged. The three locations included one station in line with the upstream edge of the sump grate and 4 ft (1.22 m) from the curb and two stations located 1 ft (0.30 m) upstream from the sump grate and 3 ft and 4 ft (0.91 m and 1.22 m) from the curb. The depth of flow, y, for all tests was the difference between the average water surface elevation and the elevation of the upstream corner (curb side) of the grate inlet. For tests of the curb opening only, the elevation of the roadbed at the upstream end of the curb opening was used instead of the upstream corner of the grate inlet. The roadway flooded for the sump test

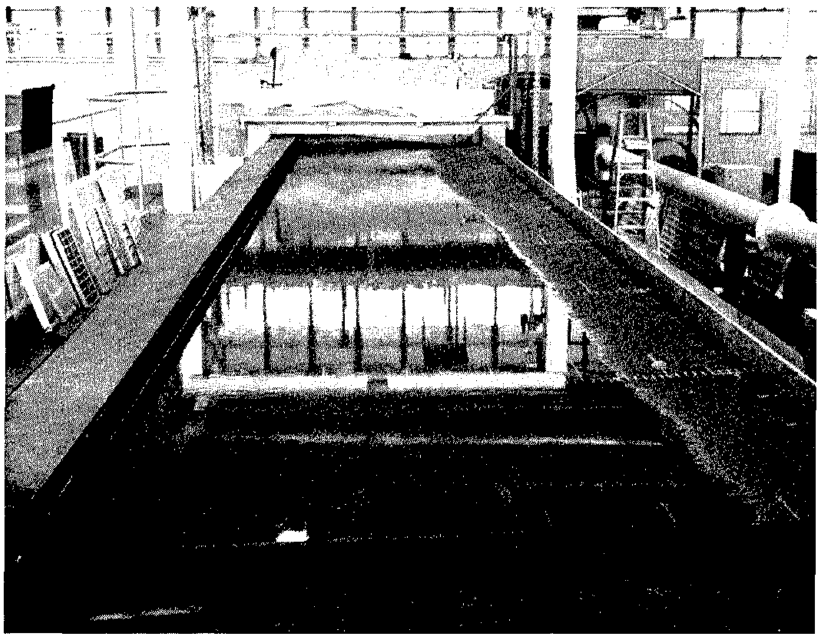


Figure 2-2. - View looking upstream at ponded water - sump test.

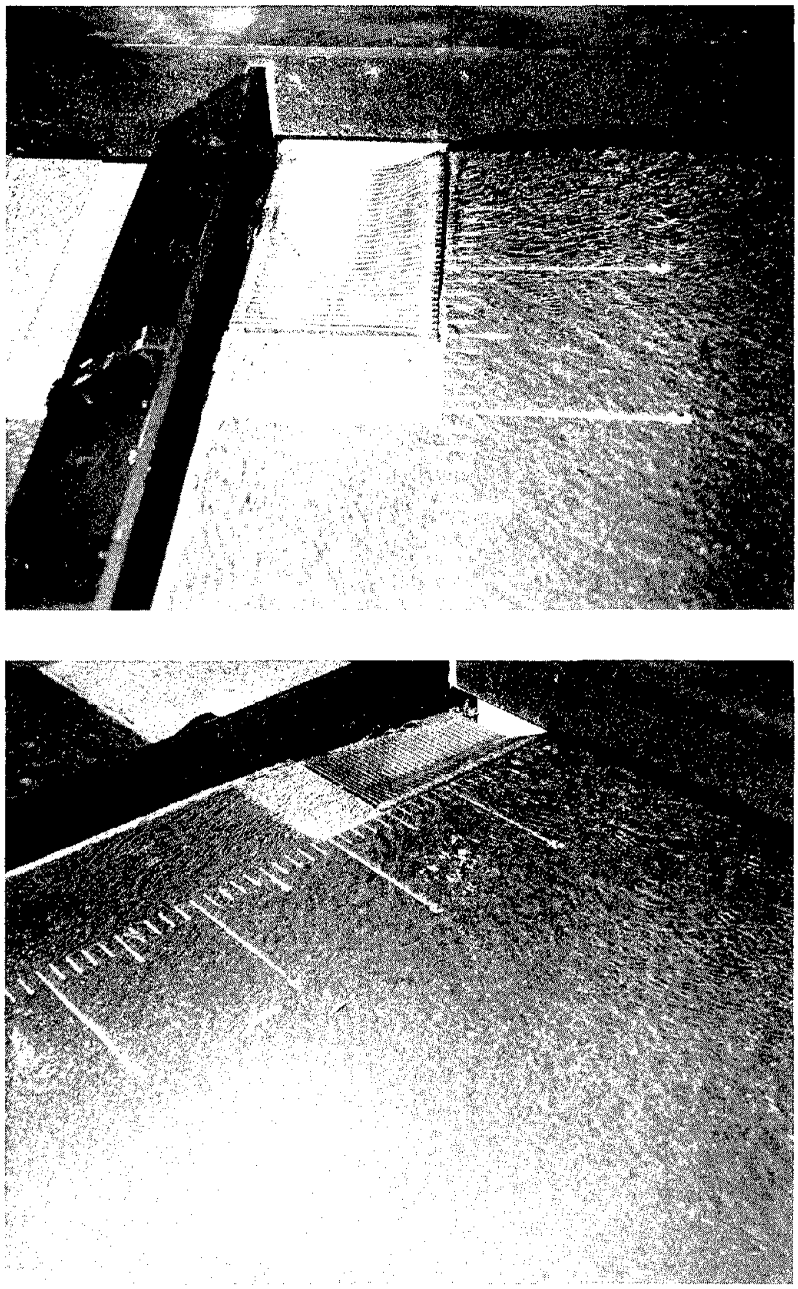


Figure 2-3. - Views of the 3.0 ft by 4.0 ft (0.91 m by 1.22 m) P - 1-1/8 sump grate under sump condition tests.

was 45 ft (13.7 m) long and 7 ft (2.13 m) wide. The time required to complete a test was governed by the time needed to reach a steady water surface elevation on the roadway. For the larger test grates, a steady-state condition could be set up quite rapidly; however for some of the smaller grates, over 1 hour was needed to establish a steady-state condition.

The procedure for making a typical test began by selecting the proper size orifice plate, based on the predicted flow through the sump grate, and inserting it into the flow meter. The pump(s) would then be started and the orifice-Venturi meter manometer bled of air. Five tests representing a range of discharges were normally conducted for a given grate design and size and cross slope condition. To insure adequate depth of flow for different measurements, roadway discharge was limited to a minimum flow of 0.44 ft^3/s (0.012 m^3/s) representing a total roadway flow from both directions of 5 ft^3/s (0.14 m^3/s). The upper discharge limit was actually a depth limit of 5 in to 7 in (127 mm to 178 mm) on the model representing 10 in to 14 in (254 mm to 356 mm) on an actual roadway.

Since the model was a 1:2 scale of one-half a sump grate, the model discharges for the two parallel bar grate designs were scaled up by $(L_r)^{2.5} = (2)^{2.5} = 5.66$ and then doubled to compensate for flow from both directions. The curved vane sump grate is directional and; therefore, test data were taken for the grate placed frontward and backward. After multiplying the model discharges by 5.66, the frontward and backward discharges were added together to arrive at the total discharge. The average measured flow depth, y, was doubled for all sump tests. The graphical plots in each chapter present the data for full scale roadway conditions.

Debris Tests. - Debris tests were conducted for all six grate sizes. As with the debris tests conducted in volume 1, a cross slope of $1/Z = 1/24$ was used for all tests. The longitudinal slope was held constant at $S_O = 0.2$ percent. The debris tests were conducted using 150 pieces of 1.5 in by 2 in (38 mm by 61 mm) kraft paper to represent 3 in by 4 in (76 mm by 122 mm) leaves. The leaves were first saturated and placed on the wet road surface in an area representing a 4 ft (1.22) wide by 70 ft (21.3 m) long roadway section immediately upstream from the sump grate, figure 2-4. Gutter flow was slowly brought on to the roadway until advancing water reached the first leaves, this was considered the start of the test. Over the next two minutes, the flow was slowly increased until the full width of the roadway was covered with water. The discharge was then held constant for 5 minutes. Debris which failed to move naturally was loosened from the road surface and floated downstream. Thus all 150 leaves came into contact with the sump grate.

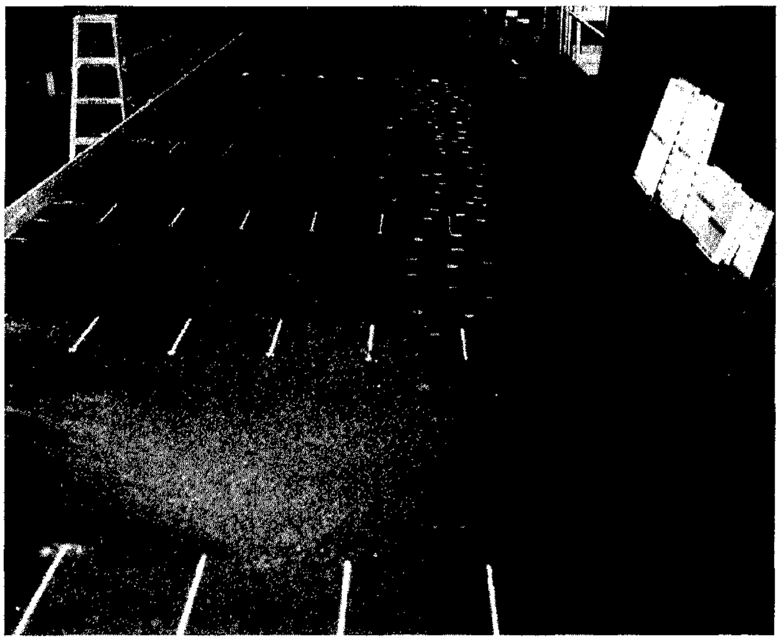


Figure 2-4. - View looking downstream at debris on the roadway prior to debris sump test.

Five minutes into the test, the debris which passed into the sump grate was recovered from the collecting screen and counted. At 7 minutes, the gutter discharge was increased until a depth representing approximately 1 ft (0.30 m) was established at the inlet. At 15 minutes, the debris test was stopped. The debris that passed through the sump grate and the debris caught on the grate were counted. Each test was repeated three times to average the results. The debris handling efficiency was calculated as the ratio of debris that passed through the sump grate to the total debris on the roadway at the start of the test.

CHAPTER 3

HYDRAULIC CONSIDERATIONS

Figure 2-1 shows the 1:2 laboratory gutter section used during the sump test program. The curb opening height of 2-1/8 in (54 m) represents a 4-1/4 in (108 mm) high curb opening. Tests were conducted for both the curb opening only and the sump grate.

There are two hydraulic equations which are used to define the flow characteristics at a sump grate. They are the weir and orifice equations:

$$Q = C_w L y^{3/2} \text{ (weir equation)} \qquad (3\text{-}1)$$

$$Q = C_o A(2g(y-h/2))^{1/2} \text{ (orifice equation)} \qquad (3\text{-}2)$$

Where, C_w = weir discharge coefficient

C_o = orifice discharge coefficient

L = length of curb opening, ft (m)

y = depth of water at curb, ft (m)

A = cross sectional flow area, ft^2 (m^2)

g = acceleration of gravity, ft/s^2 (m/s^2)

h = height of curb opening, ft (m)

Figure 3-1 illustrates these two equations with the actual model data plotted for the 8 in (203 mm) long curb opening. The weir coefficient used for this curve was 3.0 and the orifice coefficient was 0.7. As discussed in "Drainage of Highway Pavements," (1) the inlet operates as a weir until the water submerges the curb opening entrance. When the water depth, y, exceeds the height of the curb opening, h, by approximately 0.4 h, the inlet operates as an orifice. For gutter flow depths between the curb opening height and 1.4 h, the inlet discharge control passes through a transition zone. For the curb opening only test, the resulting depth vs. discharge curves (presented in chapter 4) have a shape similar to that shown in figure 3-1.

The sump grate study, which was the major portion of the test series, included a grate inlet along with the curb opening. For all sump grates the curb opening was the same length as the grate inlet.

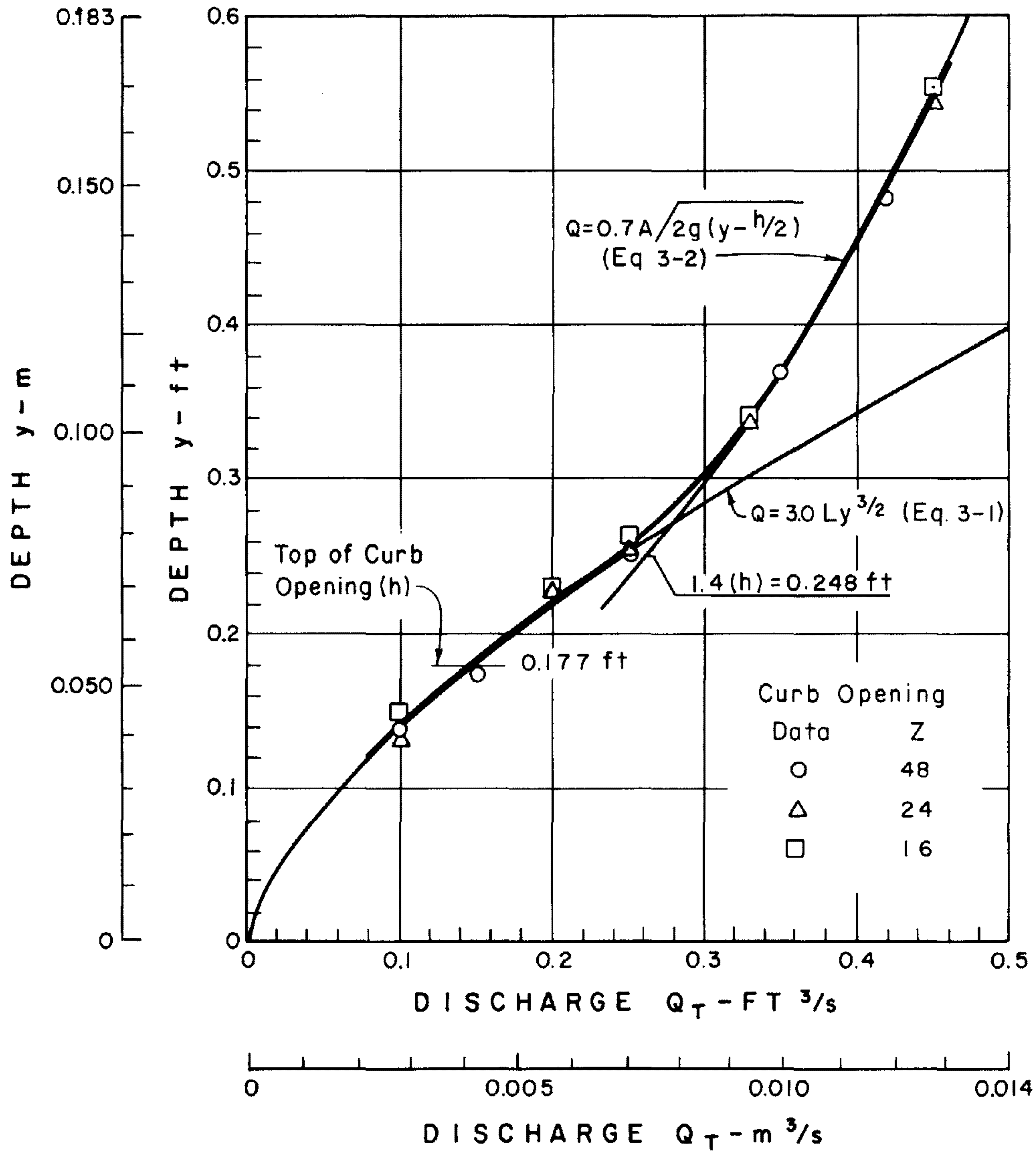


Figure 3-1. - Capacity curve for 8 in (203 mm) long curb opening tested.

As with the curb opening configuration, the inlet capacity for the sump grate can also be described by equations. With the sump grate, weir flow conditions control until the flow depth is sufficient to submerge the grate as well as the curb opening. The flow depth required to submerge the sump grate is a function of the grate surface area. The larger the surface area, the more depth will be required for submergence - orifice flow.

Equations 3-1 and 3-2 can be modified to account for the sump grate and the change in flow depth resulting from the cross slope effect (y' is less than y in figure 2-1) across the width of the grate.

$$Q(\text{weir}) = C_W(L)(y')^{3/2} + C_W(2)(W)\left(\frac{y+y'}{2}\right)^{3/2} \qquad (3\text{-}3)$$

and

$$Q_{(\text{orifice})} = C_O(A_O)[2g(y-h/2)]^{1/2} + C_O(A_g)[g(y+y')]^{1/2} \qquad (3\text{-}4)$$

Where, $y' = y - W/Z$, ft (m)

L = grate length, ft (m)

W = grate width, ft (m)

A_O = cross sectional area of curb opening, ft^2 (m^2)

A_g = cross sectional area of clear opening of grate, ft^2 (m^2)

Figure 3-2 illustrates equations 3-3 and 3-4 ($C_W = 3.0$ and $C_O = 0.7$) for three sizes of the P - 1-1/8 sump grate. The full-scale test data are plotted to show the functional relationship between the depth of flow, y, and discharge, Q_T, through the sump grate. In figure 3-2a for the smallest sump grate (1.25 ft by 2 ft (0.38 m by 0.61 m)), an inflection point in the curve is noted, where; as the depth increases the flow control changes from weir control to a transition phase and asymptotically approaches orifice control. The trend is also noted in figure 3-2b for the 2 ft by 2 ft (0.61 m by 0.61 m) sump grate. In figure 3-2c for a 3 ft by 4 ft (0.91 m by 1.2 m) sump grate, it is evident that the flow characteristics are defined by equation 3-3 (weir equation), even for a flow depth in excess of 1 ft (0.3 m).

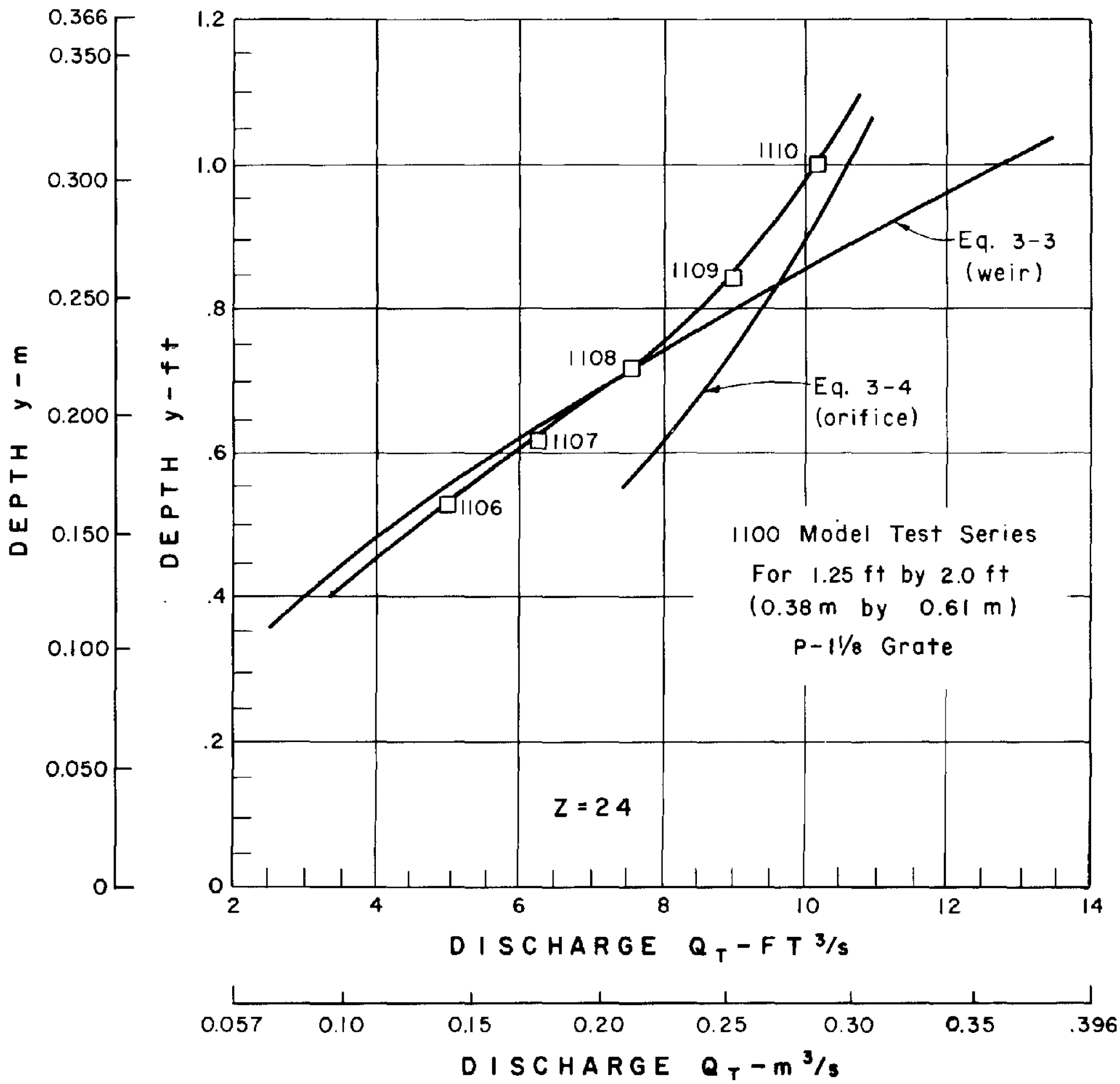


Figure 3-2a. - Weir and orifice equations for P - 1-1/8 sump grate (1.25 ft by 2 ft (0.38 m by 0.61 m)).

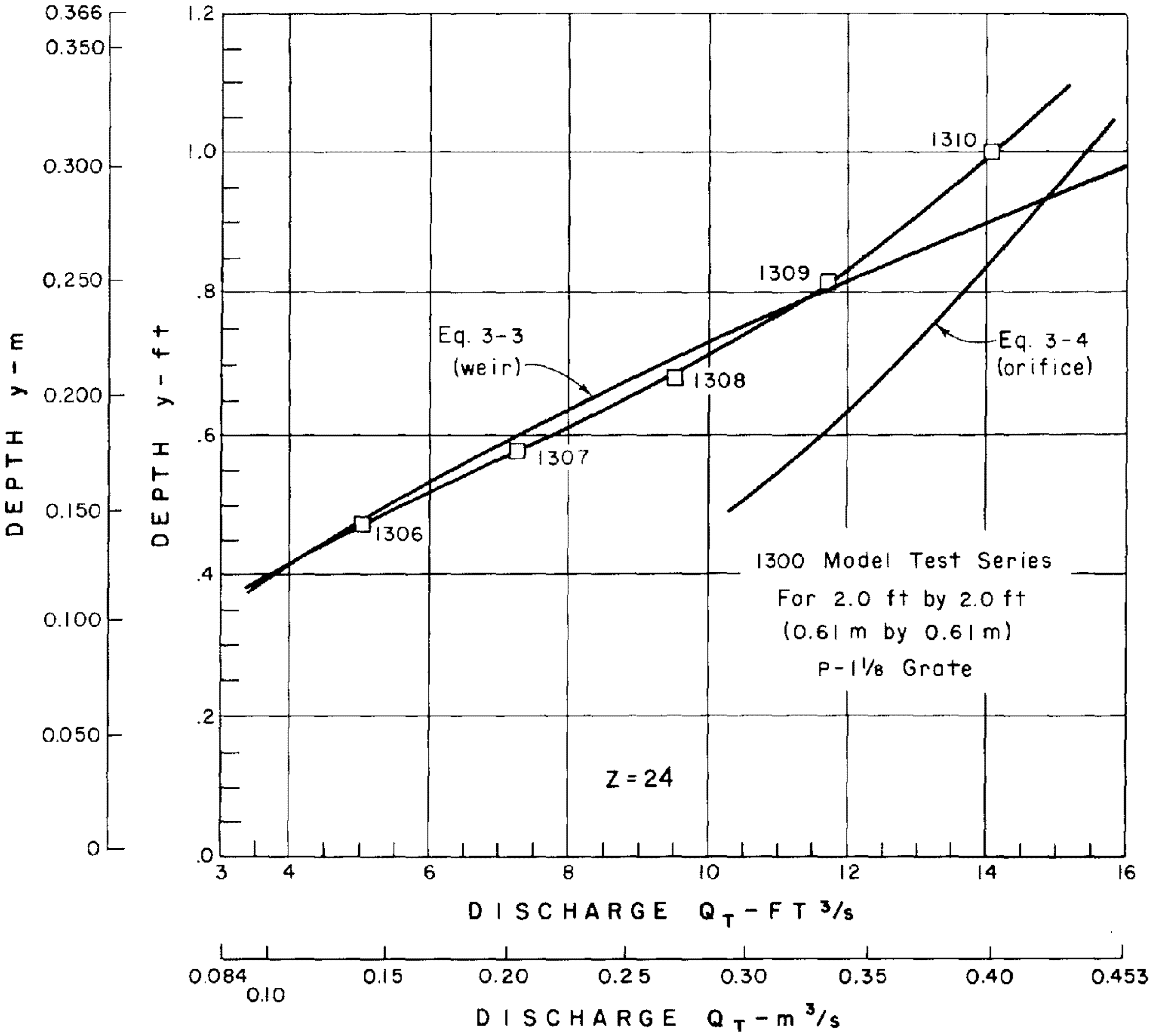


Figure 3-2b. - Weir and orifice equations for P - 1-1/8 sump grate (2 ft by 2 ft (0.61 m by 0.61 m)).

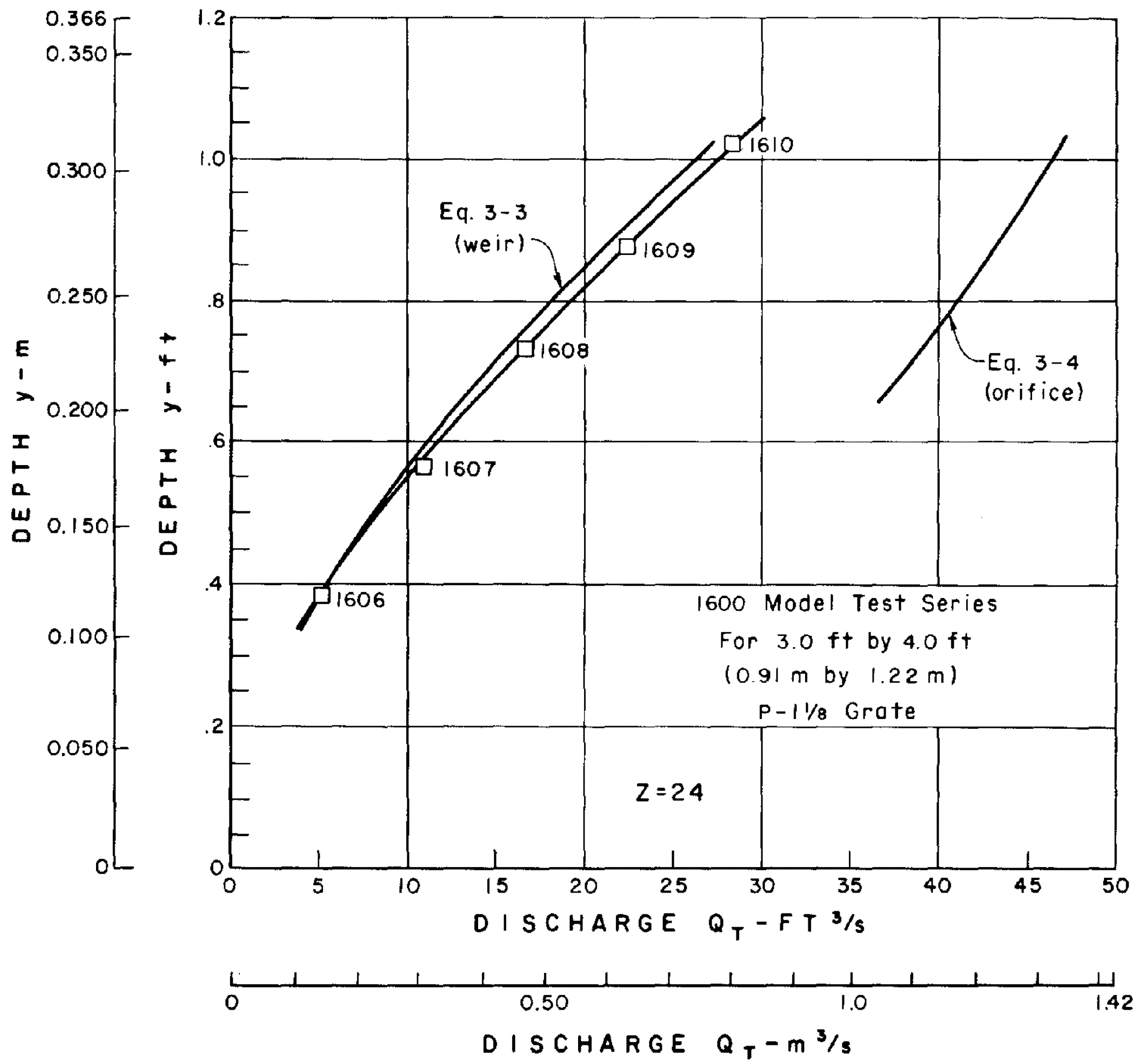


Figure 3-2c. - Weir and orifice equations for P - 1-1/8 sump grate (3 ft by 4 ft (0.91 m by 1.22 m)).

REFERENCES

1. Drainage of Highway Pavements, Hydraulic Engineering Circular No. 12, Federal Highway Administration, March 1969.

CHAPTER 4

TEST RESULTS - CURB OPENING

Hydraulic tests were conducted for three lengths of curb opening in a sump condition. The height of the curb openings tested was 2-1/8 in (54 mm) representing 4-1/4 in (108 mm) on a roadway. The three lengths tested represented curb openings, 24 in, 32 in, and 48 in (0.61 m, 0.81 m, and 1.22 m) long. Flow depths at the curb ranged from 1.75 in to 7 in (44.5 mm to 178 mm) representing depths of 3.5 in to 14 in (89 mm to 356 mm) on a roadway. For the remainder of this volume units will be expressed as full scale.

Figure 4-1 describes the relationship between the depth of water, y, at the curb and the curb opening capacity, Q_T, for the three lengths of 2.0 ft, 2.67 ft, and 4.0 ft (0.61 m, 0.81 m, and 1.22 m). Unlike the sump grates which will be discussed in chapters 5 through 7, the control section of the weir and orifice for the curb opening is at the curb face. For this reason, the discharge-depth relationship is not very dependent on the cross slope, 1/Z. Therefore in figure 4-1, the data for the various cross slopes results in almost identical curves for a specific length of curb opening. As pointed out in chapter 3, the test data for the curb opening follows the weir-orifice equations very closely. The curb opening functions as a weir up to a point where the depth of flow submerges the curb opening. As the flow depth continues to increase, the discharge increases at a slower rate and the curb opening functions as an orifice. This phenomena occurred for all three lengths of curb opening tested.

Figure 4-2 represents flow into a 4-1/4 in (108 mm) high by 2.67 ft (0.813 m) long curb opening for depths of 0.262 ft, 0.674 ft, and 1.086 ft (80 mm, 205 mm, and 331 mm). The lines marked 2, 4, and 6 indicate flow depths on the model of 2 in, 4 in, and 6 in (51 mm, 102 mm, and 152 mm) representing flow depths at the curb of 4 in, 8 in, and 12 in (102 mm, 203 mm, and 305 mm).

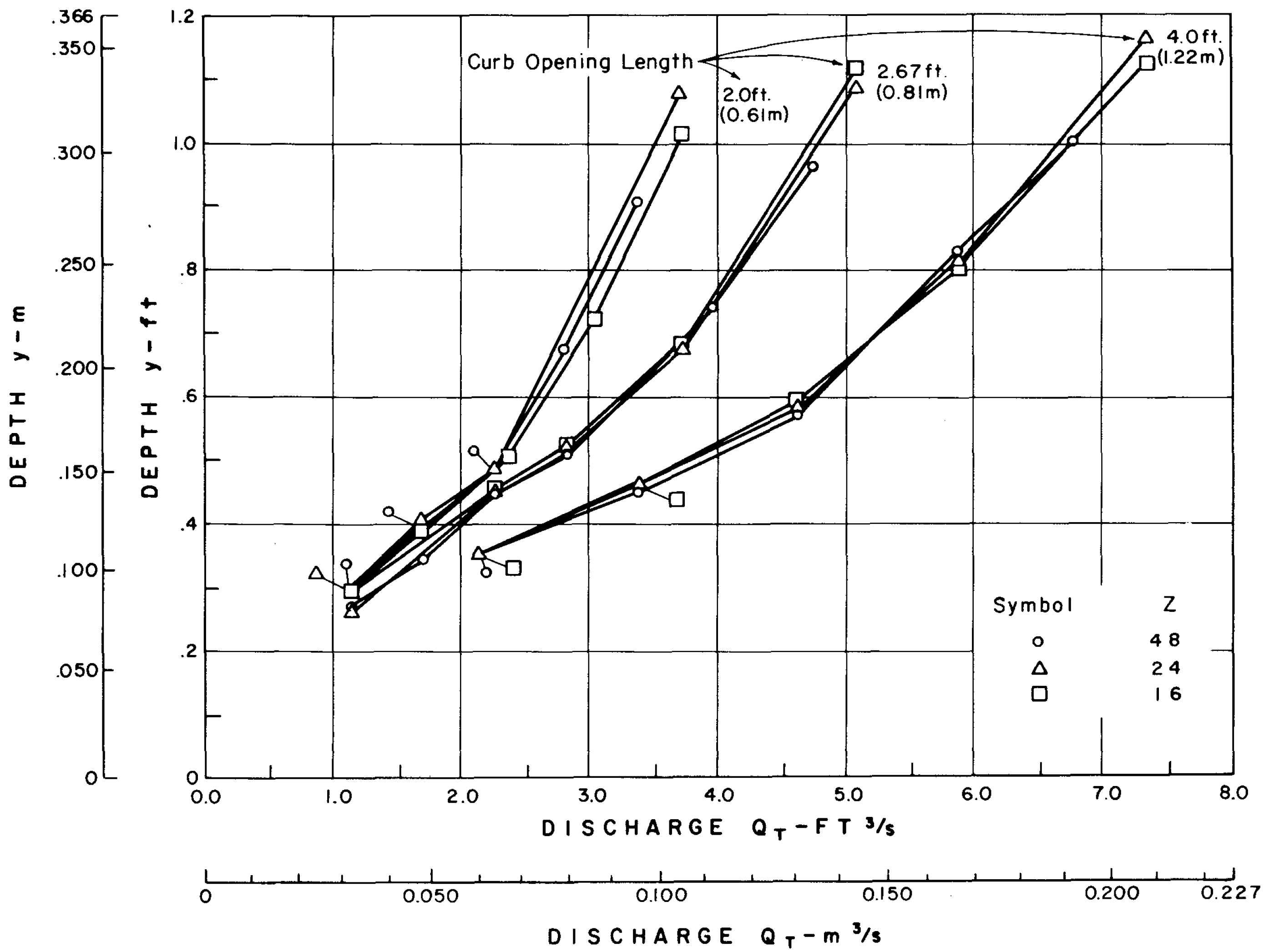
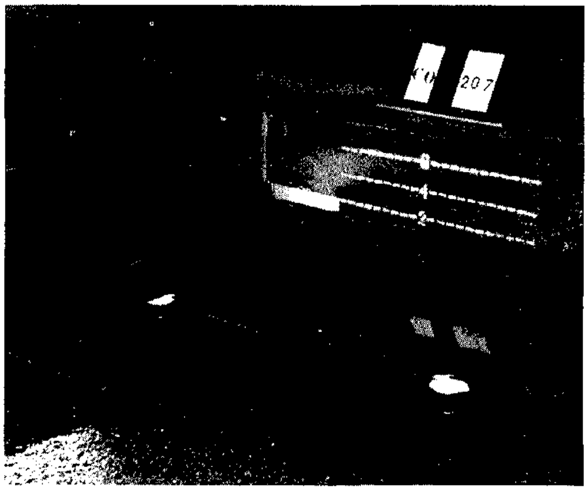
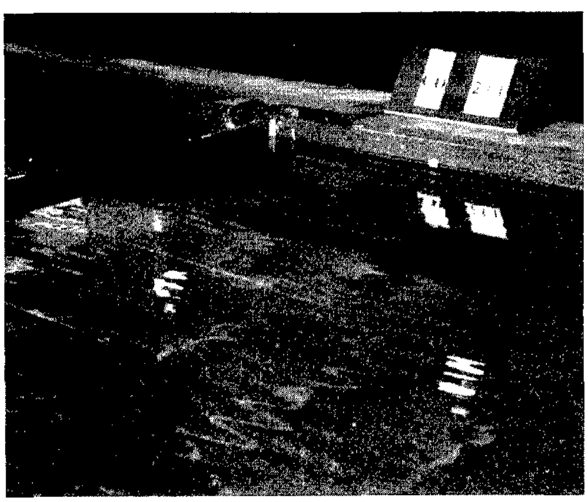


Figure 4-1. - Curb opening capacity curves.



a. Flow depth at the curb,
y = 0.262 ft (0.080 m)
Q_T = 1.13 ft^3/s (0.032 m^3/s)

b. Flow depth at the curb,
y = 0.674 ft (0.205 m)
Q_T = 3.73 ft^3/s (0.106 m^3/s)



c. Flow depth at the curb,
y = 1.086 ft (0.331 m)
Q_T = 5.09 ft^3/s (0.144 m^3/s)

Figure 4-2. - View of 2.67 ft (0.813 mm) long curb opening for three flow depths.

CHAPTER 5

TEST RESULTS - PARALLEL BAR SUMP GRATE WITH SPACERS - P - 1-1/8

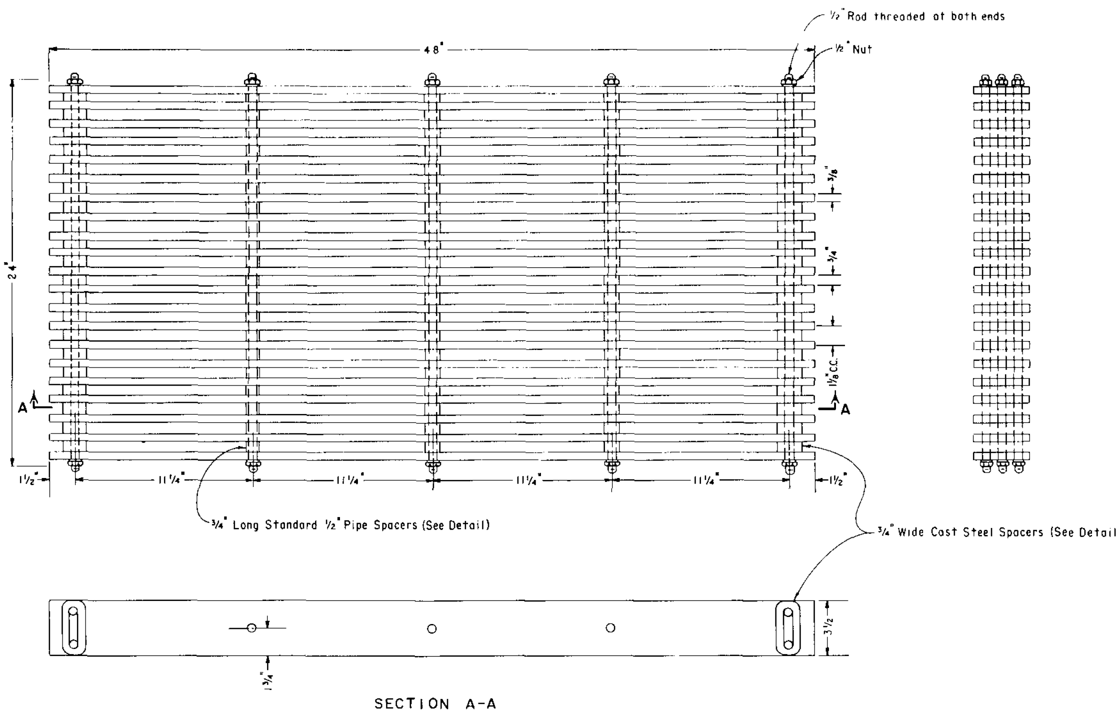
This chapter contains the results of sump condition tests for six sizes of the parallel bar grate with a 3/4 in (19 mm) clear spacing between 3/8 in (9.5 mm) wide longitudinal bars and with a 4-1/4 in (108 mm) curb opening. This grate is referred to as a P - 1-1/8 sump grate since longitudinal bars are placed on 1-1/8 in (28.6 mm) centers. The sizes tested included: two lengths of a 1.25 ft (0.38 m) wide grate, 2.67 ft and 2 ft (0.81 m and 0.61 m) long; two lengths of a 2 ft (0.61 m) wide grate, 4 ft and 2 ft (1.22 m and 0.61 m) long; and two lengths of a 3 ft (0.91 m) wide grate, 4 ft and 2 ft (1.22 m and 0.61 m) long. A 2 ft by 4 ft (0.61 m by 1.22 m) P - 1-1/8 grate is shown in figure 5-1. These grate sizes are the same as the six grate sizes tested in volumes 1 and 2 for continuous grade tests.

Experimental Results and Observations

Hydraulics. - Hydraulic test results for the P - 1-1/8 sump grates are shown in figures 5-2, 5-3, and 5-4. For the sump condition test, there is no carryover flow; all the roadway flow passes through the sump grate. Therefore, the important hydraulic relationship is that of the flow depth at the curb, y, to the roadway discharge, Q_T, which is also the intercepted flow, Q_I.

For a curb opening only, once the flow depth at the curb, y, is approximately 1.4 times the height of the opening, the flow is under orifice control. When a grate is placed in front of the curb opening, flow depths at the curb opening will not normally exceed the 1.4 curb opening height and the sump grate will remain under weir control. However, at some depth it is possible to submerge the grate and curb opening and thus produce orifice control at the sump grate. For sump grates, the depth of flow required to lose weir control is primarily related to the size of the open area of the grate. This can best be illustrated by comparing the smallest sump grate to the largest sump grate for three flow depths, figures 5-5 and 5-6. It is evident that at a flow depth of 1 ft (0.3 m), the 1.25 ft by 2 ft (0.38 m by 0.61 m) sump grate is submerged and operates under orifice control while the larger 3 ft by 4 ft (0.91 m by 1.22 m) sump grate is not submerged and operates under weir control.

By comparing the curves in figures 5-2 through 5-4, with the weir and orifice curves in figure 3-2, one can determine if the sump grates are operating under orifice or weir control. The 3 ft by



1 in=25.4 mm

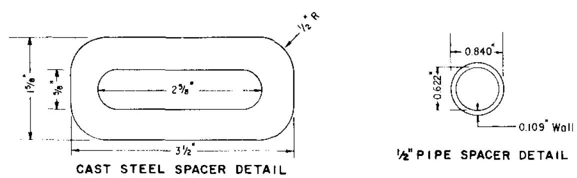


Figure 5-1. - 2.0 ft by 4.0 ft (0.61 m by 1.22 m) fabricated steel - P - 1-1/8 grate.

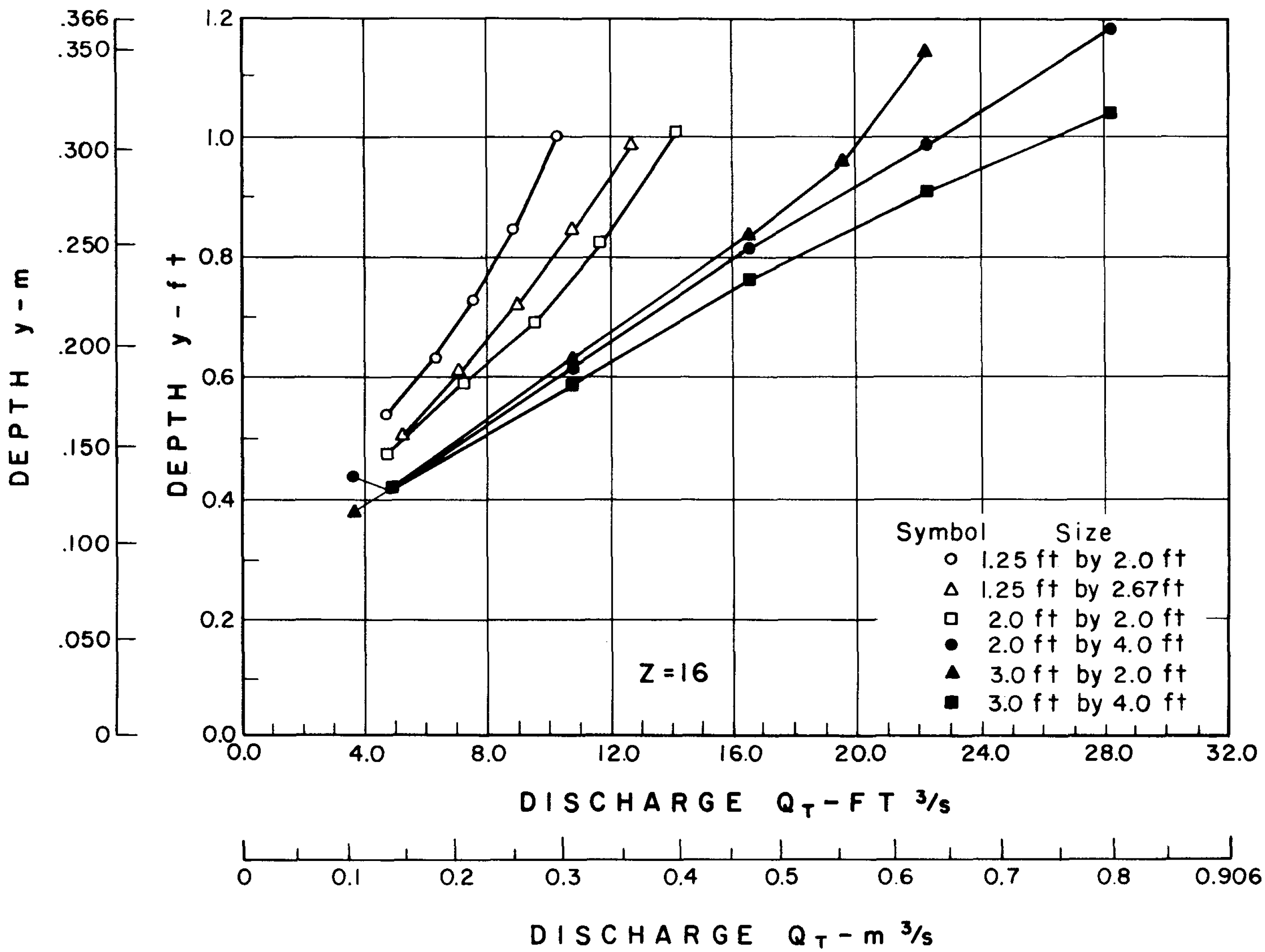


Figure 5-2. - Inlet capacity curves, P - 1-1/8 sump grate, Z = 16.

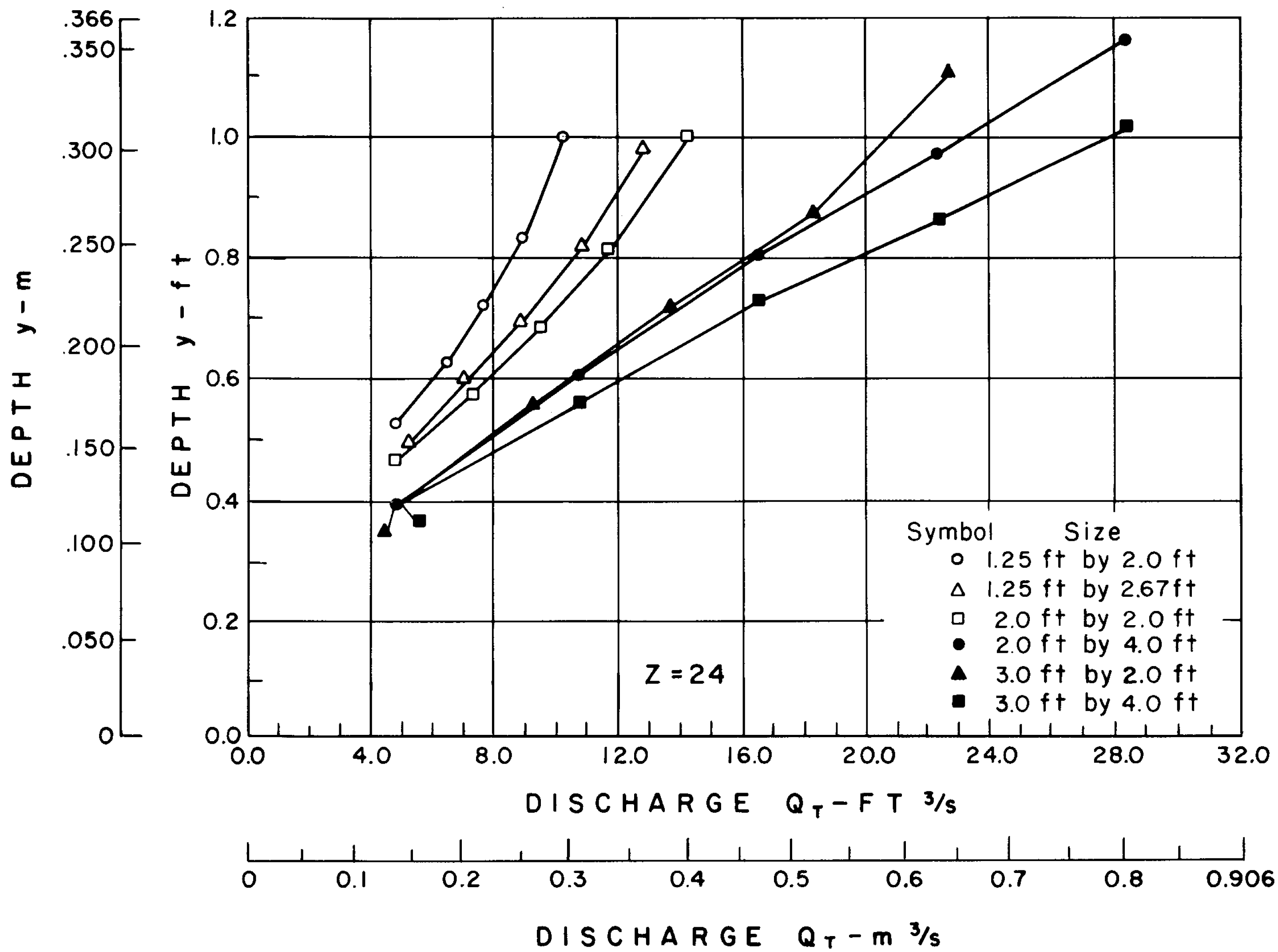


Figure 5-3. - Inlet capacity curves, P - 1-1/8 sump grate, Z = 24.

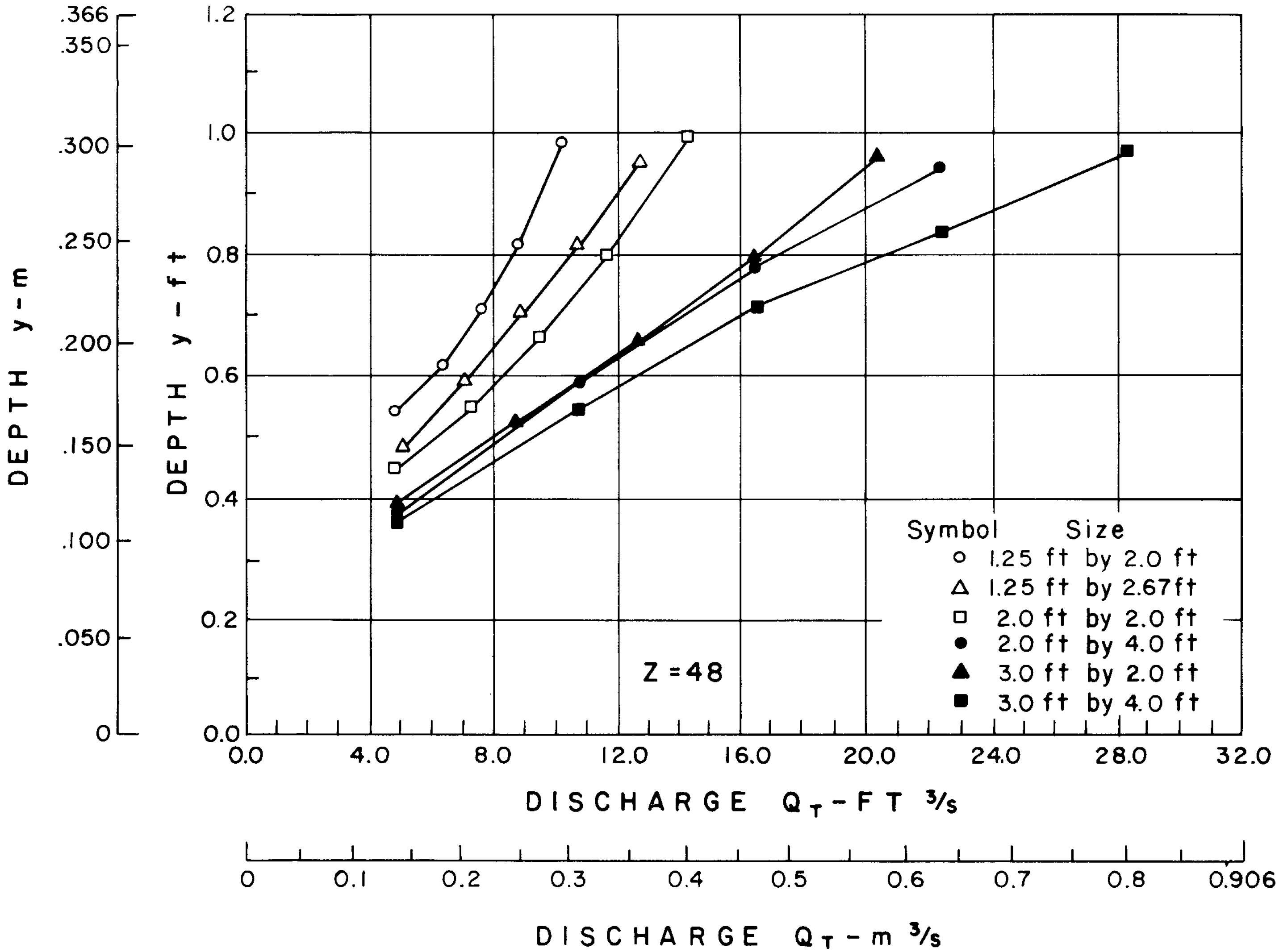
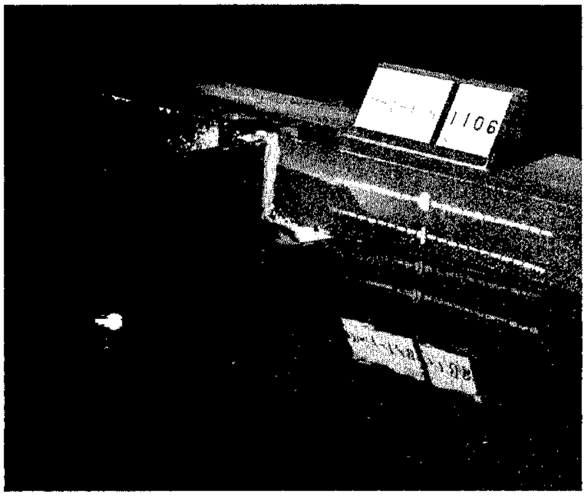
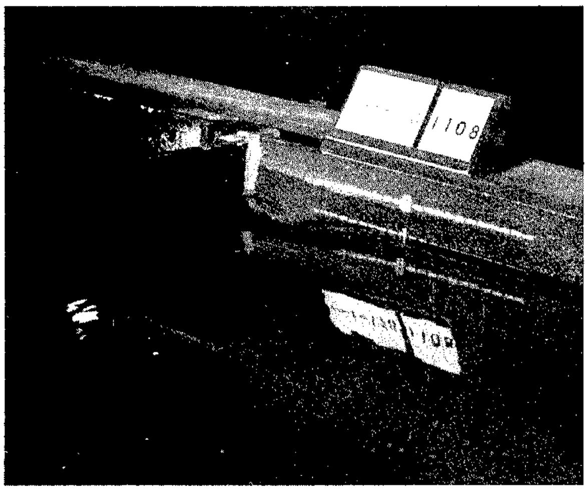


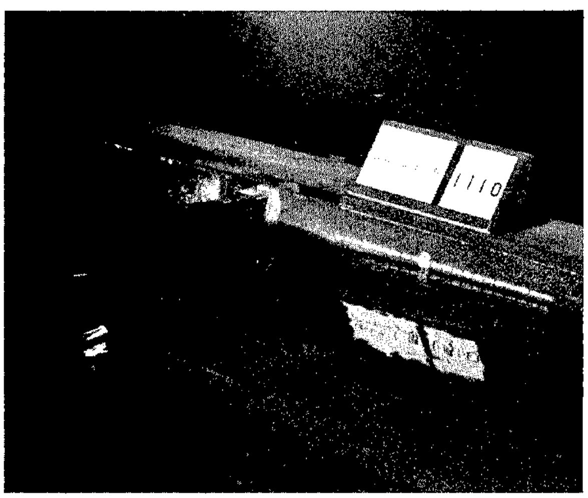
Figure 5-4. - Inlet capacity curves, P - 1-1/8 sump grate, Z = 48.



a. Flow depth at the curb,
y = 0.528 ft (0.161 m)
Q_T = 4.98 ft^3/s
(0.141 m^3/s)

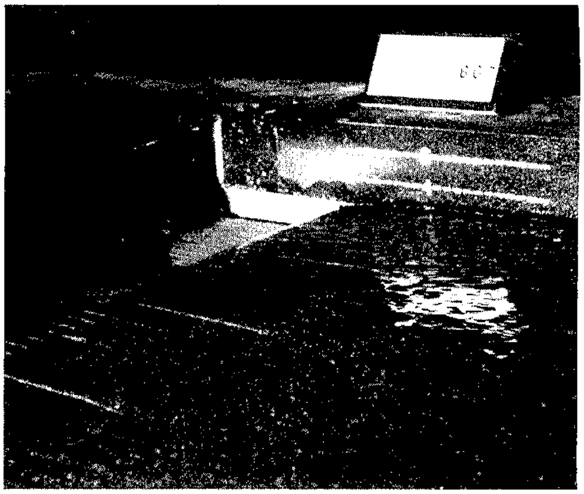


b. Flow depth at the curb,
y = 0.720 ft (0.219 m)
Q_T = 7.58 ft^3/s
(0.215 m^3/s)



c. Flow depth at the curb,
y = 1.00 ft (0.305 m)
Q_T = 10.18 ft^3/s
(0.288 m^3/s)

Figure 5-5. - 1.25 ft by 2.0 ft (0.38 m by 0.61 m) P - 1-1/8 sump grate at three flow depths, Z = 16.



a. Flow depth at the curb,
y = 0.568 ft (0.173 m)
Q_T = 10.75 ft^3/s (0.304 m^3/s)

b. Flow depth at the curb,
y = 0.730 ft (0.223 m)
Q_T = 16.52 ft^3/s (0.468 m^3/s)

c. Flow depth at the curb,
y = 1.02 ft (0.311 m)
Q_T = 28.29 ft^3/s (0.801 m^3/s)

Figure 5-6. - 3.0 ft by 4.0 ft (0.91 m by 1.22 m) P - 1-1/8 sump grate at three flow depths, Z = 16.

4 ft (0.91 m by 1.22 m) sump grate operates under weir control throughout the flow depth range tested for all three cross slope conditions. The five smaller sump grates operate under weir control at the lower flow depths. As the flow depth increases, the rate of increase in discharge decreases. The flow control at the sump grate passes from weir control through a transition zone and for the smaller sump grates, to orifice control at the larger flow depths.

The capacity of the various sizes of sump grates is primarily dependent upon the weir length of the sump grate. The greater the effective perimeter of the sump grate, the more capacity it has for a specific flow depth. It is interesting to note the close comparison of the 2 ft by 4 ft (0.61 m by 1.22 m) and 3 ft by 2 ft (0.91 m by 0.61 m) sump grates in figures 5-2 through 5-4. The effective perimeter of the two sizes is the same (P = 8 ft (2.44 m)) and, therefore, as long as the flow is controlled as a weir, the curves plot very close to each other. It is only when the smaller 3 ft by 2 ft (0.91 m by 0.61 m) sump grate becomes submerged at the deeper flow depths, that its capacity decreases over that of the 2 ft by 4 ft (0.61 m by 1.22 m) sump grate.

The roadway cross slope, 1/Z, has a minor effect on the sump grate capacity. For a curb opening only, the roadway cross slope has minimal effect; however, for sump grates, the wider the grate, the more impact the cross slope has on its capacity. Figure 5-7 illustrates the flow depth at the curb, y, vs. discharge, Q_T, curves for three widths of 2 ft (0.61 m) long P - 1-1/8 sump grates. Since the flow depth over the outer edge of the grate is deeper for flatter cross slopes, one would expect higher capacities at the flatter cross slopes for the same flow depth at the curb, y. This trend is evident in figure 5-7. The wider the grate, the greater is the difference between the cross slope curves.

Debris Tests. - The six P - 1-1/8 sump grate sizes were tested for debris handling ability using the test procedure described in chapter 2. All debris tests were conducted at a longitudinal slope of S_O = 0.2 percent and a cross slope, 1/Z = 1/24. Table 5-1 summarizes the test data for the P - 1-1/8 sump grates. In general the P - 1-1/8 grate has a very low debris handling efficiency. The only exception occurred for the 1.25 ft by 2 ft (0.38 m by 0.61 m) sump grate size. As shown in figure 5-8, both the smallest and largest sump grate sizes collected debris. However, once the small grate became completely covered with debris, a large number of the leaves approaching the sump grate were diverted through the curb opening resulting in a higher debris efficiency. This did not occur on the larger grate sizes because the flow dropped through the grate; therefore, the debris continued to collect on the parallel bars.

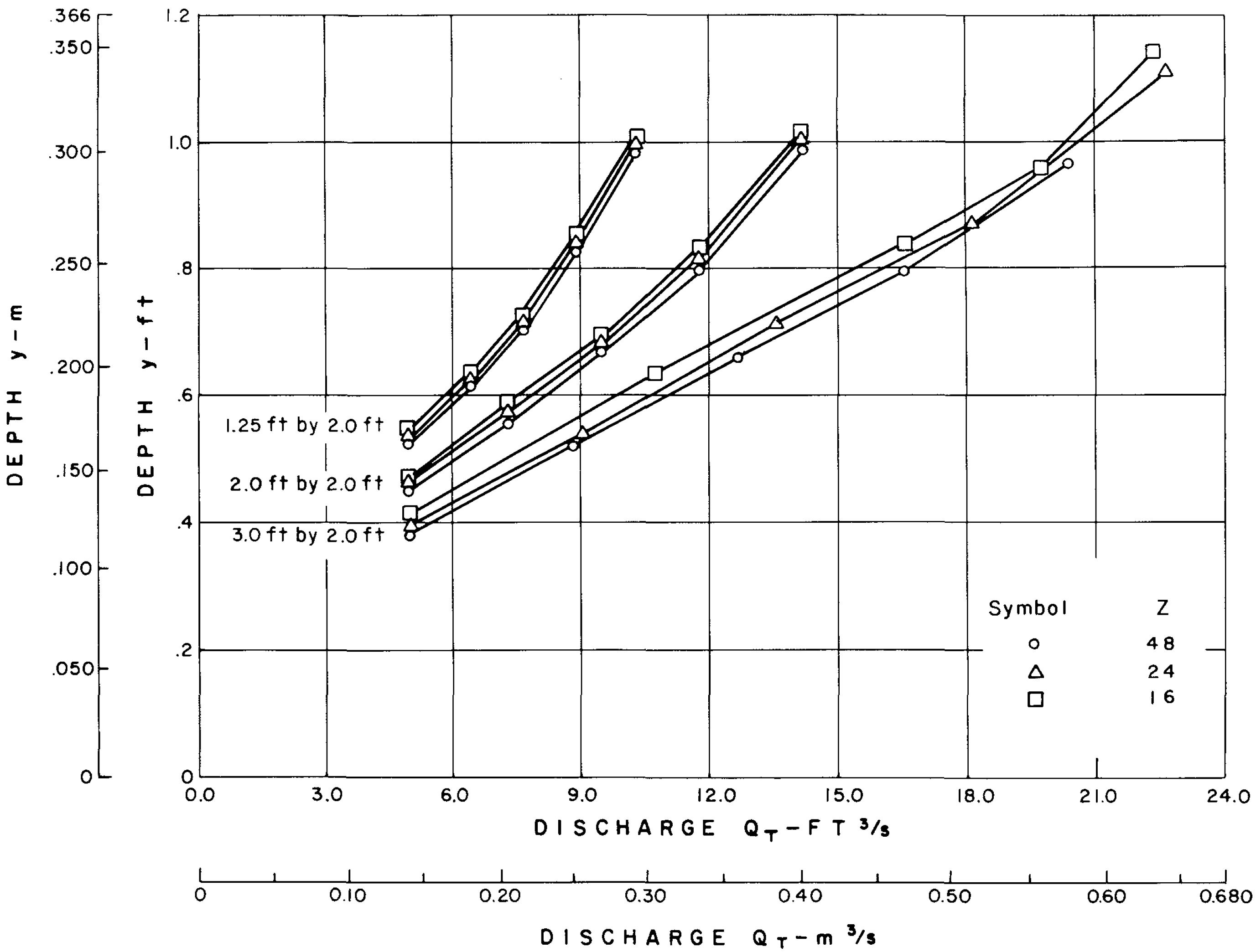


Figure 5-7. - Inlet capacity curves for 2 ft (0.61 m) long P - 1-1/8 sump grates.

Table 5-1

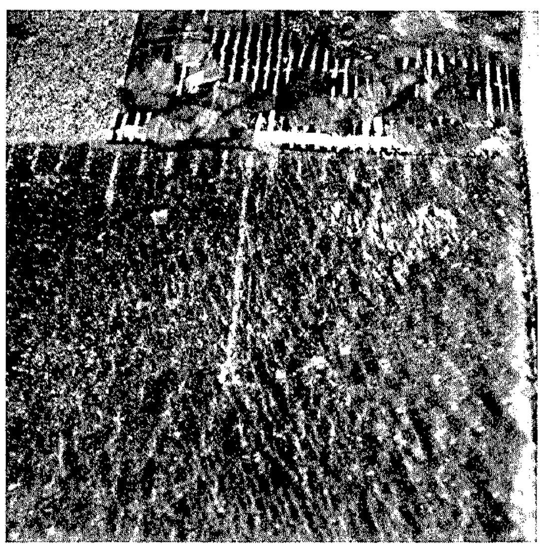
DEBRIS TEST RESULTS - P - 1-1/8 SUMP GRATES

$S_0 = 0.20\%$

Test No.	Number of leaves lodged on grate* 5 minutes	Number of leaves lodged on grate* 15 minutes	Test No.	Number of leaves lodged on grate* 5 minutes	Number of leaves lodged on grate* 15 minutes
	1.25 ft by 2.0 ft grate (0.38 m by 0.61 m)			1.25 ft by 2.67 ft grate (0.38 m by 0.81 m)	
1	95	86	1	127	122
2	85	79	2	126	121
3	91	87	3	126	118
Debris handling efficiency (%)	40	44		16	20
	2.0 ft by 2.0 ft grate (0.61 m by 0.61 m)			2.0 ft by 4.0 ft grate (0.61 m by 1.22 m)	
1	126	123	1	131	124
2	125	125	2	137	133
3	124	122	3	122	114
4	125	124			
Debris handling efficiency (%)	17	18		13	18
	3.0 ft by 2.0 ft grate (0.91 m by 0.61 m)			3.0 ft by 4.0 ft grate (0.91 m by 1.22 m)	
1	124	124	1	136	130
2	130	128	2	131	125
3	137	132	3	131	130
Debris handling efficiency (%)	13	15		12	14

* Based on 150 "leaves" arriving at the grate.

a. 1.25 ft by 2.0 ft
(0.38 m by 0.61 m)



b. 3.0 ft by 4.0 ft
(0.91 m by 1.22 m)

Figure 5-8. - Debris tests - P - 1-1/8 sump grates.

Results of the debris tests for the P - 1-1/8 sump grate proved similar to those discussed in chapter 12, volume 1, for the continuous grade tests. Due to the close spacing of the parallel bars, the P - 1-1/8 sump grate is not an efficient debris handling grate.

CHAPTER 6

TESTS RESULTS - PARALLEL BAR SUMP GRATE WITH TRANSVERSE RODS - P - 1-7/8 - 4

This chapter presents the results of sump condition tests for six sizes of the parallel bar with transverse rod grates and with a 4-1/4 in (108 mm) curb opening. The grate is referred to as the P - 1-7/8 - 4 because the longitudinal bars are placed on 1-7/8 in (48 mm) centers and the 3/8 in (9.5 mm) diameter transverse rods are on 4 in (102 mm) centers. The sizes tested included two lengths of 1.25 ft (0.38 m) wide grate, 2.67 ft and 2.0 ft (0.81 m and 0.61 m) long; two lengths of a 2 ft (0.61 m) wide grate, 4.0 ft and 2.0 ft (1.22 m and 0.61 m) long; and two lengths of a 3 ft (0.91 m) wide grate, 4.0 ft and 2.0 ft (1.22 m and 0.61 m) long. A 2 ft by 4 ft (0.61 m by 1.22 m) P - 1-7/8 - 4 grate is shown in figure 6-1. These grate sizes are the same as the six grate sizes tested in volumes 1 and 2 for continuous grade tests.

Experimental Results and Observations

Hydraulics. - Hydraulic test results for the P - 1-7/8 - 4 sump grates are shown in figures 6-2, 6-3, and 6-4. Since all the roadway flow passes through the sump grate, there is a 100 percent hydraulic efficiency. The major variable is the depth of flow at the curb, y, to pass the flow, given the sump grate size and the roadway cross slope, 1/Z.

The shape of the curves in figures 6-2, 6-3, and 6-4 are similar to those presented in chapter 5 for the P - 1-1/8 sump grate. The sump grates are under weir control at lower flow depths. As the flow depth increases and the sump grates are submerged, the flow control enters a transition stage between weir and orifice control. As flow depths continue to increase, the smaller sump grates eventually come under orifice control. Figures 6-5 and 6-6 illustrate various stages of weir, transition zone, and orifice flow for the 1.25 ft by 2.0 ft (0.38 m by 0.61 m) and the 3.0 ft by 4.0 ft (0.91 m by 1.22 m) P - 1-7/8 - 4 sump grates for three flow depths.

The curves in figures 6-2 through 6-4 follow the theory presented in chapter 3 for weir and orifice flow. For a given flow depth, the sump grate capacity increases with weir length (sump grate perimeter) or surface area for orifice flow conditions. For the P - 1-7/8 - 4 sump grate, the 2 ft by 4 ft (0.61 m by 1.22 m) size has a slightly greater capacity than the 3 ft by 2 ft (0.91 m by 0.61 m) size even though their perimeters are the same length.

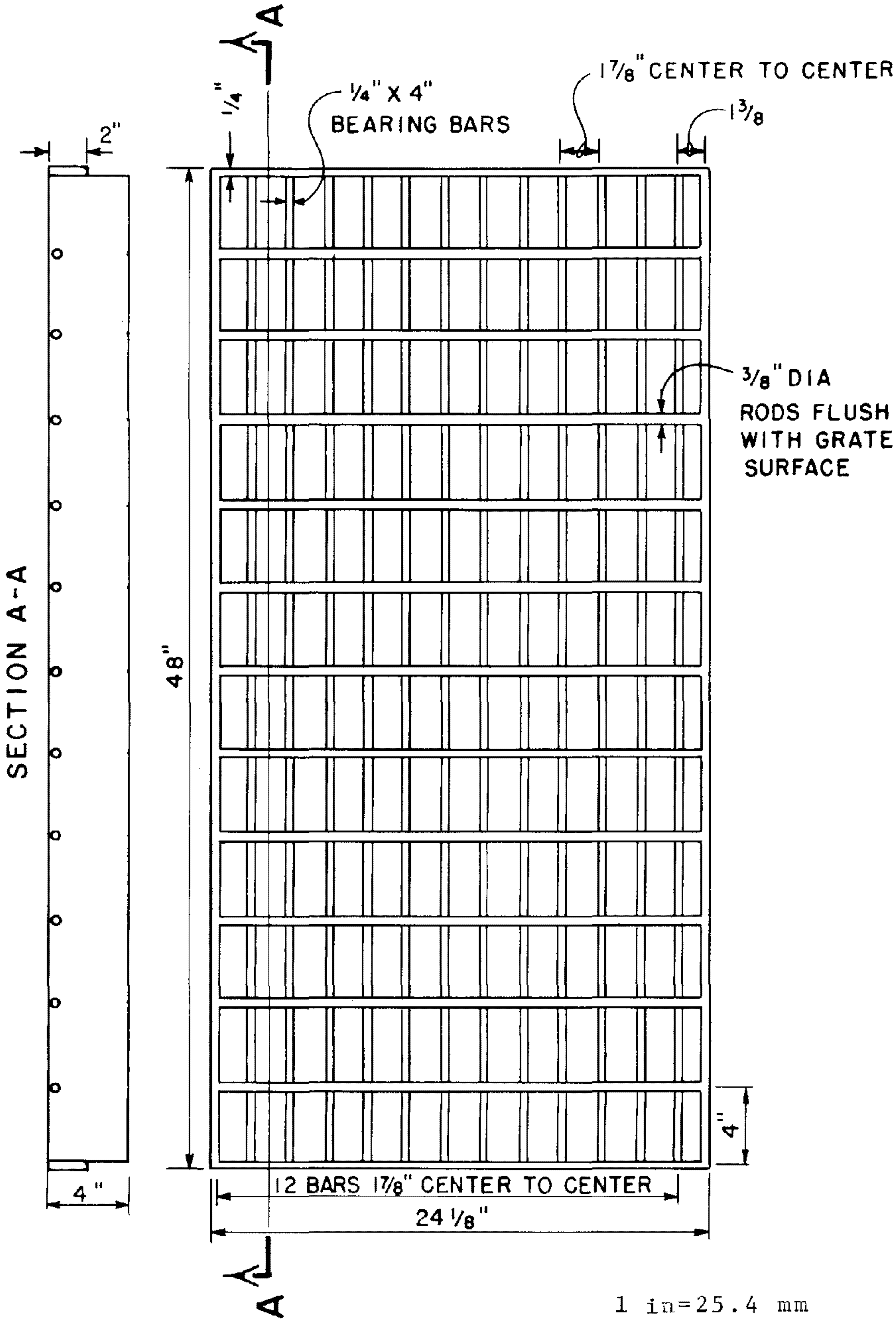


Figure 6-1. - 2 ft by 4 ft (0.61 m by 1.22 m) fabricated steel P - 1-7/8 - 4 grate.

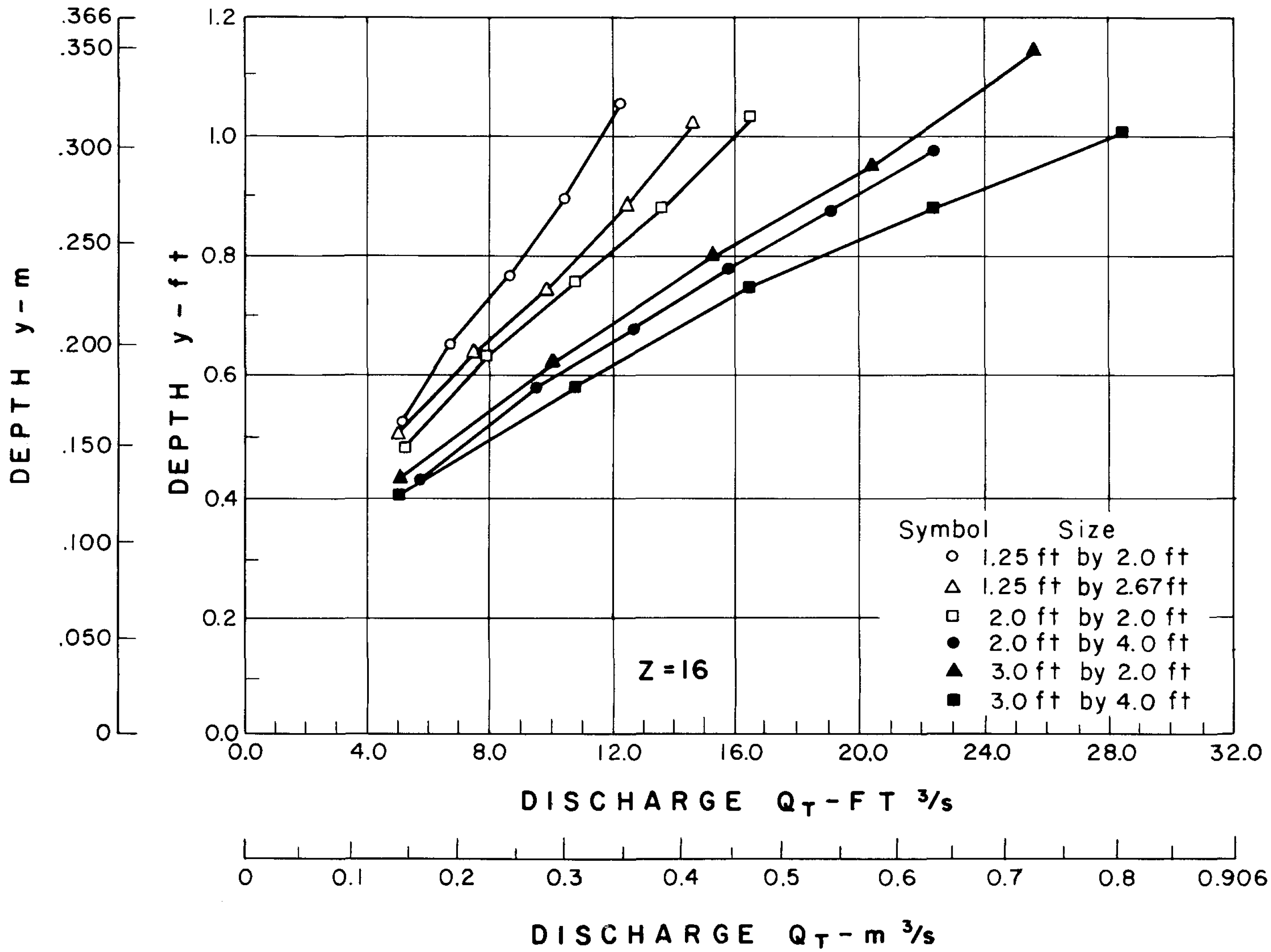


Figure 6-2. - Inlet capacity curves, P - 1-7/8 - 4 sump grate, Z = 16.

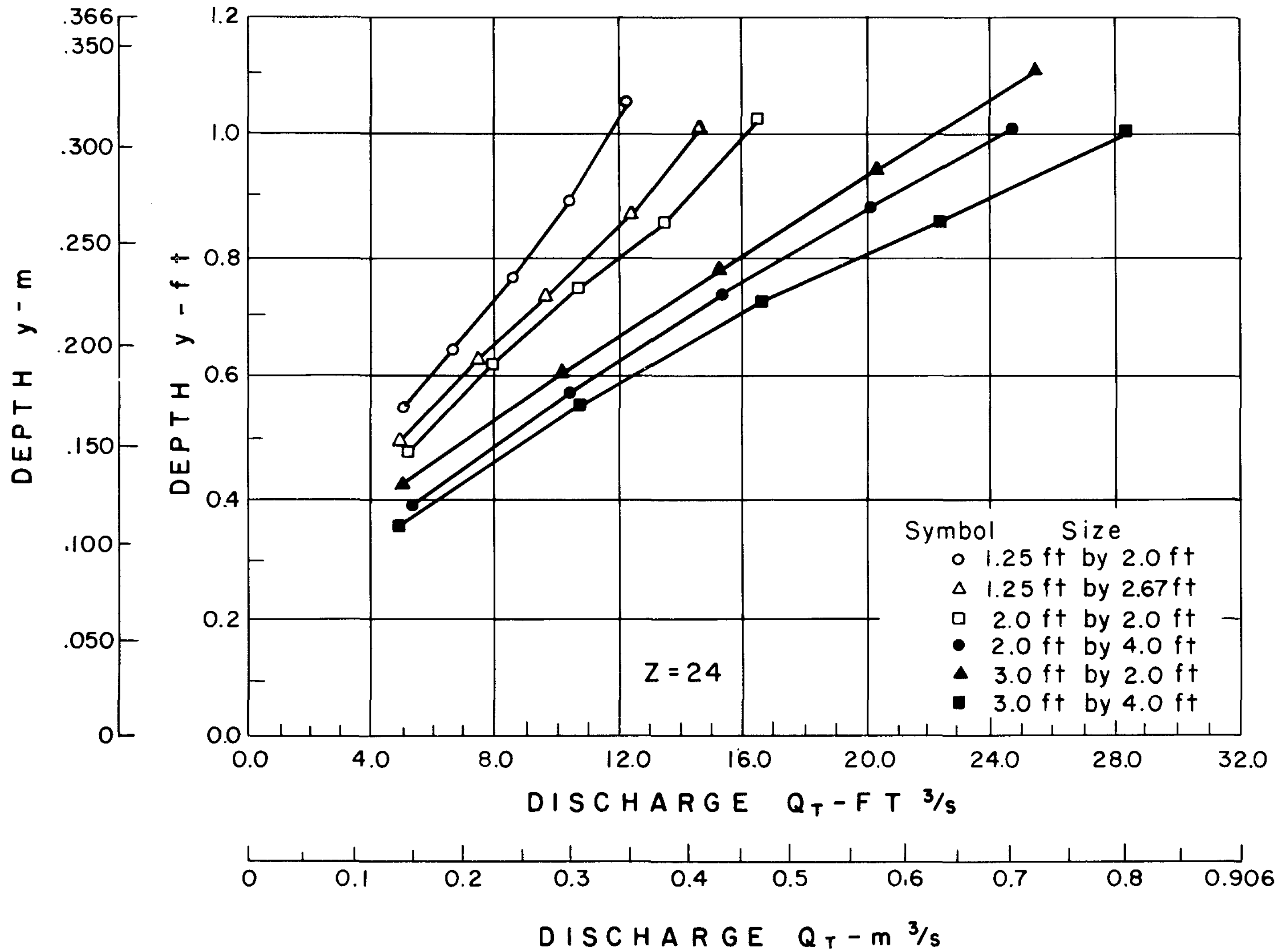


Figure 6-3. - Inlet capacity curves, P - 1-7/8 - 4 sump grate, Z = 24.

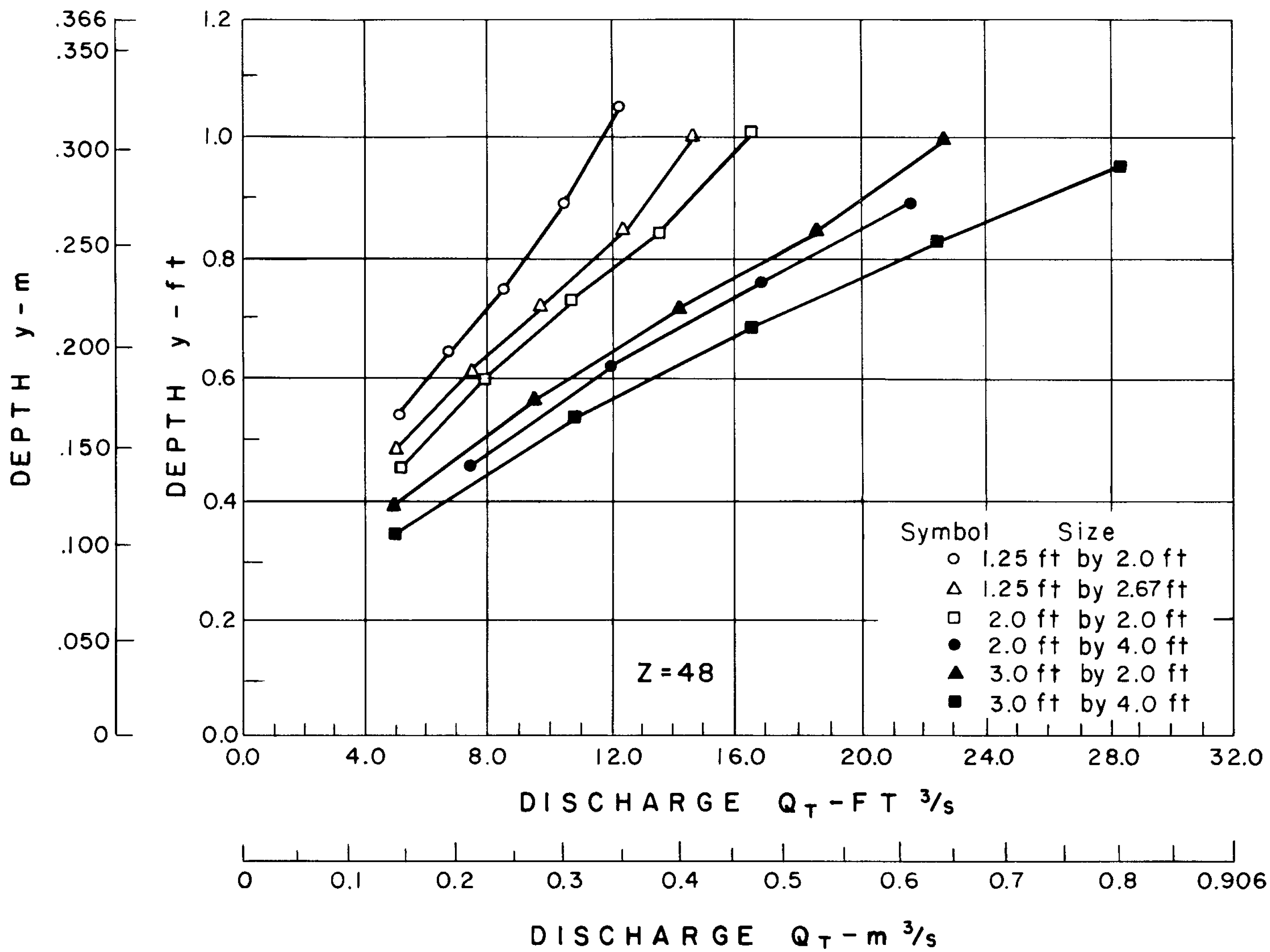
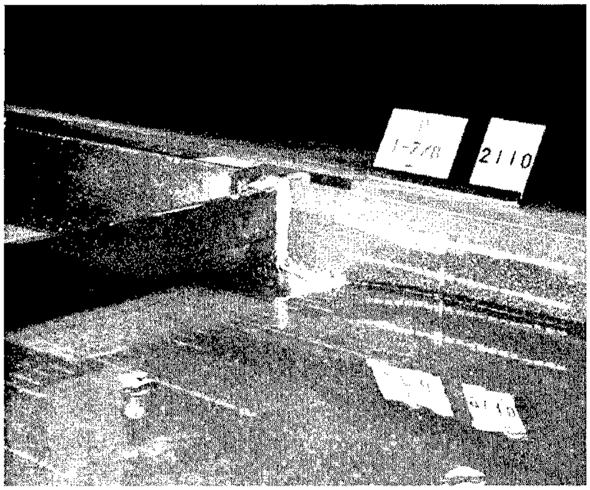
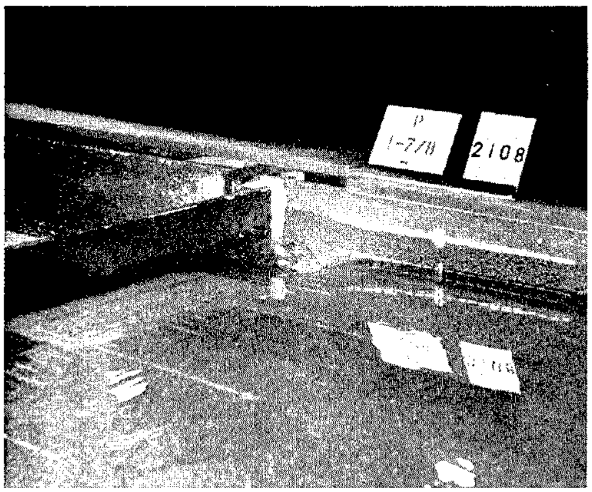


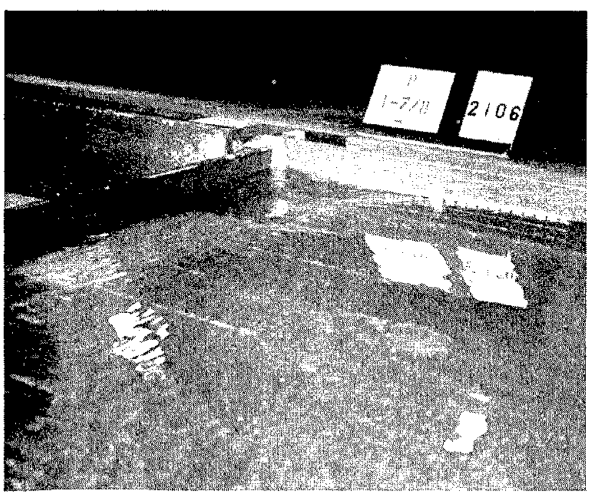
Figure 6-4. - Inlet capacity curves, P - 1-7/8 - 4 sump grate, Z = 48.



a. Flow depth at the curb,
y = 0.548 ft (0.167 m)
Q_T = 5.09 ft^3/s
(0.144 m^3/s)

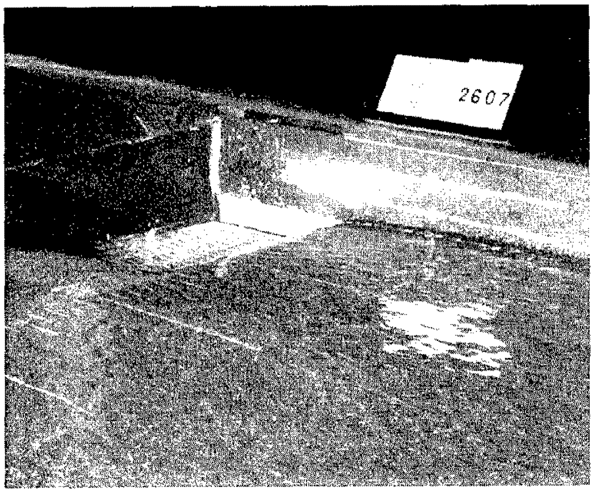


b. Flow depth at the curb,
y = 0.766 ft (0.233 m)
Q_T = 8.60 ft^3/s
(0.244 m^3/s)

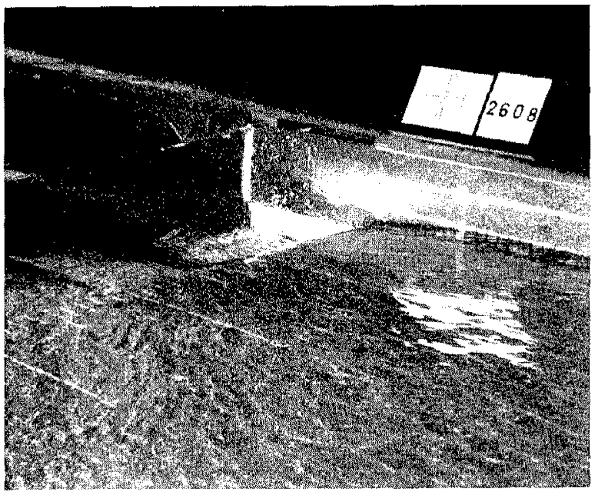


c. Flow depth at the curb,
y = 1.06 ft (0.323 m)
Q_T = 12.11 ft^3/s
(0.343 m^3/s)

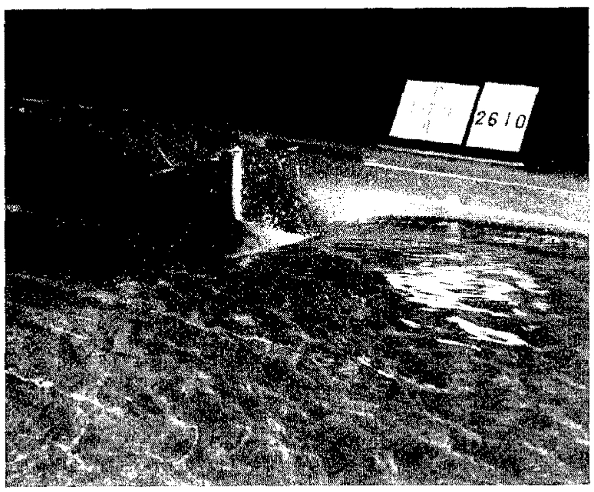
Figure 6-5. - 1.25 ft by 2.0 ft (0.38 m by 0.61 m) P - 1-7/8 - 4 sump grate at three flow depths, Z = 16.



a. Flow depth at the curb,
y = 0.560 ft (0.171 m)
Q_T = 10.75 ft^3/s
(0.304 m^3/s)



b. Flow depth at the curb,
y = 0.730 ft (0.223 m)
Q_T = 16.52 ft^3/s
(0.468 m^3/s)



c. Flow depth at the curb,
y = 1.012 ft (0.308 m)
Q_T = 28.29 ft^3/s
(0.801 m^3/s)

Figure 6-6. - 3.0 ft by 4.0 ft (0.91 m by 1.22 m) P - 1-7/8 - 4 sump grate at three flow depths, Z = 16.

The average weir flow depth is greater for the 2 ft (0.61 m) wide grate than the 3 ft (0.91 m) wide grate since it is closer to the deep flow at the curb and, therefore, its flow capacity is slightly greater.

The effect of roadway cross slope, 1/Z, on the capacity of the P - 1-7/8 - 4 sump grate is a function of the grate width. The wider the grate, the more effect the cross slope has on the depth of flow over the side of the grate farthest from the curb. Figure 6-7 shows the inlet capacity curves for the three sump grate sizes having a length of 2 ft (0.61 m) and widths of 1.25 ft, 2 ft, and 3 ft (0.38 m, 0.61 m, and 0.91 m).

For any grate size, the flow capacity is greater at the flatter roadway cross slopes, 1/Z, for a constant flow depth, y. In studying figure 6-7, it is evident that the effect of roadway cross slope, 1/Z, on sump grate capacity is related to the grate width - the wider the grate, the greater is the effect of roadway cross slope. As expected, the larger grate sizes have the larger flow capacities for the same flow depth, y.

Debris Tests. - The six P - 1-7/8 - 4 sump grate sizes were tested for debris handling ability using the test procedure described in chapter 2. All debris tests were conducted on a longitudinal slope, S_0 = 0.2 percent. Table 6-1 summarizes the test data for the P - 1-7/8 - 4 sump grates. As was found with the P - 1-1/8 sump grate, the P - 1-7/8 - 4 sump grate is not efficient at handling the debris tested. The exception is the smallest size - the 1.25 ft by 2 ft (0.38 m by 0.61 m) sump grate. The small grate plugged with debris very quickly and the remainder of the leaves were carried through the relatively large curb opening. The surface area of the larger sump grate had such capacity, that the flow continued to pass down through the grate causing the leaves to catch on the longitudinal and transverse members of the grate. Figure 6-8 illustrates this operation for the smallest and largest P - 1-7/8 - 4 sump grates. The grate was also found to be inefficient in handling debris on continuous grades as reported in chapter 11 of volume 1.

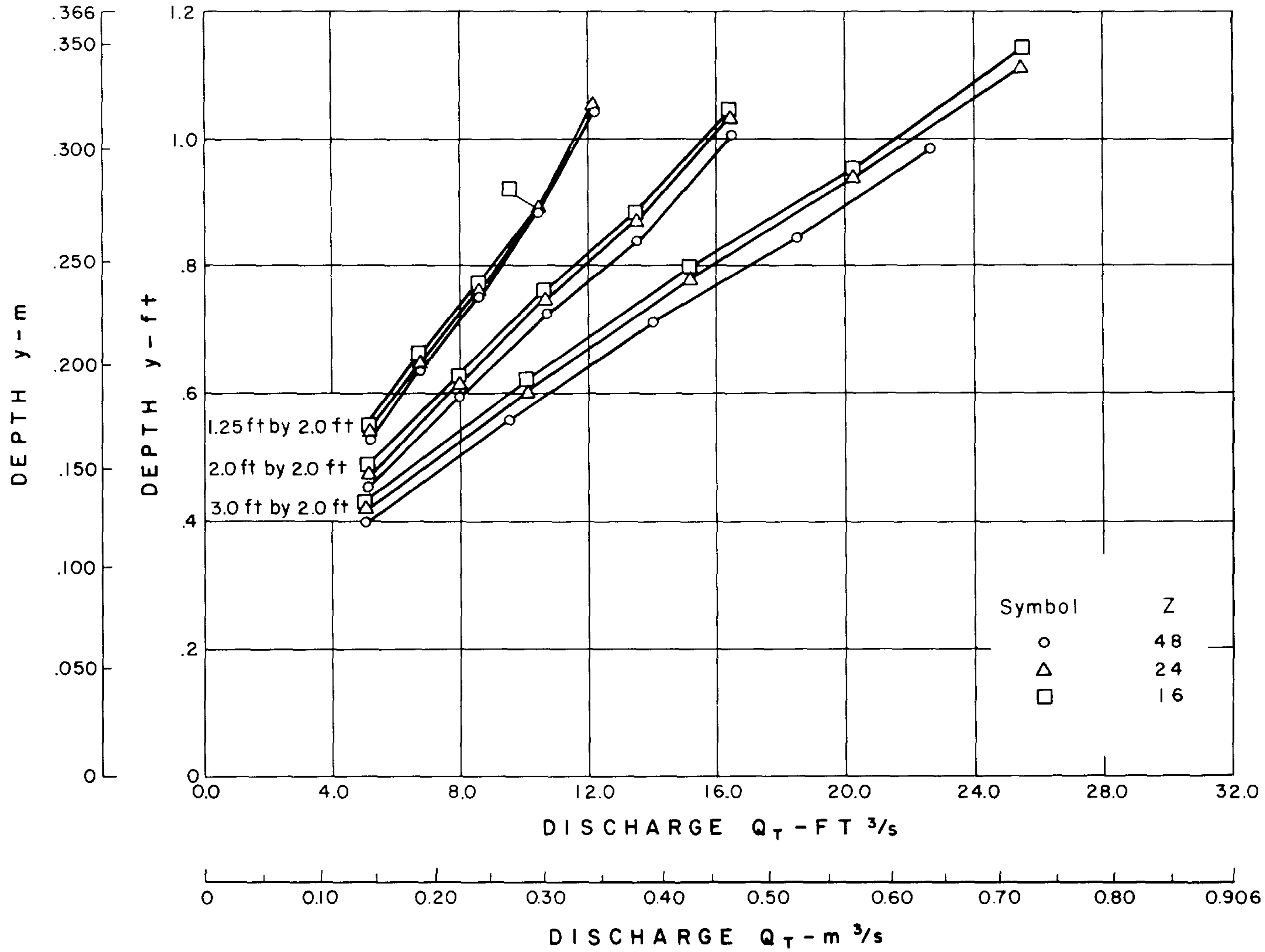


Figure 6-7. - Inlet capacity curves for 2 ft (0.61 m) long P - 1-7/8 - 4 sump grates.

Table 6-1

DEBRIS TEST RESULTS - P - 1-7/8 - 4 SUMP GRATES

$S_0 = 0.20\%$

Test No.	Number of leaves lodged on grate* 5 minutes	Number of leaves lodged on grate* 15 minutes	Test No.	Number of leaves lodged on grate* 5 minutes	Number of leaves lodged on grate* 15 minutes
	1.25 ft by 2.0 ft grate (0.38 m by 0.61 m)			1.25 ft by 2.67 ft grate (0.38 m by 0.81 m)	
1	87	82	1	128	127
2	100	87	2	142	129
3	90	81	3	140	128
Debris handling efficiency (%)	38	44		9	15
	2.0 ft by 2.0 ft grate (0.61 m by 0.61 m)			2.0 ft by 4.0 ft grate (0.61 m by 1.22 m)	
1	132	130	1	146	142
2	146	142	2	131	131
3	141	137	3	145	142
			4	141	136
Debris handling efficiency (%)	7	9		6	8
	3.0 ft by 2.0 ft grate (0.91 m by 0.61 m)			3.0 ft by 4.0 ft grate (0.91 m by 1.22 m)	
1	144	141	1	140	139
2	135	134	2	136	133
3	141	138	3	145	144
			4	143	140
Debris handling efficiency (%)	7	8		6	7

* Based on 150 "leaves" arriving at the grate.

a. 1.25 ft by 2.0 ft
(0.38 m by 0.61 m)

b. 3.0 ft by 4.0 ft
(0.91 m by 1.22 m)

Figure 6-8. - Debris tests - P - 1-7/8 - 4 sump grates.

CHAPTER 7

TEST RESULTS - CURVED VANE SUMP GRATE - CV - 3-1/4 - 4-1/4

This chapter presents the results of sump condition tests for six sizes of the curved vane grate with a 4-1/4 in (108 mm) curb opening. The grate is referred to as the CV - 3-1/4 - 4-1/4 because the longitudinal bars are placed on 3-1/4 in (83 mm) centers and the transverse curved vane bars on 4-1/4 in (108 mm) centers. The sizes tested included two lengths of a 1.25 ft (0.38 m) wide grate, 2.67 ft and 2 ft (0.81 m and 0.61 m) long; two lengths of a 2 ft (0.61 m) wide grate, 4.0 ft and 2 ft (1.22 m and 0.61 m) long; and two lengths of a 3 ft (0.91 m) wide grate, 4 ft and 2 ft (1.22 m and 0.61 m) long. A 2 ft by 4 ft (0.61 m by 1.22 m) grate is shown in figure 7-1. The grate sizes are the same as the six grate sizes tested in volumes 1 and 2 for continuous grade tests.

Experimental Results and Observations

Hydraulics. - Hydraulic test results for the curved vane sump grate are shown in figures 7-2, 7-3, and 7-4. Since under sump condition tests, all of the roadway flow passed through the sump grate, the major variable is the depth of flow, y, to pass a given amount of flow, Q_T, for a specific design and size sump grate and under specific roadway cross slope conditions. Since the curved vanes are directional, the flow capacity of one-half the grate in a sump condition is less than the flow capacity of the other half. The curves presented in figures 7-2 through 7-4 are a summation of the results of testing one-half the curved vane grate forward and one-half of the grate backward.

As with the other two sump grate designs, the smaller curved vane sump grates function as a weir for small flow depths, y, but change to orifice flow as the depth increases. The 3 ft by 4 ft (0.91 m by 1.22 m) sump grate is the only size which continues to function as a weir up through a flow depth of 0.95 ft (0.29 m). Figures 7-5 and 7-6 illustrate the various stages of weir, transition zone, and orifice flow for the 1.25 ft by 2 ft (0.38 m by 0.61 m) and the 3 ft by 4 ft (0.91 m by 1.22 m) curved vane sump grates in the forward position for three flow depths.

The curves in figures 7-2 through 7-4 follow the trends presented in chapters 5 and 6 and the theory described in chapter 3. The curved vane sump grate is a cast grate with larger members than the two fabricated steel grates. Therefore, the effective weir length of the grate is smaller and the capacity somewhat less. When the cast grate is under orifice control, the effective open area is also less than that of the fabricated steel grates. In

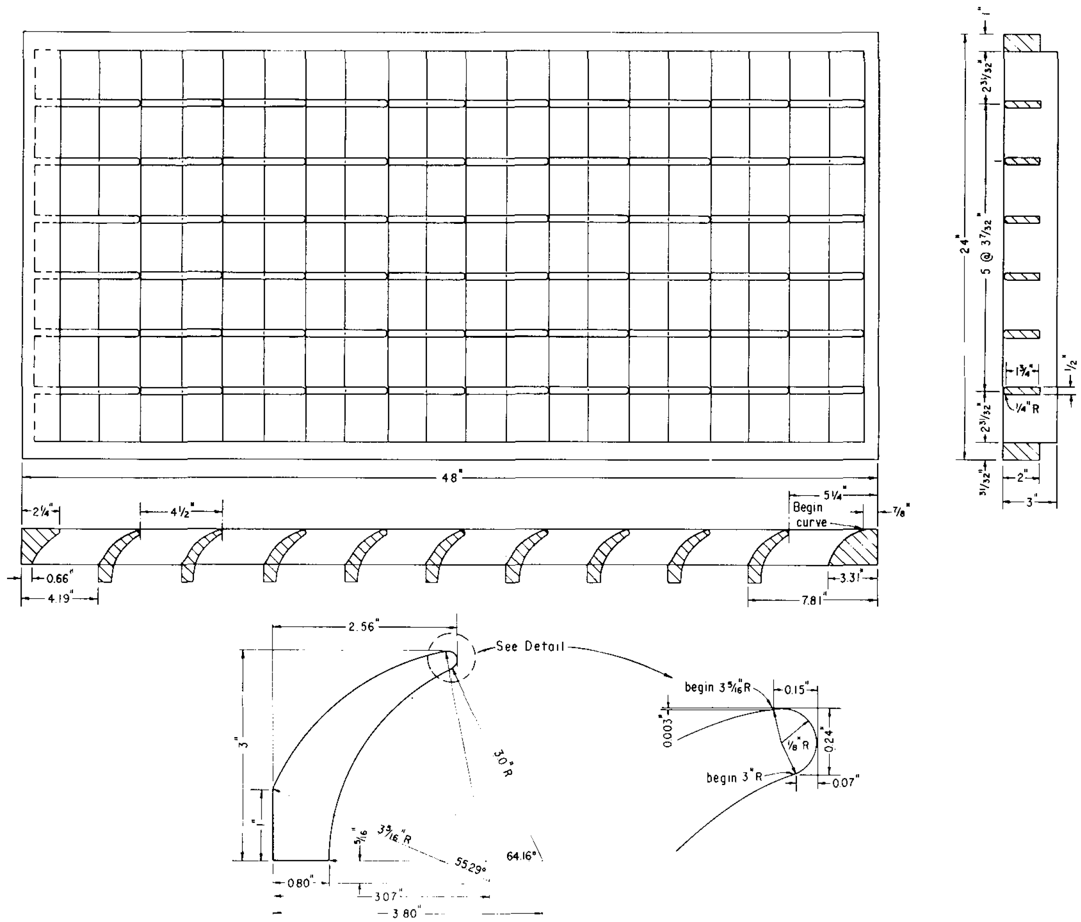


Figure 7-1. - 2.0 ft by 4.0 ft (0.61 m by 1.22 m) curved vane - CV - 3-1/4 - 4-1/4 grate.

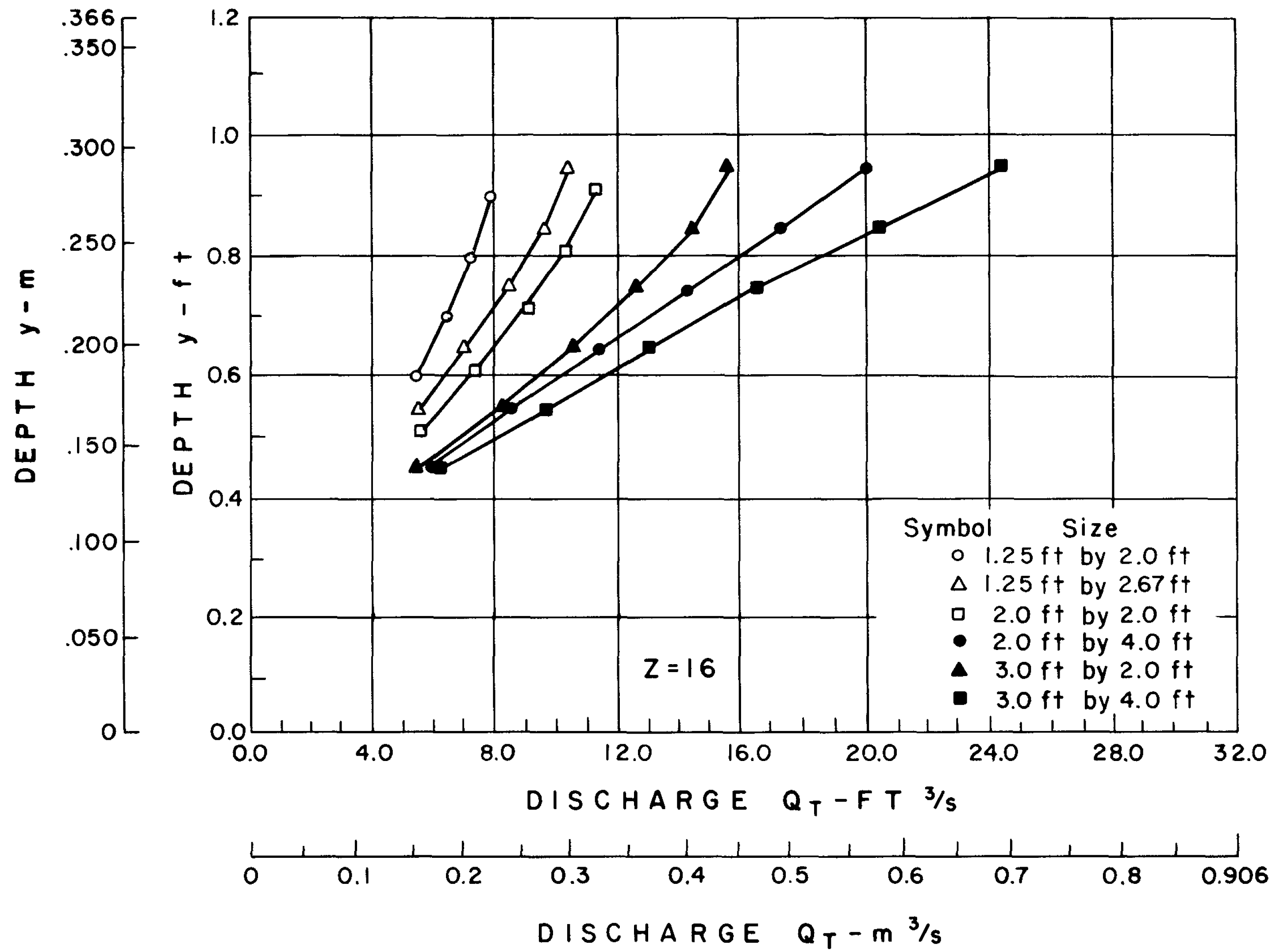


Figure 7-2. - Inlet capacity curves, CV - 3-1/4 - 4-1/4 sump grate, Z = 16.

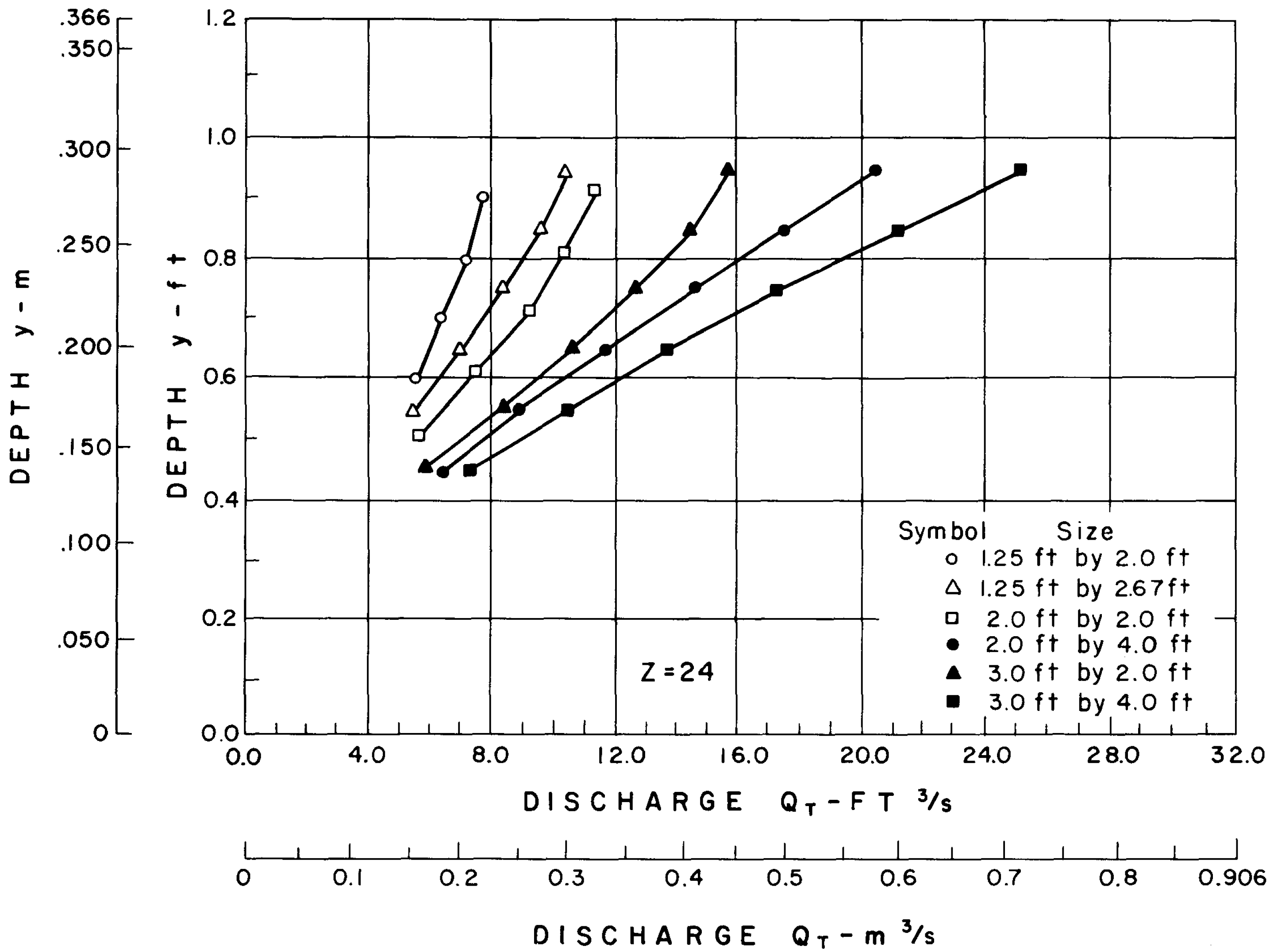


Figure 7-3. - Inlet capacity curves, CV - 3-1/4 - 4-1/4 sump grate, Z = 24.

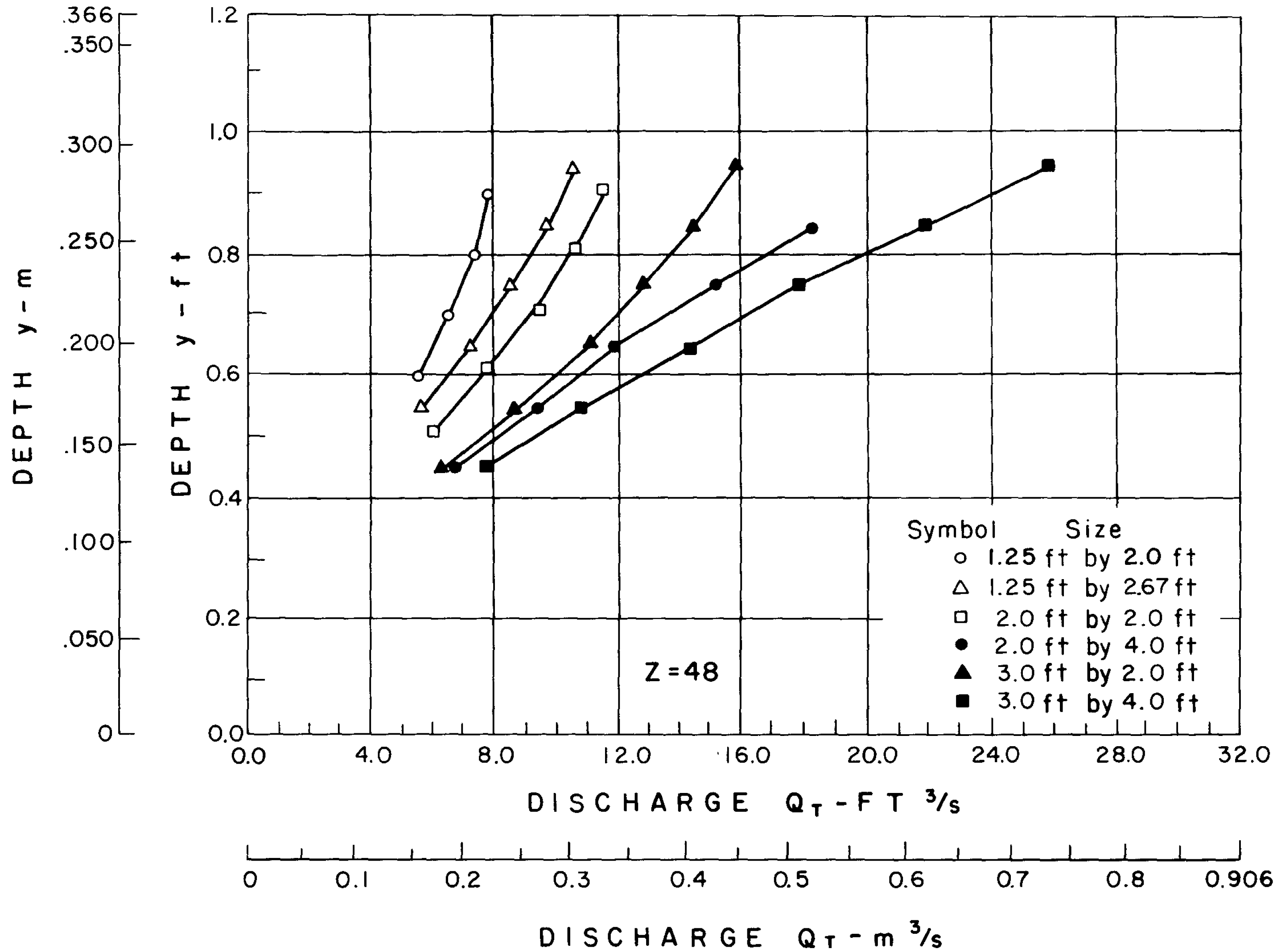
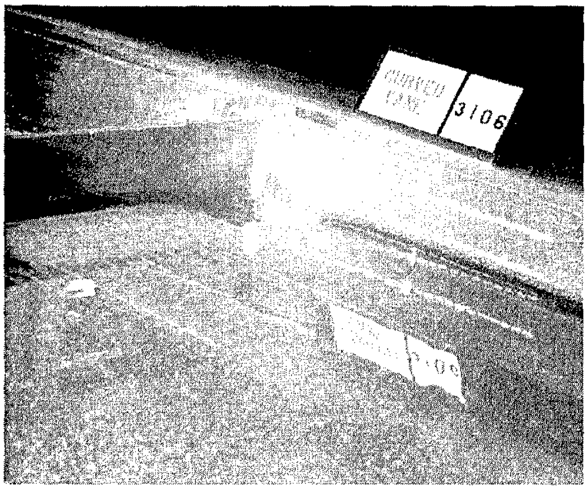
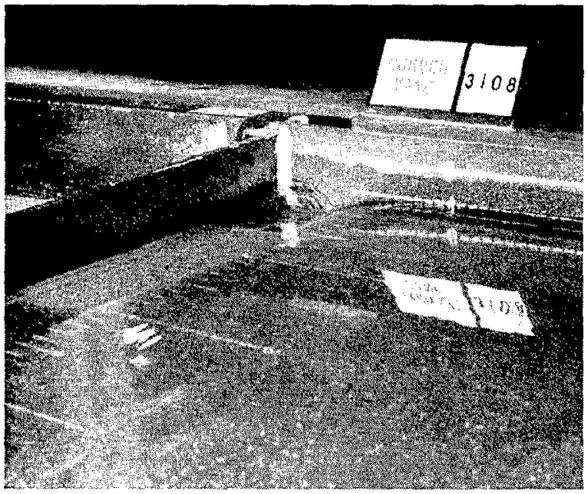


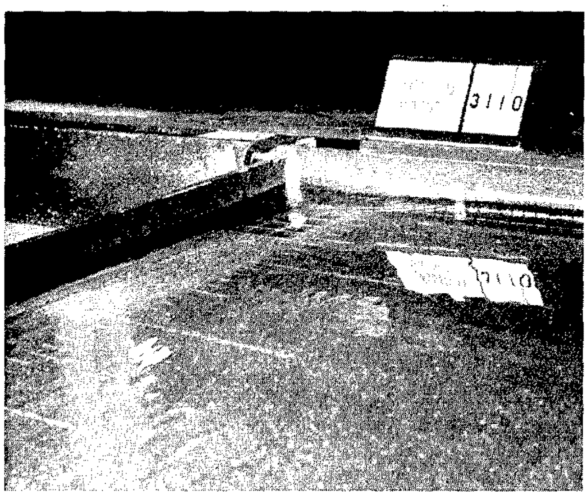
Figure 7-4. - Inlet capacity curves, CV - 3-1/4 - 4-1/4 sump grate, Z = 48.



a. Flow depth at the curb,
y = 0.554 ft (0.169 m)
Q_T = 4.98 ft^3/s
(0.141 m^3/s)

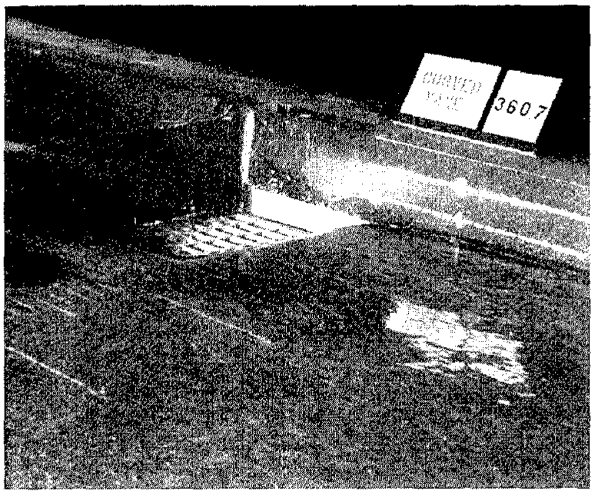


b. Flow depth at the curb,
y = 0.718 ft (0.219 m)
Q_T = 6.90 ft^3/s
(0.195 m^3/s)

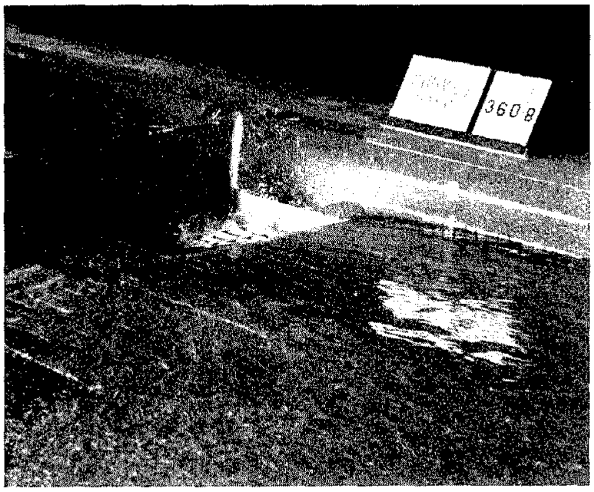


c. Flow depth at the curb,
y = 0.976 ft (0.297 m)
Q_T = 8.82 ft^3/s
(0.250 m^3/s)

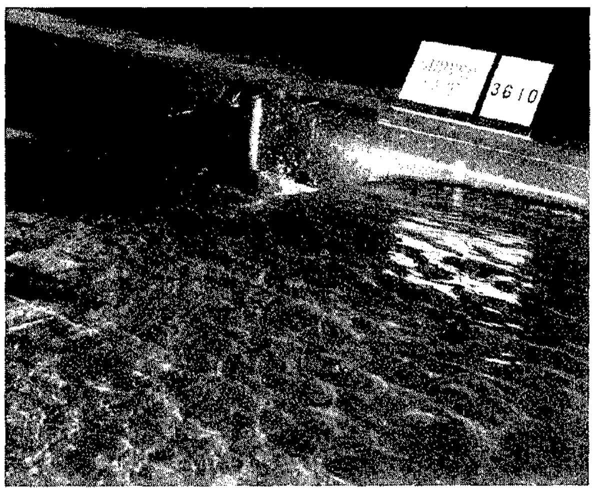
Figure 7-5. - 1.25 by 2.0 ft (0.38 m by 0.61 m) CV - 3-1/4 - 4-1/4 sump grate at three flow depths, Z = 16.



a. Flow depth at the curb,
$y = 0.552$ ft (0.168 m)
$Q_T = 10.75\ ft^3/s$ ($0.304\ m^3/s$)



b. Flow depth at the curb,
$y = 0.722$ ft (0.220 m)
$Q_T = 16.52\ ft^3/s$ ($0.468\ m^3/s$)



c. Flow depth at the curb,
$y = 1.004$ ft (0.306 m)
$Q_T = 28.29\ ft^3/s$ ($0.801\ m^3/s$)

Figure 7-6. - 3.0 ft by 4.0 ft (0.91 m by 1.22 m) CV - 3-1/4 - 4-1/4 sump grate at three flow depths, Z = 16.

comparing the 3 ft by 2 ft (0.91 m by 0.61 m) and the 2 ft by 4 ft (0.61 m by 1.22 m) curved vane sump grate sizes at the higher flow depths, it is clear that the 3 ft by 2 ft (0.91 m by 0.61 m) inlet does not have the capacity that the 2 ft by 4 ft (0.61 m by 1.22 m) inlet has. This difference was not so great with the fabricated steel grate inlets. The reduction in capacity results from the fact that the curved vane members of the grate are directional. This directional characteristic is more detrimental to flow capacity than the size of the cast members. Figure 7-7 illustrates the capacities of the two halves of the 2 ft by 2 ft (0.61 m by 0.61 m) curved vane sump grate with the curved vanes placed forward and backward to the approach flow. Although the two halves have similar capacities under weir control (low flow depths), the curved vane grate placed backward comes under orifice control at a lower flow depth, y, than when it is placed in the forward position. This results in a lower flow capacity for the curved vane sump grate placed backward and a lower total capacity in a sump condition.

The roadway cross slope, 1/Z, has a minor effect on the curved vane sump grate capacity as it did with the fabricated steel grates. The flatter cross slopes result in a higher capacity for the same flow depth, y. In figure 7-8, the difference in inlet capacity, Q_T, as it relates to roadway cross slope, 1/Z, does not vary with grate width, W, to the extent it did with the fabricated grates in figures 5-6 and 6-6.

Debris Tests. - The six curved vane sump grate sizes were tested backward and forward for debris handling ability. Tables 7-1 and 7-2 summarize the test data for the curved vane sump grates. Figure 7-9 shows the flow conditions for the 1.25 ft by 2 ft (0.38 m by 0.61 m) and the 3 ft by 4 ft (0.91 m by 1.22 m) curved vane sump grates during the debris tests. As noted with the fabricated steel sump grates, the two smaller curved vane sump grates show a considerably higher debris handling efficiency than the larger grates. This is due to the fact that the grate becomes covered with the initial debris and the flow and debris are diverted through the curb opening. For the small sump grates, the debris handling performance of the curved vane installed backward is superior to the grate installed forward. Initial debris collects on the backward curved vane members and diverts the flow and remaining debris through the curb opening more efficiently than when the curved vane is placed forward. The debris handling efficiency of the curved vane sump grate is similar to the two fabricated steel sump grates. In comparing the debris results of this chapter with those of chapter 10 of volume 1 for continuous grades, it is clear that the curved vane sump grate is not nearly as efficient in the sump condition as it is on the continuous grades.

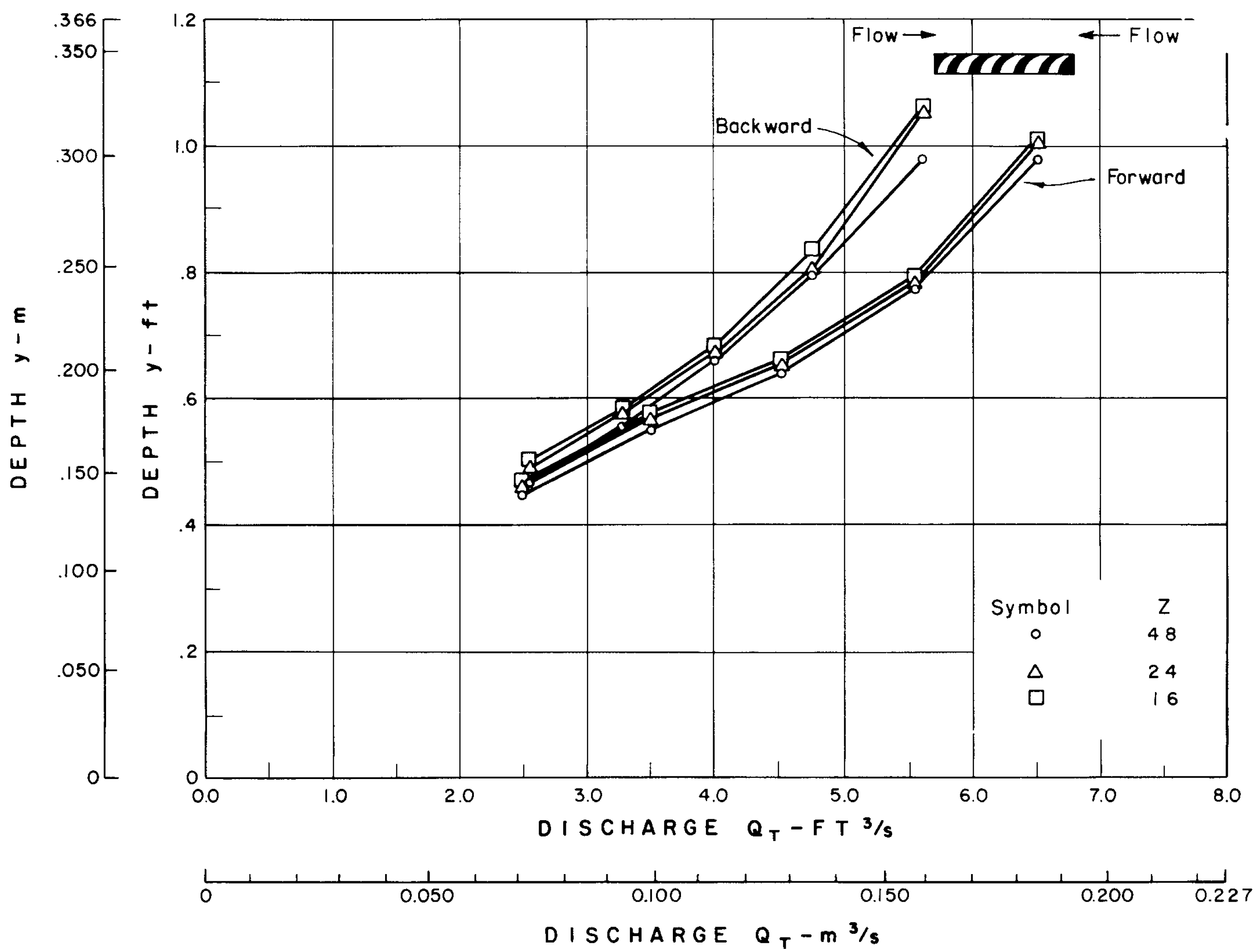


Figure 7-7. - Inlet capacity curves for the two halves of the CV - 3-1/4 - 4-1/4 sump grate placed forward and backward.

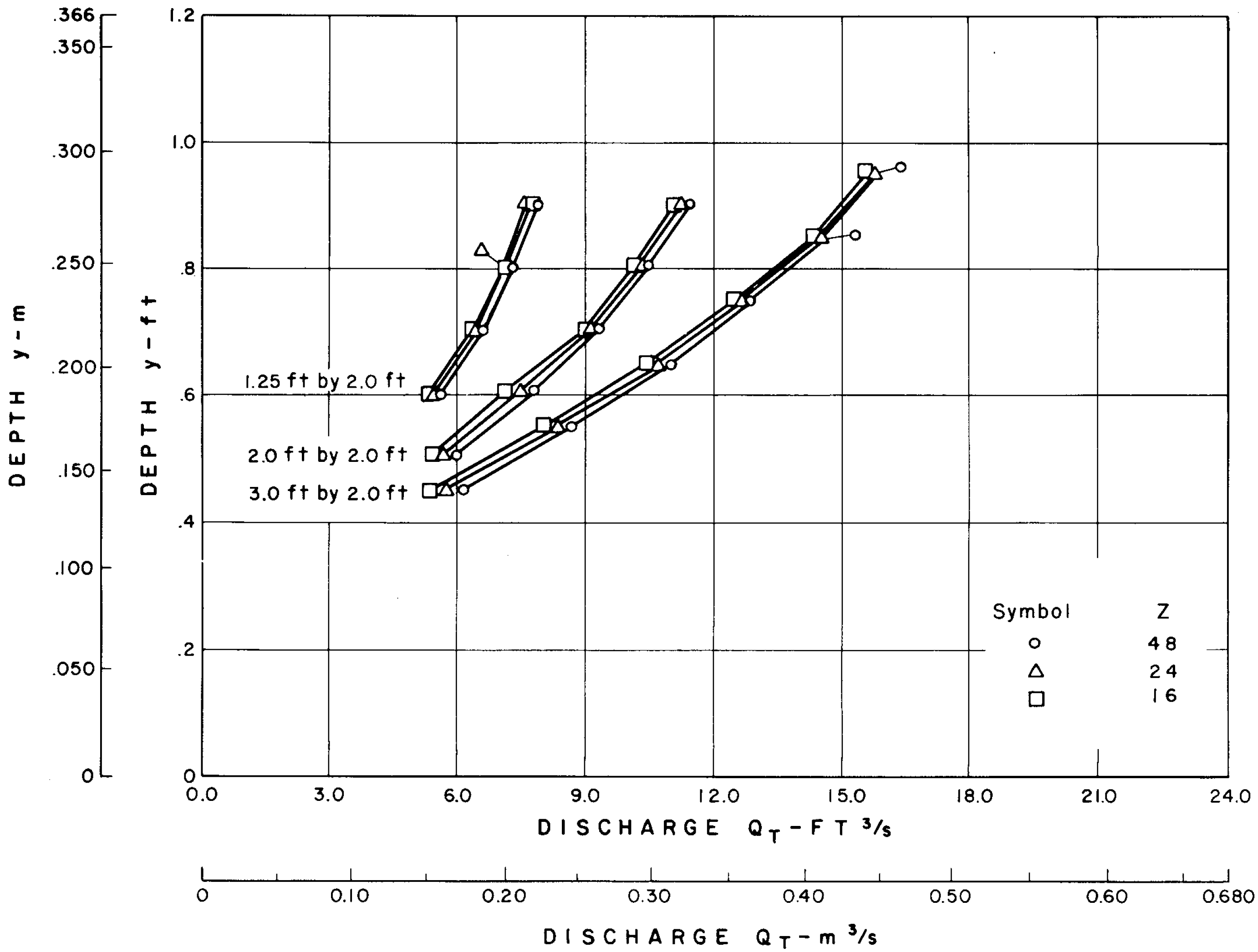


Figure 7-8. - Inlet capacity curves for 2 ft (0.61 m) long CV - 3-1/4 - 4-1/4 sump grates.

Table 7-1

DEBRIS TEST RESULTS - CV - 3-1/4 - 4-1/4
SUMP GRATES - FORWARD

$S_0 = 0.20\%$

Test No.	Number of leaves lodged on grate* 5 minutes	Number of leaves lodged on grate* 15 minutes	Test No.	Number of leaves lodged on grate* 5 minutes	Number of leaves lodged on grate* 15 minutes
	1.25 ft by 2.0 ft grate (0.38 m by 0.61 m)			1.25 ft by 2.67 ft grate (0.38 m by 0.81 m)	
1	105	94	1	126	125
2	134	117	2	144	130
3	112	110	3	130	128
Debris handling efficiency (%)	22	29		11	15
	2.0 ft by 2.0 ft grate (0.61 m by 0.61 m)			2.0 ft by 4.0 ft grate (0.61 m by 1.22 m)	
1	138	131	1	143	136
2	144	140	2	139	137
3	137	132	3	138	133
Debris handling efficiency (%)	7	10		7	10
	3.0 ft by 2.0 ft grate (0.91 m by 0.61 m)			3.0 m by 4.0 ft grate (0.91 m by 1.22 m)	
1	140	136	1	142	136
2	144	137	2	127	119
3	136	136	3	121	116
			4	119	117
Debris handling efficiency (%)	7	9		15	19

* Based on 150 "leaves" arriving at the grate.

Table 7-2

DEBRIS TEST RESULTS - CV - 3-1/4 - 4-1/4
SUMP GRATES - BACKWARD

$S_0 = 0.20\%$

Test No.	Number of leaves lodged on grate* 5 minutes	Number of leaves lodged on grate* 15 minutes	Test No.	Number of leaves lodged on grate* 5 minutes	Number of leaves lodged on grate* 15 minutes
	1.25 ft by 2.0 ft grate (0.38 m by 0.61 m)			1.25 ft by 2.67 ft grate (0.38 m by 0.81 m)	
1	77	72	1	131	100
2	70	66	2	121	104
3	80	73	3	118	113
Debris handling efficiency (%)	50	53		18	30
	2.0 ft by 2.0 ft grate (0.61 m by 0.61 m)			2.0 ft by 4.0 ft grate (0.61 m by 1.22 m)	
1	145	142	1	132	125
2	135	123	2	141	135
3	138	132	3	139	135
Debris handling efficiency (%)	7	12		8	12
	3.0 ft by 2.0 ft grate (0.91 m by 0.61 m)			3.0 ft by 4.0 ft grate (0.91 m by 1.22 m)	
1	142	139	1	140	136
2	135	130	2	134	123
3	134	131	3	134	128
Debris handling efficiency (%)	9	11		9	14

* Based on 150 "leaves" arriving at the grate.

a. 1.25 ft by 2.0 ft
(0.38 m by 0.61 m)

b. 3.0 ft by 4.0 ft
(0.91 m by 1.22 m)

Figure 7-9. - Debris tests - CV - 3-1/4 - 4-1/4 sump grates.

CHAPTER 8

DISCUSSION OF RESULTS

Results of the hydraulic tests for the curb opening only and the three sump grate designs show that these configurations perform in a manner similar to the hydraulic theory presented in chapter 3. Under sump conditions, the performance of the sump grates can best be represented by the weir equation 3-1 for small flow depths, y. As the flow depth near the inlet rises, and the inlet becomes submerged, the hydraulic conditions change from weir flow through a transition zone to orifice flow at the deeper depths. The curves presented in figure 3-2 describe the characteristic patterns for the three stages of hydraulic control evident during the test program for the sump grates. For the small size sump grates, 1.25 ft by 2 ft (0.38 m by 0.61 m), the flow characteristics are described by the weir equation 3-3 for low flow depths (y less than 0.6 ft (0.18 m)). As the flow depth rises, the flow characteristics pass through a transition zone and then into a zone described by the orifice equation 3-4. For larger sump grate sizes, the grate was not submerged for the range of flow depths tested (y = 0.4 ft to 1.0 ft (0.12 m to 0.30 m)). Performance of the 3 ft by 4 ft (0.91 m by 1.22 m) sump grate design was characterized by the weir equation for all depths of flow tested.

Figures 8-1 through 8-9 present the test results in a graphical comparison of the three sump grate designs. Figures 8-1 through 8-3 show the results of the two 1.25 ft (0.38 m) wide grate sizes where the cross slopes, 1/Z = 1/16, 1/24, 1/48. Figures 8-4 through 8-6 show the results for the two 2.0 ft (0.61 m) wide grate sizes for the same cross slope conditions and figures 8-7 through 8-9 show the results for the two 3.0 ft (0.91 m) wide grate sizes.

For all the sump conditions tested, the parallel bar with transverse rods P - 1-7/8 - 4 sump grate, in general, has the highest inlet flow capacity for a given flow depth, y. The parallel bar with spacers, P - 1-1/8 sump grate is second and the curved vane, CV - 3-1/4 - 4-1/4 sump grate has the least flow capacity. The variation in flow capacity for the three sump grate designs depends on grate size and flow depth, y. The greatest variation occurs for the 1.25 ft by 2 ft (0.38 m by 0.61 m) sump grate size at y = 0.9 ft (0.27 m), 1/Z = 1/16, figure 8-1. The curved vane sump grate has 74 percent the capacity of the P - 1-7/8 - 4 sump grate and the P - 1-1/8 sump grate has 89 percent the capacity of the P - 1-7/8 - 4 sump grate. However, for the 3 ft by 4 ft (0.91 m by 1.22 m) inlet size at y = 0.9 ft (0.27 m), 1/Z = 1/16, these percentages become 96 percent and 97 percent, respectively, figure 8-7.

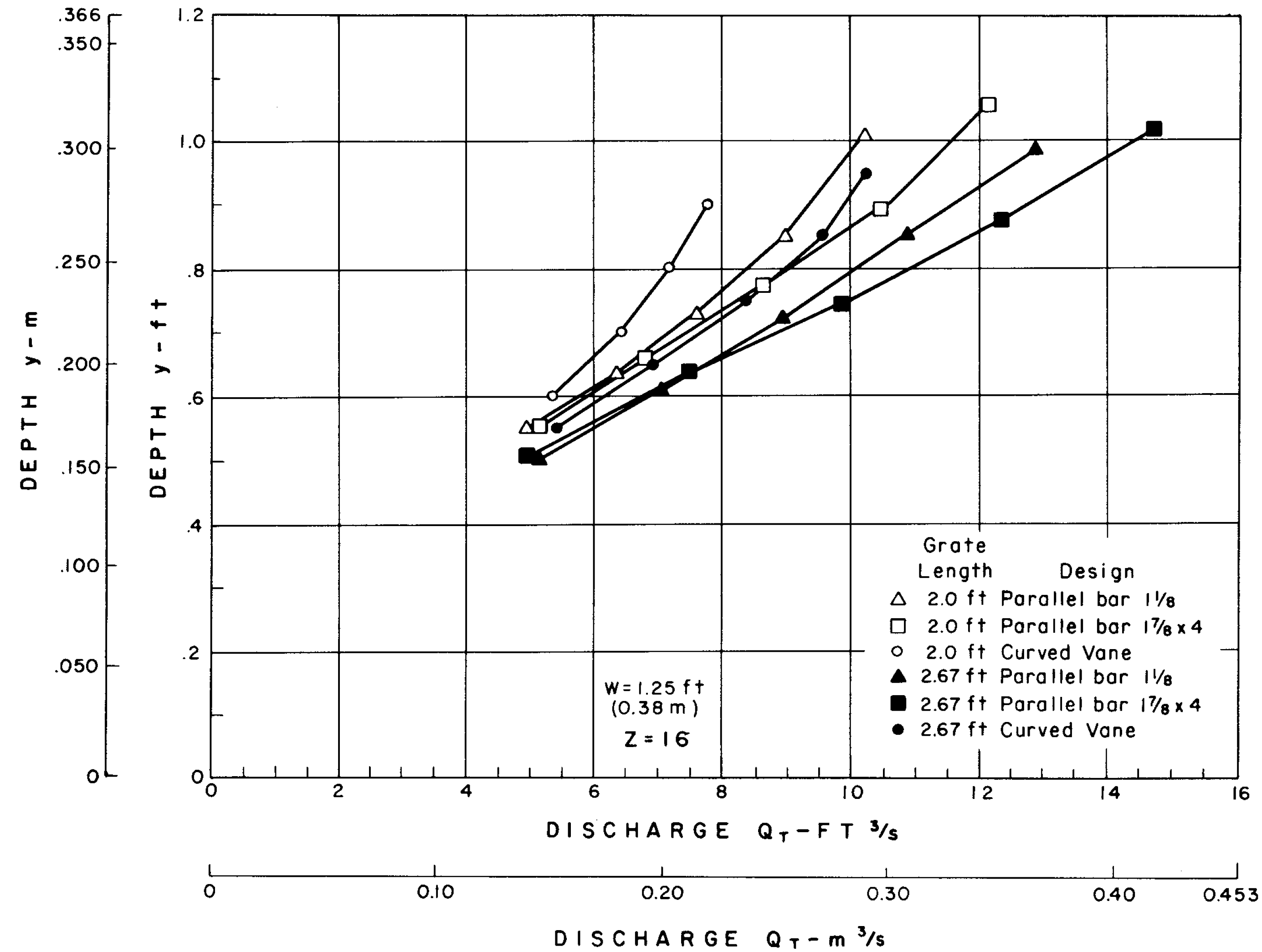


Figure 8-1. - Inlet capacity curves, 1.25 ft by 2.0 ft (0.38 m by 0.61 m) and 1.25 ft by 2.67 ft (0.38 m by 0.81 m) sump grates, Z = 16.

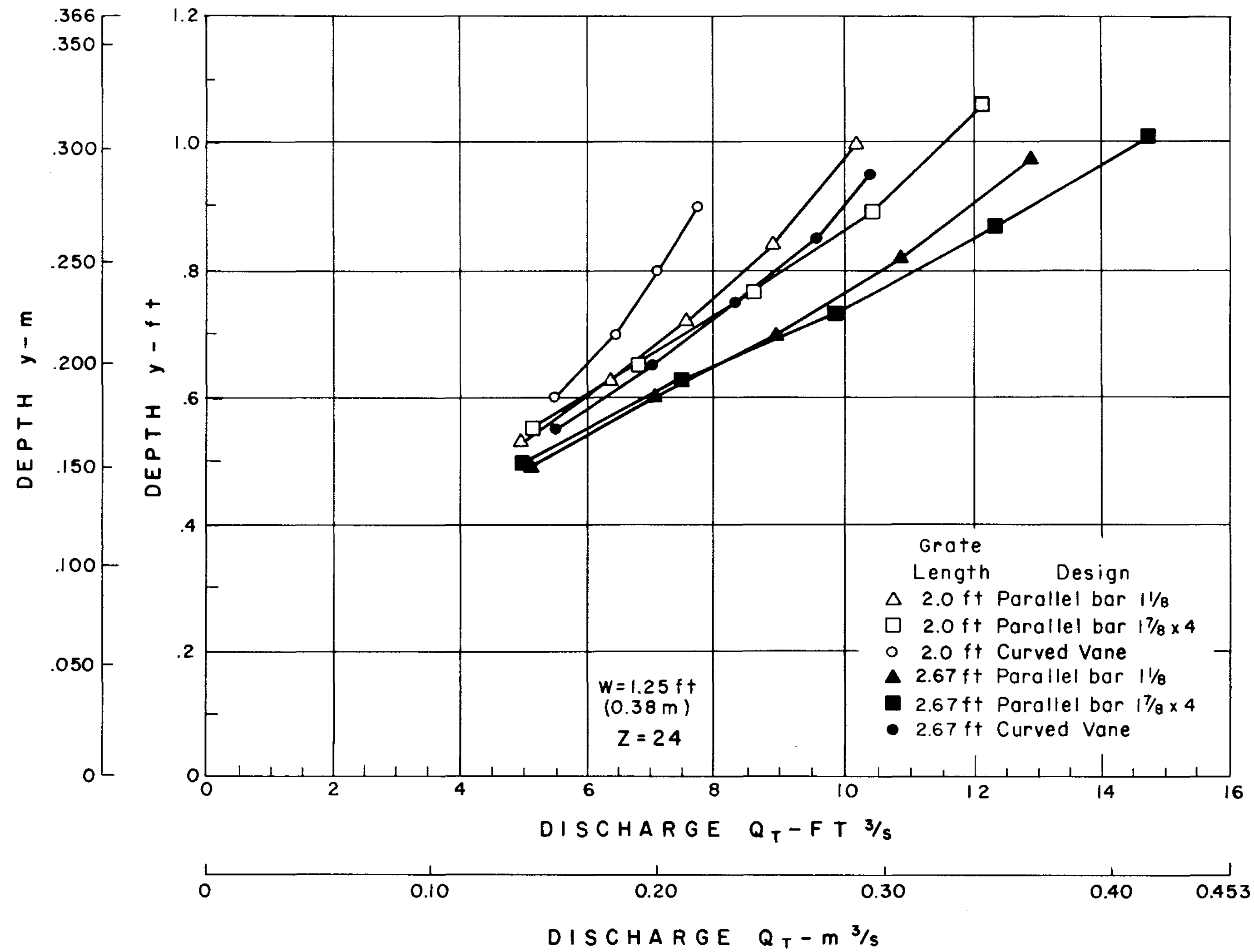


Figure 8-2. - Inlet capacity curves, 1.25 ft by 2.0 ft (0.38 m by 0.61 m) and 1.25 ft by 2.67 ft (0.38 m by 0.81 m) sump grates, Z = 24.

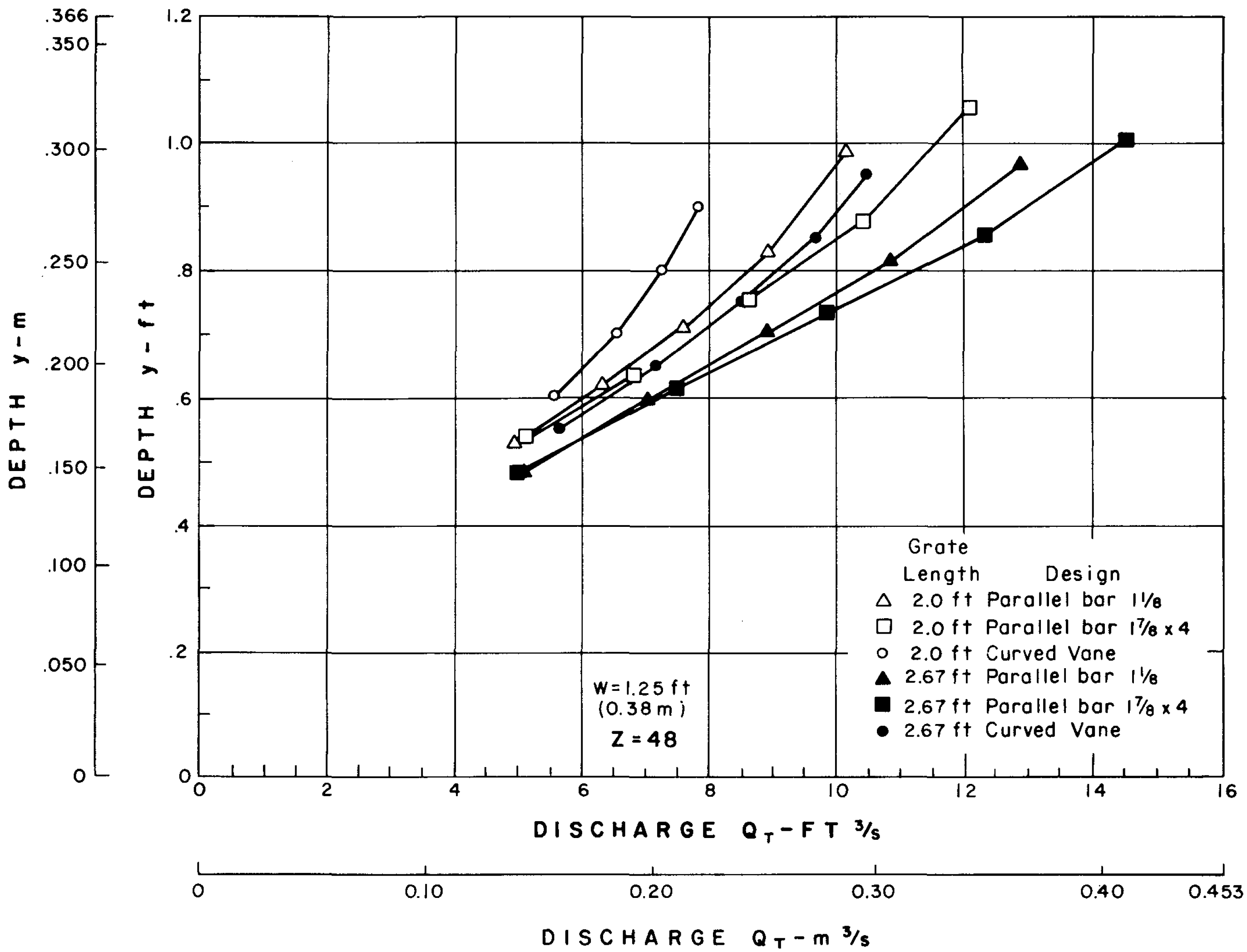


Figure 8-3. - Inlet capacity curves, 1.25 ft by 2.0 ft (0.38 m by 0.61 m) and 1.25 ft by 2.67 ft (0.38 m by 0.81 m) sump grates, Z = 48.

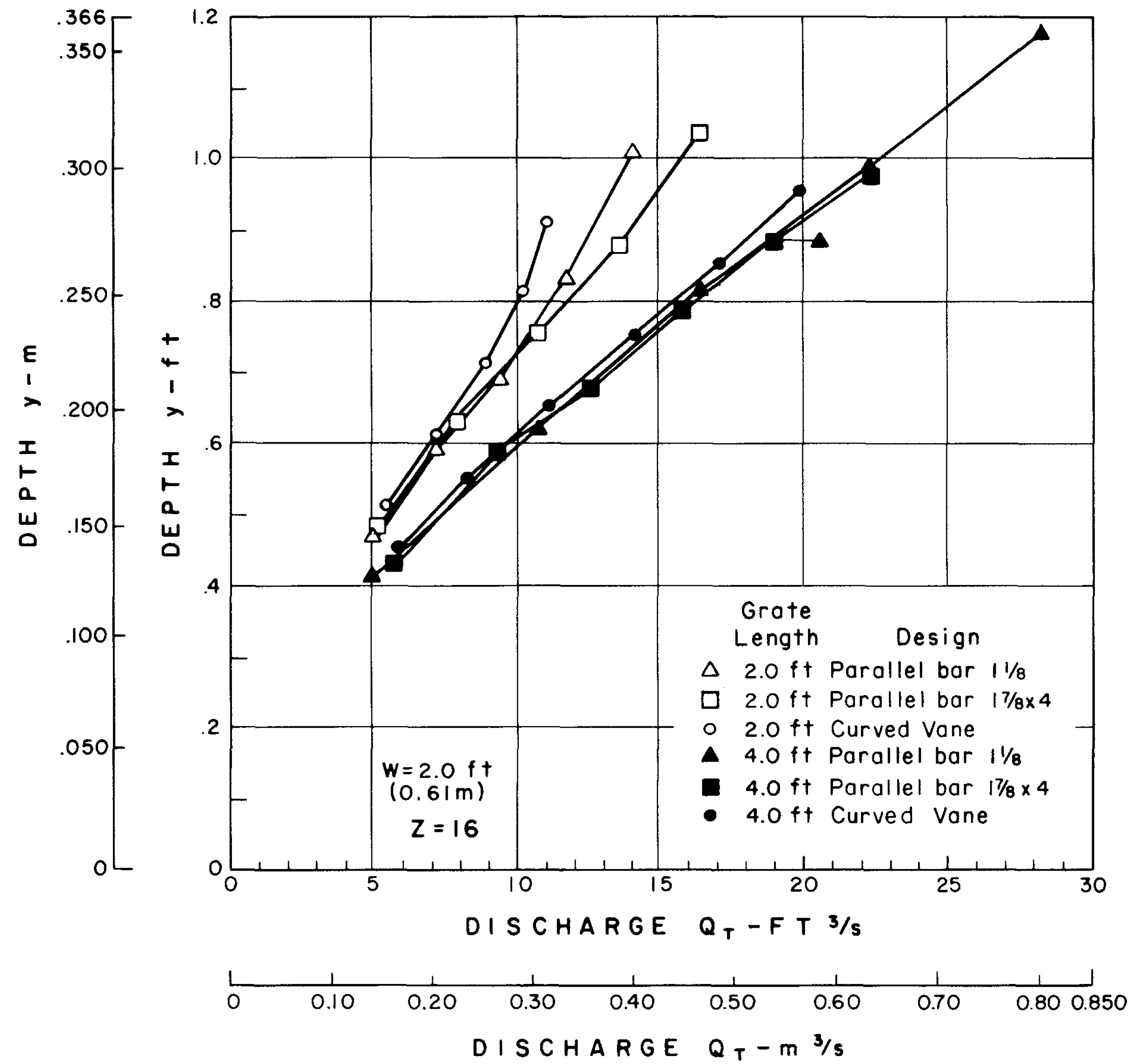


Figure 8-4. - Inlet capacity curves, 2.0 ft by 2.0 ft (0.61 m by 0.61 m) and 2.0 ft by 4.0 ft (0.61 m by 1.22 m) sump grates, Z = 16.

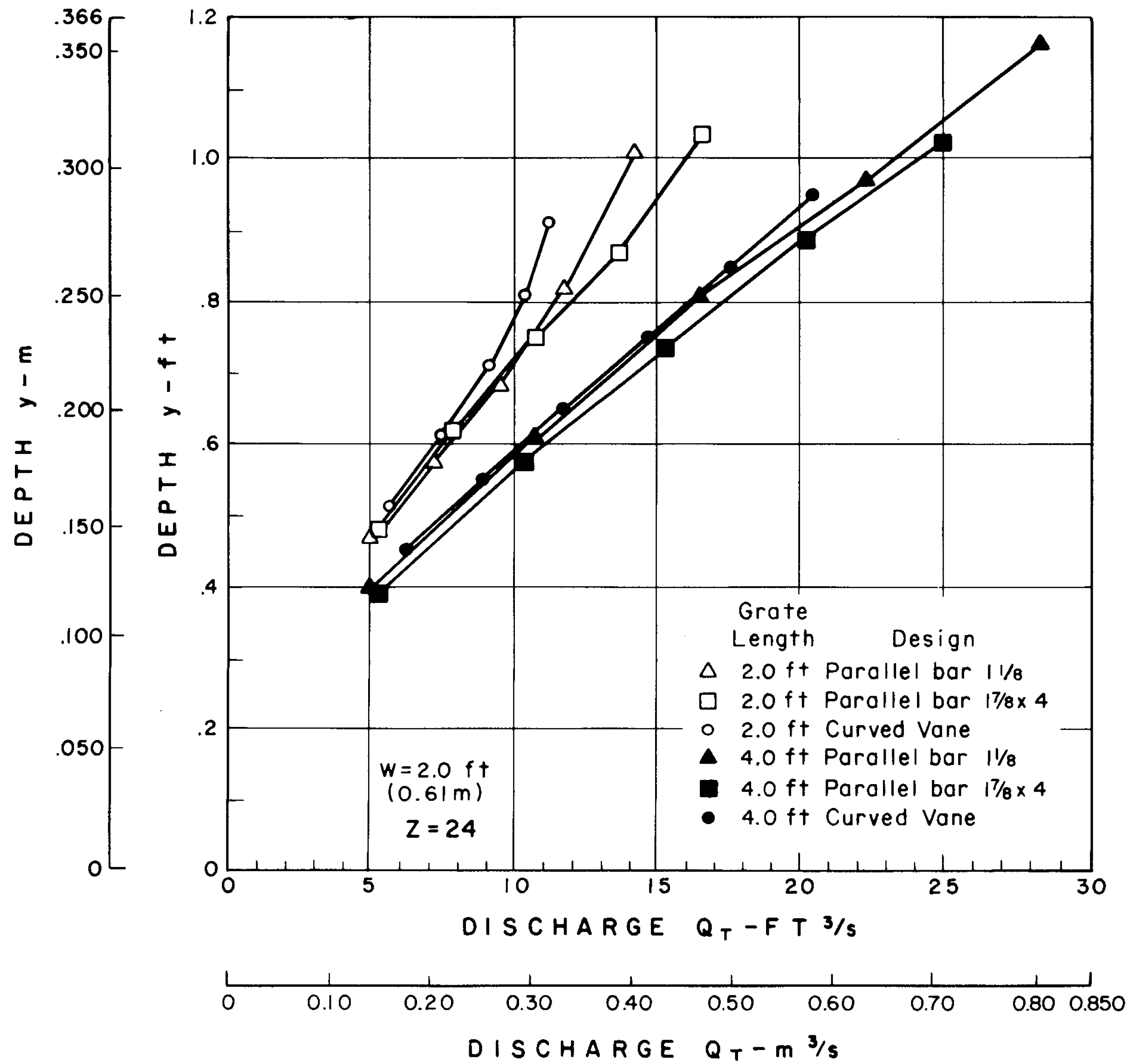


Figure 8-5. - Inlet capacity curves, 2.0 ft by 2.0 ft (0.61 m by 0.61 m) and 2.0 ft by 4.0 ft (0.61 m by 1.22 m) sump grates, Z = 24.

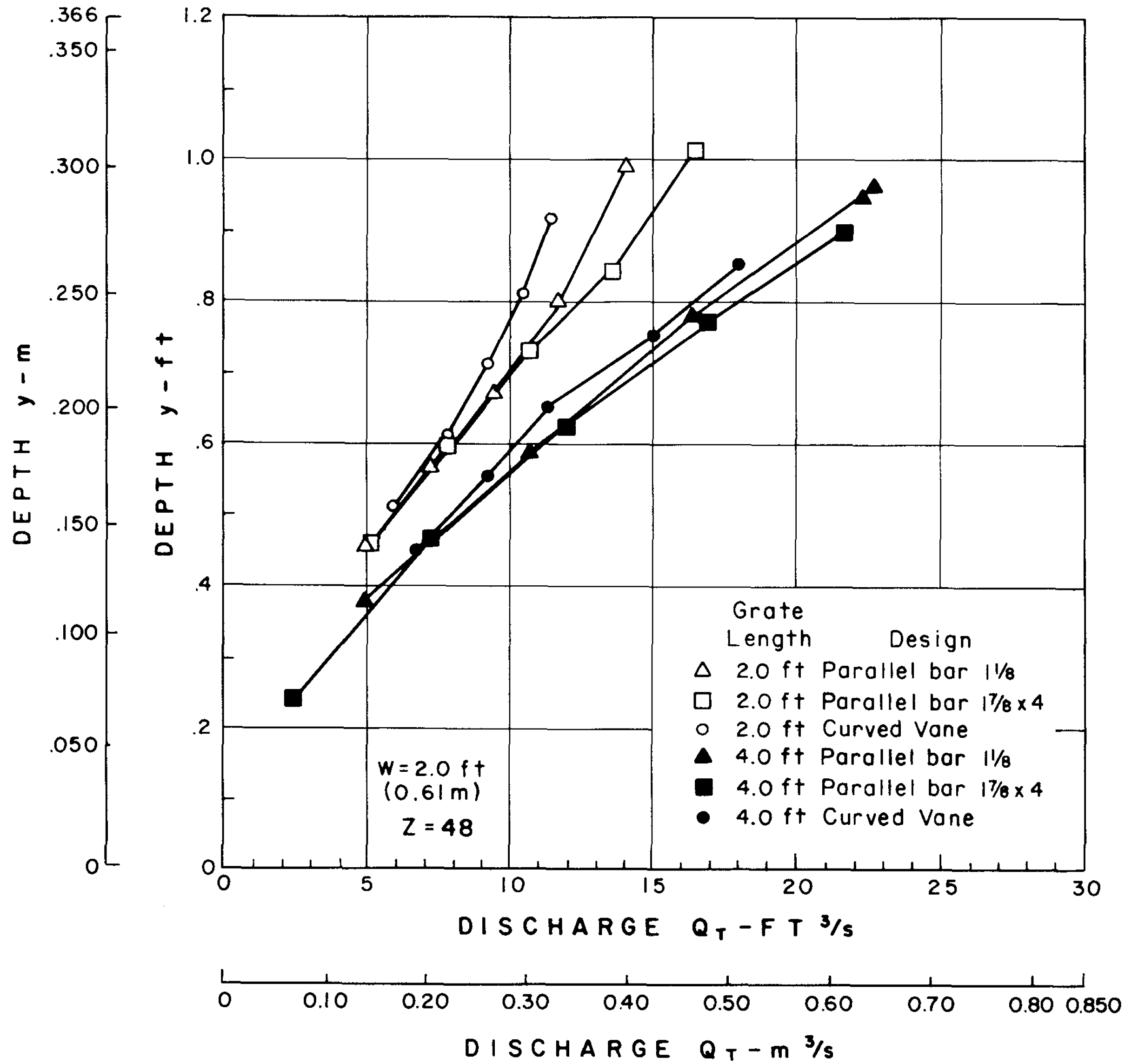


Figure 8-6. - Inlet capacity curves, 2.0 ft by 2.0 ft (0.61 m by 0.61 m) and 2.0 ft by 4.0 ft (0.61 m by 1.22 m) sump grates, Z = 48.

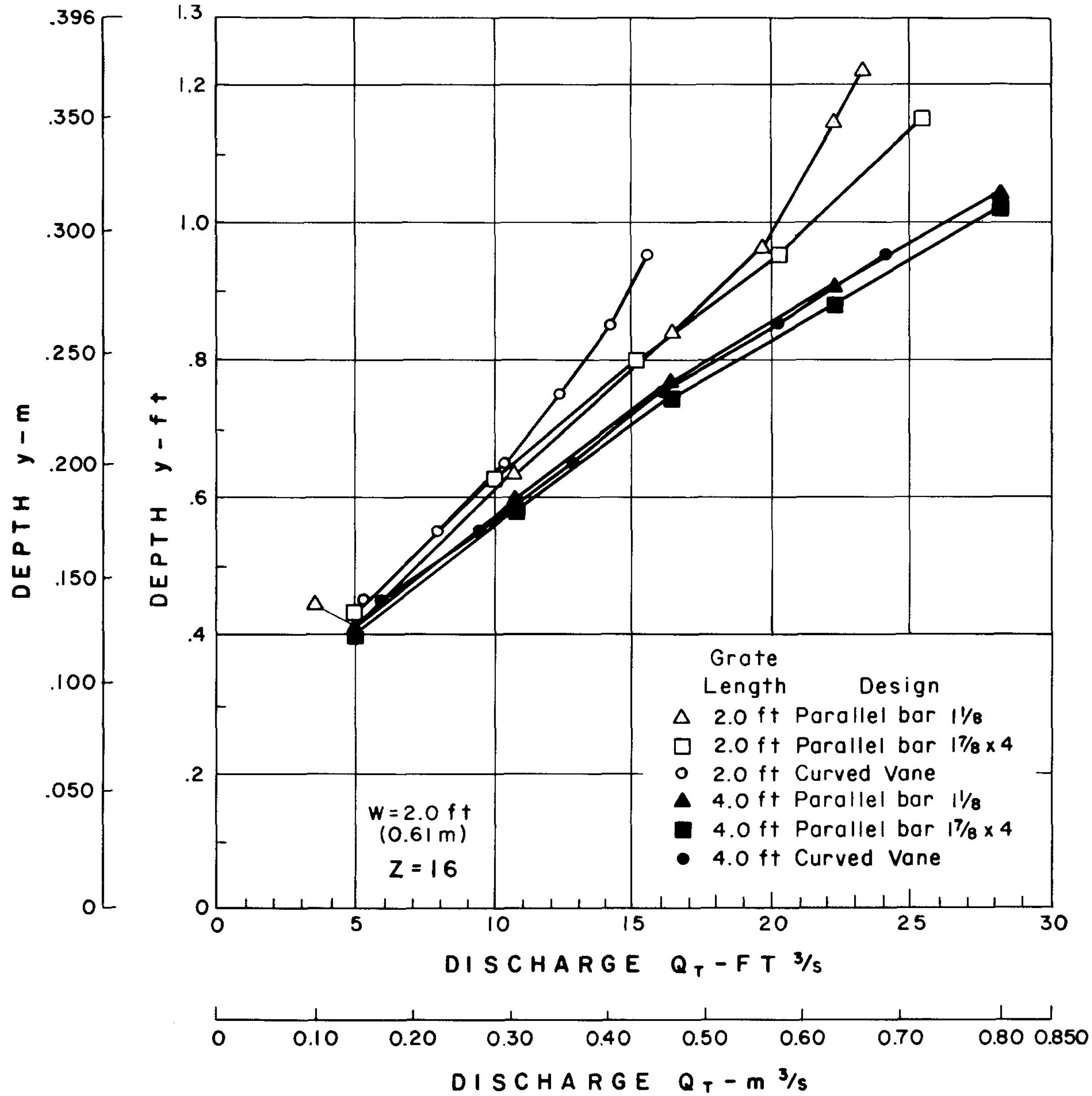


Figure 8-7. - Inlet capacity curves, 3.0 ft by 2.0 ft (0.91 m by 0.61 m) and 3.0 ft by 4.0 ft (0.91 m by 1.22 m) sump grates, Z = 16.

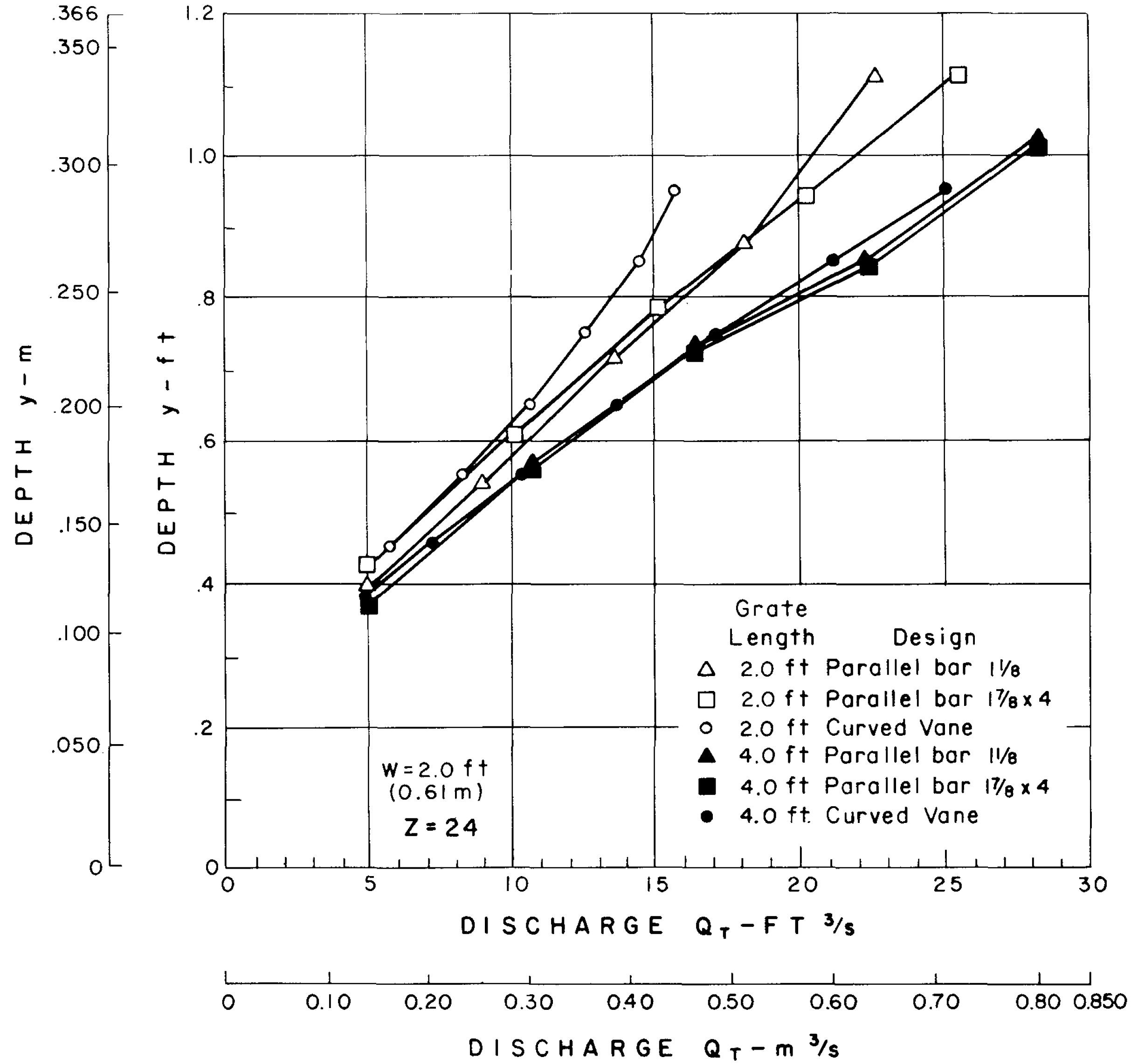


Figure 8-8. - Inlet capacity curves, 3.0 ft by 2.0 ft (0.91 m by 0.61 m) and 3.0 ft by 4.0 ft (0.91 m by 1.22 m) sump grates, Z = 24.

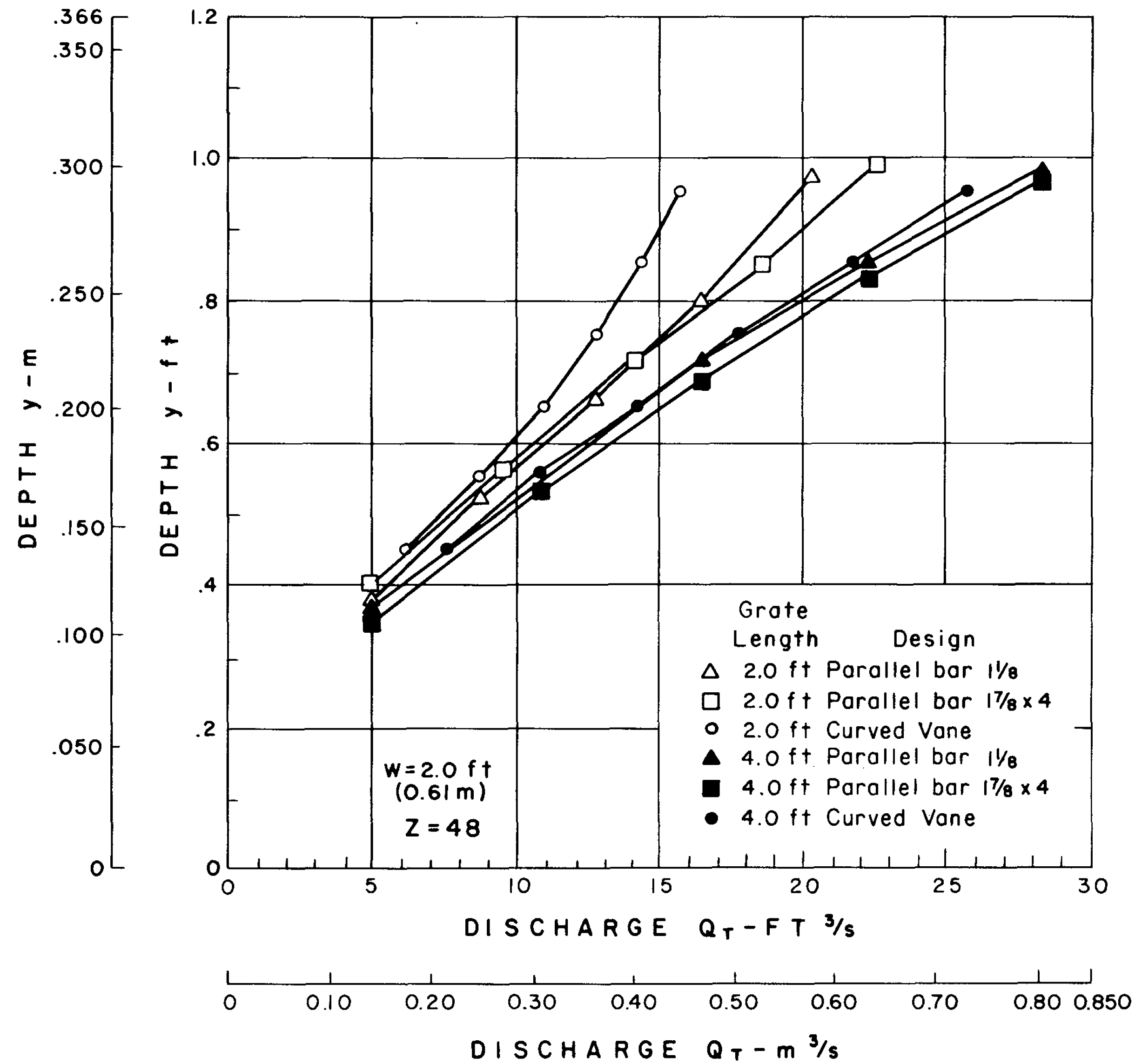


Figure 8-9. - Inlet capacity curves, 3.0 ft by 2.0 ft (0.91 m by 0.61 m) and 3.0 ft by 4.0 ft (0.91 m by 1.22 m) sump grates, Z = 48.

It is interesting to note in reviewing these figures, that when the flow characteristics are dominated by weir control, the three designs have similar capacities. When the flow characteristics are dominated by orifice control (generally, the smaller sump grate sizes), the variation in capacity of the three sump grate designs is more evident. The smaller orifice area of the curved vane sump grate and the P - 1-1/8 sump grate produce lower capacities than the P - 1-7/8 - 4 sump grate.

As was pointed out in chapters 5 through 7, there is an increase in inlet capacity for all three sump grate designs at the flatter roadway cross slope, $1/Z = 1/48$. However, for the same capacity (flow depth, y, approximately the same) the flatter cross slope requires a larger roadway ponding area than the steeper cross slopes, $1/Z = 1/16$ and 1/24.

Debris Tests

Table 8-1 shows the ranking of the three sump grate designs based on the debris tests conducted according to the procedure described in chapter 2.

The results presented are based on the debris handling efficiencies at the end of 15 minutes. Efficiencies of the six sump grate sizes were averaged. The P - 1-1/8 sump grate proved to be the least efficient for continuous grade tests (see table 13-3, volume 1), but the P - 1-1/8 sump grate excels the other two sump grate designs for sump conditions.

Table 8-1. - *Average debris handling efficiencies for sump grates*

Rank	Sump grate design	Efficiency (%)
1	P - 1-1/8	22
2	CV - 3-1/4 - 4-1/4	19
3	P - 1-7/8 - 4	15

CHAPTER 9

SUMMARY

Hydraulic and debris tests were conducted to determine the capacity and debris handling capabilities of three sump grate designs placed in a sump condition. The three grate designs, P - 1-1/8, P - 1-7/8 - 4, and the CV - 3-1/4 - 4-1/4 were identified in volume 1 as hydraulically efficient and bicycle safe. Six sizes of each sump grate design were tested on a 1:2 scale model representing a sump condition at the bottom of a vertical sag. Inlet capacity data are presented in chapters 5 through 7 for the sump grates. Chapter 4 summarizes the capacity data for three lengths of a 4.25 in (108 mm) high curb opening.

The results of the sump tests should prove to be very helpful to highway design engineers. Although, in general, the three sump grate designs have similar flow capacities, once they become submerged, the two fabricated steel sump grates have the greatest capacity and the P - 1-7/8 - 4 sump grate is the best.

The debris handling capabilities of the sump grates are not as good as would be expected. In fact, once the smaller-sized sump grates become plugged, the remainder of the debris is diverted through the curb opening resulting in a higher debris efficiency than that for the larger size sump grates which plugged with more debris.

Chapter 4 provides additional information on the hydraulic behavior of a sump grate when the grate is completely plugged by street debris.

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