US Army Corps
of Engineers

HYDRAULICS
LABORATORY

**ELECTRICAL/MECHANICAL
RESEARCH PROGRAM**

TECHNICAL REPORT HL-90-1

FORMED SUCTION INTAKE APPROACH APPURTENANCE GEOMETRY

by

B. P. Fletcher

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

February 1990
Final Report

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Under Work Unit No. 31166

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report HL-90-1	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION USAEWES, Hydraulics Laboratory 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) 3909 Halls Ferry Road Vicksburg, MS 39180-6199	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION US Army Corps of Engineers 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Washington, DC 20314-1000	10. SOURCE OF FUNDING NUMBERS See Reverse PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Formed Suction Intake Approach Appurtenance Geometry

12. PERSONAL AUTHOR(S)
Fletcher, B. P.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final report	FROM May 1988 TO Feb 1989	February 1990	45

16. SUPPLEMENTARY NOTATION
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Approach flow; Pump bay; Pump intake; Sump; Vortices

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Physical hydraulic model tests were conducted to investigate the hydraulic characteristics of a selected formed suction intake (FSI) design subjected to various hydraulic conditions. A variety of pump bay lengths and widths were evaluated. Hydraulic performance was evaluated by measuring flow distribution, swirl angle, and vortex intensity. Test results revealed that the FSI provided satisfactory flow to the pump with adverse flow in the approach. Test results are presented in dimensionless terms in plots and sketches.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

10. WORK UNIT ACCESSION NO. (Continued).

Funding provided by the Electrical/Mechanical research program Work Unit No. 31166, sponsored by the Headquarters, US Army Corps of Engineers.

PREFACE

The model investigation reported herein was authorized under the Electrical/Mechanical research program sponsored by the Headquarters, US Army Corps of Engineers (USACE), under Work Unit No. 31166, "Pump Station Inflow-Discharge Hydraulics." Messrs. Mohan Singh and Bob Pletka were USACE Technical Monitors.

The study was conducted during the period May 1988 to February 1989 in the US Army Engineer Waterways Experiment Station (WES) Hydraulics Laboratory (HL) under the direction of Messrs. F. A. Herrmann, Jr., Chief, HL, and R. A. Sager, Assistant Chief, HL, and under the general supervision of Messrs. G. A. Pickering, Chief, Structures Division, and N. R. Oswalt, Chief, Spillways and Channels Branch. Technical instrumentation support was provided by Messrs. H. Greer, J. Ables, and A. Morton of the Instrumentation Services Division, WES. The project engineer for the study was Mr. B. P. Fletcher, assisted by Messrs. R. B. Bryant and J. R. Rucker, Jr., all of the Spillways and Channels Branch. This report was prepared by Mr. Fletcher.

During the course of the study, Messrs. Singh, Pletka, and S. Powell of USACE; L. Holman and J. McCormick of the US Army Engineer Division (USAED), Lower Mississippi Valley/Mississippi River Commission; C. Thomas of USAED, Ohio River; J. Luther of USAED, St. Louis, and B. Moentenich of USAED, North Pacific, participated as advisory board members and visited WES to discuss the program and results of the investigation.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	2.54	centimetres

FORMED SUCTION INTAKE APPROACH APPURTENANCE GEOMETRY

PART I: INTRODUCTION

Background

1. This research is an extension of tests conducted in the site-specific model of the sump for the Yazoo Backwater Pumping Station.* In the model of the Yazoo pumping station sump a selected formed suction intake (FSI) design was investigated. The investigation indicated that the FSI design would provide satisfactory hydraulic performance for all anticipated flow conditions.

2. The research presented herein was initiated following numerous requests for guidance on how the appurtenance geometry (pump bay width and/or length) to the FSI could be varied relative to the direction of flow approaching a pumping station sump, discharge, and submergence.

Purpose and Scope of Research

3. The purpose of this research was to develop criteria needed for the design of the pump bay width and length relative to direction of approach flow, discharge, and submergence. The objective of the tests was accomplished by investigating each of the five variables independently by holding four variables constant while varying one until adverse hydraulic performance occurred.

4. The study was conducted in a flume that permitted simulation of various hydraulic conditions and pump bay geometries. The limiting values were determined by flow distribution and stability in the pump intake and the intensity of surface vortices.

---

* Bobby P. Fletcher. "Yazoo Backwater Pumping Station Sump, West-Central Mississippi; Hydraulic Model Investigation" (in preparation), US Army Engineer Waterways Experiment Station, Vicksburg, MS.

PART II: MODEL AND EVALUATION PROCEDURES

Test Facilities

5. The investigation was conducted in a flume 45 ft* long, 35 ft wide, and 4 ft deep. A sketch of the test facility including the location of the FSI is shown in Figure 1. A sketch and a photograph of the FSI used in the tests are shown in Plate 1 and Figure 2, respectively. The dimensions of the FSI, discharge, submergence, pump bay width, and pump bay length, are presented in the plates in terms of the throat (pump column) diameter d. The maximum discharge Q simulated in the model was equivalent to a dimensionless value $Q/\sqrt{gd^5}$ of 2.9, where g is the acceleration due to gravity. Flow through the FSI was provided by centrifugal pumps. A weir was constructed across the upstream end of the flume to provide evenly distributed

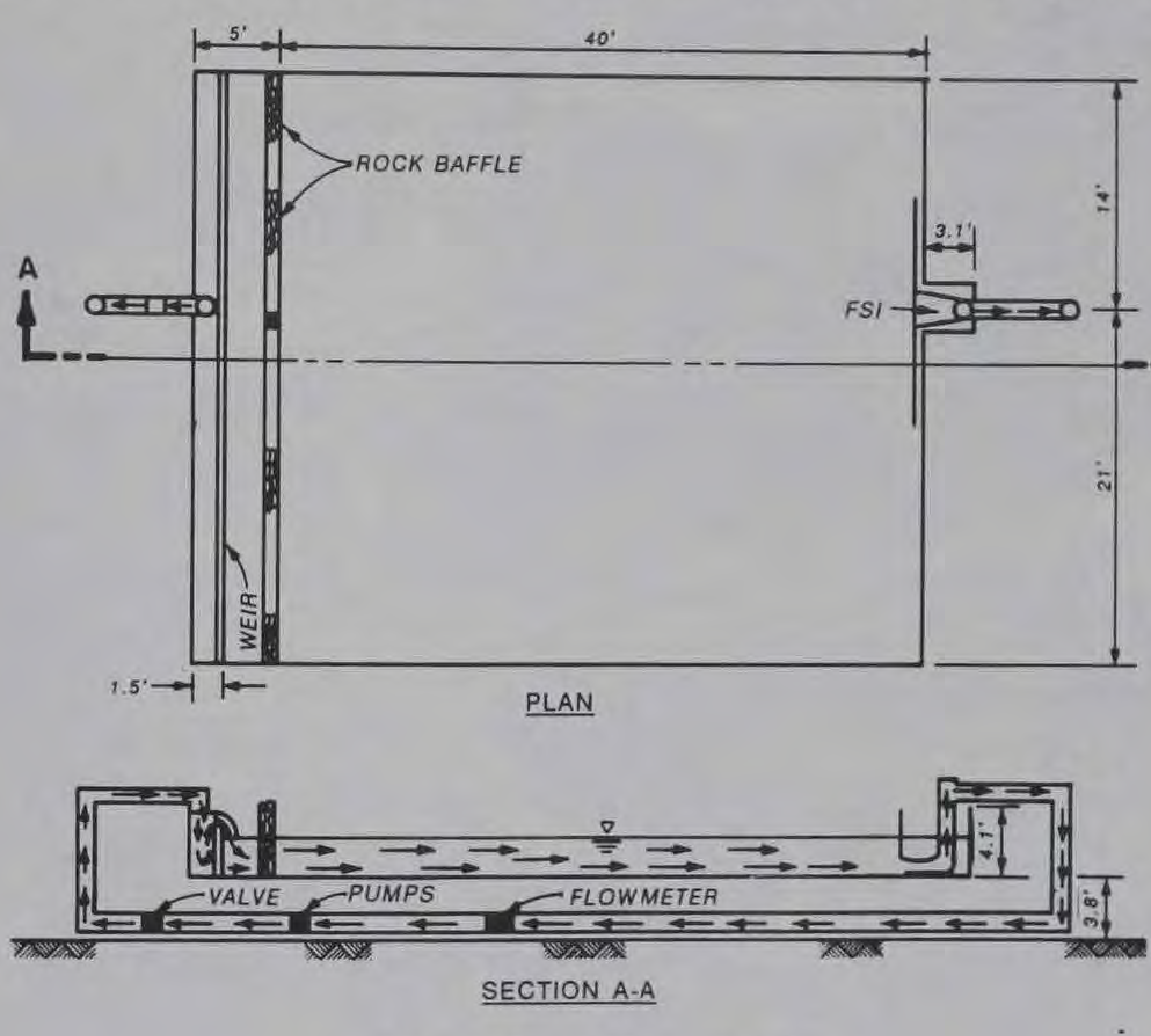


Figure 1. FSI study flume

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

Figure 2. FSI with impact tubes

return flow from the pumps. An 8-in. rock baffle wall was constructed across the flume to baffle the return flow. The wooden flume was designed to facilitate simulation of various approach flow geometries. The sump sidewalls, FSI, and pump column were constructed of transparent plastic to permit observation of subsurface currents and turbulence. Water used in the operation of the model was supplied by pumps, and discharges were measured by means of magnetic flowmeters. Steel rails set to grade provided reference planes for measuring devices. Water-surface elevations were obtained by staff gages.

Evaluation Techniques

6. Visual observation and measurement of the swirl angle, velocity distribution, and flow stability were techniques used for evaluation of hydraulic performance of the FSI.

Visual observations

7. In order to detect surface vortices, visual observations were made. A design that permits a Stage E surface vortex is considered unacceptable. Stages of surface vortex development are shown in Plate 2. A typical test consisted of documenting, for given flow conditions, the most severe vortex that occurred in a 5-min (model time) time period.

Swirl angle measurement

8. Measurement of the swirl angle was made to indicate the strength of swirl entering the pump intake. Swirl angle is a qualitative parameter commonly used by pump station sump modelers. It provides an index of comparison of hydraulic performance. A swirl angle of 3 deg or less usually indicates acceptable flow distribution in the pump intake. A swirl angle that exceeds 3 deg is considered unacceptable. Swirl in the pump column was indicated by a vortimeter (freewheeling propeller with zero pitch blades) located inside the pump column (Plate 1). Swirl angle is defined as the arc tangent of the ratio of the blade speed V_θ at the tip of the vortimeter blade to the average velocity V_a for the cross section of the pump column. The swirl angle θ is computed from the following formula:

$$\theta = \tan^{-1} \frac{V_\theta}{V_a}$$

where

$$V_\theta = \pi dn$$

$$V_a = \frac{Q}{A}$$

and

n = revolutions per second of the vortimeter

Q = pump discharge, cfs

A = cross-sectional area of the pump column, ft^2

Velocity and flow measurement

9. Velocity distribution and flow stability in the pump column were measured by impact tubes located as shown in Plate 1. A deviation in the ratio of the average measured velocity at a point to the average computed velocity in the cross section of 10 percent or greater was considered unacceptable. Four piezometers were located around the periphery of the pump column (Plate 1) to measure an average static pressure at this location. Impact tubes (copper tubes with 1/8-in. ID) were installed with their tips in the same plane as the four piezometers to measure the total pressure at 25 various points (Plate 3 and Figure 2) in the pump column. The head differential between the total pressure at each point in the pump column and the average static pressure provides a velocity at each point in the pump column. This was measured by means of 25 individual electronic pressure differential cells. The differential cells were connected to a data acquisition system capable of collecting data for various lengths of time and sampling at various rates. The data acquisition system was also capable of analyzing the data and providing the deviation in velocity ratio for each probe in the same time frame that the maximum instantaneous velocity ratio deviation for any single probe occurred. The magnitude of the maximum velocity deviation that should be considered unacceptable has not been established.

Typical Test

10. A typical test to measure velocity distribution in the pump column consisted of stabilizing the water-surface elevation and discharge through the

pump prior to collecting data. Data were collected for 1 min (model time), and each of the 25 differential pressure cells was sampled at a rate of 100 samples per second. The average and maximum velocities detected by each of the differential cells during the minute of data collection were divided by the theoretical average velocity in the cross section. The ratio (measured/computed) of the average velocities and ratio (measured/computed) of the velocities at all points that occurred in the same time frame of the maximum velocity deviation ratio anywhere in the cross section were tabulated and plotted by a computer as contour lines of equal velocity ratios. The ratio of the average velocities and the ratio of the velocities that occurred in the same time frame of the maximum velocity deviation were used as parameters for evaluating flow conditions, because the average velocity was an indicator of flow distribution and the maximum velocity ratio deviation was sensitive to a change in flow distribution and stability.

PART III: TESTS AND RESULTS

Effects of Vortices on Flow Distribution

11. Initial tests were conducted to determine how the velocity distribution in the pump intake is affected by surface vortices. Velocity distribution was measured during various stages of vortex development (Plate 2). Average velocity ratio distribution with a Stage D vortex is illustrated by the contour line in Plate 4. This condition is considered satisfactory as the deviation of the average velocity ratio depicted by the contour lines does not exceed 10 percent. The velocity distribution that occurred during the period of maximum deviation in velocity is shown in Plate 5. A time-history plot of one of the probes (channel 11) is shown as Test 1 in Plate 6. This time-history plot reflects a stable condition. Average velocity ratio distribution with a Stage E vortex is shown in Plate 7. Although the plot of average velocity ratio distribution is satisfactory, the plot of maximum velocity ratio deviation (Plate 8) shows a severe velocity differential at 2.10 sec. Also, the presence of a vortex at 2.1 sec was confirmed by a time-history plot of channel 11 (Plate 6, Test 2) and by visual observations. Various other flow conditions were investigated, and the test results revealed that only the Stage E vortex (sustained air-entraining vortex) had an adverse effect on the velocity distribution or flow stability in the pump intake. Therefore, other stages of vortex development (A, B, C, and D) were considered to have no adverse effect on flow distribution or flow stability in the pump intake.

Effects of Submergence on Flow Distribution

12. Tests were conducted to investigate the effects of a low submergence, $S = 0.94d$, on velocity distribution and flow stability where S is the vertical distance from the invert of the roof curve to the water-surface elevation (Plate 1) and d is the top diameter of the cone (Plate 1). Average velocity distribution with a Stage D vortex is shown by the contour lines in Plate 9. The maximum velocity deviation is shown in Plate 10, and time-history plots of channels 1 and 7 are shown in Plate 11. A comparison of Plates 9, 10, and 11 with the plots obtained at a higher submergence (Plates 4, 5, and 6) indicates that the lower submergence has no

significant effect on the average velocity distribution, but does slightly increase the deviation in velocity. Results of additional tests conducted at a low submergence ($S = 0.94d$) and a higher flow rate $\left(Q = 2.47 \sqrt{gd^5}\right)$ indicated satisfactory flow distribution. Test results conducted to investigate flow distribution with a higher submergence ($S = 4.69d$) are presented in Plates 12 and 13. Plate 12 shows the average distribution, and Plate 13 shows the maximum velocity deviation. Satisfactory test results were also obtained with a higher submergence and a lower discharge $\left(Q = 0.97 \sqrt{gd^5}\right)$ as shown in Plate 14. Tests conducted at various submergences revealed that flow distribution and stability were satisfactory for submergences equal to or greater than $0.94d$.

Approach Flow from 0, 45, and 90 Degrees

13. Tests were conducted with the flow approaching the pump bay at angles with the longitudinal center line of the pump bay of 0, 45, and 90 deg. A typical approach flow current pattern with an angle of 0 deg is shown in Figure 3. The 12 approach configurations tested (types 1-12) with the 0-deg approach flow are shown in Plate 15. A dimensionless plot of the discharge parameter $Q/\sqrt{gd^5}$ versus the critical submergence parameter S_c/d is shown in Plate 16. The data points on the plot (Plate 16) show the hydraulic conditions that produce critical submergence and discharge. Critical submergence is defined as the submergence S that generates incipient Stage E vortices. The basic data are tabulated in Table 1. Plate 16 also shows anticipated minimum submergences and maximum flow rates per pump for two proposed typical pump stations (Yazoo and St. Johns). The data points in Plate 16 generally indicate satisfactory hydraulic performance for typical hydraulic conditions regardless of the pump bay width W or length L with flow approaching the sump at an angle of 0 deg. Measured swirl angles were satisfactory and did not exceed a value of 0.5 deg for any of the designs tested.

14. Typical current patterns generated by a 45-deg approach flow pattern are shown in Plate 17. The 12 approach configurations tested (types 13-24) with a 45-deg approach flow are shown in Plate 18. A plot of the data points is shown in Plate 19. Basic data are tabulated in Table 2.

15. Current patterns generated by a 90-deg approach flow are shown in Plate 20. The 12 approach configurations tested (types 25-36) with a 90-deg

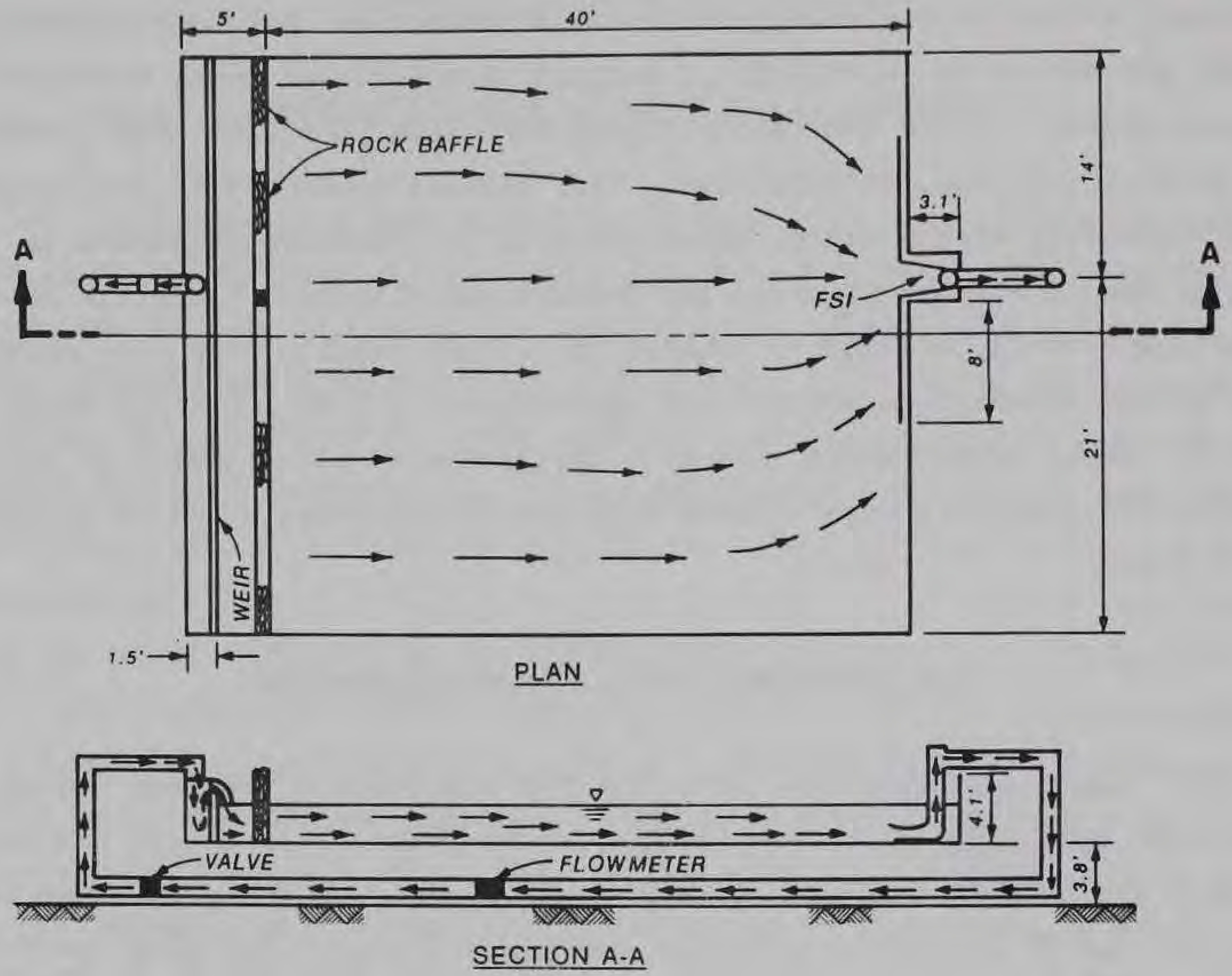


Figure 3. FSI 0-deg approach to pump intake

approach flow are shown in Plate 21. A plot of the data points is shown in Plate 22. Basic data are tabulated in Table 3. The data points in Plate 22 indicate that the tendency for vortices is more severe with the 90-deg approach flow. However, Plate 22 does indicate that satisfactory hydraulic performance should be anticipated for typical maximum discharges and minimum submergences similar to St. John and Yazoo Pumping Stations.

PART IV: RESULTS AND DISCUSSION

16. Results of this research to define the limitations and to identify advantages of the FSI subjected to five pumping station variables (discharge, submergence, pump bay width, pump bay length, and angle of approach) are significant for future Corps pumping station designs. Future Corps pumping stations designed with an appropriate FSI have the potential for cost savings due to the enhanced hydraulic performance without the typical long straight approach channel and pump bay walls. Adequate hydraulic performance was obtained for flows approaching the pump bay at angles of 0 to 90 deg with the Yazoo type FSI. This indicates that the previous extensive approach channel straightening and expensive pump bay divider walls can be reduced in length and/or omitted for new FSI-equipped pumping stations. Also the FSI may be considered for retrofitting for existing pumping stations experiencing hydraulic problems.

17. The test results indicate that the FSI design presented in this report (Plate 1) will provide satisfactory hydraulic performance for discharges equal to or less than a value of $1.99 \sqrt{gd^5}$, submergences equal to or greater than a value of 0.94d , bay widths equal to or wider than a value of 2.28d , pump bay length equal to or longer than a value of 0d , and approach flow angle to the pump bay of equal to or less than 90 deg. It should be noted that this guidance is appropriate only for the FSI design shown in Plate 1. Site-specific tests have demonstrated that changing one or more of the internal dimensions may adversely affect the performance of the FSI.

18. Due to inquiries from Corps Districts about varying the internal geometry of the FSI, research is in progress to investigate the hydraulic limits of its internal geometry. Variables to be evaluated include sidewall and roof flare, roof curve, invert curve, and cone angle.

Table 1

Critical Submergence and Discharge for 0-deg Approach Flow Angle

FSI Type	$\frac{Q}{\sqrt{gd^5}}$	$\frac{S_c}{d}$	$\frac{L}{d}$	$\frac{W}{d}$	Vortex Stage
1	2.9	0.94	0	2.28	D
		1.69			C
		2.44			C
		3.19			B
		3.94			B
		4.69			B
2	2.3	0.94	3		D
	2.3	1.69			
	2.5	2.44			
	2.9	3.19			
	2.9	3.94			
	2.9	4.69			
3	1.9	0.94	6		
	2.6	1.69			
	2.9	2.44			
	2.9	3.19			
		3.94			
		4.69			C
4		0.94	0	2.55	B
		1.67			D
		2.44			D
		3.19			B
		3.94			B
		4.69			B
5	2.0	0.94	3		D
	2.9	1.69			
		2.44			
		3.19			
		3.94			
		4.69			
6	2.0	0.94	6		
	2.5	1.69			
	2.9	2.44			
	2.9	3.19			
	2.9	3.94			
	2.9	4.69			

(Continued)

Table 1 (Concluded)

FSI Type	$\frac{Q}{\sqrt{gd^5}}$	$\frac{S_c}{d}$	$\frac{L}{d}$	$\frac{W}{d}$	Vortex Stage
7	2.7	0.94	0	3.15	D
	2.9	1.69	↓	↓	D
	↓	2.44	↓	↓	D
	↓	3.19	↓	↓	B
	↓	3.94	↓	↓	B
	↓	4.69	↓	↓	B
8	1.9	0.94	3	↓	D
	2.9	1.69	↓	↓	↓
	↓	2.44	↓	↓	↓
	↓	3.19	↓	↓	↓
	↓	3.94	↓	↓	↓
	↓	4.69	↓	↓	↓
9	1.9	0.94	6	↓	↓
	2.9	1.69	↓	↓	↓
	↓	2.44	↓	↓	↓
	↓	3.19	↓	↓	↓
	↓	3.94	↓	↓	↓
	↓	4.69	↓	↓	↓
10	↓	0.94	0	3.92	B
	↓	1.69	↓	↓	D
	↓	2.44	↓	↓	B
	↓	3.19	↓	↓	B
	↓	3.94	↓	↓	B
	↓	4.69	↓	↓	B
11	2.3	0.94	3	↓	D
	2.9	1.69	↓	↓	↓
	↓	2.44	↓	↓	↓
	↓	3.19	↓	↓	↓
	↓	3.94	↓	↓	↓
	↓	4.69	↓	↓	↓
12	1.9	0.94	6	↓	↓
	2.9	1.69	↓	↓	↓
	↓	2.44	↓	↓	↓
	↓	3.19	↓	↓	C
	↓	3.94	↓	↓	C
	↓	4.69	↓	↓	D

Table 2

Critical Submergence and Discharge for 45-deg Approach Flow Angle

FSI Type	$\frac{Q}{\sqrt{gd^5}}$	$\frac{S_c}{d}$	$\frac{L}{d}$	$\frac{W}{d}$	Vortex Stage
13	1.0	0.94	0	2.28	D
	1.4	1.69	↓	↓	D
	2.9	2.44	↓	↓	B
	2.9	3.19	↓	↓	D
	2.9	3.94	↓	↓	↓
	2.9	4.69	↓	↓	↓
14	1.0	0.94	3	↓	↓
	1.4	1.69	↓	↓	↓
	2.1	2.44	↓	↓	↓
	2.1	3.19	↓	↓	↓
	1.6	3.94	↓	↓	↓
	1.8	4.69	↓	↓	↓
15	1.3	0.94	6	↓	↓
	2.4	1.69	↓	↓	↓
	2.9	2.44	↓	↓	↓
	2.9	3.19	↓	↓	↓
	2.1	3.94	↓	↓	↓
	2.9	4.69	↓	↓	↓
16	1.9	0.94	0	2.55	↓
	1.5	1.67	↓	↓	↓
	2.9	2.44	↓	↓	C
	2.9	3.19	↓	↓	C
	2.9	3.94	↓	↓	B
	2.9	4.69	↓	↓	B
17	1.8	0.94	3	↓	D
	2.0	1.69	↓	↓	↓
	1.6	2.44	↓	↓	↓
	1.4	3.19	↓	↓	↓
	1.6	3.94	↓	↓	↓
	2.3	4.69	↓	↓	↓
18	2.0	0.94	6	2.55	↓
	2.6	1.69	↓	↓	↓
	2.7	2.44	↓	↓	↓
	2.0	3.19	↓	↓	↓
	2.6	3.94	↓	↓	↓
	2.5	4.69	↓	↓	↓

(Continued)

Table 2 (Concluded)

FSI Type	$\frac{Q}{\sqrt{gd^5}}$	$\frac{S_c}{d}$	$\frac{L}{d}$	$\frac{W}{d}$	Vortex Stage
19	1.7	0.94	0	3.15	D
	2.9	1.69			D
		2.44			B
		3.19			B
		3.94			B
	↓	4.69	↓		A
20	1.8	0.94	3		D
	2.7	1.69			
	1.7	2.44			
	2.0	3.19			
	2.1	3.94			
	2.3	4.69	↓		
21	1.9	0.94	6		
	2.3	1.69			
	1.8	2.44			
	2.2	3.19			
	2.3	3.94			
	2.3	4.69	↓	↓	
48	2.0	0.94	0	3.92	
	2.9	1.69			↓
		2.44			C
		3.19			C
		3.94			B
	↓	4.69	↓		B
47	2.0	0.94	3		D
	2.5	1.69			
	2.6	2.44			
	2.1	3.19			
	2.6	3.94			
	2.9	4.69	↓		
40	1.9	0.94	6		
	2.9	1.69			
	2.2	2.44			
	2.5	3.19			
	2.9	3.94			
	2.9	4.69	↓	↓	↓

Table 3

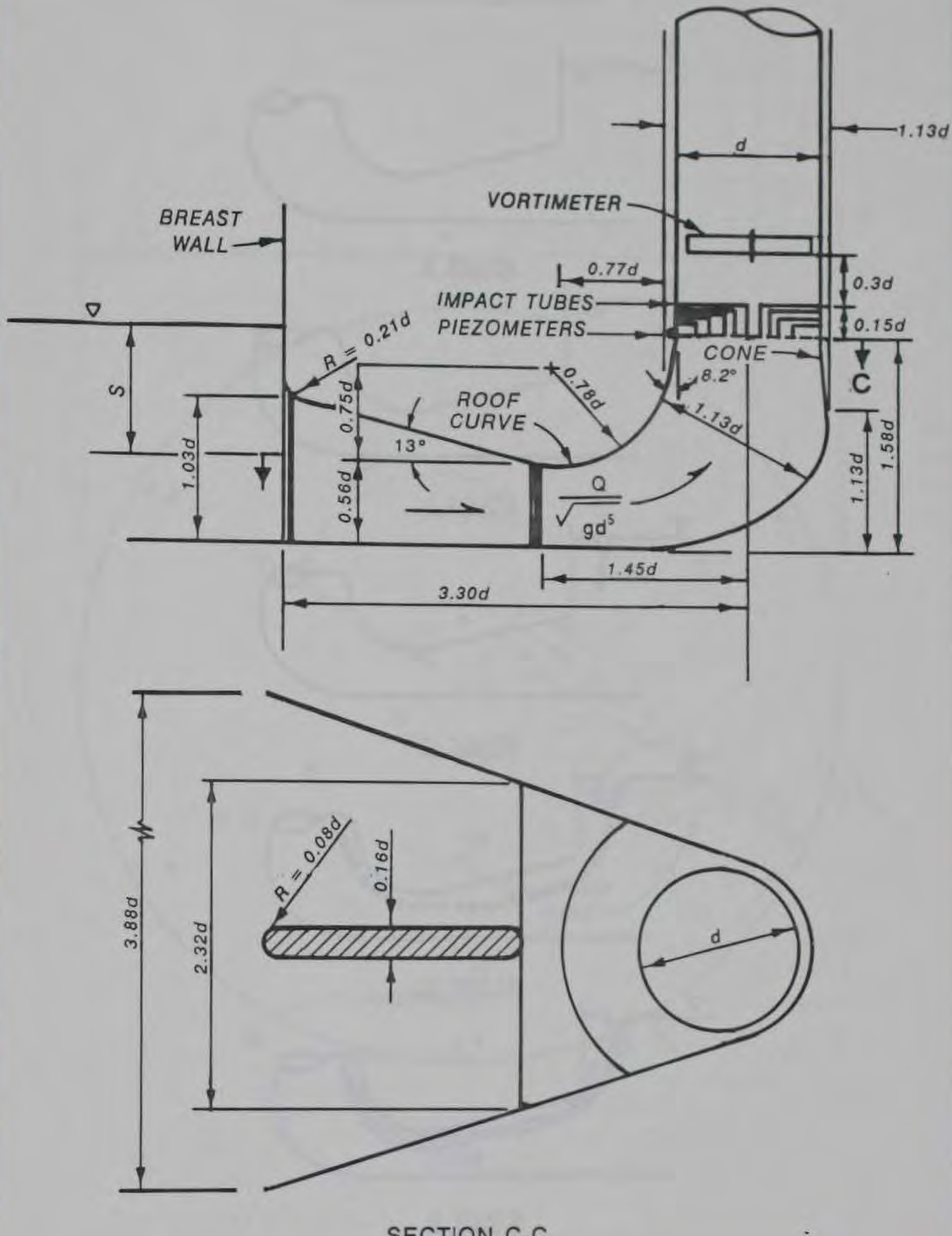
Critical Submergence and Discharge for 90-deg Approach Flow Angle

FSI Type	$\frac{Q}{\sqrt{gd^5}}$	$\frac{S_c}{d}$	$\frac{L}{d}$	$\frac{W}{d}$	Vortex Stage
25	1.5	0.94	0	2.28	D
	1.2	1.69	↓	↓	↓
	1.2	2.44			
	1.3	3.19			
	2.0	3.94			
	2.9	4.69			
26	1.7	0.94	3		
	2.2	1.69	↓		
	2.4	2.44			
	2.9	3.19			
	2.0	3.94			
	2.9	4.69			
27	1.8	0.94	6		
	1.1	1.69	↓		
	0.9	2.44			
	1.1	3.19			
	1.2	3.94			
	1.9	4.69			
28	1.9	0.94	0	2.55	
	1.4	1.67	↓	↓	
	1.2	2.44			
	1.5	3.19			
	1.0	3.94			
	1.8	4.69			
29	1.9	0.94	3		
	2.1	1.69	↓		
	2.4	2.44			
	2.9	3.19			
	2.0	3.94			
	2.1	4.69			
30	1.8	0.94	6		
	2.2	1.69	↓		
	2.7	2.44			
	1.9	3.19			
	2.0	3.94			
	2.2	4.69			

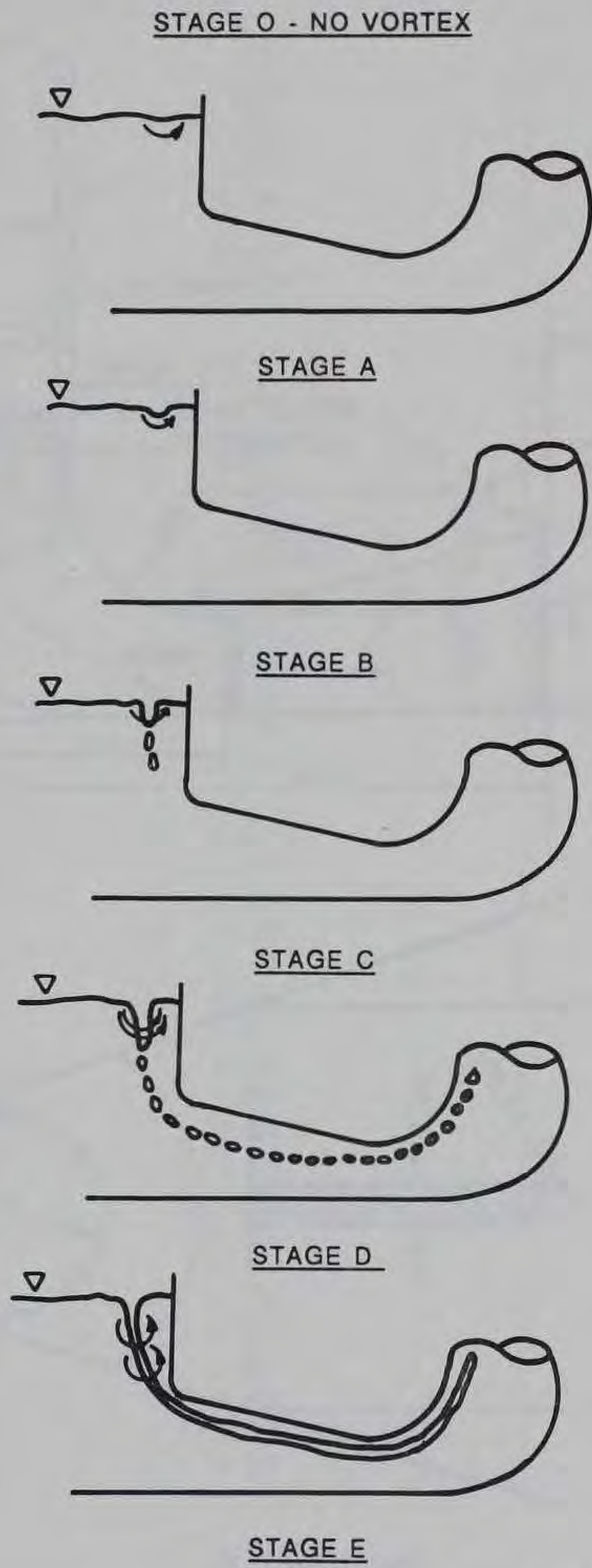
(Continued)

Table 3 (Concluded)

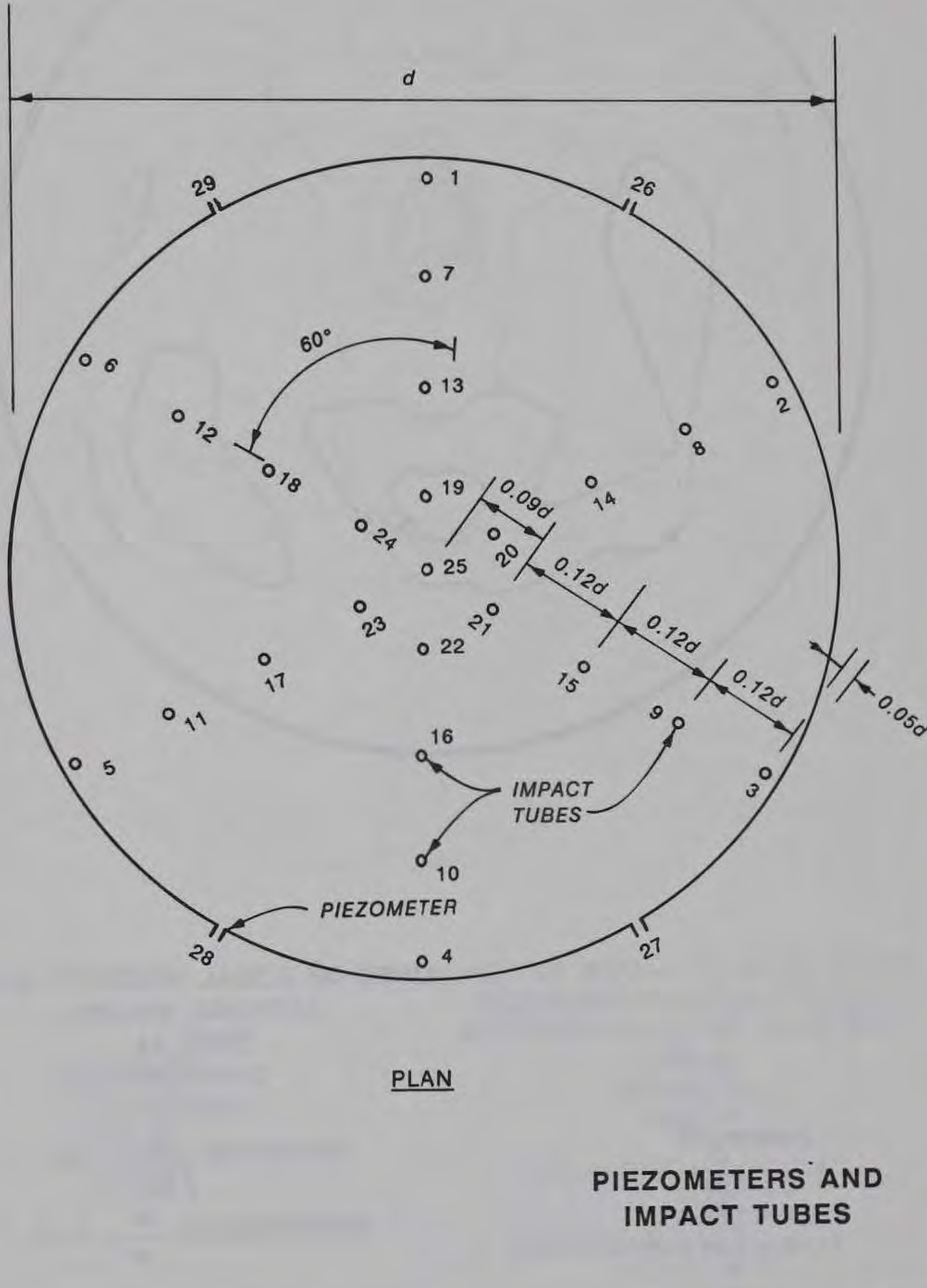
FSI Type	$\frac{Q}{\sqrt{gd^5}}$	$\frac{S_c}{d}$	$\frac{L}{d}$	$\frac{W}{d}$	Vortex Stage
31	1.9	0.94	0	3.15	D
	1.0	1.69			
	1.2	2.44			
	1.6	3.19			
	1.7	3.94			
	2.1	4.69			
32	1.9	0.94	3		
	2.9	1.69			
	2.9	2.44			
	2.0	3.19			
	1.6	3.94			
	1.6	4.69			
33	1.4	0.94	6		
	1.8	1.69			
	1.1	2.44			
	1.8	3.19			
	2.7	3.94			
	2.3	4.69			
34	2.2	0.94	0	3.92	
	1.4	1.69			
	1.3	2.44			
	1.6	3.19			
	1.4	3.94			
	1.9	4.69			
35	2.6	0.94	3		
	2.9	1.69			
	2.9	2.44			
	1.3	3.19			
	1.5	3.94			
	1.3	4.69			
36	1.6	0.94	6		
	1.8	1.69			
	1.9	2.44			
	2.2	3.19			
	2.2	3.94			
	2.6	4.69			



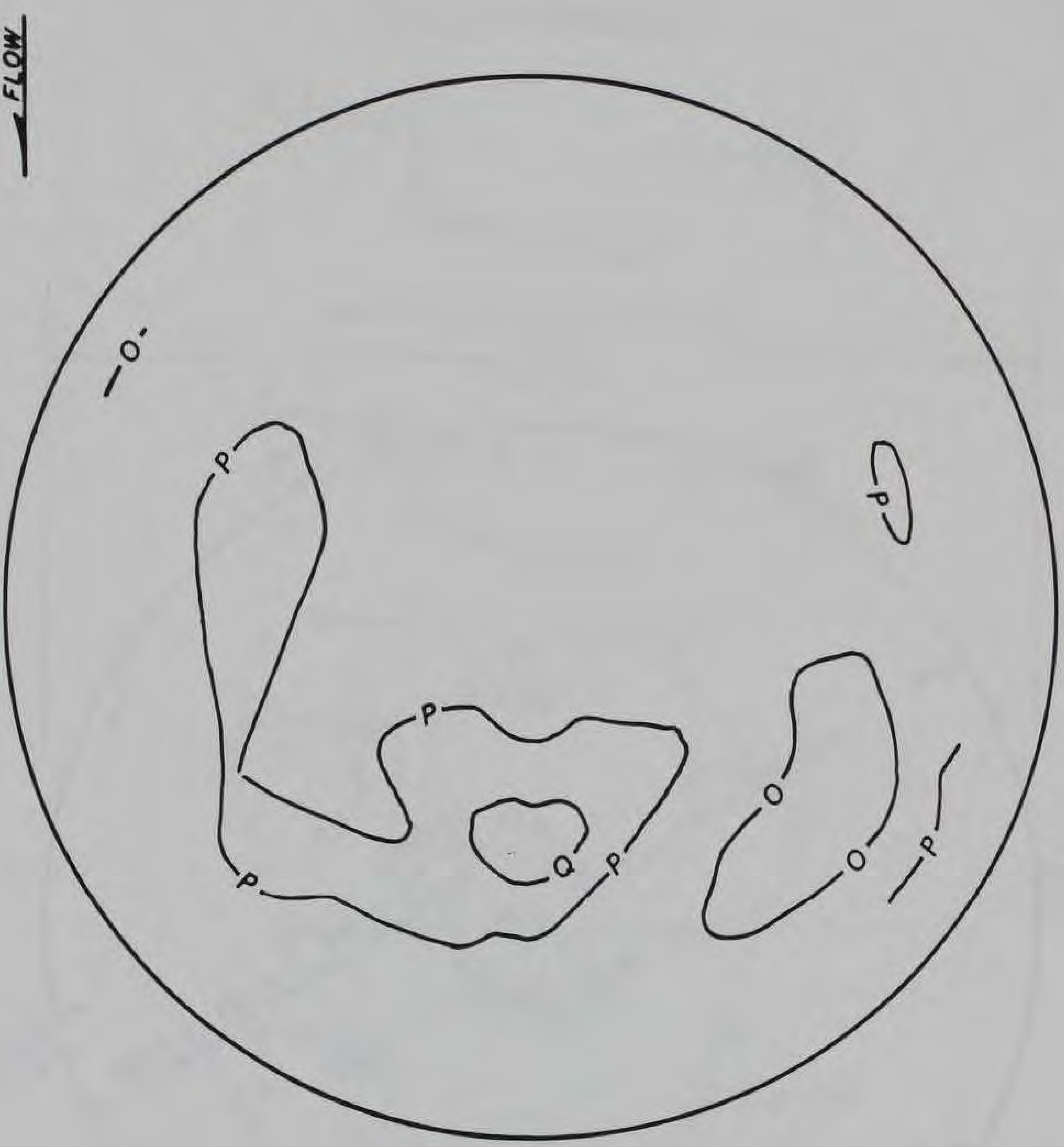
FORMED SUCTION INTAKE



FORMED SUCTION INLET
STAGES IN SURFACE
VORTEX DEVELOPMENT



PIEZOMETERS AND IMPACT TUBES



LINES OF EQUAL VELOCITY RATIO
AVERAGE VALUES
TYPE 34
D VORTEX
TEST 1

DISCHARGE $\frac{Q}{\sqrt{gd^5}} = 1.99$

SUBMERGENCE $\frac{S}{d} = 3.19$

CONTOURS

O = 0.90
P = 1.00
Q = 1.10

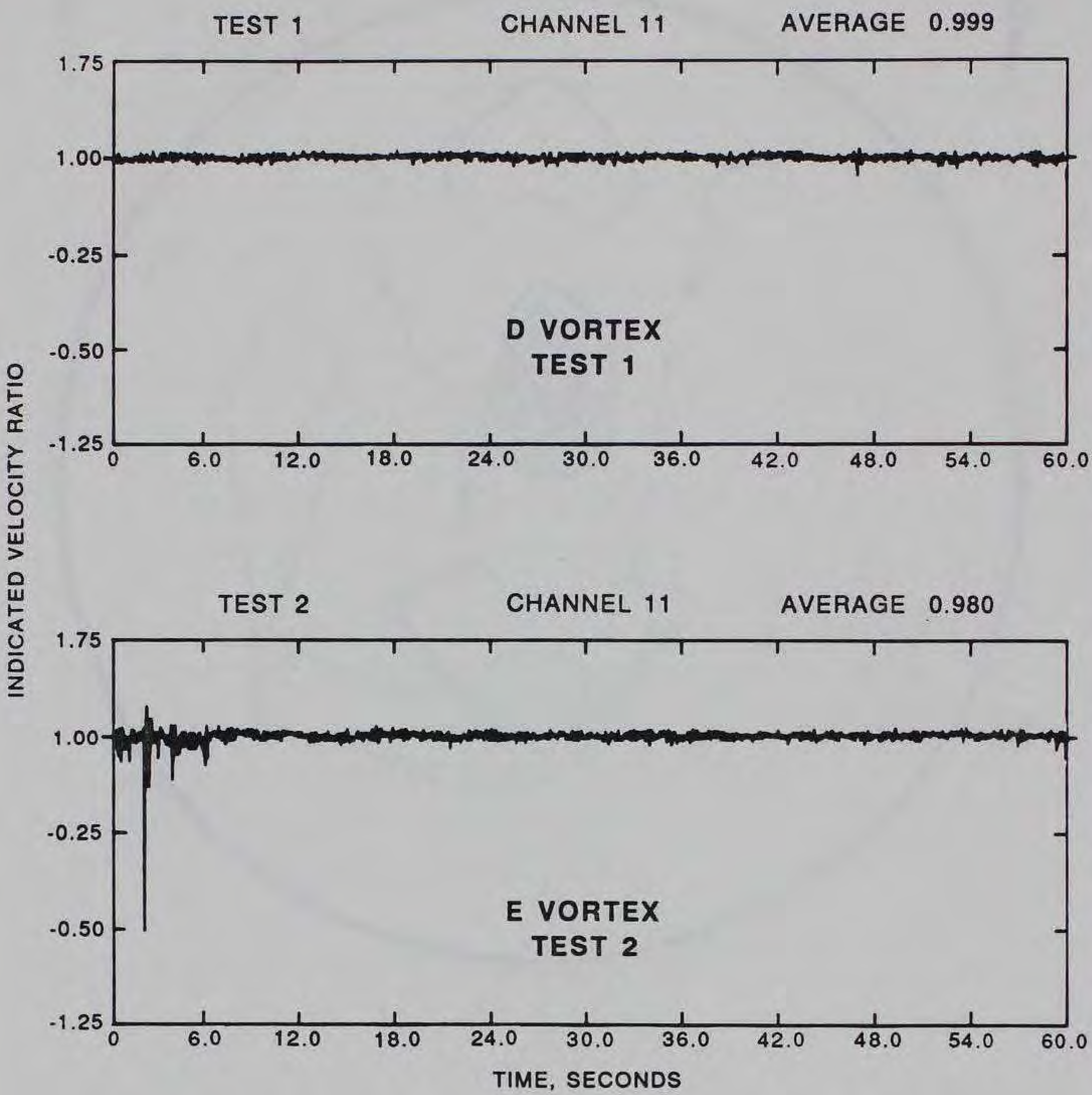
CONTOURS

B = 0.10
C = 0.20
D = 0.30
E = 0.40
F = 0.50

LINES OF EQUAL VELOCITY RATIO
MAXIMUM DEVIATION VALUES
BETWEEN 54.15 AND 54.29 SEC
TYPE 34
D VORTEX
TEST 1

DISCHARGE $\frac{Q}{\sqrt{gd^5}} = 1.99$

SUBMERGENCE $\frac{S}{d} = 3.19$



TIME-HISTORY
D AND E VORTEX
TEST 1 AND 2

DISCHARGE $\frac{Q}{\sqrt{gd^5}} = 1.99$

SUBMERGENCE $\frac{S}{d} = 3.19$

LINES OF EQUAL VELOCITY RATIO
AVERAGE VALUES
TYPE 34
E VORTEX
TEST 2

DISCHARGE $\frac{Q}{\sqrt{gd^5}} = 1.99$

SUBMERGENCE $\frac{S}{d} = 3.19$

CONTOURS

O = 0.90
P = 1.00
Q = 1.10

CONTOURS

A = 0.00
B = 0.10
C = 0.20
D = 0.30
E = 0.40
F = 0.50
G = 0.60
H = 0.70
I = 0.80
J = 0.90
K = 1.00
L = 1.10
M = 1.20
N = 1.30
O = 0.90
P = 1.00
Q = 1.10

LINES OF EQUAL VELOCITY RATIO
MAXIMUM DEVIATION VALUES
BETWEEN 2.10 AND 2.18 SEC
TYPE 34
E VORTEX
TEST 2

DISCHARGE $\frac{Q}{\sqrt{gd^5}} = 1.99$

SUBMERGENCE $\frac{S}{d} = 3.19$

CONTOURS

O = 0.90
P = 1.00
Q = 1.10

LINES OF EQUAL VELOCITY RATIO
AVERAGE VALUES
TYPE 34
D VORTEX
TEST 3

DISCHARGE $\frac{Q}{\sqrt{gd^5}} = 1.99$

SUBMERGENCE $\frac{S}{d} = 0.94$

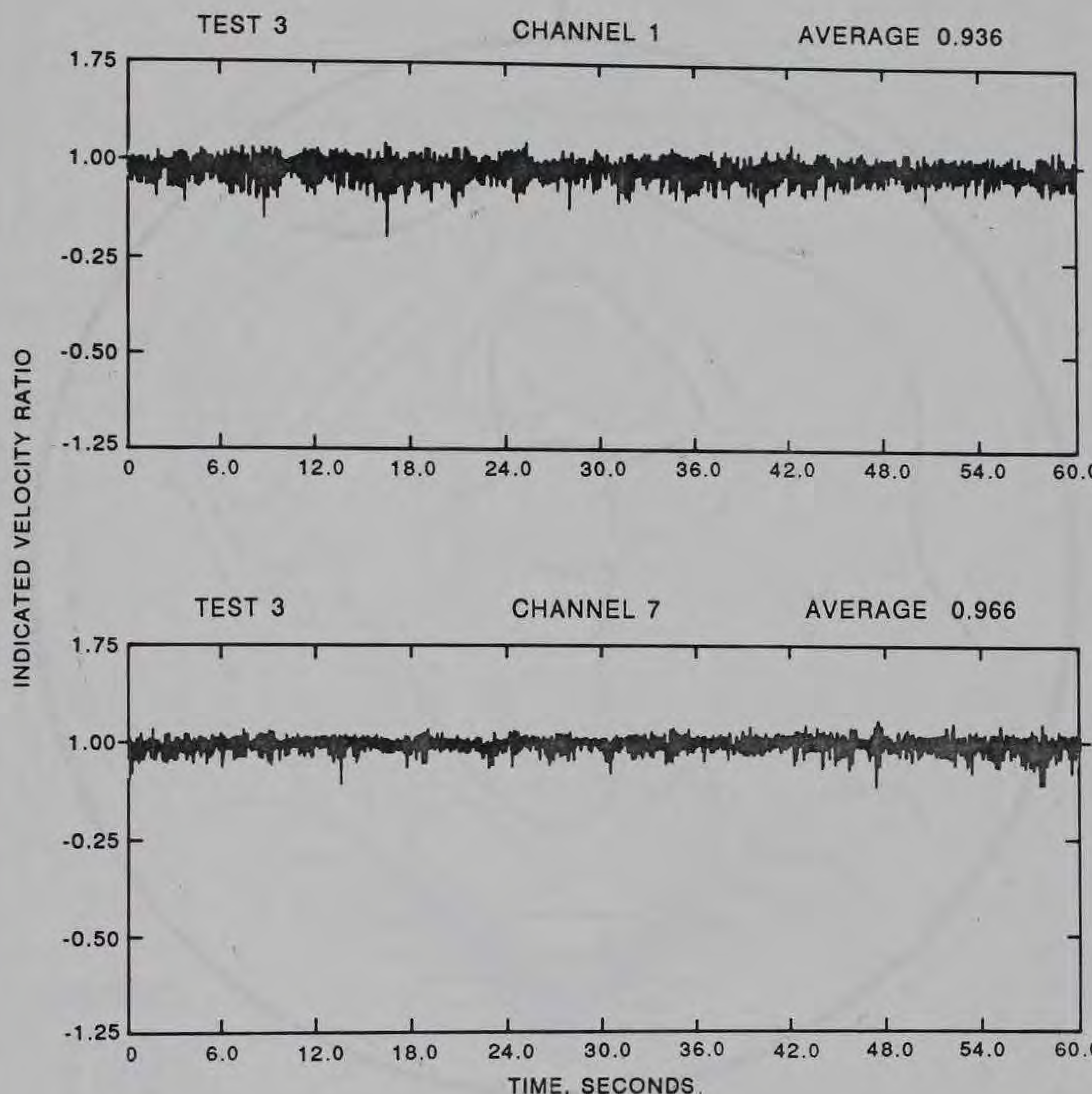
CONTOURS

B = 0.10
C = 0.20
D = 0.30
E = 0.40
F = 0.50
G = 0.60
H = 0.70
I = 0.80

LINES OF EQUAL VELOCITY RATIO
MAXIMUM DEVIATION VALUES
BETWEEN 2.17 AND 2.29 SEC
TYPE 34
D VORTEX
TEST 3

DISCHARGE $\frac{Q}{\sqrt{gd^5}} = 1.99$

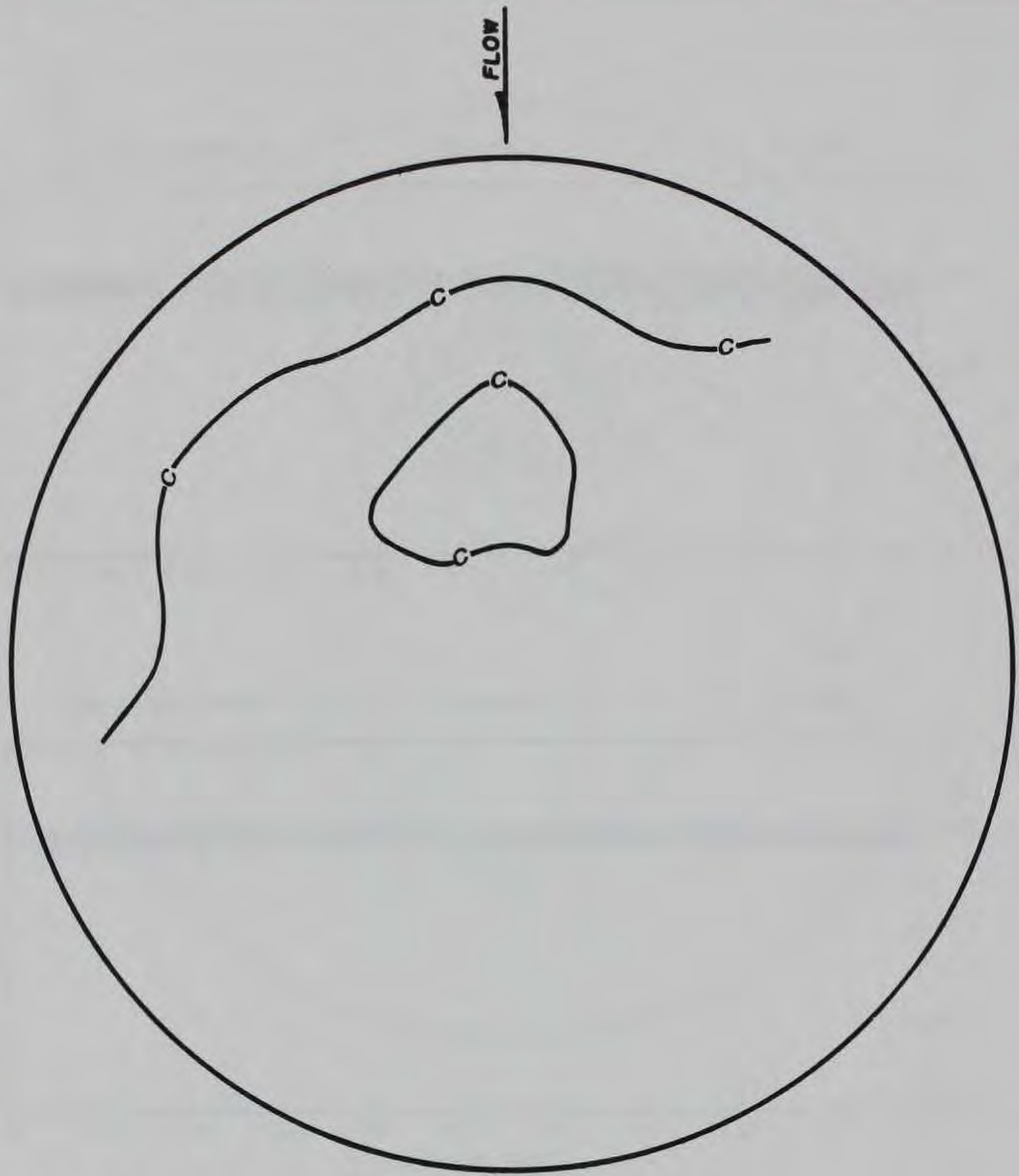
SUBMERGENCE $\frac{S}{d} = 0.94$



TIME-HISTORY
D VORTEX
TEST 3

DISCHARGE $\frac{Q}{\sqrt{gd^5}} \doteq 1.99$

SUBMERGENCE $\frac{S}{d} = 0.94$



CONTOURS

C = 1.00

LINES OF EQUAL VELOCITY RATIO
AVERAGE VALUES
TYPE 35
D VORTEX
TEST 5

DISCHARGE $\frac{Q}{\sqrt{gd^5}} = 1.99$

SUBMERGENCE $\frac{S}{d} = 4.69$

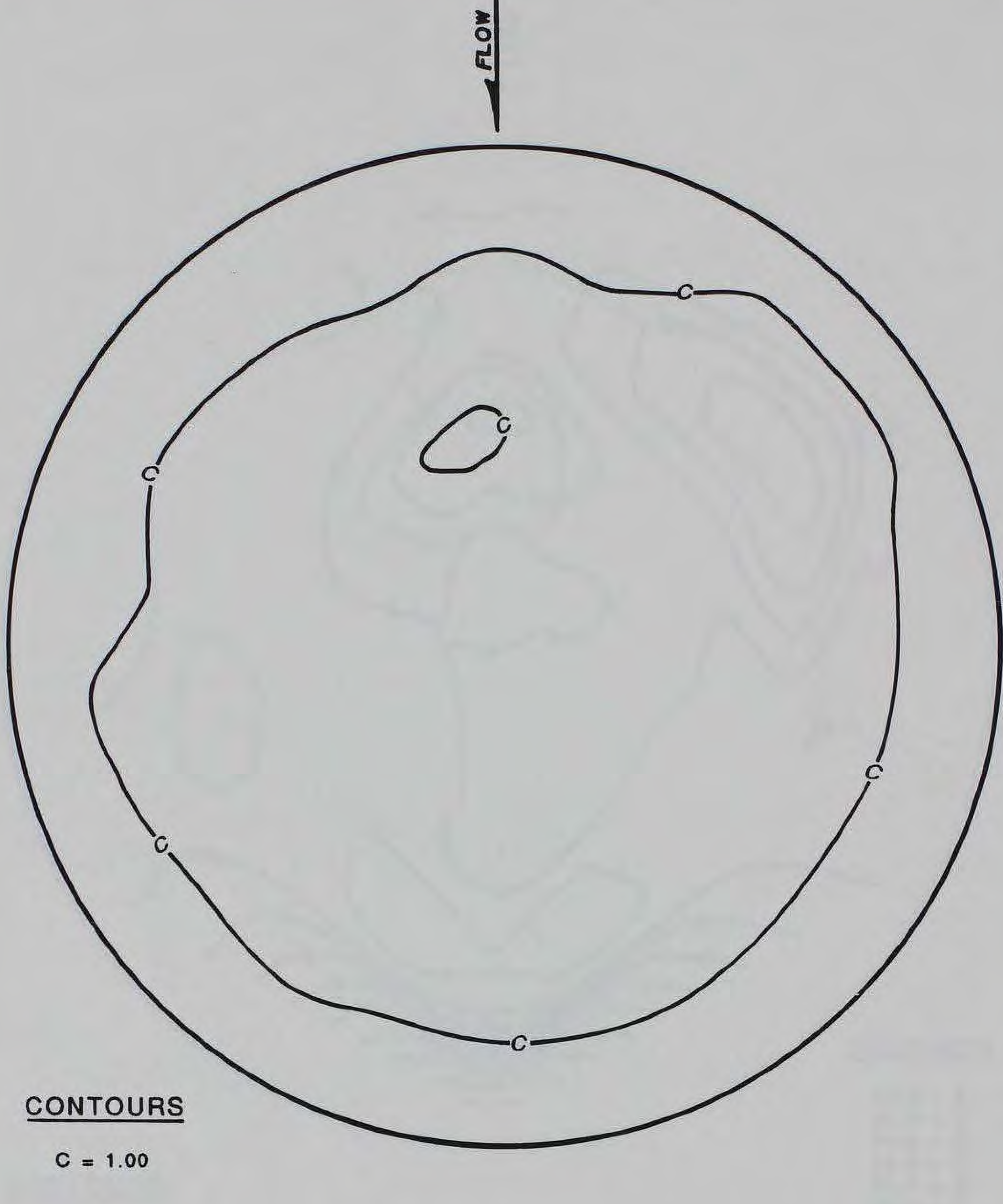
CONTOURS

A = 0.00
B = 0.10
C = 0.20
D = 0.30
E = 0.40
F = 0.50
G = 0.60
H = 0.70
I = 0.80
J = 0.90

LINES OF EQUAL VELOCITY RATIO
MAXIMUM DEVIATION VALUES
BETWEEN 47.96 AND 48.03 SEC
TYPE 35
D VORTEX
TEST 5

DISCHARGE $\frac{Q}{\sqrt{gd^5}} = 1.99$

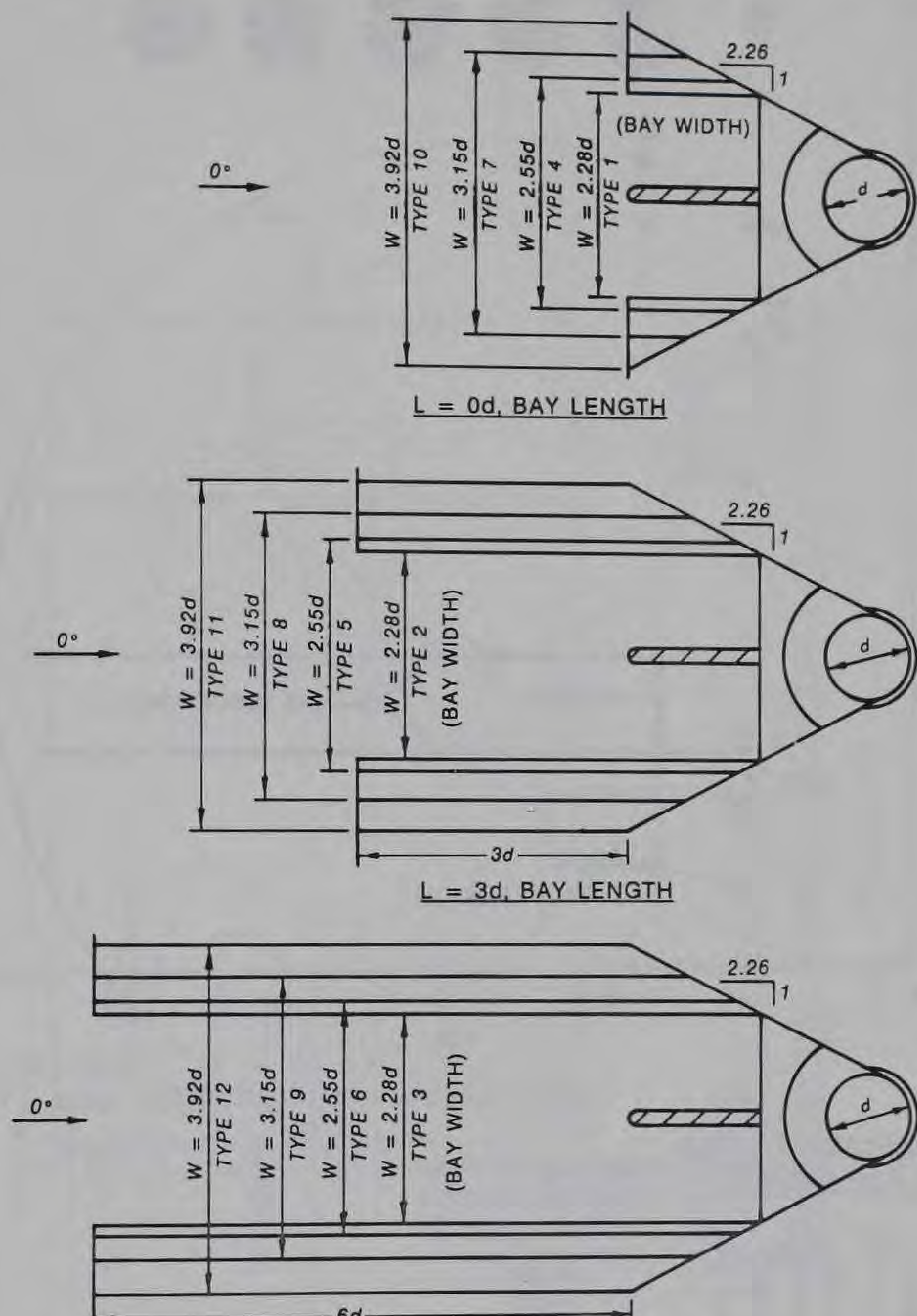
SUBMERGENCE $\frac{S}{d} = 4.69$



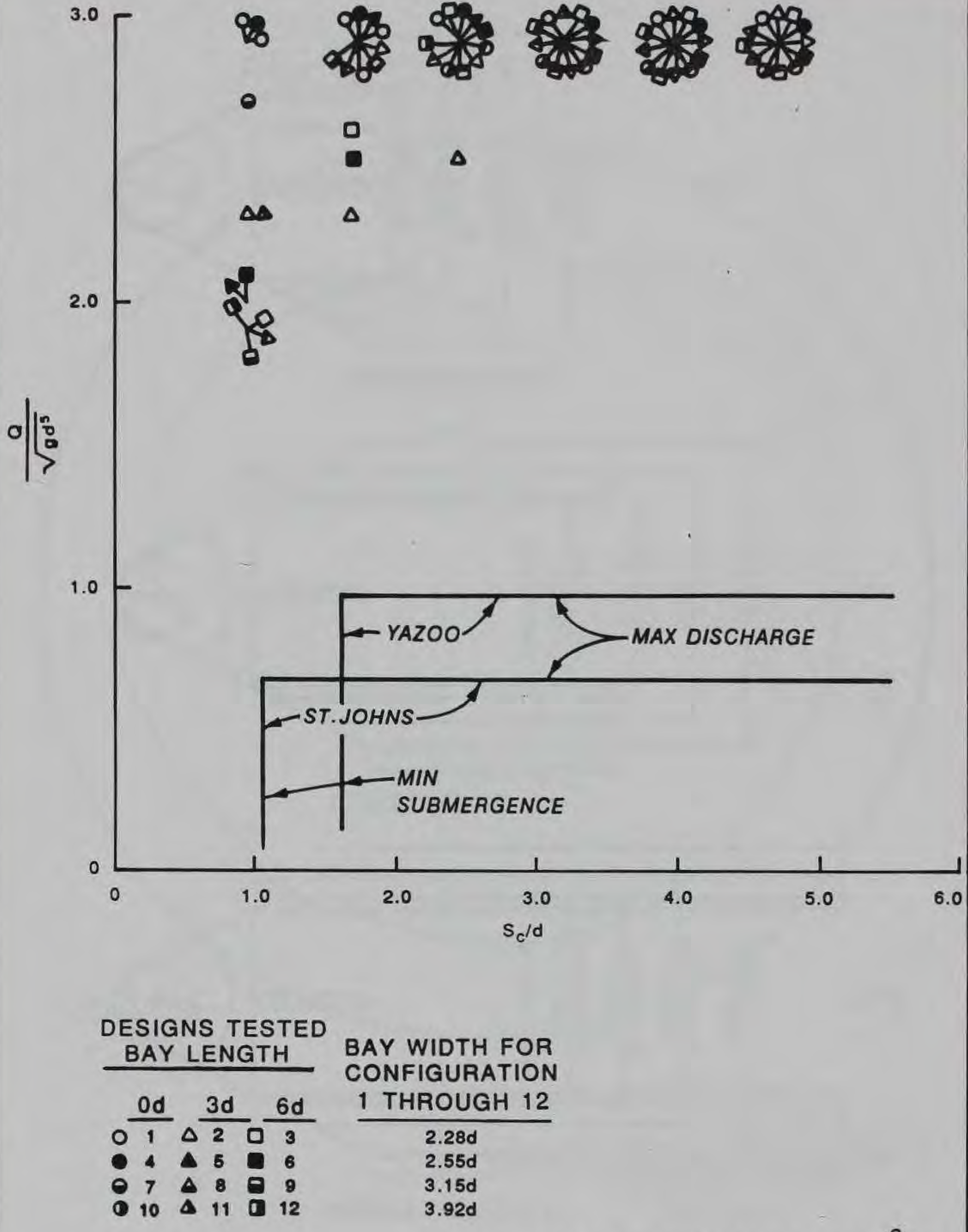
LINES OF EQUAL VELOCITY RATIO
AVERAGE VALUES
TYPE 35
D VORTEX
TEST 6

DISCHARGE $\frac{Q}{\sqrt{gd^5}} = 0.97$

SUBMERGENCE $\frac{S}{d} = 4.69$



FSI TYPES 1-12
0-DEG APPROACH FLOW



CRITICAL SUBMERGENCE $\frac{S_c}{d}$

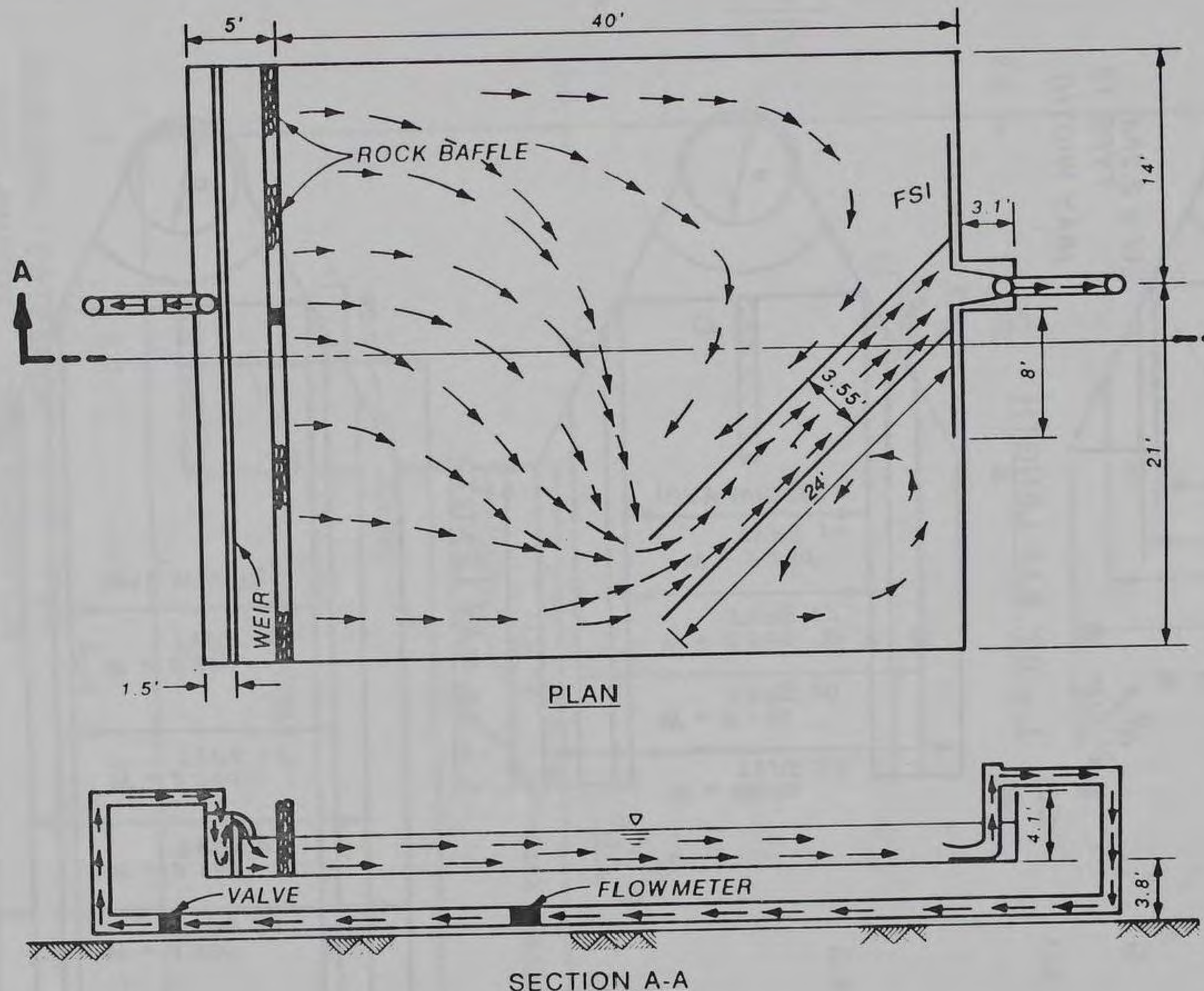
VS

DISCHARGE $\frac{Q}{\sqrt{gd^5}}$

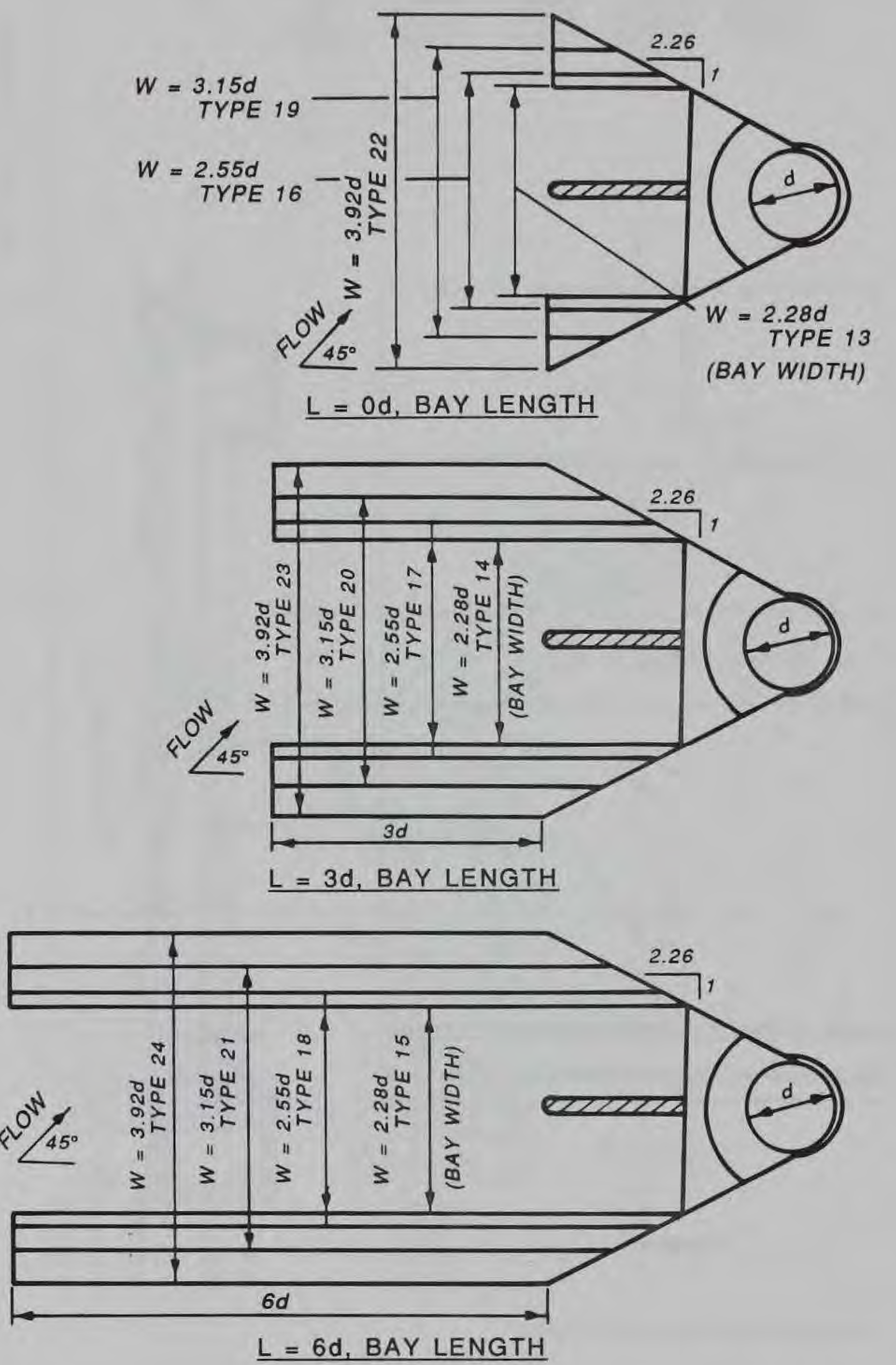
INCIPIENT STAGE E VORTICES

0-DEG APPROACH FLOW

PLATE 16

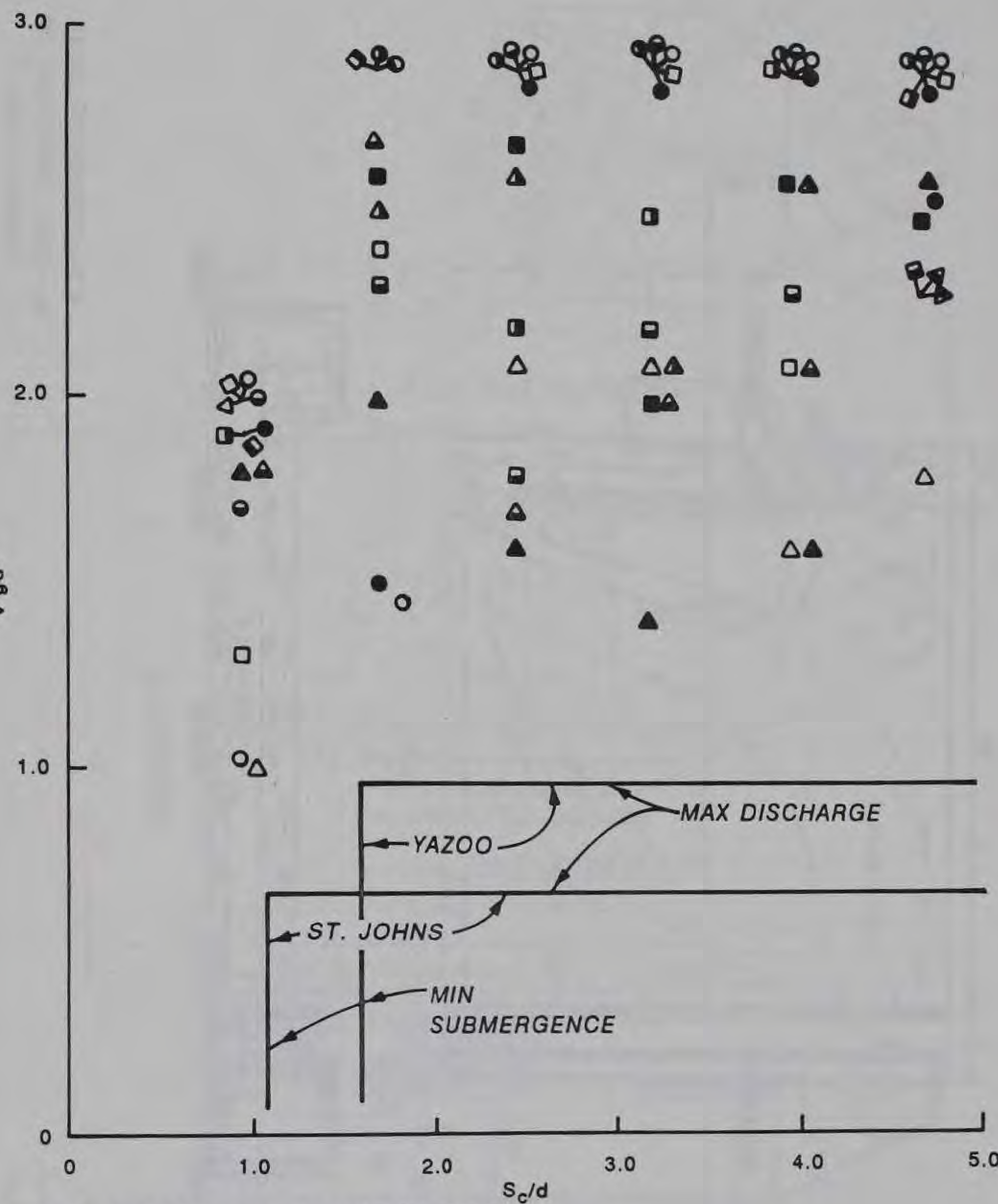


FSI STUDY FLUME
45-DEG APPROACH TO
PUMP INTAKE



FSI TYPES 13-24
45-DEG APPROACH FLOW

PLATE 18



DESIGNS TESTED BAY LENGTH			BAY WIDTH FOR CONFIGURATION 13 THROUGH 24
0d	3d	6d	
○ 13	△ 14	□ 15	2.28d
● 16	▲ 17	■ 18	2.55d
⊖ 19	▲ 20	⊟ 21	3.15d
◑ 22	▲ 23	◧ 24	3.92d

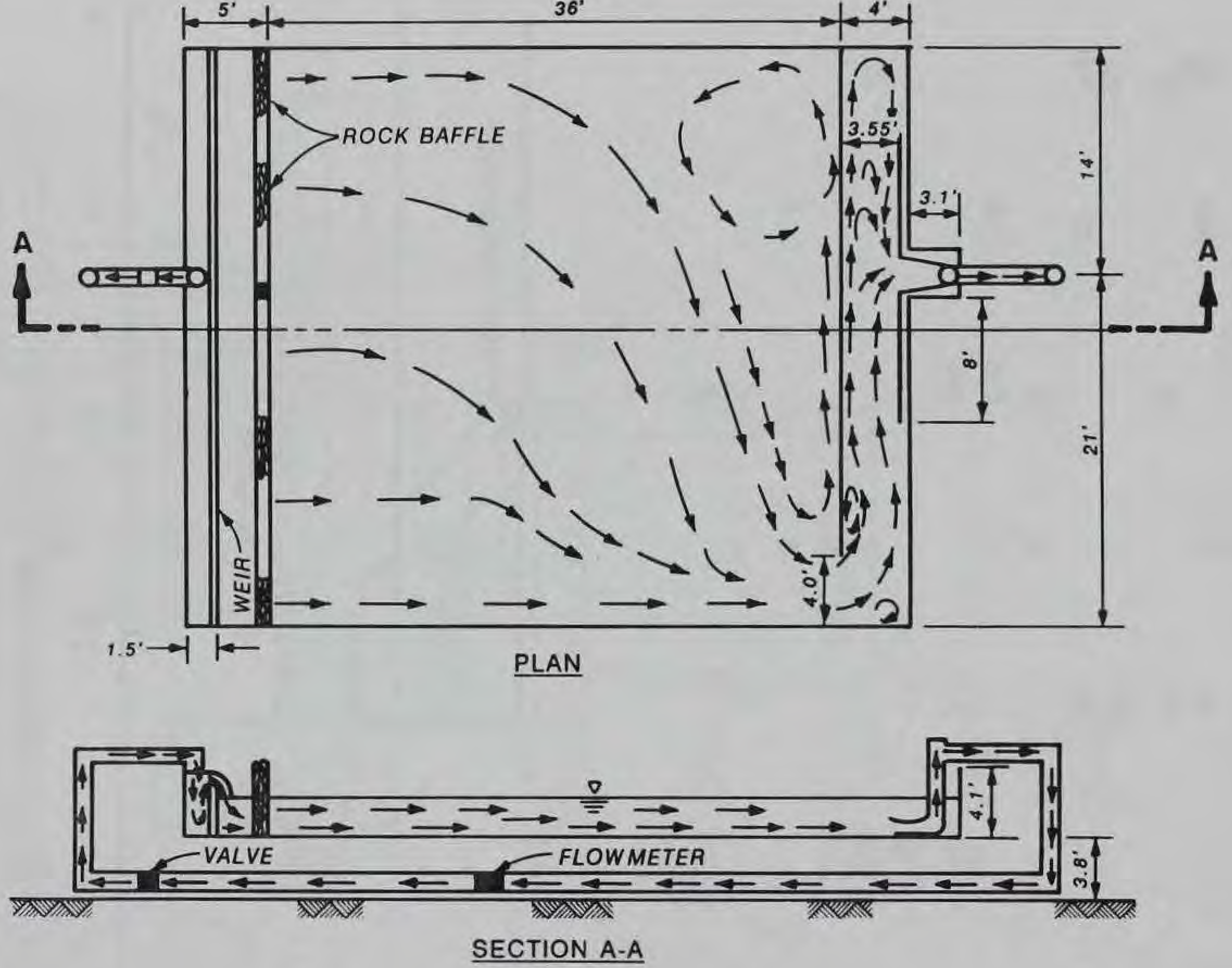
CRITICAL SUBMERGENCE $\frac{S_c}{d}$

VS

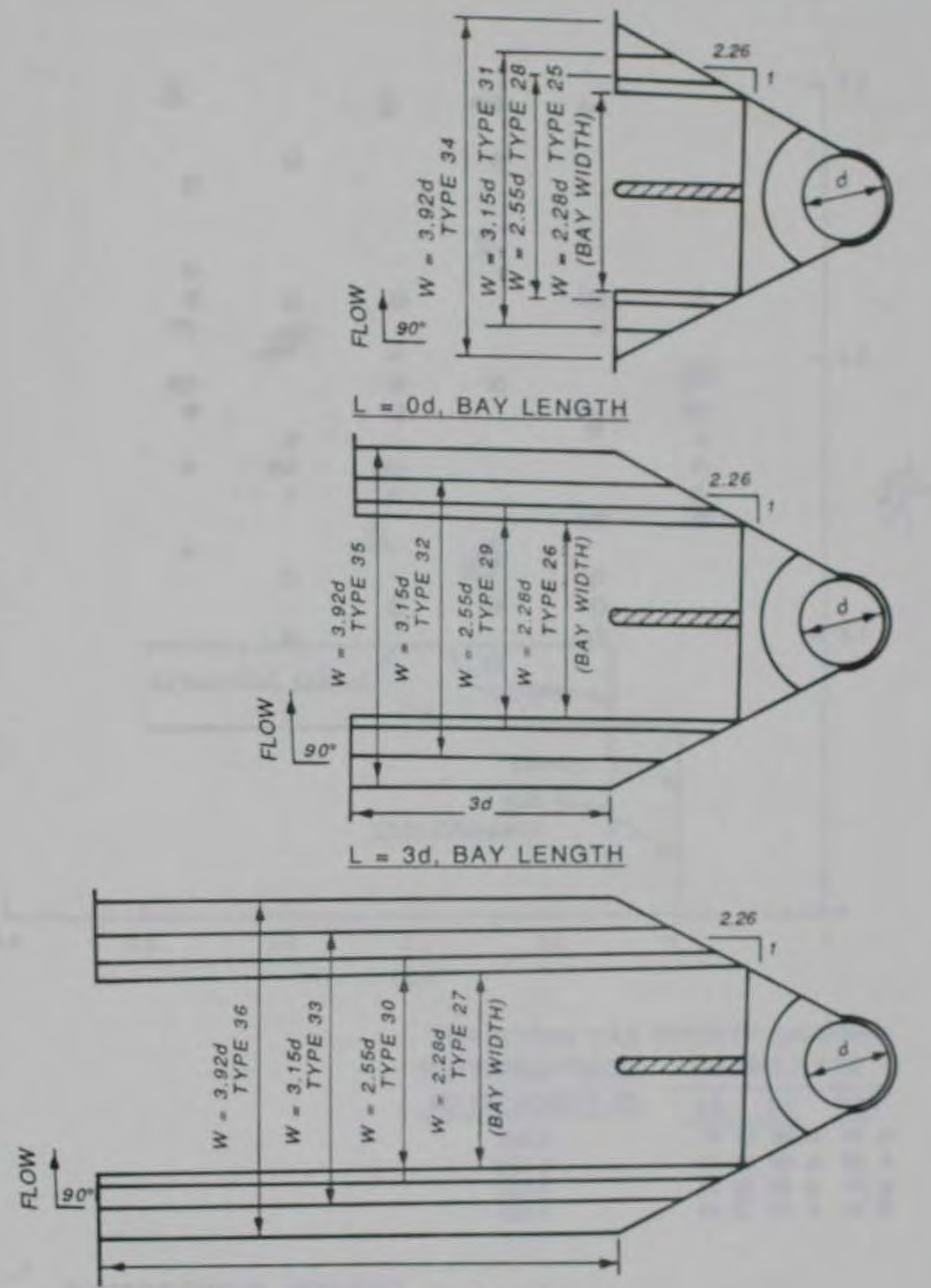
DISCHARGE $\frac{Q}{\sqrt{gd^5}}$

INCIPIENT STAGE E VORTICES

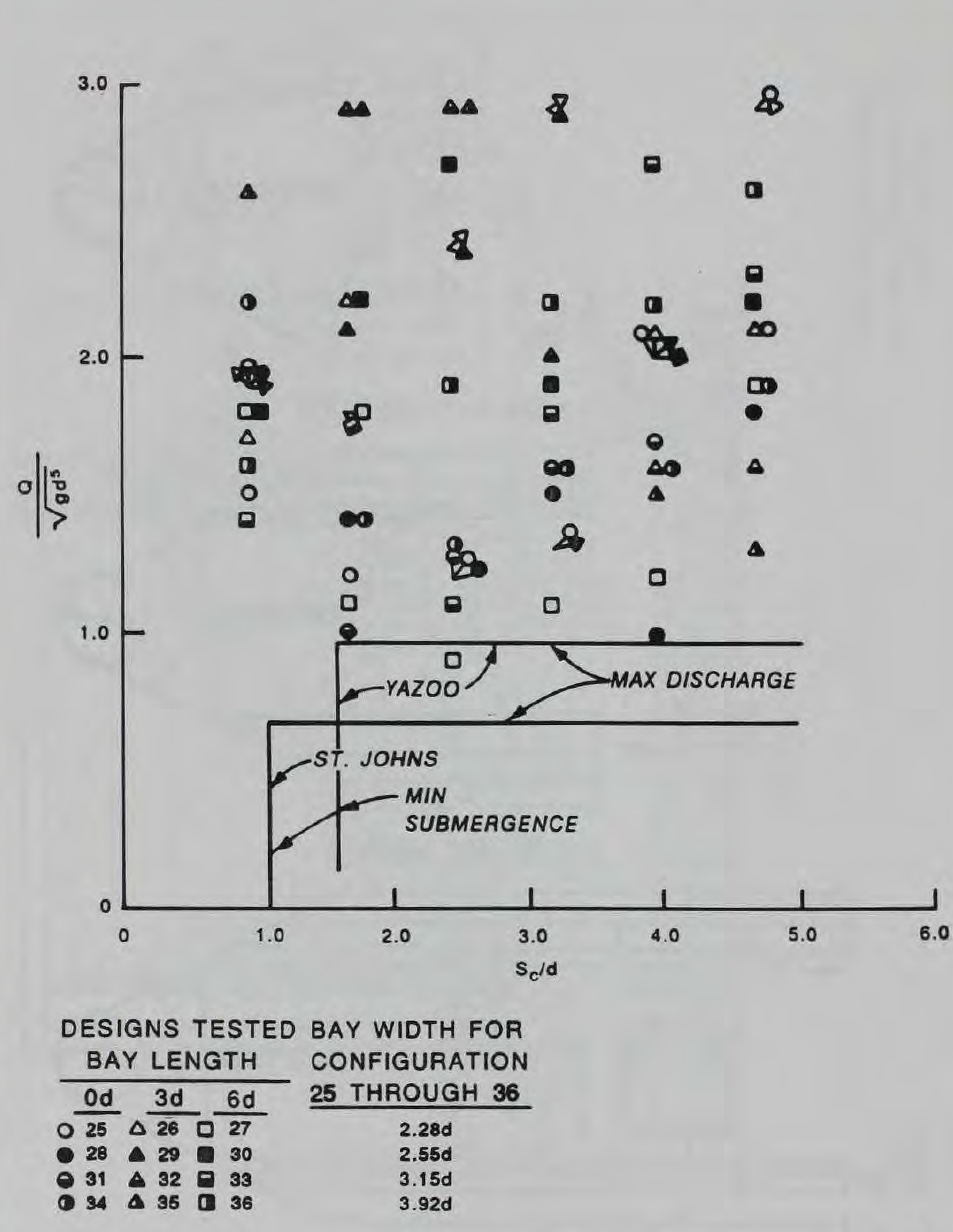
45-DEG APPROACH FLOW



FSI STUDY FLUME
90-DEG APPROACH TO PUMP INTAKE



FSI TYPES 25-36
90-DEG APPROACH FLOW



CRITICAL SUBMERGENCE $\frac{S_c}{d}$

VS

DISCHARGE $\frac{Q}{\sqrt{gd^5}}$

INCIPIENT STAGE E VORTICES

90-DEG APPROACH FLOW