NUREG/CR-2772
ARL-398A
SAND82-7064

Hydraulic Performance of Pump Suction Inlets for Emergency Core Cooling Systems in Boiling Water Reactors

Containment Sump Reliability Studies
Generic Task A-43

Prepared by M. Padmanabhan/ARL

Alden Research Laboratory
Worcester Polytechnic Institute

Sandia National Laboratories

Prepared for
U.S. Nuclear Regulatory
Commission

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Manuscript Completed: May 1982
Date Published: June 1982

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Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN A1296

ABSTRACT

This document reports on the hydraulic performance of two representative Boiling Water Reactor (BWR) Residual Heat Removal (RHR) suction inlet configurations; namely, those of the Mark I, and Mark II and Mark III designs. Key parameters of interest were air-ingestion levels, vortex types, suction pipe swirl, and the RHR inlet pressure loss coefficient. Tests were conducted with nearly uniform and non-uniform approach flows to the inlets. Flows and submergences were in the range of from 2000 to 12000 gpm per pipe and 2 to 5 ft, respectively, giving a Froude number range of from 0.17 to 1.06.

Zero air-withdrawal was measured for both configurations for Froude numbers equal to or less than 0.8 even under non-uniform approach flows; likewise, no air-core vortices were observed for the same flow conditions. At a Froude number above 1.0 and with non-uniform approach flows, air-withdrawals up to 4% by volume (1 minute average) were observed in the Mark I design (designated Configuration B in this report) and air-withdrawals up to 0.5% by volume (1 minute average) were observed in the Mark II and Mark III designs (designated Configuration A in this report).

Swirl levels in the pipe up to 7 degrees were measured in Configuration A and up to 3 degrees were measured in Configuration B. Inlet loss coefficients were about 1.7 for Configuration A (including "tee" losses) and about 1.0 for Configuration B.

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ACKNOWLEDGEMENTS

This research program was funded by the U.S. Nuclear Regulatory Commission (NRC), and their support is sincerely appreciated. The scope of work was developed and significant technical contributions were made by personnel from the NRC and the Sandia National Laboratories (Sandia), and the efforts of these organizations are gratefully acknowledged. Particular thanks are due to Mr. Aleck Serkiz of NRC, and Messrs. Peter Strom and Gilbert Weigand of Sandia for their efforts and valuable contributions in making the program effective.

The help provided by all members of the staff at the Alden Research Laboratory associated with this research project is gratefully acknowledged. Special mention must be made of the technical contributions of Professor George E. Hecker and Dr. Shih-kuan Hsu, and the actual conduct of the experiments by Messrs. John Noreika and Russell Dube.

1.0 INTRODUCTION

The objective of the investigations described in this report was to ascertain and quantify the pertinent hydraulic variables of major concern regarding the Emergency Core Cooling System (ECCS) pump performance, as influenced by the flow patterns at the suction inlets of Boiling Water Reactor (BWR) Residual Heat Removal (RHR) system within the containment and the typical geometrical features of the inlet itself. This study phase is to provide full scale experimental data which would be useful in the evaluation and design of representative inlets for Mark I, and Mark II and Mark III configurations.

The Alden Research Laboratory (ARL) of Worcester Polytechnic Institute (WPI) was contracted by the Sandia National Laboratories (Sandia) on behalf of the U.S. Nuclear Regulatory Commission (NRC) and the U.S. Department of Energy (DOE) to conduct full scale experimental research investigations on ECCS sump reliability, mainly for Pressurized Water Reactor (PWR) sump geometries. Inasmuch as the BWR plants do not have a sump or a floor depression with surrounding screens and gratings, it was considered important to investigate a few typical suction pipe inlet configurations applicable to Mark I, and Mark II and Mark III designs as a continuation of the ECCS sump reliability studies. This later part of the program is the subject of this report. Details of the ECCS sump studies applicable to PWR type stations (which formed the major portion of total test plan) have been presented in separate reports [1, 2, 3, 4].

The test facility designed and built at the ARL for containment sump reliability studies and described in [5], was used to conduct the full scale BWR suction pipe inlet tests. A test plan was developed jointly by ARL and Sandia based on discussions with personnel from the NRC. The test plan considered two different suction pipe inlet configurations, Mark I, and Mark II and Mark III designs, both of which are common to existing BWR power stations [6].

The major items of concern regarding the performance of RHR suction inlets are:

1. Entrained Air - Air entrainment in the suction lines, due to air entraining vortices existing at the inlet, is of concern. It has been found that air concentrations of greater than about 3 to 5 percent by volume in a suction line can lower the head-discharge curves of centrifugal pumps considerably, causing lower pump capacities at given head [7, 8, 9].

2. Swirl - Approach flow patterns could induce a swirling flow in the inlet area which could be transmitted to the suction pipe and might increase the losses at the intake. Swirling flow in suction pipes could also affect the performance of pumps located close to the inlet, depending on the intensity of swirl.

3. Losses Leading to Reduced Net Positive Suction Head (NPSH) - A poorly designed inlet geometry could result in excessive head losses. Entrance losses cause by swirling flow, pipe inlet geometry, and strainer, may add up to a value such that the required NPSH of the pump is not satisfied, especially if the available submergence is low.

Description of the test facility, measurement techniques, and data acquisition are all given in detail in earlier reports [1, 5, 10]. However, a brief description of these items is provided in Appendix A for convenience. Section 2.0 provides the details of the ECCS suction pipe inlet test program for BWR type power stations, which forms the subject of this report. Descriptions of the overall test plan, including the containment sump test plan for PWR type stations, are available in other reports [1,4]. A key findings summary is given in Section 3.0 followed by the detailed discussion of results in Section 4.0.

2.0 TEST DETAILS

A test plan was developed jointly by Sandia, NRC, and ARL. Two typical BWR pipe inlet configurations (i.e., Mark I, and Mark II and Mark III designs), which are similar to those used in existing or planned installations [6], were selected for testing. As shown in Figure 1, the two inlet configurations used single 24 inch diameter outlet pipes.

Configuration A, which conforms to Mark II and Mark III designs, had two conical strainers, of perforated plate with 5/8 inch holes covered with a fine screen, one on either end of a "tee" attached to the pipe entrance. Configuration B, which conforms to Mark I design, had a single conical strainer of perforated plate with 1/8 inch holes attached to the pipe entrance (Figure 1). As shown in Table 1, tests covered a range of flows of about 3000 to 12000 gpm under submergences of about 2, 3.5, and 5 ft, giving Froude numbers ($F = u/\sqrt{gs}$ with u = velocity in the main 24 inch pipe; g = acceleration due to gravity; s = submergence of pipe centerline to water surface) of 0.17 to 1.06. The ranges of flow and submergences cover the typical values for Mark I, and Mark II and Mark III designs.

A general piping layout is shown in Figure 2 indicating locations of the swirl meter, the void fraction meter, and the pressure taps for the hydraulic gradeline. Each test was of 30 minute duration to obtain data on vortex types, air-withdrawals, pipe swirl and inlet losses. Instrumentation, measuring techniques, and data acquisition were the same as described in reference [1], and are briefly discussed in Appendix A. Four approach flow distributions from nearly uniform to non-uniform were tested for each case. The non-uniform approach flow schemes, obtained by blockage of flow distributors in the facility, are shown in Figure 3. Tests of Configuration B were also performed with no strainer for all submergences and also with the conical strainer (no "tee") of Configuration A for a nearly uniform approach flow case at a submergence of 2 ft. These tests enabled a direct comparison of the performance of the strainer.

TABLE 1
Test Flows and Submergences

Item	Flows, gpm	Submergences, ft
Configuration A Tests	3000, 6000, 9000, 12000	2, 3.5 and 5
Configuration B Tests	3000, 6000, 9000, 12000	2, 3.5 and 5
Configuration B, but with strainer of A	3000, 6000, 9000, 12000	2 only
Configuration B, but without strainer	3000, 8000, 12000	2, 3.5 and 5

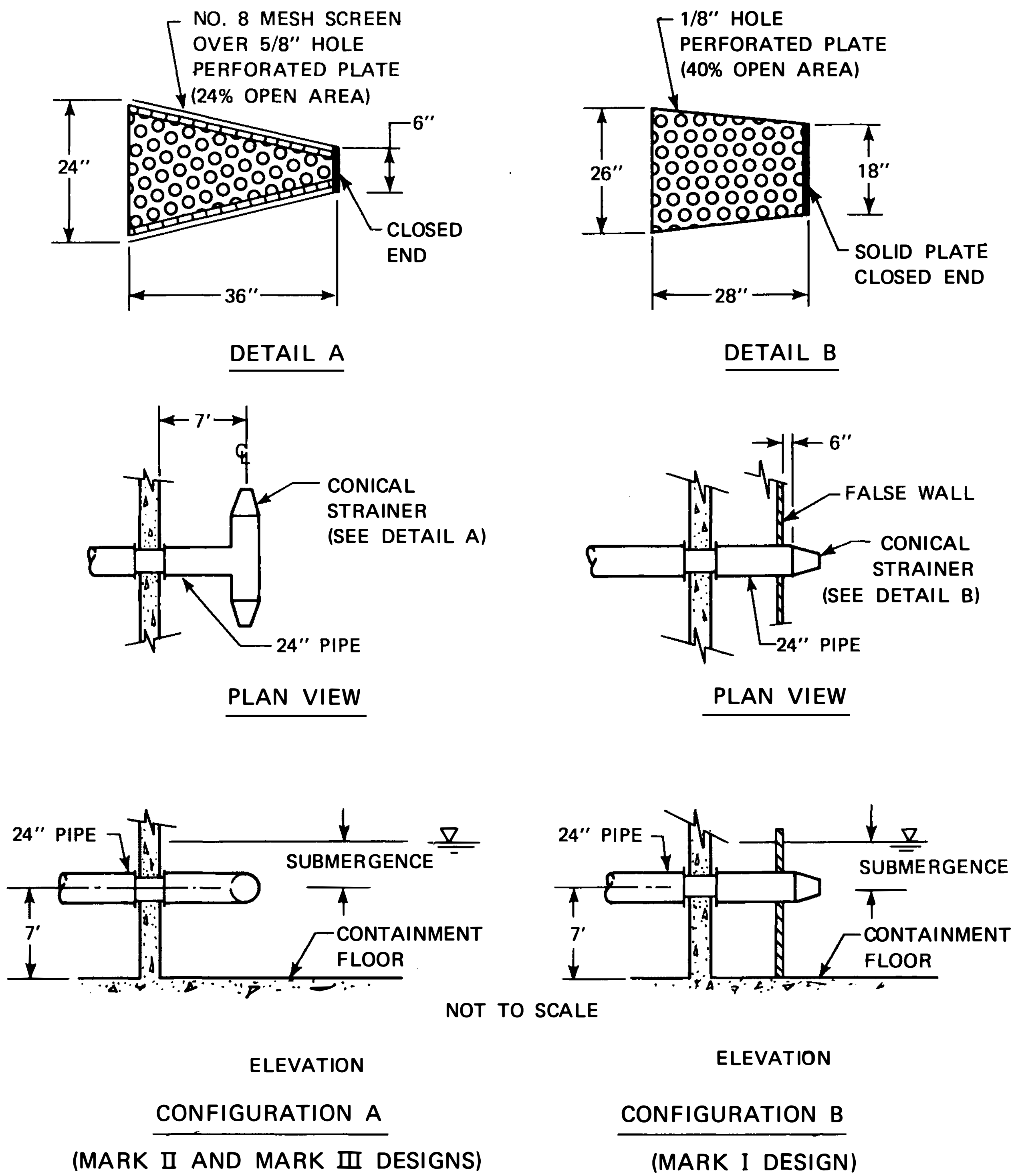


FIGURE 1 BWR/PIPE INLET CONFIGURATIONS AS BUILT IN FULL SIZE FACILITY

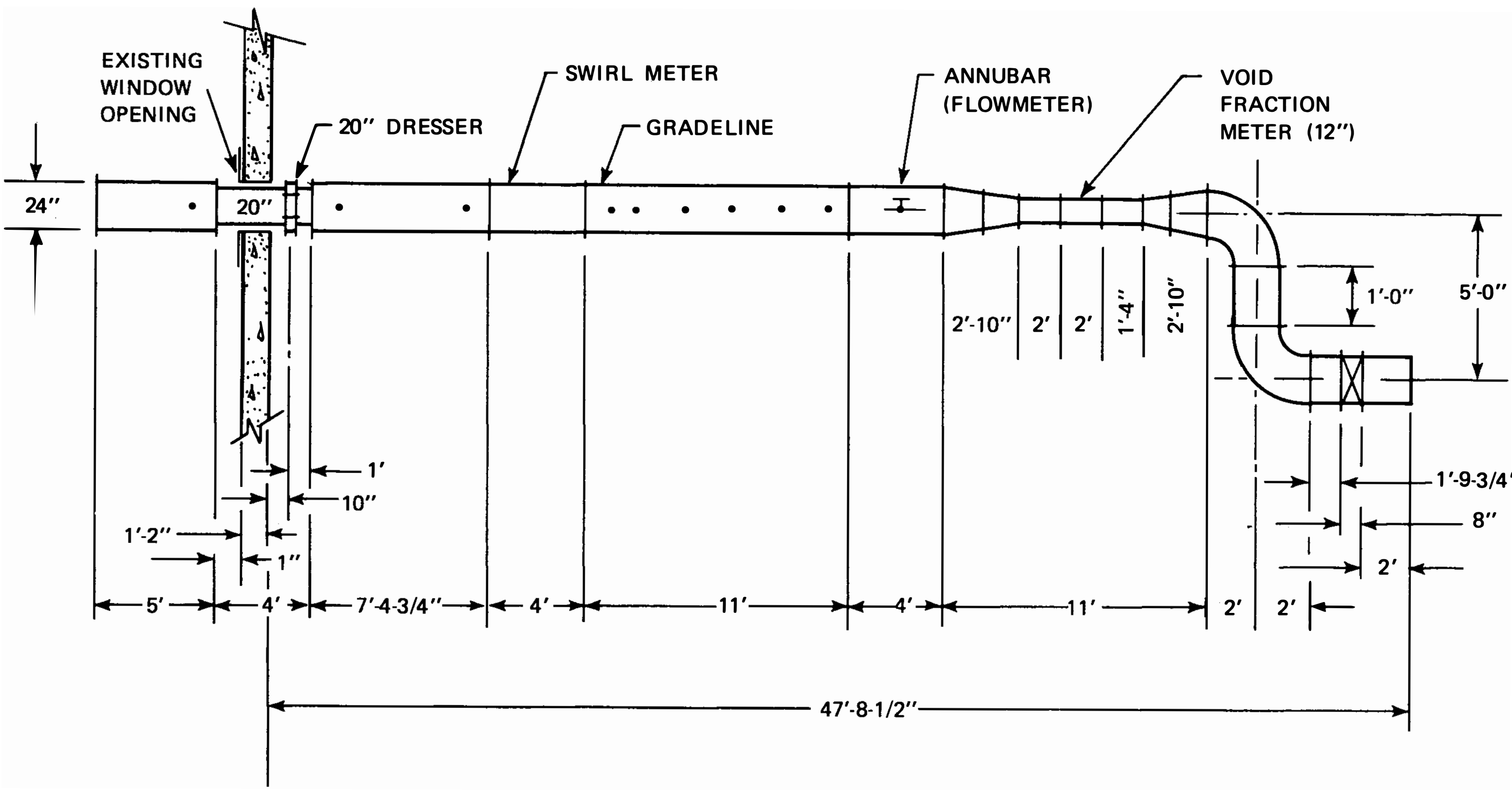
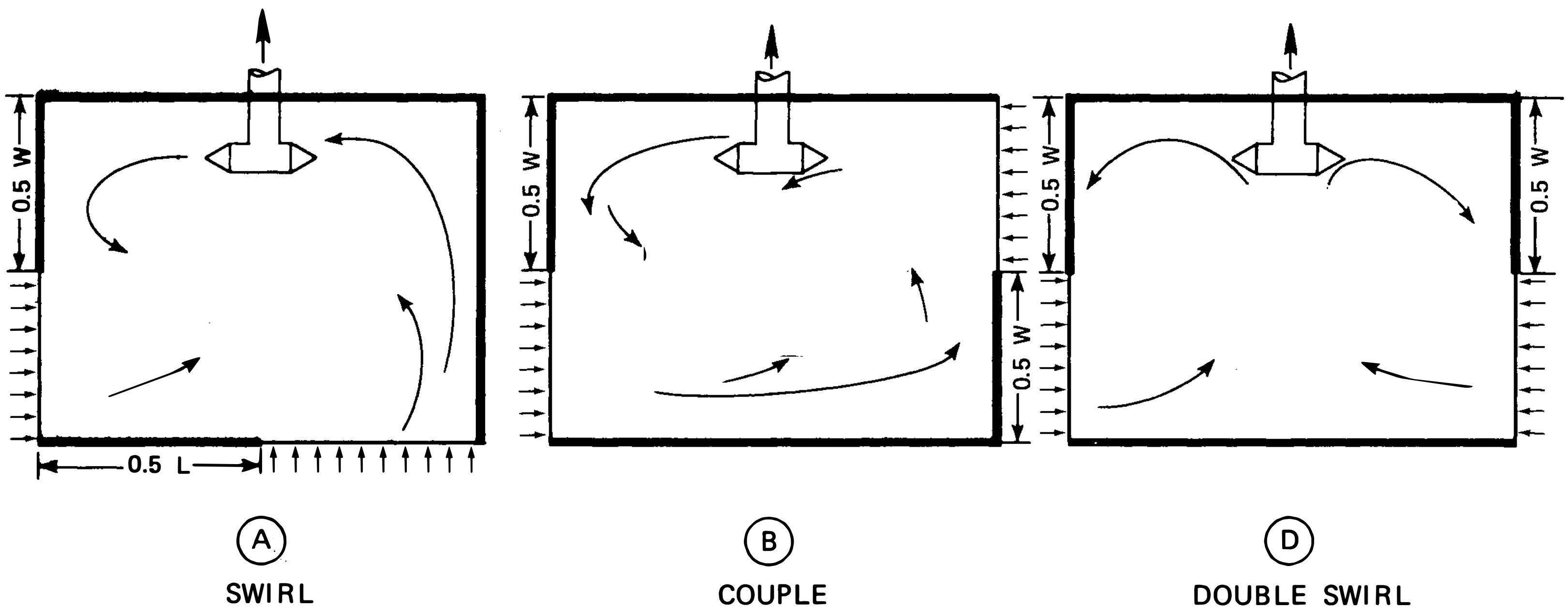


FIGURE 2 PIPING DETAILS FOR BWR CONFIGURATIONS



NON-UNIFORM FLOW
(FLOW DISTRIBUTOR BLOCKAGE)

W=30 FEET
L=60 FEET

FIGURE 3 NON-UNIFORM FLOW SCHEMES; SCHEMES A, B AND D USED FOR BWR INLET TESTS

3.0 KEY FINDINGS SUMMARY

a. With approximately uniform approach flows, air-withdrawals were zero or nearly zero with both configurations for all tested flows and submergences.

b. With non-uniform approach flow patterns (see Figure 3) for all tested flows and submergences corresponding to Froude numbers equal to or less than 0.8, measured air-withdrawals were zero or nearly zero for both configurations. At higher Froude numbers, the maximum air-withdrawal for Configuration A (Mark II and Mark III designs) was less than 0.5 percent void fraction (both 30 minute and 1 minute average), while for Configuration B (Mark I design), a maximum air-withdrawal of about 3 to 4 percent void fraction (both 30 minute and 1 minute average) was recorded for a Froude number of 1.06.

c. No air-core vortices were observed for either configurations for the entire range of tested flows of 3000 to 12000 gpm at submergences equal to or above 3.5 ft (or Froude numbers less than 0.8), irrespective of the approach flow distributions tested.

d. The test average swirl angles were higher for Configuration A compared to Configuration B, perhaps due to additional swirl generated by the "tee". Configuration A indicated swirl angles as high as 7 degrees, whereas Configuration B indicated swirl angles up to 3 degrees (measured at about 8 pipe diameters from the inlet). Swirl angles varied with the approach flow distribution, especially for Configuration B, indicating considerable influence of approach flow pattern.

e. Including the entrance, strainer, and "tee" losses, the inlet loss coefficient for Configuration A averaged about 1.7. For Configuration B, including the entrance and strainer losses, the loss coefficient averaged about 1.0 (Figure 11). The higher value for Configuration A is due to the added "tee" losses which are estimated to be about 0.65 [11]. Inlet loss coefficients reported herein are expressed in terms of the velocity head in the main pipe and not that in the "tee" or strainer.

f. One of the strainers of Configuration A was installed in place of the strainer of Configuration B, and compared with respect to the influence on void fraction, average vortex type, pipe swirl angle, and inlet losses. In terms of air-withdrawal, vortexing, and pipe swirl, both strainers performed similarly, but the strainer loss for the Configuration A strainer was found to be three times that for the Configuration B strainer under the same suction pipe velocity. This is due to a lower open area and the added fine screen in the case of the Configuration A strainer, compared to the strainer of Configuration B.

g. To compare the hydraulic performance with and without a strainer, limited tests were conducted on Configuration B with nearly uniform approach flows. Even without the strainer, no air-core vortices were indicated for Froude number less than 0.7. The maximum void fraction was 0.8% (1 minute average) at F = 1.06 without the strainer compared to 0.2% with the strainer. Within the accuracy of void fraction measurements, the effect of the strainer on air-withdrawal is not significant. Hence, a strainer of this type should not be considered as a good vortex suppressor. However, the strainer acts as a swirl reducer since the swirl angles were essentially zero with the strainer, while swirl angles of up to about 1.3 degrees were measured without the strainer. Adding a strainer at the inlet increased the inlet losses from about 0.65 to about 1.0.

4.0 DETAILED RESULTS

The hydraulic performance variables of interest; namely, test average values of vortex type, void fraction (indicating air-withdrawals), swirl angle, and inlet loss coefficient, are plotted against the Froude number, $u/\sqrt{gs}$, where u is the velocity of flow in the main suction pipe (after the "tee", if any), g the acceleration due to gravity and, s the submergence of the pipe centerline from the water surface. Wherever a direct comparison of two cases (such as strainer of Configuration A to that of B) are desired, the variables for each case are plotted against one another so that the deviations of test points from a 45 degree line through the origin would indicate any differences in performance.

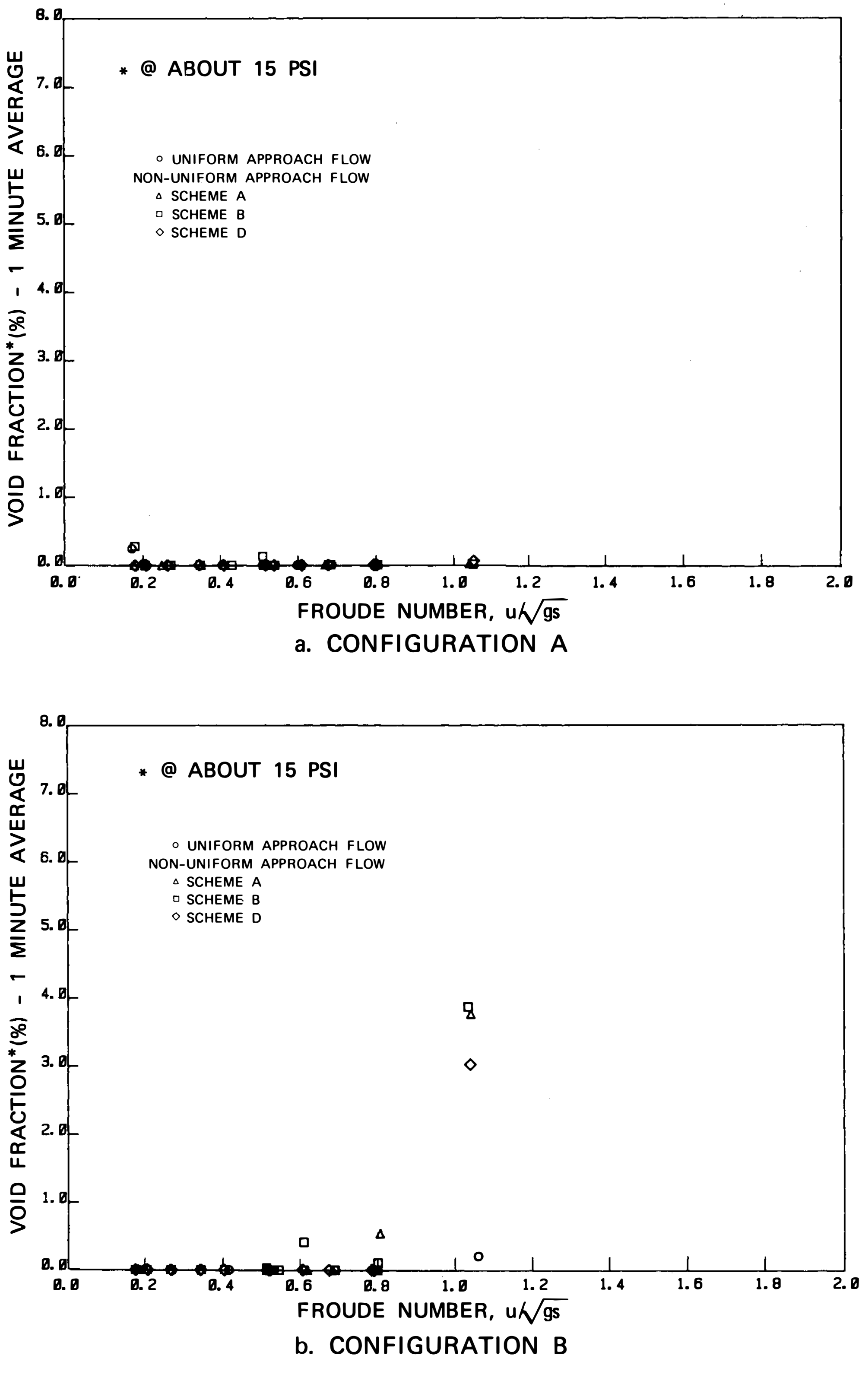
4.1 Air-Withdrawals

Figures 4 and 5 show the 1 minute and 30 minute average void fractions (indicative of air-withdrawals) for both configurations plotted against the Froude number, F, and these data include all tests with uniform and non-uniform approach flows. It can be seen that for F equal to or less than 0.8, the air-withdrawals were essentially zero. For Configuration A, the maximum air-withdrawal was less than 0.5 percent (both 30 minute and 1 minute average void fractions) even at a Froude number of 1.06 (corresponding to a flow of about 11900 gpm at a submergence of about 2 ft with non-uniform approach flow). For Configuration B, the maximum air-withdrawal was about 3 to 4 percent (both 30 minute and 1 minute average) at a Froude number of 1.05 (corresponding to a flow of about 11800 gpm at a submergence of about 2 ft with non-uniform approach flows).

4.2 Vortexing

Figures 6 and 7 show average and observed vortex types respectively for both configurations over the tested Froude number range. No air-core vortices (type 6) occurred for the entire range of tested flows (up to 12000 gpm) for submergence equal to or above 3.5 ft or Froude numbers less than 0.8, irrespective of the approach flow patterns. For the submergence of 2 ft, air-core vortices appeared at flows above 11500 gpm for Configuration A (or $F > 1.0$) and above 9000 gpm for Configuration B (or $F > 0.8$).

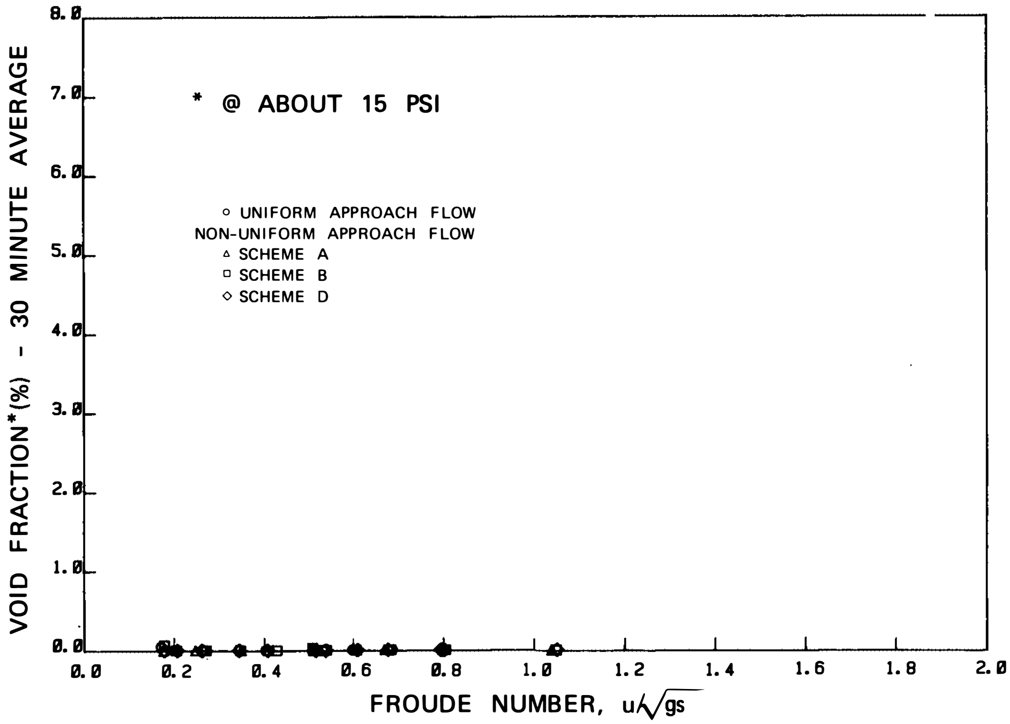
Figures 8 and 9 show photographs of some of the vortices observed in Configurations A and B, respectively. The vortices were observed to form very close to the pipe entrance and based on dye tracing, most of the flow was also observed to enter through the first 25% or so of the strainer area close to the pipe entrance. This suggests that increasing the strainer length may not always be effective in distributing the inflow and reducing entrance velocities.



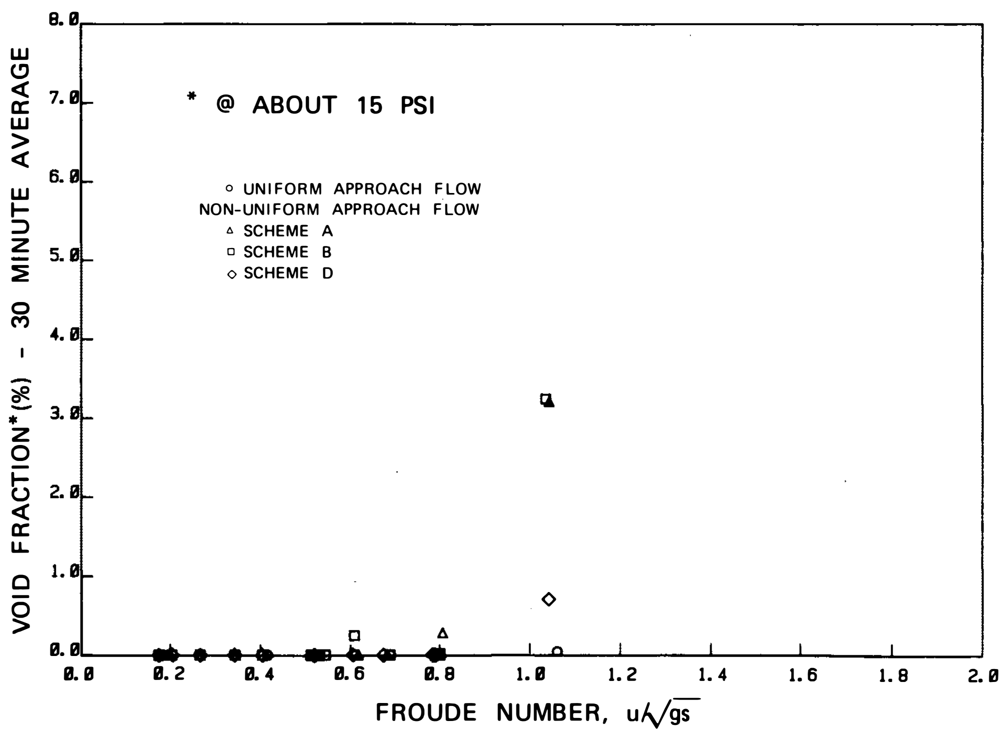
a. CONFIGURATION A

b. CONFIGURATION B

FIGURE 4 ONE MINUTE AVERAGE VOID FRACTION FOR TESTED FROUDE NUMBER RANGE

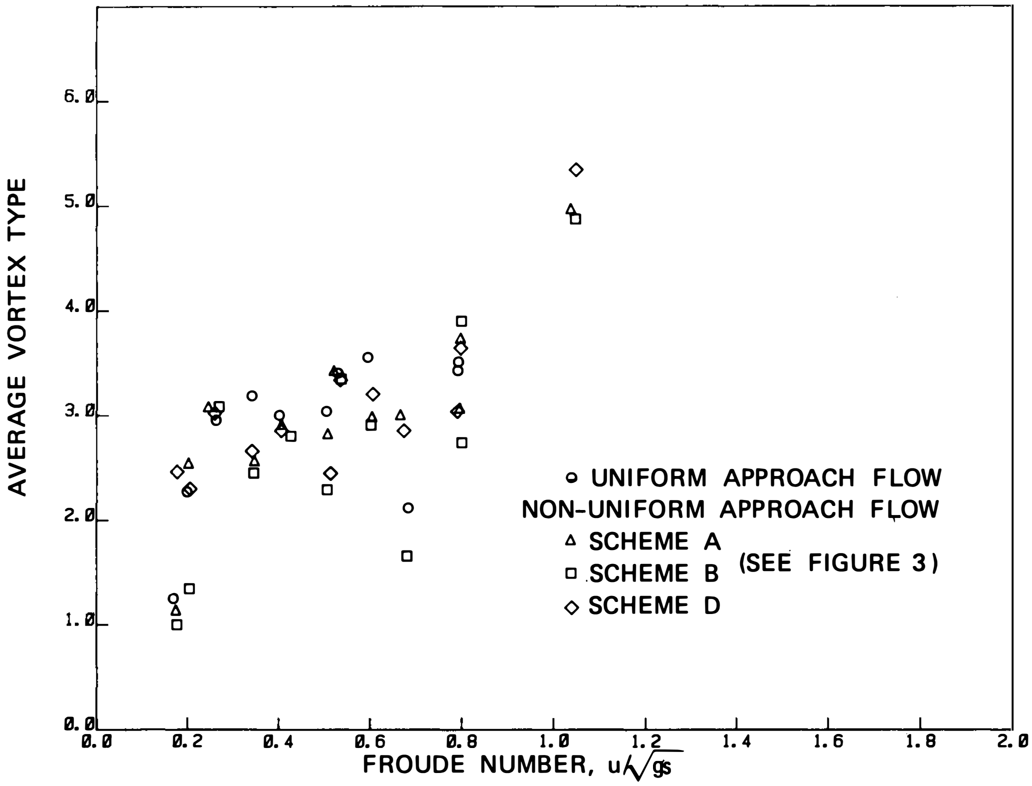


a. CONFIGURATION A

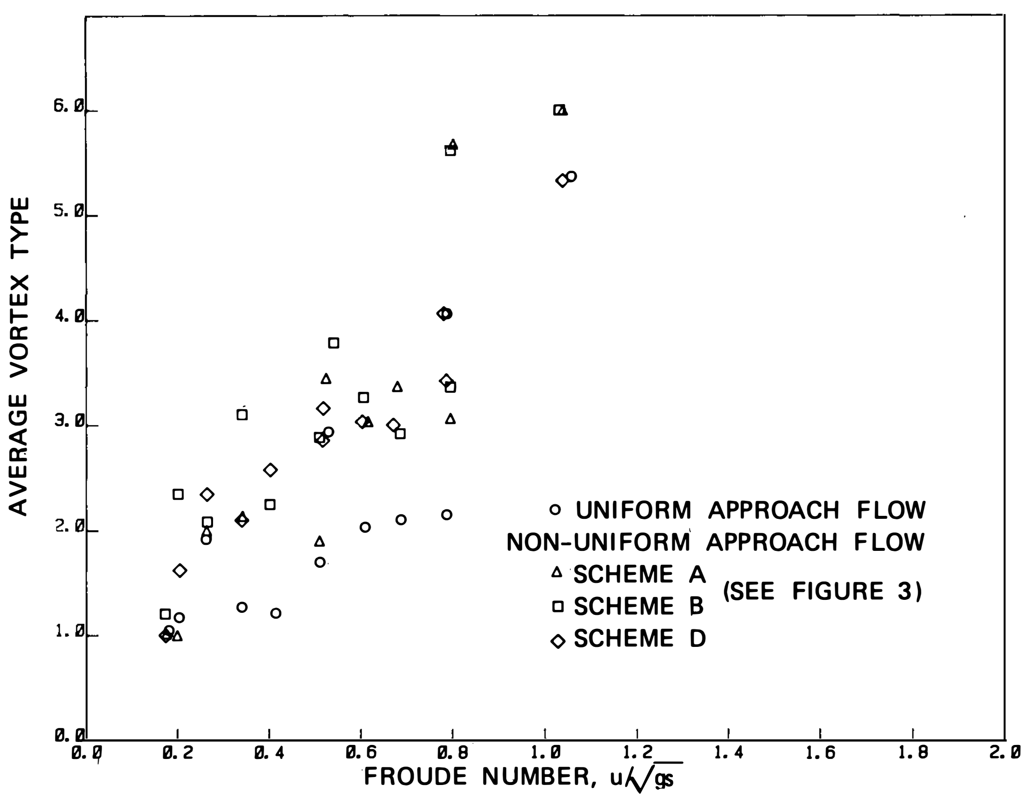


b. CONFIGURATION B

FIGURE 5 TEST AVERAGE VOID FRACTIONS FOR THE TESTED FROUDE NUMBER RANGE

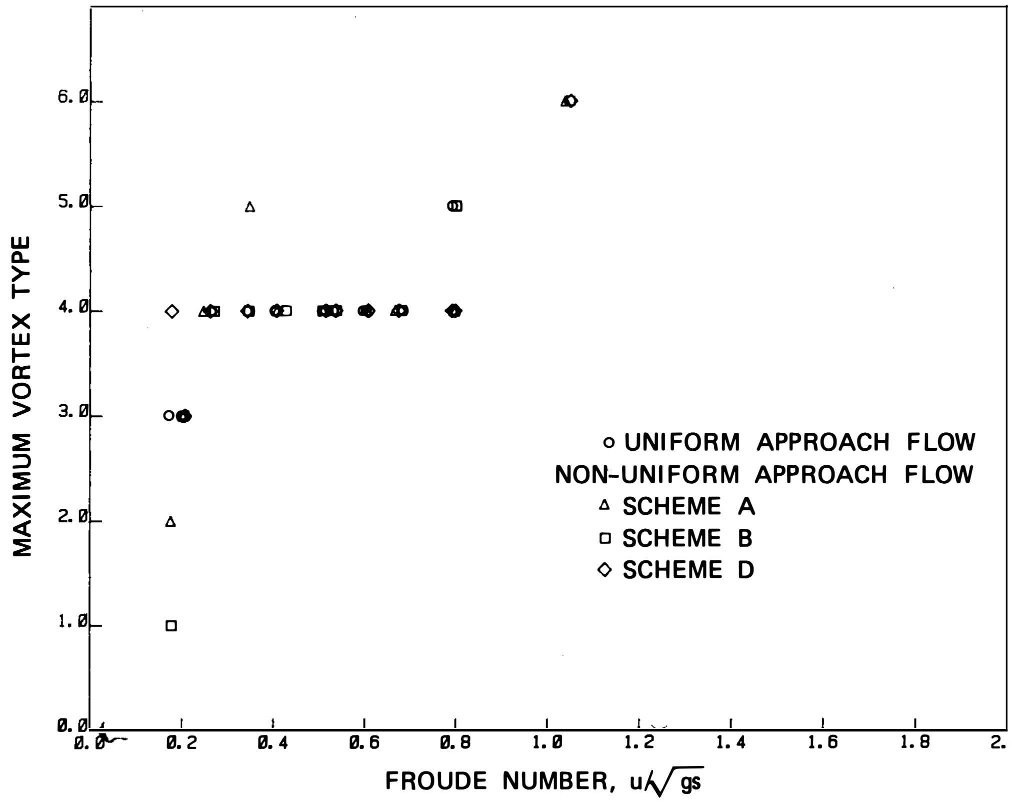


a. CONFIGURATION A

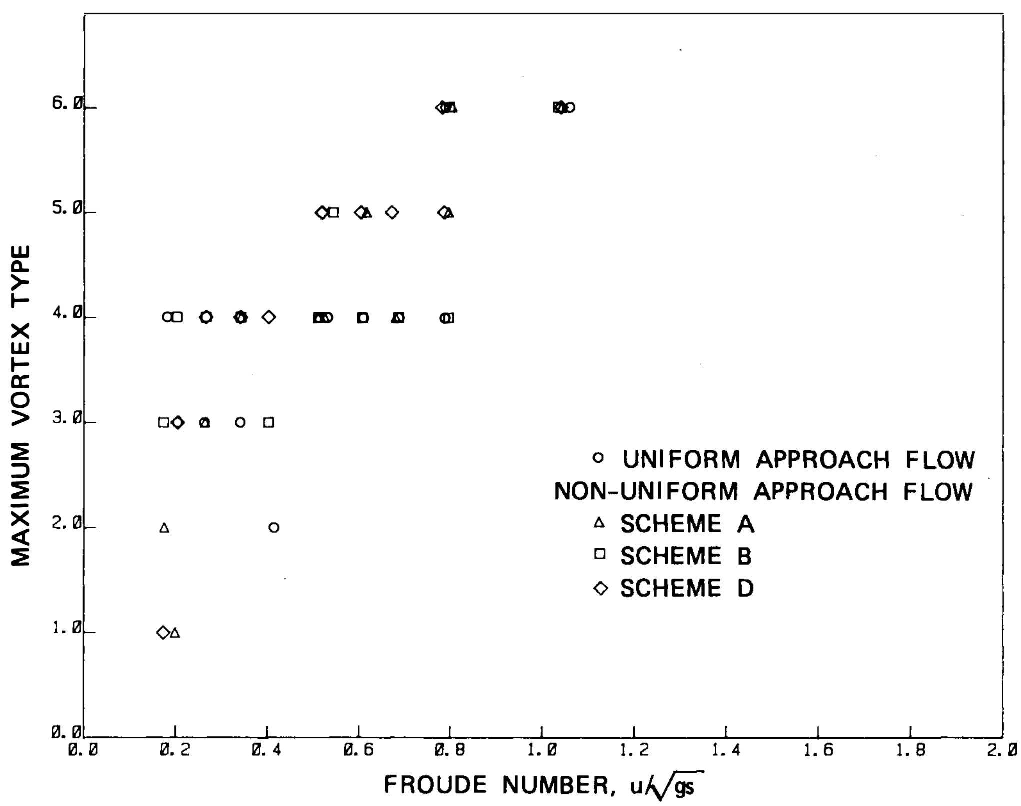


b. CONFIGURATION B

FIGURE 6 TEST AVERAGE VORTEX TYPES FOR THE FROUDE NUMBER RANGES TESTED

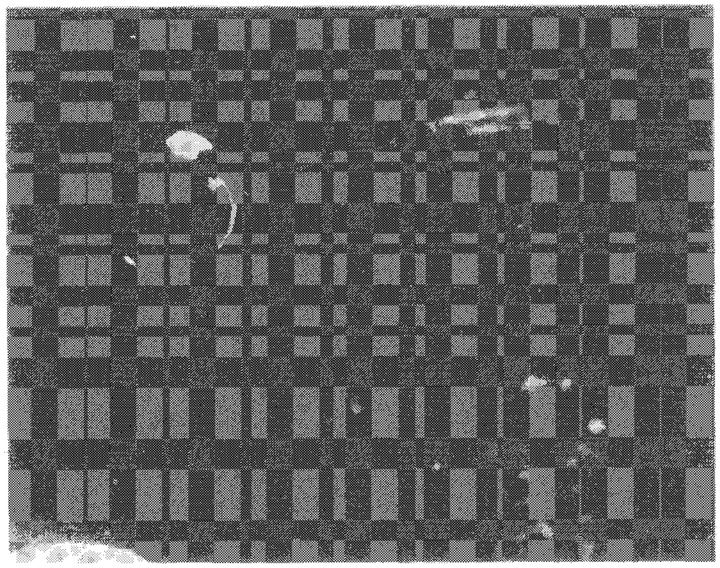


a. CONFIGURATION A

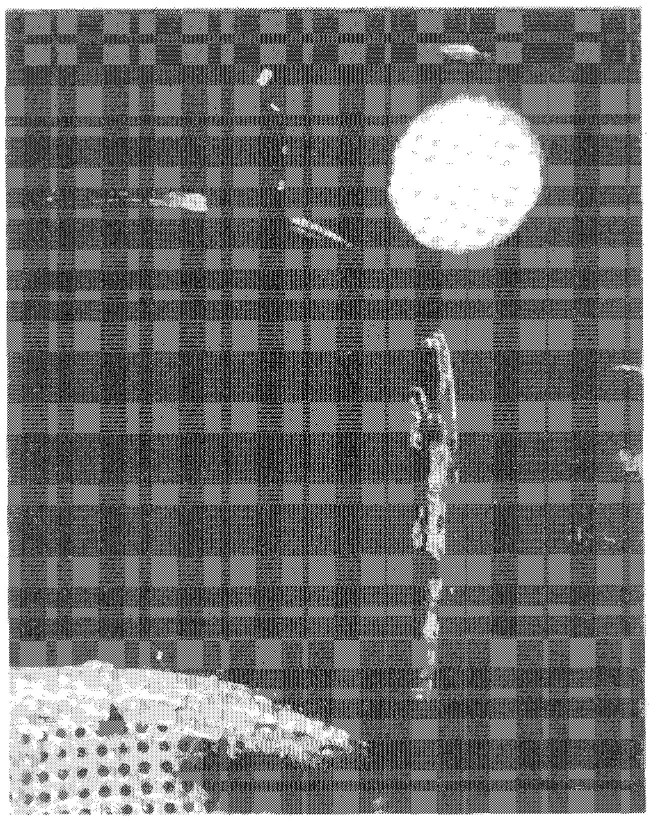


b. CONFIGURATION B

FIGURE 7 MAXIMUM VORTEX TYPES FOR THE FROUDE NUMBER RANGES TESTED

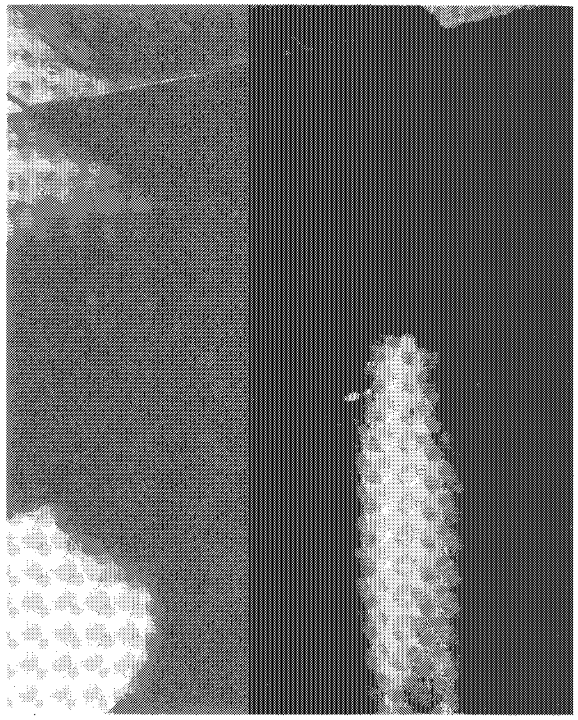


a. A STRONG TYPE 3 VORTEX IN CONFIGURATION A; Q = 9093 GPM; s = 3.5 FT NON-UNIFORM APPROACH FLOW; VOID FRACTION 0.0; PIPE FLOW SWIRL ANGLE = 4.0 DEGREES; INLET LOSS COEFFICIENT = 1.78

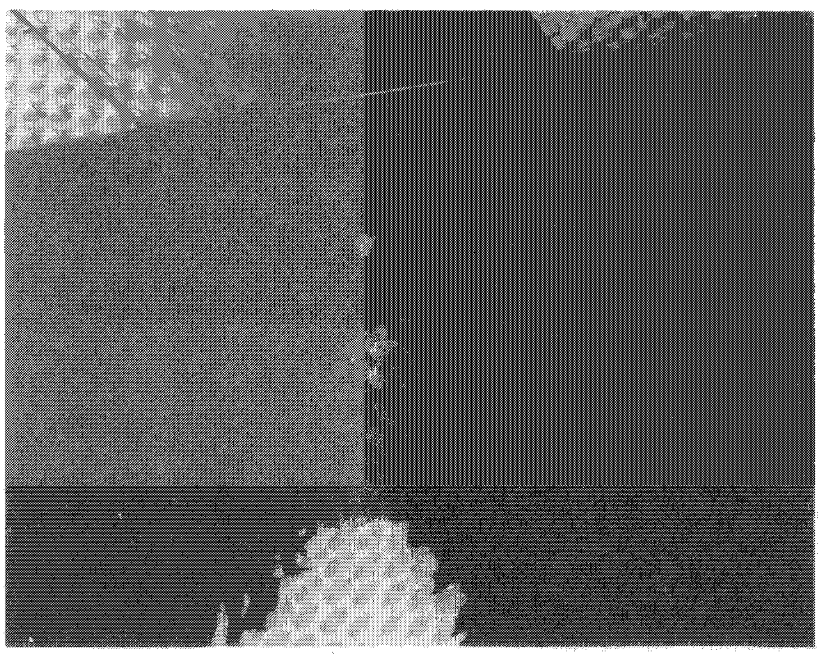


b. A STRONG TYPE 4 VORTEX IN CONFIGURATION A; Q = 9040 GPM; s = 2 FT; UNIFORM APPROACH FLOW; VOID FRACTION = 0.0; PIPE FLOW SWIRL ANGLE = 3.2 DEGREES; INLET LOSS COEFFICIENT = 1.7

FIGURE 8 VORTICES IN CONFIGURATION A



a. TYPE-4 VORTEX IN CONFIGURATION B; Q = 9069 GPM; s = 3.5 FT UNIFORM APPROACH FLOW; VOID FRACTION = 0.0%; PIPE SWIRL ANGLE = 2.3 DEGREES; INLET LOSS COEFFICIENT = 1.0



b AN AIR CORE VORTEX IN CONFIGURATION B; Q = 9078 GPM; s = 2 FT NON UNIFORM APPROACH FLOW; VOID FRACTION = 0 3%; PIPE SWIRL ANGLE = 2 4 DEGREES; INLET LOSS COEFFICIENT = 1 0

FIGURE 9 VORTICES IN CONFIGURATION B

4.3 Pipe Swirl

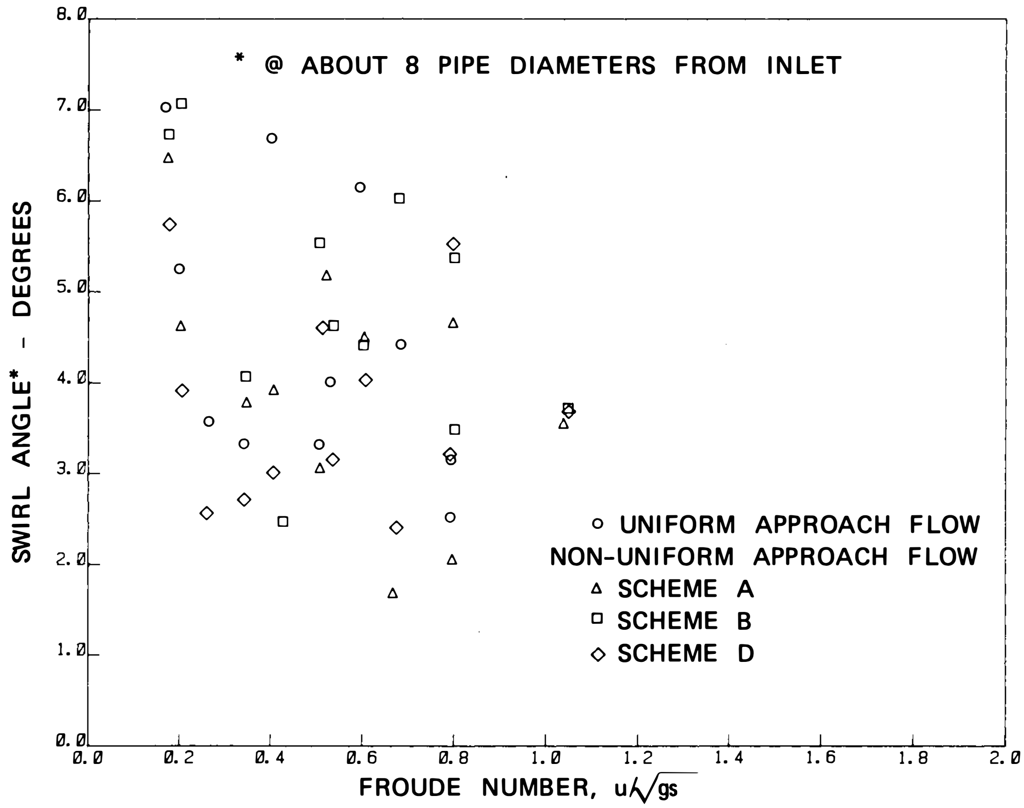
Figure 10 shows the test average swirl angles measured at about 8 pipe diameters from the pipe inlet. Configuration A with the "tee" showed swirl angles, ranging from 2 to 7 degrees, compared to Configuration B, which indicated swirl angles from 0 to 3 degrees. Presumably, the higher swirl in Configuration A is due to the additional swirl generated by the "tee". The approach flow patterns are seen to affect the swirl angles, especially for Configuration B, where swirl angles up to 3 degrees were measured with non-uniform approach flows compared to zero swirl angles with uniform approach flow.

4.4 Inlet Losses

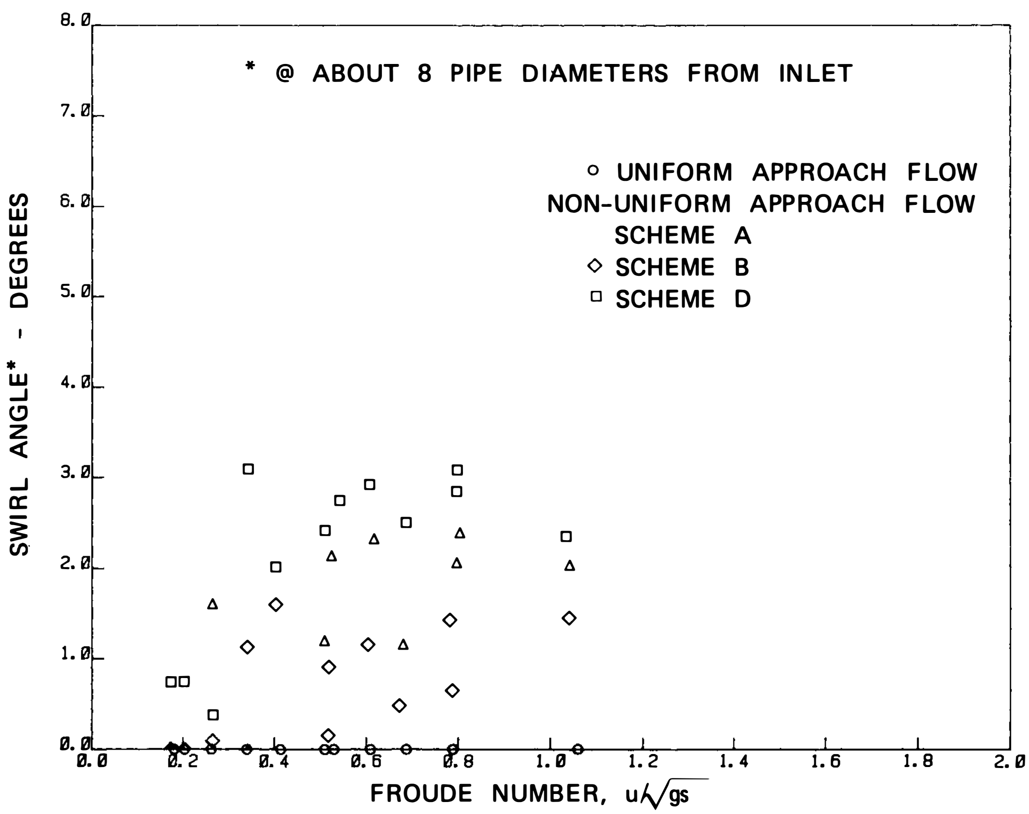
Inlet loss coefficients that include entrance, strainer, and "tee" losses, if any, were calculated using the average velocity head in the main 24 inch pipe, i.e., after the "tee" for Configuration A. Figure 11 shows the inlet loss coefficients plotted against the Froude number. The accuracy of measurement of the loss coefficients is dependent on the velocity of flow in the pipe and for very low Froude numbers (corresponding to low velocities) the data scatter was considerable. Hence, the data for Froude numbers equal to or less than 0.3 was not included in Figure 11. The measured inlet loss coefficient for Configuration A averaged to about 1.7 (including "tee" losses), while for Configuration B, an average value of about 1.0 was measured. The higher values for Configuration A are presumably due to additional "tee" losses and the smaller open area at the strainer, compared to Configuration B. The "tee" losses are estimated to contribute a loss of head equal to about 0.65 times the velocity head in the suction pipe after the "tee" [11].

4.5 Comparison of Strainers of Configurations A and B

One of the strainers of Configuration A (Mark II and Mark III designs) was installed in place of the strainer of Configuration B (Mark I design), and compared with respect to the influence on void fraction, average vortex type, pipe swirl angle, and strainer losses as illustrated in Figure 12. The tests were conducted with uniform approach flows and only for a submergence of 2 ft. In terms of air-withdrawal, vortexing, and swirl, the two strainers performed similarly, but the strainer losses were found to be higher for the swirl Configuration A strainer (average loss coefficient of 3.5 compared to about 1.0 in terms of suction pipe velocity head), perhaps due to a lower open area at the strainer and added fine screen. The strainer of Configuration A has an open area of only about 24% compared to a 40% open area for strainer B. This underlines the importance of using a "tee" to divide the total flow and hence, to reduce inlet losses when a low open area strainer is used.

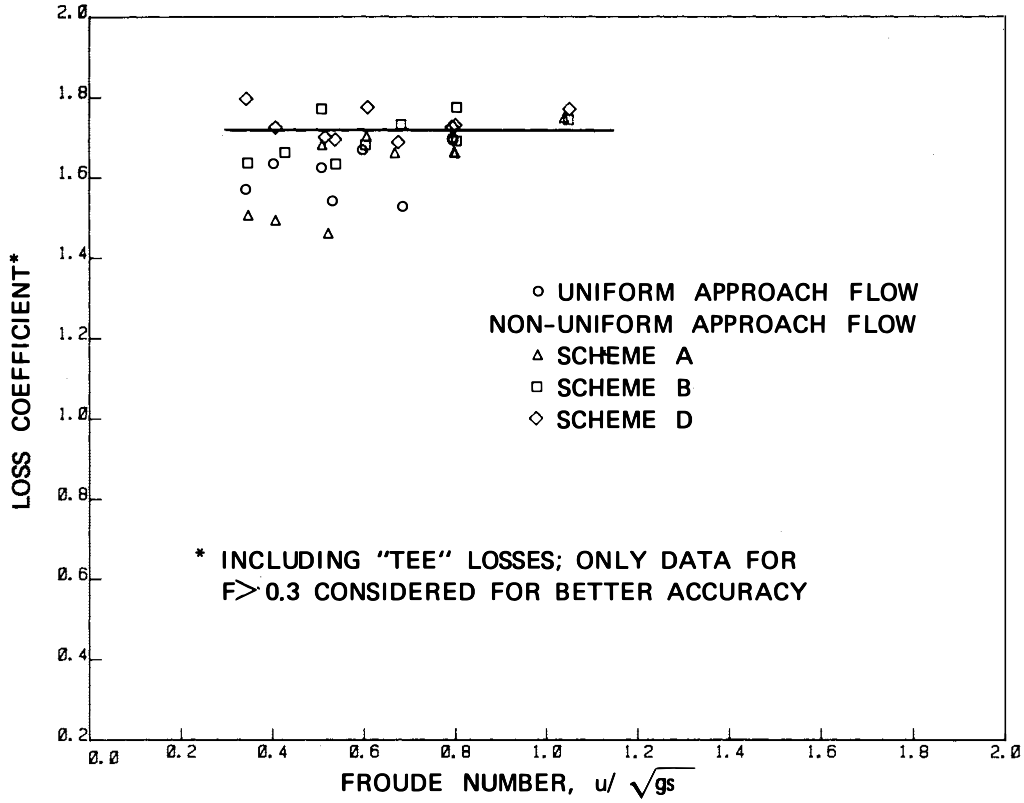


a. CONFIGURATION A

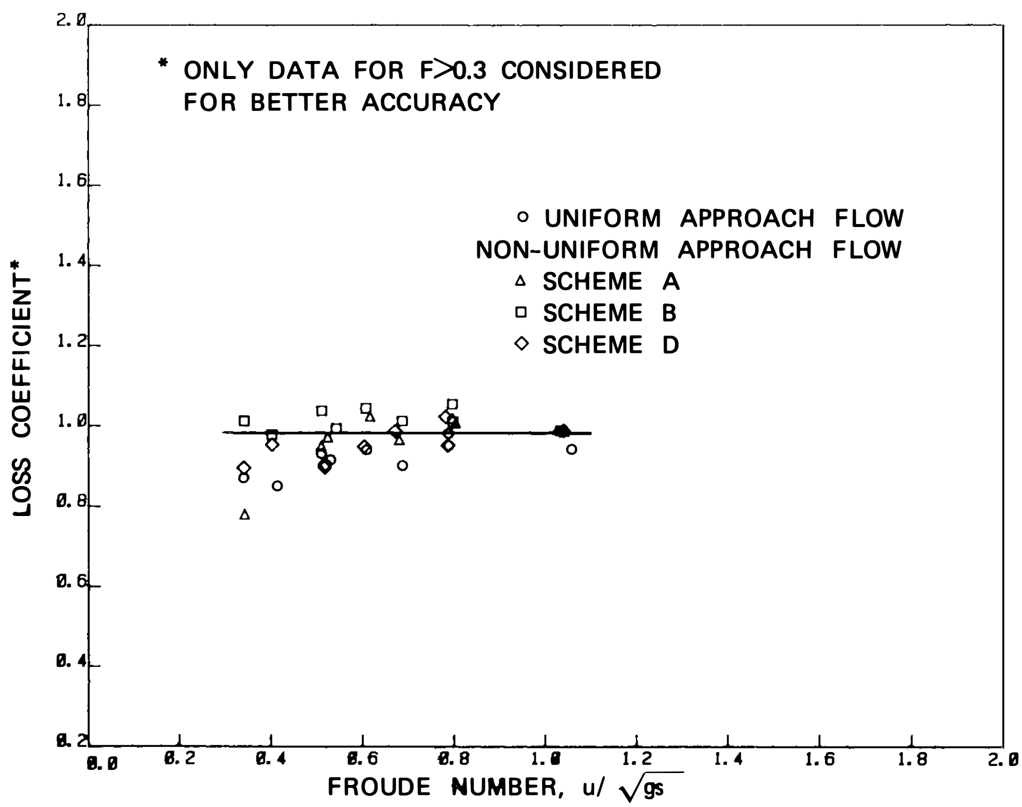


b. CONFIGURATION B

FIGURE 10 TEST AVERAGE SWIRL ANGLES FOR THE TESTED FROUDE NUMBER RANGE

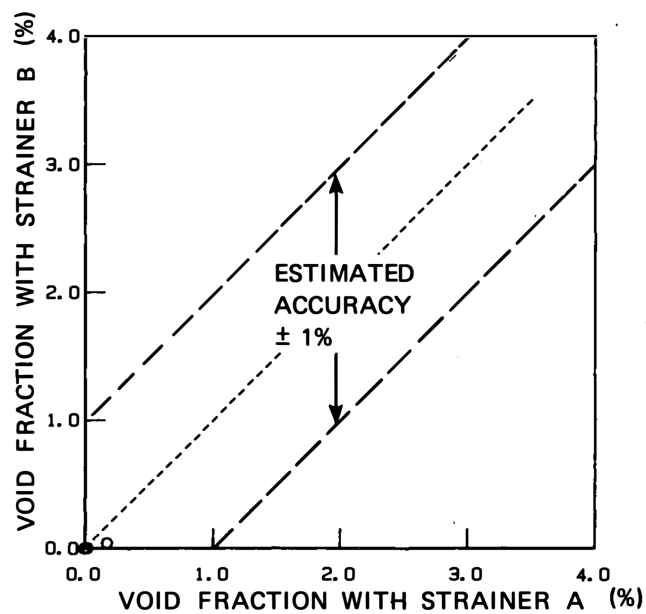


a. CONFIGURATION A

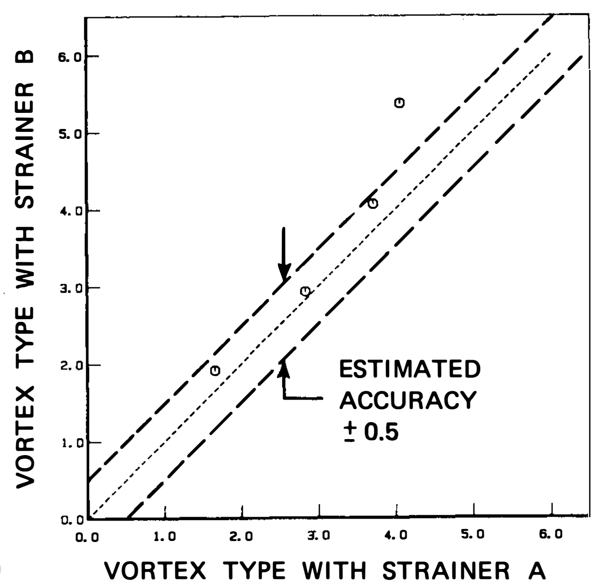


b. CONFIGURATION B

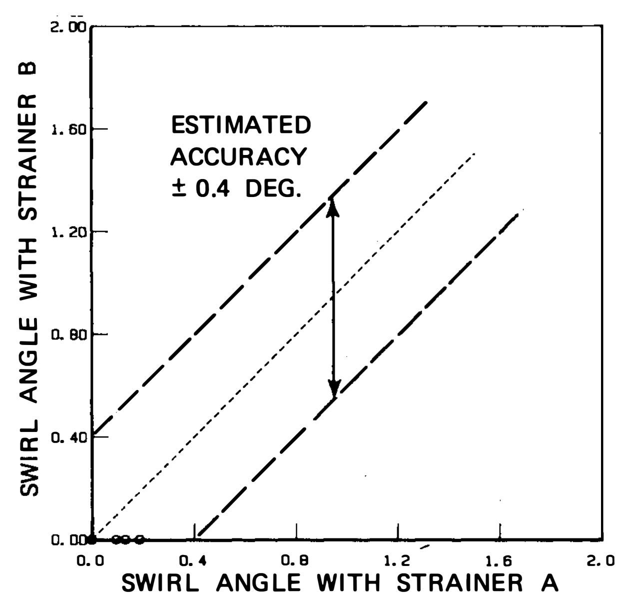
FIGURE 11 LOSS COEFFICIENTS FOR TESTED FROUDE NUMBER RANGE



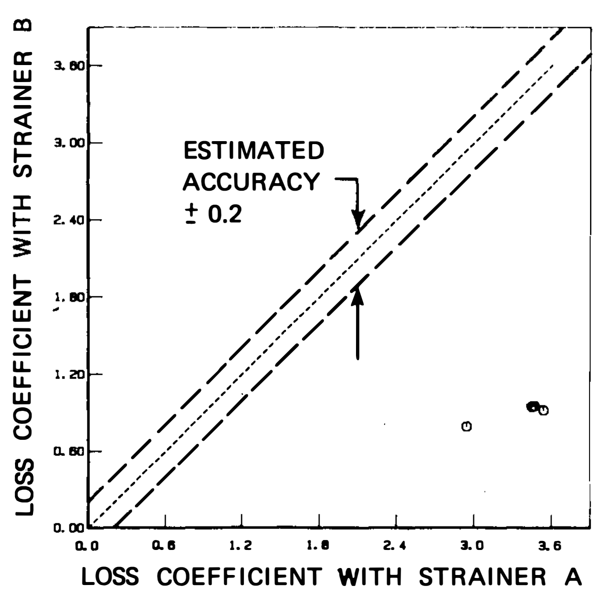
a. TEST AVERAGE VOID FRACTIONS INDICATING AIR-WITHDRAWALS



b. TEST AVERAGE VORTEX TYPE



c. TEST AVERAGE SWIRL ANGLES

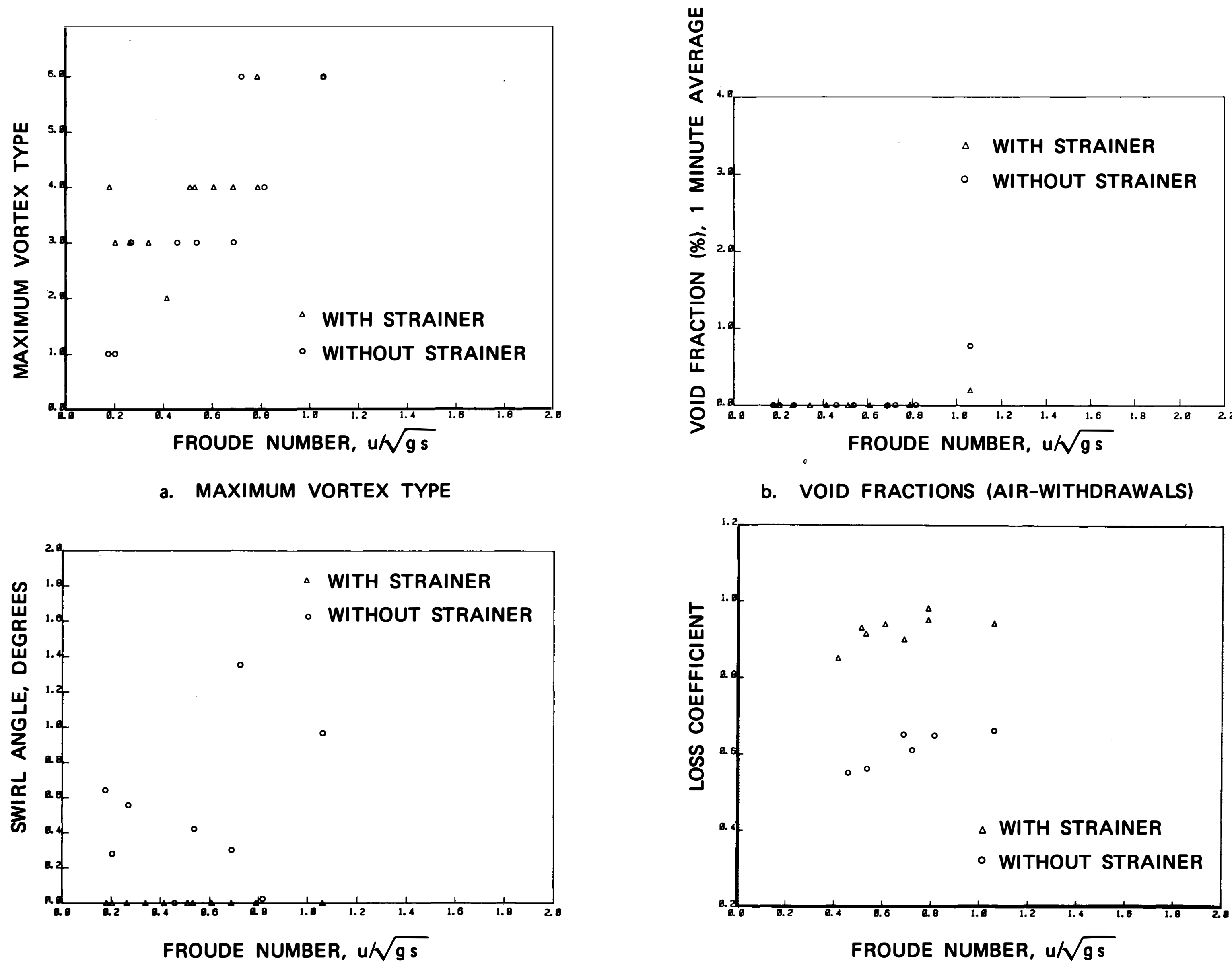


d. INLET LOSS COEFFICIENT

FIGURE 12 COMPARISON OF PERFORMANCE OF STRAINERS A (WITHOUT "TEE") AND B; UNIFORM APPROACH FLOW; s/d = 1

4.6 Effect of Removing Strainers

Figure 13 compares the maximum vortex types, air-withdrawals, swirl angles, and inlet losses with and without the strainer for Configuration B under uniform approach flows. Even without the strainer, no air-core vortices were indicated for Froude number less than 0.7. The maximum void fraction was 0.8% (1 minute average) at F = 1.06 without the strainer compared to 0.2% with the strainer. The effect of the strainer in reducing air-entrainment is not significant considering the accuracy of void fraction measurement; namely, about ±1%. In spite of the strainer, air-core vortices existed at the high Froude number ranges of F greater than 0.8 as discussed in Section 4.2. Based on these observations, a strainer of this type may not be considered as a good vortex suppressor. The strainer acts as a swirl reducer since the swirl angles were essentially zero with strainers, while swirl angles of up to about 1.3 degrees were measured without the strainer. Adding a strainer at the inlet increased the inlet losses from about 0.65 to about 1.0.



a. MAXIMUM VORTEX TYPE

b. VOID FRACTIONS (AIR-WITHDRAWALS)

c. TEST AVERAGE SWIRL ANGLES

d. INLET LOSS COEFFICIENT

FIGURE 13 PERFORMANCE OF CONFIGURATION B WITH AND WITHOUT A STRAINER; UNIFORM APPROACH FLOW

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APPENDIX A

FACILITY, MEASUREMENT TECHNIQUES, AND DATA ACQUISITION

A.1 The Facility

An isometric sketch, plan, and sections of the facility are shown in Figures A1 and A2. The test facility was designed so that any of the flow or geometric parameters of the sump could be varied over typical ranges with least time and effort by simple alterations of floors, walls, and pipe fittings. The facility consists of a concrete main tank, 70 ft x 35 ft x 12.5 ft, and a concrete sump tank, 20 ft x 15 ft x 10 ft, situated within the main tank. Inflow was distributed along three sides of the main tank, and provision was made to produce non-uniform approach flows using blockage. False walls and tank floors were provided such that sump geometries could be varied. For the BWR configurations, the sump floor depression was covered with a false floor. Four rows of outlet holes in the front wall were provided with each row having five holes of 24 inch diameter at 4 ft centers. Sets of two holes in a row were used to attach the suction pipes which could be of any diameter in the range of 8 inches to 24 inches. For the BWR configurations, even the uppermost row of holes did not provide the required floor clearance at the inlet and consequently, one of the available window holes at about 7 ft from the containment floor was used instead.

The suction pipes extend from the sump tank to a suction chamber 50 ft away and are long enough to facilitate swirl, pressure gradient, and discharge measurements. The suction pipe accommodates a vortimeter for swirl measurement and ten pressure taps one pipe diameter apart for pressure gradient measurements. Flow in the suction pipe (up to 20,000 gpm) can be remotely regulated and measured.

Details of the test facility including the design and construction aspects were included in a separate ARL report [5] submitted to Sandia. The test facility was verified for its functional capability and thorough checks of the operation of its components were conducted. Calibration of instruments and check-out of the data acquisition system was also a part of the check-out phase. Details of the verification program are contained in a separate ARL report [10] submitted to Sandia.

A.2 Measurement Techniques

The observed free surface vortices are an indication of sump performance and a numerical scale is used which is indicative of the types which form. The graduations run from "0" for no visible activity to "6" for a vortex with defined air-core entering the inlet. Intermediate numerical values were assigned to discernible stages of development (see Figure A3). An observer entered the vortex type on a keypad at preselected intervals of 30 seconds. These data were then available for time series analysis in the acquisition system. Further documentation of the observations was achieved using photographs, movies, and video recordings.

Pipeline swirl was indicated by crossed-vane swirl meters commonly called vortimeters. These devices rotate about the pipe central axis and the vanes span about 75% of the cross-section. Under most circumstances, the angular rotation speed is indicative of the average swirl angle of the rotational core region of flow [12].

The inlet loss coefficients (including screen and grating losses) were established by measuring the hydraulic gradeline at 1 minute intervals in the discharge line and extrapolating the average hydraulic gradeline over a test back to the entrance. Ten piezometers were provided in the line and individual locations were selected via multiport scanning valve under control of the data acquisition system. The water depth outside the sump screens and gratings was also measured with the scanning valve. Figure A4 explains the method of inlet loss coefficient determination.

The void fraction due to air transported in the discharge line was determined using a conductivity meter of the rotating electric field type [13, 14]. The cross-sectional average conductivity was measured and was proportional to the volume of conductive component of the two-phase flow. The calibration data reported in reference [14] for a range of void fractions of 0 to 20 percent indicated a standard deviation of about 1 percent void fraction.

A.3 Data Acquisition

A mini-computer based data acquisition system was used to record measurements and observations for each test, as shown in Figure A5. At intervals of 30 seconds, an observer entered the vortex type and location using a small terminal. For the same interval, the system counted the number and direction of vortimeter revolutions in the test line. The pressure gradient in the suction pipe was measured using a duplicate systems consisting of ten gradeline taps, a scanning valve, and differential pressure cells. The taps were monitored for five seconds each including some allowance for settling and averaging of the signal. The gradeline was established every 60 seconds. A similar pressure scanning system was used to monitor seven differential flowmeters on a 30 second cycle. The analog output from the void fraction meters was sampled every 5 seconds and the water temperature sampled every 30 seconds.

The data were displayed on a video terminal in suitable formats to aid the operators in setting up test runs. During a test, various data summaries were presented to monitor the test progress. At the end of each test run, all data were transferred to disc files for storage and further processing and display.

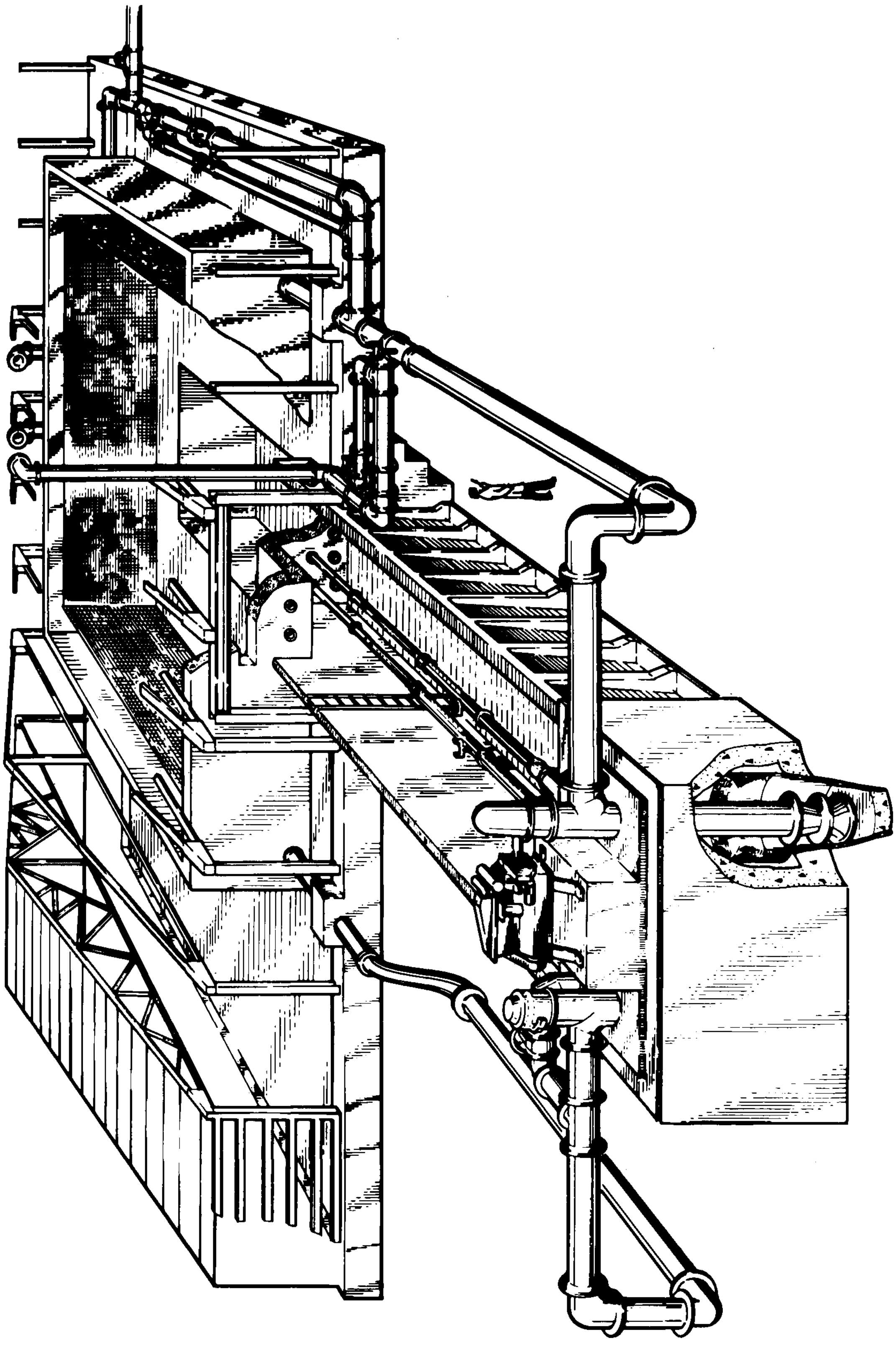
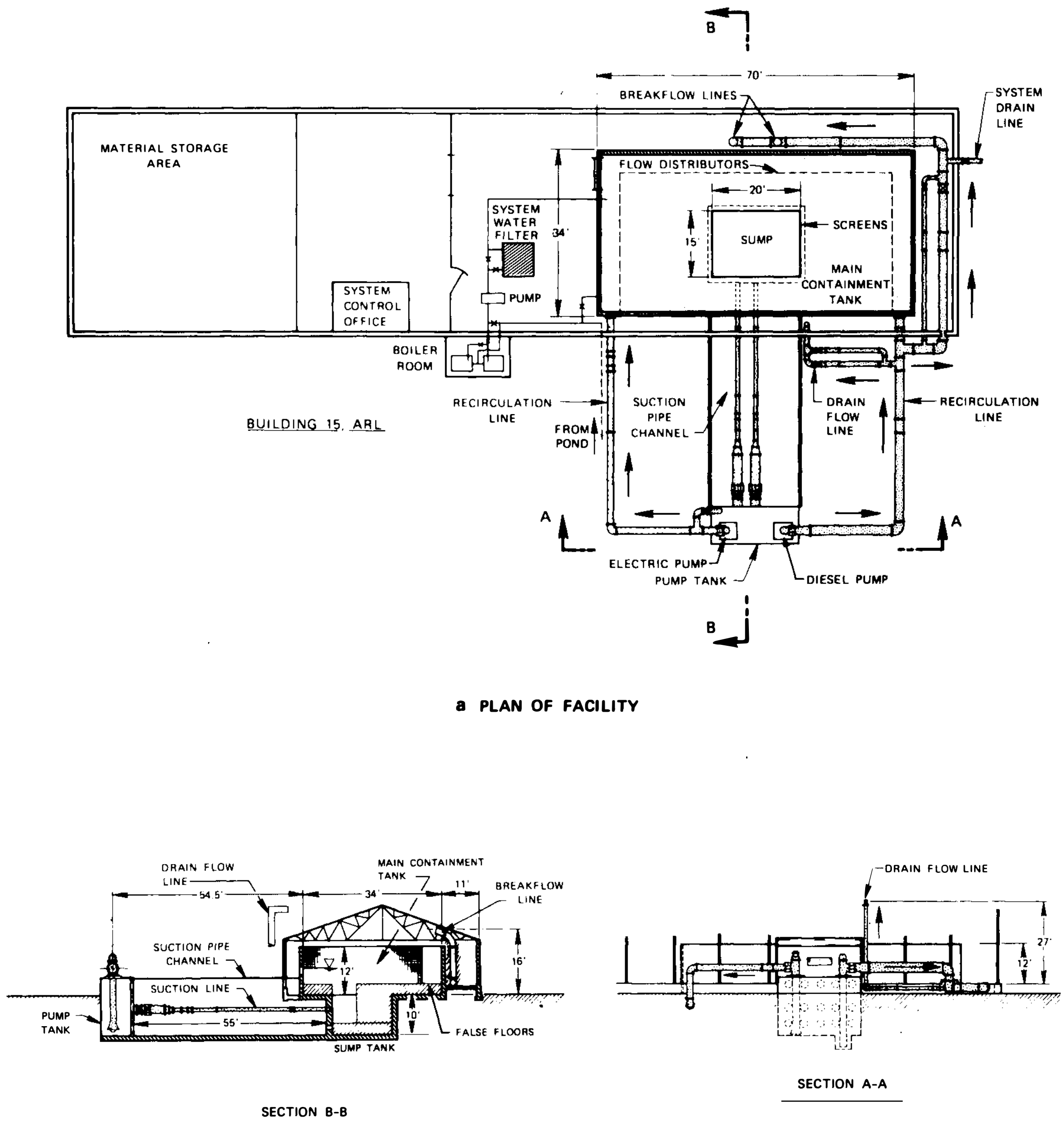


FIGURE A1 PERSPECTIVE VIEW OF THE FACILITY



a PLAN OF FACILITY

SECTION A-A

SECTION B-B

b SECTIONAL VIEWS OF FACILITY

FIGURE A2 DETAILS OF THE FACILITY

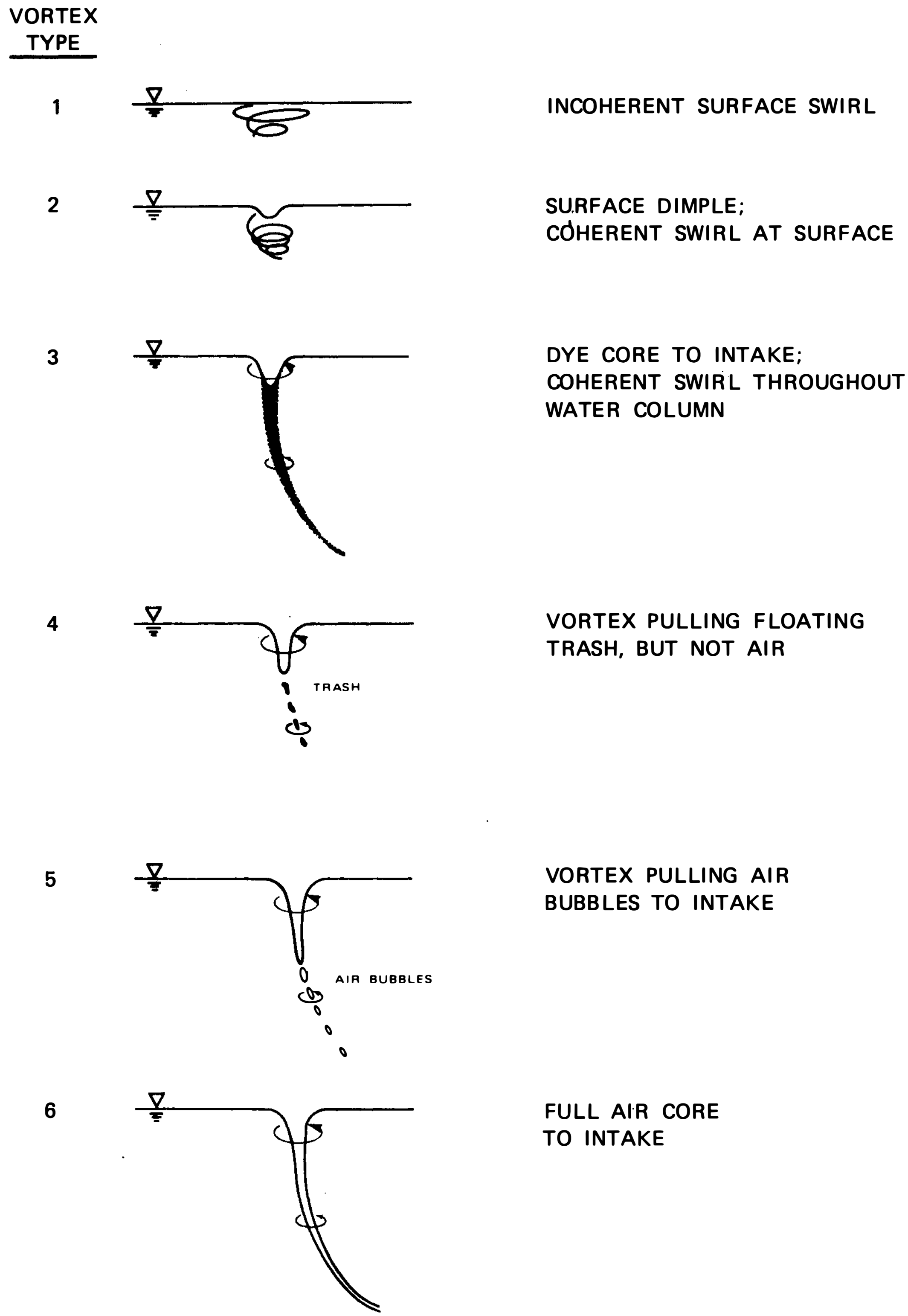


FIGURE A3 VORTEX TYPE CLASSIFICATION

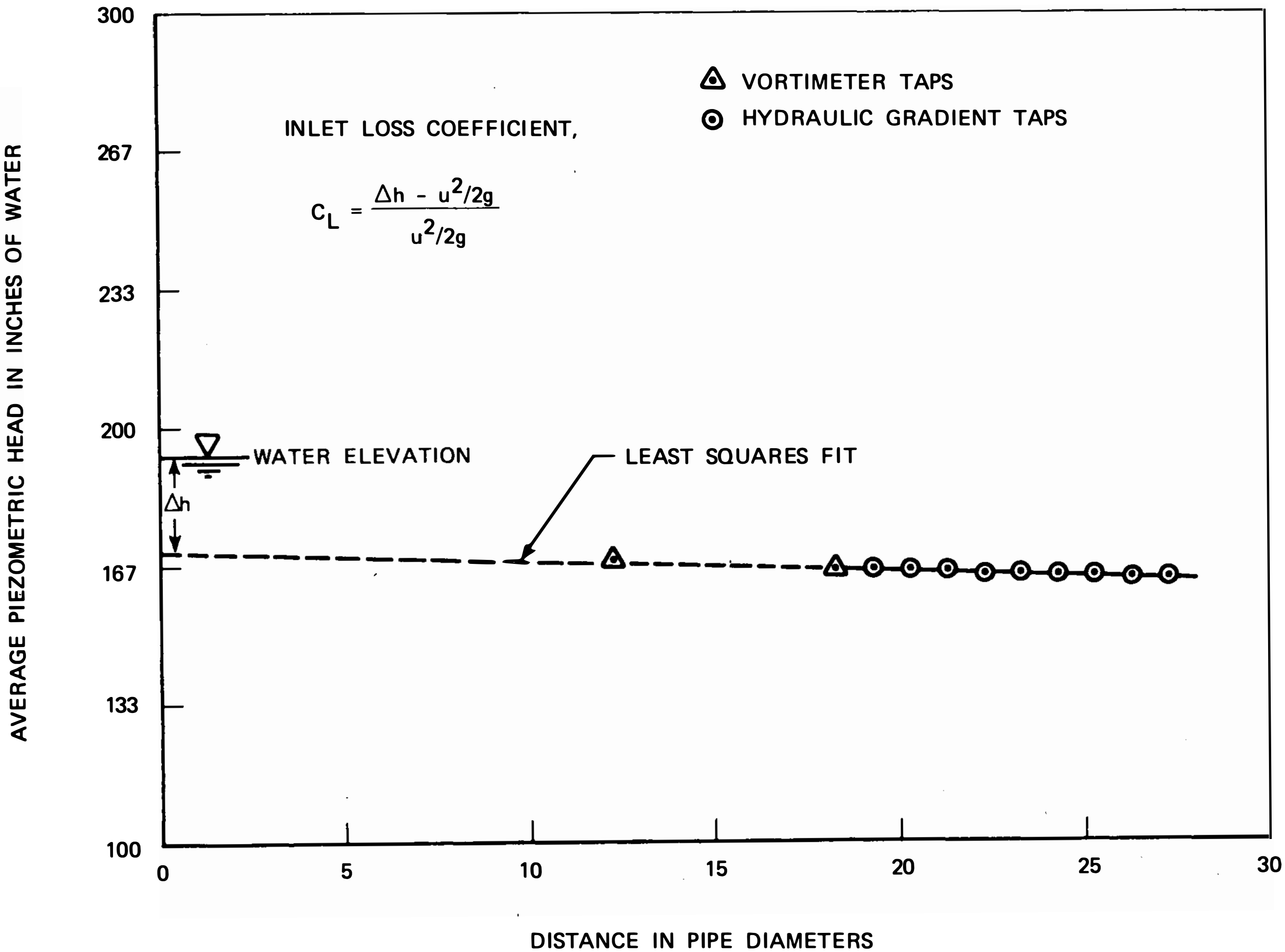


FIGURE A4 INLET LOSS COEFFICIENT DETERMINATION

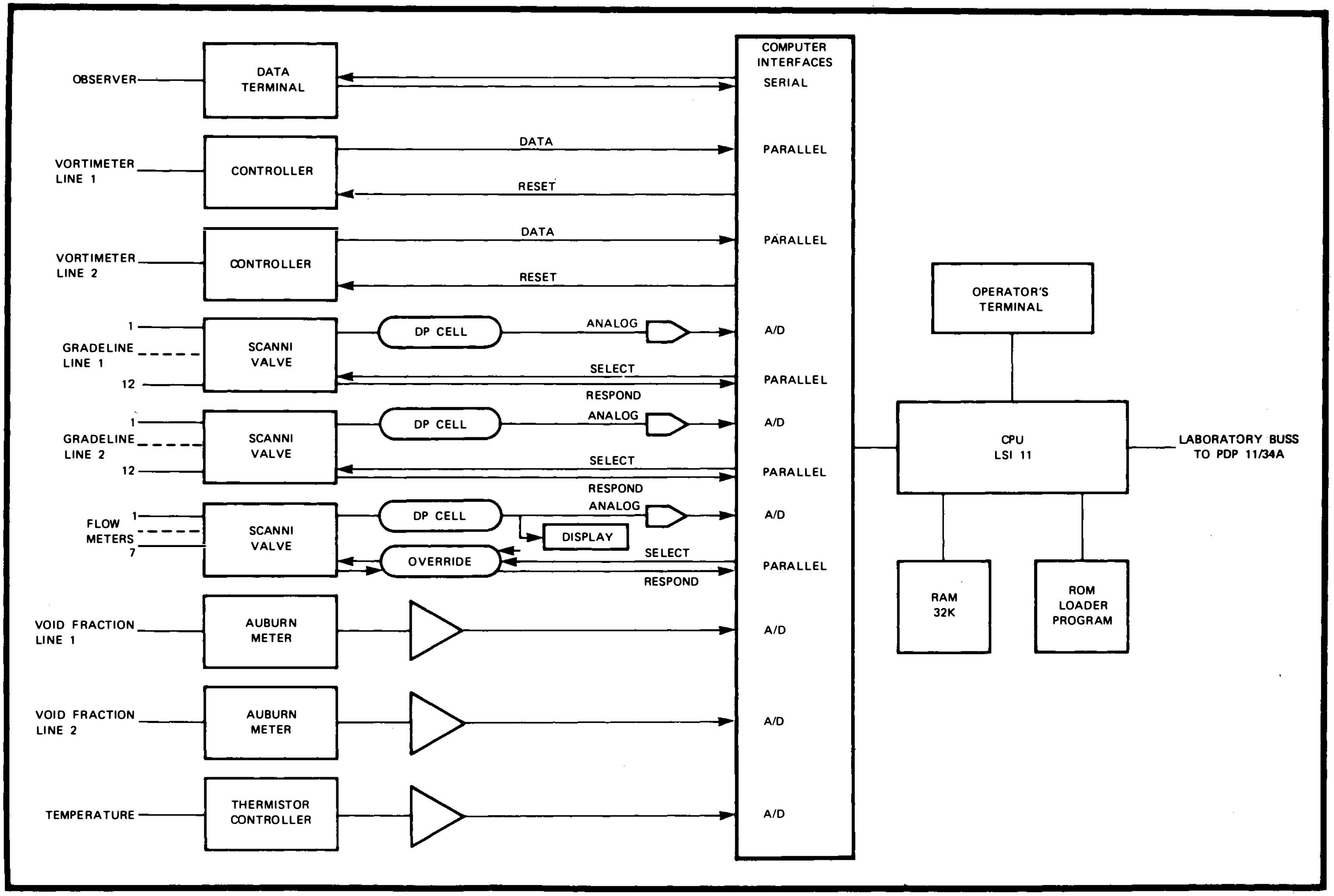


FIGURE A5 DATA ACQUISITION SCHEME

NRC FORM 335 (7-77)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER (Assigned by DDC)	NUREG/CR-2772 ARL-398A SAND82-7064
2. (Leave blank)	
3. RECIPIENT'S ACCESSION NO.	
4. TITLE AND SUBTITLE (Add Volume No., if appropriate)	Hydraulic Performance of Pump Suction Inlets for Emergency Core Cooling Systems in Boiling Water Reactors
5. DATE REPORT COMPLETED	MONTH: May; YEAR: 1982
DATE REPORT ISSUED	MONTH: June; YEAR: 1982
6. (Leave blank)	
7. AUTHOR(S)	M. Padmanabhan
8. (Leave blank)	
9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)	Alden Research Laboratory Worcester Polytechnic Institute Holden, Massachusetts 01520 Under subcontract to Sandia National Laboratories Albuquerque, NM 87185
10. PROJECT/TASK/WORK UNIT NO.	
11. CONTRACT NO.	FIN A1296
12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)	Division of Safety Technology Office of Nuclear Reactor Regulation U.S. Nuclear Regulatory Commission Washington, DC 20555
13. TYPE OF REPORT	Formal Technical Report
PERIOD COVERED (Inclusive dates)	
14. (Leave blank)	
15. SUPPLEMENTARY NOTES	

16. ABSTRACT (200 words or less)

This document reports on the hydraulic performance of representative Boiling Water Reactor Residual Heat Removal suction inlet configurations; Mark I and Mark II and III designs. Parameters of interest were air-ingestion, vortex types, pipe swirl, and pressure loss coefficient. Tests were conducted with nearly uniform and non-uniform inlet approach flows. Flows and submergences ranged from 2000 to 12000 gpm per pipe and 2 to 5 ft, respectively, giving a Froude number range from 0.17 to 1.06.

Zero air-withdrawal was measured for both configurations for Froude numbers equal to or less than 0.8 even under non-uniform approach flows; no air-core vortices were observed for the same flow conditions. At a Froude number above 1.0 and with non-uniform approach flows, air-withdrawal up to 4% by volume was observed in the Mark I design and air-withdrawals up to 0.5% by volume were observed in the Mark II and III designs.

Swirl levels in the pipe up to 7 degrees were measured for Mark II and III designs and up to 3 degrees for Mark I design. Inlet loss coefficients were about 1.7 for Mark II and III designs and about 1.0 for Mark I design.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT	19. SECURITY CLASS (This report)	21. NO. OF PAGES
Unlimited	unclassified	
	20. SECURITY CLASS (This page): unclassified	22. PRICE: $

NRC FORM 335 (7-77)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555-0001

OFFICIAL BUSINESS

NUREG/CR-2772

HYDRAULIC PERFORMANCE OF PUMP SUCTION INLETS FOR EMERGENCY CORE COOLING SYSTEMS IN BOILING WATER REACTORS

JUNE 1982