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HYDRAULICS LABORATORY

TECHNICAL REPORT HL-89-4

WATER QUALITY OUTLET WORKS PROTOTYPE TESTS, WARM SPRINGS DAM DRY CREEK, RUSSIAN RIVER BASIN SONOMA COUNTY, CALIFORNIA

by

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

Prototype tests were conducted to make a comprehensive evaluation of the operating conditions of the project. Prototype measurements included butterfly valve leaf pressure fluctuations, butterfly valve leaf vibrations, intake conduit pressures, wet well pressures, elbow piezometer differential pressures, air vent, air flow, and wet well water temperatures. Data were recorded on analog magnetic tape and played back on oscillograph charts to verify the recording.

Results of the data reduction indicate that the air flow in the quality control (QC) gate air vent reached peak flows at two different QC gate openings (5 and 90 percent), similar to results obtained in other field testing. The elbow piezometer pressures from the intake conduits and the wet well appeared to be adequate for use in discharge determination. However, it is recommended that a more precise calibration be performed and

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19. ABSTRACT (Continued).

permanent instrumentation be installed for monitoring discharges. Surges in the wet well were found to be at a maximum (6.14 ft) during single-valve operations with small butterfly valve openings and large QC gate openings. These butterfly valve and QC gate combinations created unsubmerged flow at the butterfly valve. The most turbulent pressures resulted from the unsubmerged flow at the butterfly valve, creating low pressures (-17.82 ft) and increasing the potential for the occurrence of cavitation in the valve area. Multilevel intake port operation (blending) is considered to be possible as well as potentially practical in the operation of the structure. There was general agreement between the observed and predicted release temperatures.

PREFACE

The prototype investigation described herein was conducted during July 1986 by the US Army Engineer Waterways Experiment Station (WES) under the sponsorship of the US Army Engineer District, Sacramento (SPK).

Tests were conducted by Mr. T. L. Fagerburg, Prototype Evaluation Branch, Mr. C. H. Tate, Locks and Conduits Branch, and Dr. R. E. Price, Research Water Quality Branch, Hydraulic Structures Division, Hydraulics Laboratory, WES, under the general supervision of Messrs. F. A. Herrmann, Jr., Chief, Hydraulics Laboratory; M. B. Boyd, Chief, Hydraulic Analysis Division; and G. A. Pickering, Chief, Hydraulic Structures Division. This report was prepared by Messrs. Fagerburg and S. E. Howington, Research Water Quality Branch, and Dr. Price under the supervision of Mr. E. D. Hart, Chief, Prototype Evaluation Branch, Dr. B. J. Brown, Chief, Hydraulic Analysis Branch, and Dr. J. P. Holland, Chief, Research Water Quality Branch, and edited by Mrs. M. C. Gay, Information Technology Laboratory, WES. Instrumentation support was obtained from Messrs. L. M. Duke, Chief, Operations Branch, Instrumentation Services Division, WES, and S. W. Guy, Data Acquisition Section, Operations Branch.

Acknowledgment is made to SPK personnel for their assistance in the investigation.

COL Dwayne G. Lee, EN, is the Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

CONTENTS

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

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

Multiply	By	To Obtain
acceleration due to gravity	9.806650	metres per second per second
acre-feet	1,233.489	cubic metres
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
feet of water (39.2° F)	2,988.98	pascals
inches	2.54	centimetres
inch-pounds (force)	0.1129848	metre-newtons
kips (force) per square inch	6.894757	megapascals
microinches per inch	0.00001	millimetres per centimetre
miles (US statute)	1.609347	kilometres
pounds (force) per square inch	6.894757	kilopascals

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

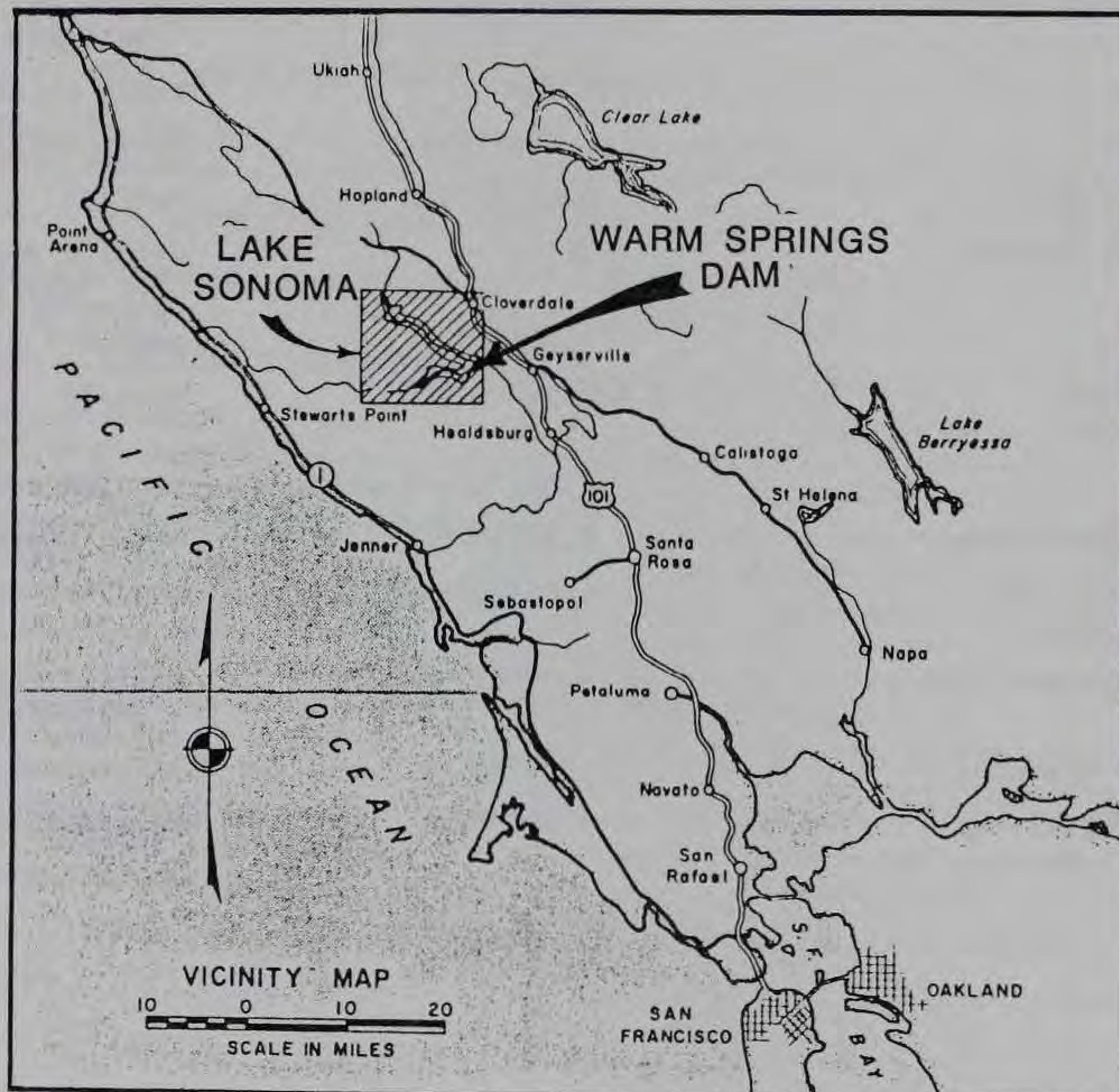

Figure 1. Vicinity map

WATER QUALITY OUTLET WORKS PROTOTYPE TESTS WARM SPRINGS DAM,

DRY CREEK, RUSSIAN RIVER BASIN

SONOMA COUNTY, CALIFORNIA

PART I: INTRODUCTION

Pertinent Features of the Project

1. The Warm Springs Dam and Reservoir are located in north-central California on Dry Creek just below the mouth of Warm Springs Creek approximately 90 miles* north of San Francisco (Figure 1). The reservoir has a gross storage capacity of about 381,000 acre-ft for flood control, water supply, recreation, fish, and wildlife.

2. The general features of the project are an earth dam, a spillway with an ungated ogee weir, a chute with a flip bucket at the downstream end, and a controlled outlet in the left abutment.

3. The controlled outlet works consist of an intake structure located at the base of the dam for a 14.5-ft-diam lined conduit passing through the left abutment, a control structure located 400 ft from the upstream portal, primary and secondary stilling basins, and a 670-ft-long discharge channel leading into Dry Creek. Multilevel intakes provide for selection of the level of withdrawal from the reservoir. The intakes, shown in Plate 1, are designated as No. 1 (el 430.0**), No. 2 (el 390.0), and No. 3 (el 352.0). Flow is controlled by a 60-in.-diam butterfly valve on each 5.0-ft-diam intake. The valves discharge into a single 6-ft-diam vertical wet well with the wet well discharge controlled by a 2- by 3-ft vertical lift quality control (QC) gate located at the lower end of the wet well at el 233.0 (Plate 2). This single wet well water quality system (600-cfs total capacity) provides the seasonal release temperatures required by the fish hatchery located immediately downstream of the dam. During October through April, release water temperatures for the fish hatchery are to be between 52° and 55° F, while during May to

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

** All elevations (el) and stages cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

September, 55° to 58° F is required. Therefore, the multilevel outlet is operated to provide a cool-water resource during the summer months for use by the fish hatchery.

Purpose and Scope of Prototype Tests

4. In November 1973, the US Army Engineer District (USAED), San Francisco, requested that the US Army Engineer Waterways Experiment Station (WES) submit a proposal for instrumentation and a subsequent testing program for Warm Springs Dam. The proposal was submitted in December 1973. A meeting of personnel from the South Pacific Division, San Francisco District, and WES was held at the District in December 1973 to discuss design matters, a proposed model study, and prototype instrumentation and testing. At that time the prototype instrumentation facilities to be used in the testing were specified. A revised testing proposal based upon the decisions from this meeting was submitted in January 1974. Testing was originally scheduled to take place in the summer of 1983; however, delays in construction and lack of available water for filling the reservoir caused the testing program to be rescheduled. During this period, responsibility for the project was transferred from San Francisco District to Sacramento District.

Purpose

5. As stated in the water control manual for Warm Springs Dam and Lake Sonoma (USAED, Sacramento, 1984), the multilevel outlet structure should allow mixing of water from different elevations. During the thermal stratification cycle, as well as during the drawdown of the pool, the operation of two ports to achieve the desired release temperature may be necessary. This simultaneous multilevel port operation in a single wet well has been termed blending. If two ports are open and the water density difference (due primarily to thermal differences) between the two ports is large, flow through the upper port (with less dense water) may be negligible. This phenomenon is termed density blockage. In this event, some flow control must be exercised at the lower port to achieve the desired release temperature. Butterfly valves were specified as the control valves for regulating flows through the three multilevel intakes during selective withdrawal operations. Some concern had been expressed by the Sacramento District over the structural response of butterfly valves, particularly under partially open conditions, and the response of the

water column in the wet well that could be related to safety and reliability of this system. Specifically, the prototype tests were requested to (a) determine the dynamic response of one of the butterfly valves for selected operating conditions in terms of the potential for vibration and cavitation, (b) determine surging and water level drops in the wet well, (c) evaluate use of elbows in the intakes and the wet well as discharge measurement facilities, (d) investigate the occurrence of stratified flow within the wet well and density blockage when two ports are operated, and (e) develop a method to evaluate the ability of a given simultaneous multiple-level port operation to achieve a given release temperature while accounting for density influences.

Scope

6. Tests were conducted at a single pool elevation (el 445.8), and the measurements consisted of the following:

a. Static and fluctuating pressures on the face of the instrumented butterfly valve leaf.

b. Uniaxial vibrations of the instrumented butterfly valve.

c. Static and fluctuating pressures in the conduit immediately downstream of the instrumented butterfly valve.

d. Static pressures along the intake conduit upstream of the instrumented butterfly valve.

e. Wet well water-surface elevation changes and detection of surging within the wet well.

f. Elbow piezometer differentials in each intake and in the lower wet well.

g. Air demand in the 14-in.-diam QC gate air vent.

h. Butterfly valve torsional strain values for opening and closing operations.

i. Wet well water temperature changes during operations.

7. A total of 161 tests were conducted for different discharges based on QC gate settings, butterfly valve settings, and combinations of intakes operated during the period 12-14 July 1986. Maximum discharges for testing purposes were limited due to downstream flow restrictions for seasonal recreation requirements.

PART II: TEST FACILITIES AND EQUIPMENT

Test Facilities

8. The locations of the instrumentation described herein are shown in Plates 1 and 2. Specifications for the instruments used are listed in Table 1.

Intake tunnel piezometers

9. During construction of the project, four pairs of piezometer lines and taps (IP1, IP2, IP3, and IP4) were installed along the center line of the middle intake conduit at 25-ft intervals. The piezometer openings were 1/4-in.-diam holes in stainless steel plates fitted to the contour of the conduit surface. The lines terminated in the intake tower at a manifold located at el 394.0. Plates 1 and 2 show the locations of these piezometers and manifold. A typical manifold is shown in Figure 2.

Figure 2. Typical piezometer manifold

Elbow piezometers

10. A pair of piezometer lines were also installed during construction in the bend of each intake tunnel (IP7, IP6, and IP5) just upstream of each butterfly valve as shown in Plate 1. The piezometer openings were the same as those of the intake conduit described in the preceding paragraph. The lines

terminated in the intake tower at manifolds located at elevations shown in Plate 2. An additional pair of elbow piezometers (TP8 and TP9) were installed in the lower transition zone of the wet well as shown in Plate 2.

Wet well pressures

11. Facilities for the installation of four pressure transducers (PR1, PR2, PR3, and PR4) to monitor pressures at various elevations in the wet well were installed during construction, as shown in Plate 2. The facilities consisted of a hole that was drilled and tapped in the wall of the wet well to accept a 1-3/8-in.-diam threaded waterproof pressure transducer adapter shown in Figure 3. An additional transducer location (PR5) was provided immediately downstream of the QC gate (Plate 2) to monitor the pressures in the expanding discharge conduit.

Figure 3. Waterproof pressure transducer adapter

Butterfly valve leaf instrumentation

12. During the fabrication of the intake butterfly valve No. 2, detailed drawings of the instrumentation facilities were submitted to the manufacturer to be incorporated in the completed valve. The locations of the instrumentation facilities are as shown in Figure 4 on the downstream face of the valve leaf. The instrumentation to be installed at the various locations

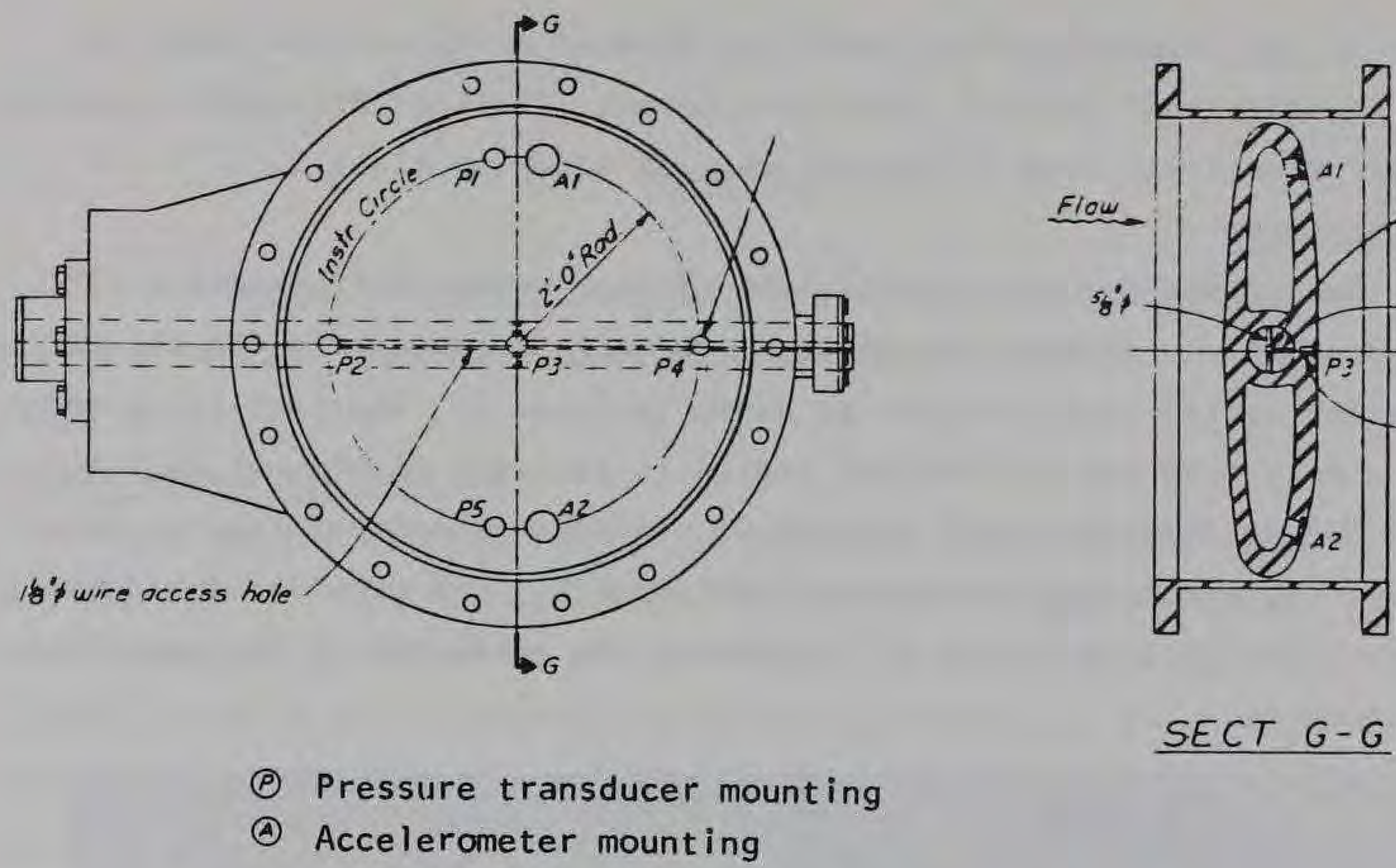


Figure 4. Butterfly valve leaf instrumentation locations and cable access

consisted of two accelerometers (A1 and A2) to monitor vibrations and motions of the butterfly valve leaf and five pressure transducers (P1, P2, P3, P4, and P5) to monitor pressures on the valve leaf. The signal cables for these instruments were passed through individual 5/8-in. cable access holes into a common 1-1/8-in. cable access hole that passed through the center of the valve shaft and exited the end of the valve shaft as shown in Figure 4.

13. For the valve leaf instrumentation installation and removal procedures, workers wearing safety lines and belts were lowered through the top of the wet well and down to the elevation of the middle butterfly valve by an air-operated manlift as shown in Figure 5. The wet well was drained of water during the installation and removal procedures. Radio communication was established between the outside and inside of the valve to aid in the work efforts and for safety purposes.

Cavitation measurements downstream of butterfly valve

14. Six locations for installation of pressure transducers were chosen downstream of the middle intake butterfly valve for measurement of or detection of possible cavitation conditions that may exist for certain operating procedures. During construction, four pressure transducer access holes were

Figure 5. Manlift used for access to instrumented butterfly valve

drilled and tapped to accept a 1-3/8-in.-diam transducer adapter. These four locations (PV3, PV6, PV9, and PV12) formed a ring around the circumference of the conduit as shown in Plate 3. Two additional transducer locations (PB1 and PB2) were added after installation of the butterfly valve to monitor pressures at the invert of the conduit at points 3/4 in. downstream of the valve seat (PB1) and 12 in. downstream of the valve seat (PB2).

Butterfly valve torque strain gages

15. The shaft of the middle intake butterfly valve was instrumented with strain gages to monitor the torsional strain values associated with the operation of the butterfly valve. The strain gage and bridge arrangement used to measure torque is shown in Figure 6. When accurate gage placement and

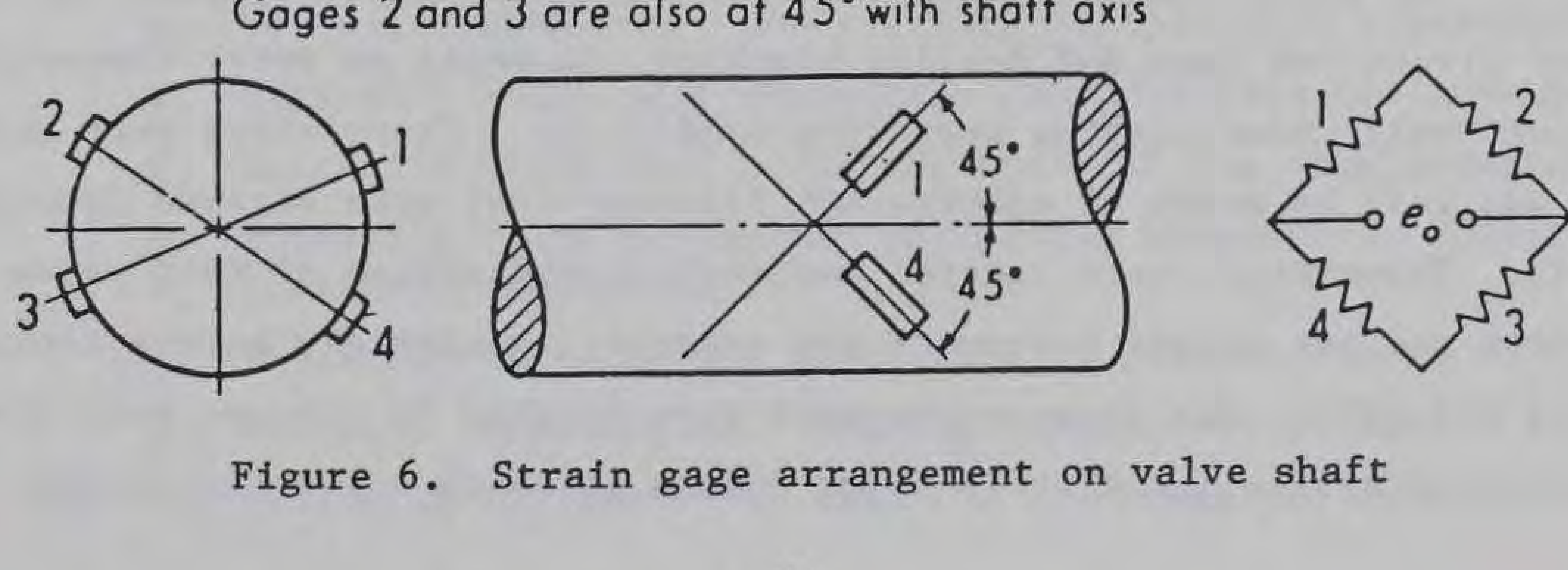


Figure 6. Strain gage arrangement on valve shaft

matched gage characteristics are used, this arrangement is temperature compensated and insensitive to bending or axial stresses.

Air demand

16. The 14-in.-diam air vent located at the lower elevation of the intake tower (Plate 2) was used for measuring air demand of the flows released through the wet well. A hole was made in the air vent at the specified location during construction and outfitted with a cover plate. A pitot tube mounted in a duplicate cover plate, similar to that shown in Figure 7, was then installed in the opening to monitor air flow during testing. The pitot tube was adjusted so that the tip of the probe was oriented into the direction of the air flow and positioned in the center of the air vent.

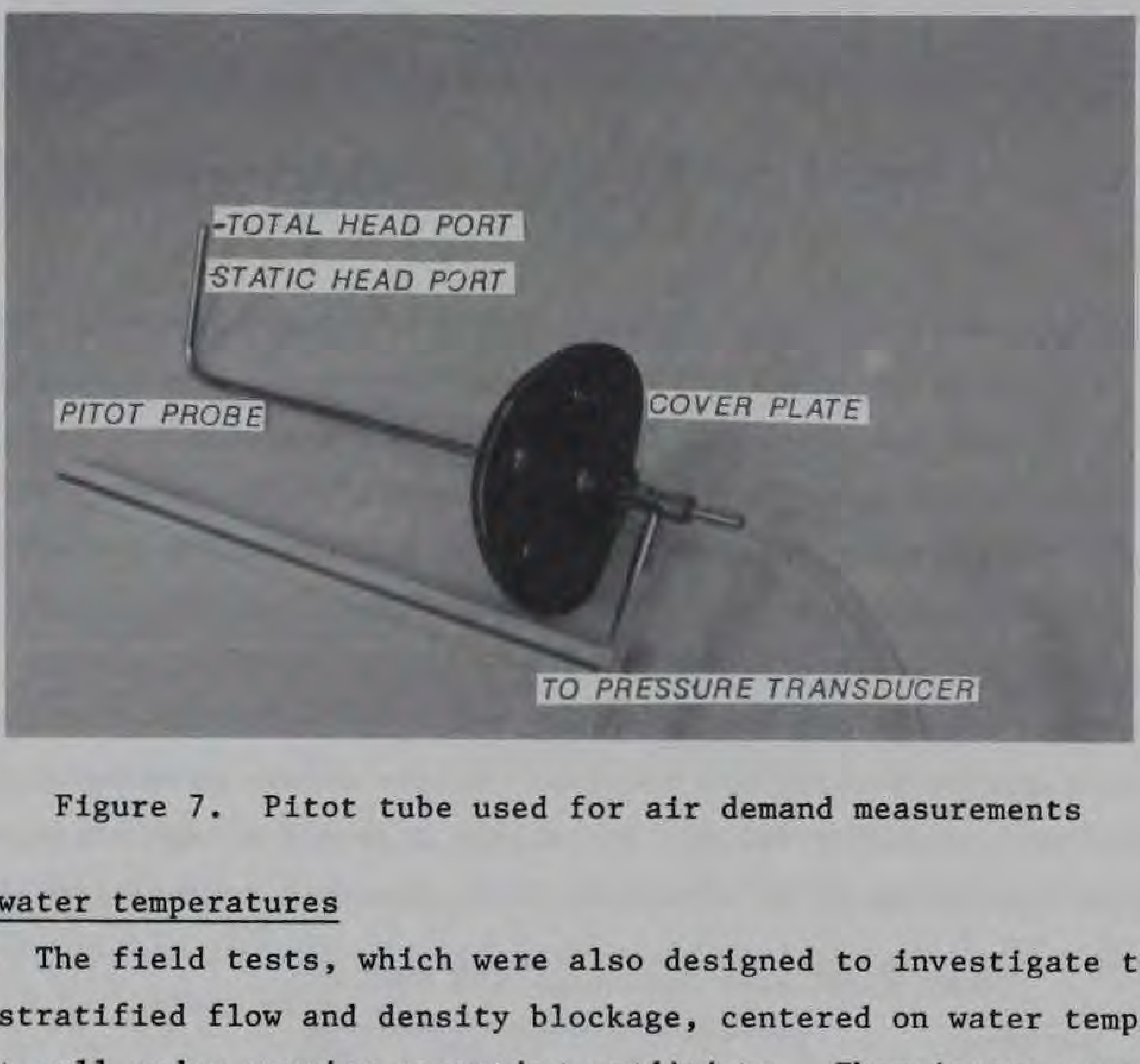


Figure 7. Pitot tube used for air demand measurements

Wet well water temperatures

17. The field tests, which were also designed to investigate the occurrence of stratified flow and density blockage, centered on water temperature in the wet well under varying operating conditions. Thermistors were attached to the wet well by means of compression fittings that were screwed into the wet well. Thermistors were located immediately downstream of each valve, one on the top and one on the bottom of the conduit, immediately before connection with the wet well. The thermistors were also located in the wet well itself at various intervals immediately below inlets for each valve and on the

opposite side of the wet well as shown in Plate 4. Although the thermistor accuracies provided by the manufacturer were considered reasonable, tests were conducted before and after the field tests to determine variablility of measurements among individual probes. All probes were placed in a water bath of uniform temperature and measurements taken. Statistical results indicated that performance of the thermistors was well within the accuracy stated by the manufacturer and that calibration after prototype tests were completed resulted in no change in accuracy. Therefore, results of the prototype tests were not adjusted to account for individual probe variability.

Other measurements

18. Other recorded data consisted of reservoir water-surface elevations, QC gate openings, butterfly valve operations and openings, and limited discharge measurements. These data were provided by the project and Sacramento District personnel. Water discharge data were provided by the District and were based on correlation of the QC gate setting with the gaging station immediately downstream of the project. Temperatures were also measured in the reservoir to determine the stratification of the lake during the testing period.

Test Equipment

19. The test equipment listed and described herein includes the transducers, cables, and recording equipment. The following transducers were used in the test:

a. Intake tunnel piezometer pressures: 50-psia pressure transducers.

b. Elbow piezometer pressures: ±0.5-psid pressure transducers.

c. Wet well transition elbow pressures: 100-psia pressure transducers.

d. Wet well pressures: 50- and 100-psia pressure transducers.

e. Butterfly valve leaf pressures: 50-psia pressure transducers.

f. Butterfly valve leaf accelerations: ±2.0-g accelerometers.

g. Butterfly valve downstream cavitation pressures: 50-psia pressure transducers.

h. Butterfly valve torque measurements: strain gages.

i. Wet well temperatures: ±40-deg temperature probes.

20. The following equipment was used for recording the data:

a. WES-fabricated bridge amplifiers for instrument output signal-conditioning.

b. A Thorn-EMI model SE7000, 32-track magnetic tape recorder.

c. CEC model 5-124 oscillograph with 6-in. chart.

d. Fluke model 8200 A digital voltmeter.

e. Techtronics model 465-R oscilloscope.

Figure 8 shows the equipment as it was set up for data recording at the project. The tape recording speed for the data collection was 7.5 ips.

Figure 8. Equipment used for data recording

PART III: TEST CONDITIONS AND PROCEDURES

Conditions

21. Measurements were made at a generally constant pool elevation of 445.8. The tests were made at various butterfly valve settings, combinations of different butterfly valves, and different QC gate openings. Table 2 lists the test conditions.

Procedures

22. The tests were conducted on 12-14 July 1986. All the test data, with the exception of the wet well temperature sensor data, were recorded on magnetic tape with individual tests being recorded for 1 min. A portion of the taped data was simultaneously transferred to oscillograms to visually confirm that the data were being recorded properly and to make some preliminary computations. Before each test series, the bleed valves to the piezometer line pressure transducers were carefully opened to allow any trapped air in the piezometer lines to bleed off. After the wet well was filled, sufficient time was allowed for the pressures and water temperatures to stabilize within the water column.

23. The procedure was generally the same for all the test series that were recorded and consisted of the following:

- a. Record test number, QC gate opening, butterfly valve opening, number of butterfly valves operating, date, time, and conditions.
- b. Record step calibrations.
- c. Record zero calibrations.
- d. Open QC gate to desired opening and allow flow to stabilize.
- e. Record data on tape and oscillograms.
- f. Record discharge (if being measured), pool elevation, and air temperatures.
- g. Change the butterfly valve setting to the next condition to be tested.
- h. Repeat steps e, f, and g for each test series.
- i. Record posttest step calibration for each test series.

The exception to these procedures occurred during the water quality tests. To initiate a water quality test series, the wet well was drained, QC gate closed, and the wet well filled from the 30-in. filling valve that leads from the roof of the flood-control conduit to the wet well at el 260. Then ports 1 and 3 (port 3 being at el 430.0; port 2 at el 390.0; and port 1 at el 352.0) were opened to allow the wet well to stratify, and the 30-in. valve was closed. The QC gate was then opened for the beginning of the test series.

24. One tape channel was used to record voice comments for later reference of special conditions or events during testing. Changes in data calibrations and signal gain factors were made as required during each test series and recorded.

PART IV: TEST RESULTS AND ANALYSIS

25. All data channels were reduced simultaneously, providing a direct time-dependent relationship among all channels. All data reduction was conducted at WES. To reduce the data, each recorded test was visually scanned and a representative sample of each data channel digitized. These data were then calibrated for the data analysis of each parameter measured.

Air Discharge

26. Pitot tube differential pressures were measured at the location shown in Plate 2 and Figure 9 for determining the air flow in the 14-in.-diam air vent feeding the outlet of the wet well just downstream of the QC gate (approximately at el 234.4). The air vent did not extend the entire length of the control structure but was connected to the larger 42-in.-diam flood-control conduit air vent at approximately el 274.0. The pitot tube installation shown in Plate 2 (el 244.0) is approximately 50 ft horizontally from the air vent culvert roof opening. This distance relates to a probe location of approximately 58 equivalent diameters. At the time of testing, the project was responsible for maintaining a minimum downstream flow requirement; therefore, the flood-control conduits were open to make a base release of 111 cfs. This circumstance created an air flow in the larger air vents that would ultimately affect the air flow in the smaller air vent.

27. Velocity at a point V_p is proportional to the recorded differential pressure when measured by a pitot tube (Rouse 1962). This relation is given by the equation

$$V_p = K\sqrt{\Delta p} \tag{1}$$

where

K = constant of proportionality, determined to be 351.6.

Δp = differential pressure between the total head and the static head, or points A and B in Figure 10.

The Mach number, defined as the ratio of the flow velocity to the sound velocity, for all point velocities measured was less than 0.30. For engineering calculations the effects of compressibility may be safely neglected if the

Figure 9. Air demand pitot tube installation

Figure 10. Pitot tube tip detail

Mach number is less than 0.30 (Vennard and Street 1975). Therefore the compressibility of air was not considered in the data analysis.

28. Table 3 lists the rates of air flow measured in the 14-in.-diam air vents. Information from prior field tests (Hart and Pugh 1975) of regulated outlet works and Hydraulic Design Criteria (HDC) Chart 050-1/1 (US Army Corps of Engineers) indicates that air demand at two gate positions greatly exceeds that of other gate positions. Initially, a large demand for air is required at gate positions of 5 percent open. The large demand is created by the breakup or fraying of the jet as it exits the gate, which entrains large quantities of air. Plate 5 shows that this phenomenon is evident at a QC gate position of 5 percent having a peak air flow of 80 cfs. A second air demand peak may also occur between gate positions 50 and 100 percent, and is generally caused by the drag force between the water surface and the air above it. This peak was not obtained during the testing due to the limitations of the maximum discharge allowed. However, as evidenced in Table 3, the air flow was seen to increase at larger gate positions (90 percent) during a single valve

test (valve 3) for a partial butterfly valve opening of 45 deg having a peak air flow of 46 cfs.

Elbow Pressures

Wet well transition zone

29. Pressures in the transition zone elbow at the base of the wet well were used in an attempt to calibrate the elbow as a differential pressure elbow meter. The locations of the piezometers TP8 and TP9 are shown in Plate 2.

30. The differential pressures between piezometers TP8 and TP9 were plotted against the few measured discharges and were found to be generally consistent for developing a discharge rating curve. The rating curve developed from the data, as shown in Plate 6, could be very useful in monitoring the total flow through the wet well system because the differential pressure is not dependent upon the pool elevation and would minimize the need for downstream discharge measurements during operation of the wet well system. The pressure differentials for the high discharge tests were found to be more consistent and have good repeatability. At extremely low discharges, ≤ 100 cfs, the differences in pressures in the transition elbow piezometers were either not consistent or could not be obtained, as noted in Table 4. This condition most likely results from the differences in pressures being extremely small and occurring within the lower limit of accuracy of the high-range (100-psi) pressure transducers required at TP8 and TP9.

Intake conduits

31. As stated previously, one of the intentions of the test was to evaluate the feasibility of using the elbow meters for discharge measurement in the individual intakes and not to develop a detailed calibration system. A detailed discharge calibration of each butterfly valve and installation of a calibrated readout system was not included in the original test proposal. It would have taken an additional week to complete this work and, due to pending contract work at the project, the time available for including this in the testing program would not have been sufficient. Development of the rating curves for each butterfly valve was attempted using the transition zone elbow pressure data for discharge estimation plotted against the individual intake elbow differential pressure data from the single-butterfly-valve operation

tests. The rating curves are presented in Plates 7-9, and the discharges are listed in Table 4. During the data analysis it was found that the same difficulties as those experienced in the measurements of the transition elbow piezometers were occurring in the pressure measurements of the intake elbow piezometers. Some general inconsistencies existed in the repeatability of pressures for identical operating conditions, especially for low discharges. Also, the maximum pressure ranges of the differential pressure transducers were exceeded during the high discharges for one- and two-valve operating conditions. Much of the literature on the use of elbow meters as discharge indicators emphasizes that the meter must be calibrated in place and have at least 25 diameters of straight pipe upstream and 10 diameters of straight pipe downstream to ensure reasonable accuracy. The intake conduit elbows do not meet either of these criteria, and each has a different angle of bend and length of upstream conduit as shown in Plate 1. This inconsistency implies that a simple formula for computing discharges in 90-deg elbows (Rouse 1962) does not apply to these intake elbows and that calibration of each elbow is required for a range of flows. It should be noted here that for easy discharge data acquisition, it is recommended that a more detailed calibration of the system be performed when sufficient time and water are available to verify the transition elbow rating curve and a calibrated discharge display instrumentation package be installed for each individual butterfly valve.

32. A determination of the discharge coefficient C_Q for butterfly valve No. 2 was made using the discharges obtained from the transition elbow pressure values. The pressure drop across valve No. 2 (ΔH) was computed using the difference between the pressure measured near the elbow (IP4) of intake No. 2 and the pressure measured in the wet well at PR4. The computed discharge coefficients are plotted versus valve opening in Plate 10. The equation used to compute C_Q is also shown in this plate. As can be seen from the plot, there are some differences between the suggested design curve (HDC Chart 331-1, US Army Corps of Engineers) and the computed values, especially at the larger valve openings. A comparison of these with the model discharge coefficients (Tullis 1974) shows a tendency for model values to be somewhat smaller than the computed values. According to Tullis, the pressures measured immediately downstream of the butterfly valve will be less than those normally used in the equations for determining C_Q and would normally be obtained at a location several diameters downstream in a straight section of conduit.

However, due to the relatively short length of conduit downstream of the valve before the flow enters the wet well, the best estimate of the downstream pressure values used in the computations could be taken from one of the wet well pressure locations. Therefore, pressure values from transducer location PR4 were used in the computations. The observed differences in the curves may be due to the fact that a short length of conduit exists immediately downstream of the valve and that the QC gate is being operated at partial openings.

Wet Well Water-Surface Elevations

33. Water-surface elevations in the wet well during the tests were determined from the pressures recorded by transducers PR1-PR4 (see Plate 2 for location). The pressures, which were recorded in pounds per square inch, were converted to feet of water and added to the elevation of the pressure transducer to obtain the wet well water-surface elevations listed in Table 5. These water-surface elevations were then compared to the butterfly valve elevations to determine for which operating conditions tested unsubmerged flow was established at the butterfly valves. Plates 11 and 12 illustrate flow condition determinations, submerged versus unsubmerged, for two-valve operations (operating at the same openings) and single-valve operations, respectively. The lines drawn in Plates 11 and 12 represent the points at which unsubmerged flow exists. The area above and to the left of the lines represents operating conditions which produce submerged flow at the butterfly valves. The area below and to the right of the lines, as well as points that fall on the lines, represents the operating conditions that produce unsubmerged flow at the butterfly valves. Generally, in a two-butterfly-valve operation with both valves at the same opening, it is the upper (highest elevation) valve which determines the operating limitations at which the unsubmerged flow condition occurs (Plate 11). Single-butterfly-valve operations at small openings combined with certain QC gate openings created unsubmerged flow at the valve. Unsubmerged flow conditions were not found to occur for two-butterfly-valve operation tests in which one valve opening was maintained at 90 deg while the other valve opening was decreased. Tests involving the operation of all three valves also did not indicate the occurrence of unsubmerged flow at any of the butterfly valves. The same pressure transducers used to record the elevation of the wet well water surface were also used to

detect the fluctuations of the water surface during the tests for determination of surging. Plates 13-15 show the typical response of the wet well water surface for various operating conditions. Surging of wet well water surface for multiple valve operations was generally small, less than 2.0 ft, at the maximum QC gate opening of 70 percent. The largest change in water-surface elevation due to surging (6.14 ft) occurred during Test B1-G for a single-butterfly-valve operation. The wet well pressures measured during this test indicated that the water surface (el 372.8) was well below the center-line elevation of the operating valve (el 391.0) and that an unsubmerged flow condition existed at the valve. This large fluctuation observed in the wet well water surface under these conditions is the result of the plunging jet from the unsubmerged butterfly valve.

Butterfly Valve Leaf Pressures

34. Five pressure transducers (P1-P5) were mounted on the downstream face of the No. 2 butterfly valve leaf to record the dynamic pressures resulting from the flow across the valve. The recorded pressures are listed in Table 6. From the data presented in the table, it is seen that for the tests in which the operating butterfly valve remained submerged (as noted in Table 5), the pressures remained generally positive. The most severe pressure responses were found to occur during the single-valve operation, with the butterfly valve at a partially closed position ($\leq$60 deg), and at a high discharge rate ($\geq$200 cfs). The pressure transducers were overranged, as noted in Table 6 for Test B2-G, due to the turbulence of the unsubmerged jet passing through the partially open butterfly valve and the lack of back pressure. The existence of this condition would not be recommended for long-term continuous operation. If operating conditions involving partial valve openings through a single valve are required to regulate the discharge, it is recommended that the maximum QC gate setting be limited to 50 percent to keep the pressures at a safe level. If higher discharges are required for emergency releases, such as a QC gate opening of 70 percent, the partial opening of the butterfly valve should be limited to no less than 70 deg to avoid the turbulent condition that exists when the valve is operating in an unsubmerged state.

35. No severe flow conditions were experienced for operations involving two valves, each operating at partial openings, for the discharges tested.

The lowest pressure recorded for the two-valve operation at partial openings was -3.16 ft at transducer location P2, which occurred during Test F2-J. The operating conditions for this test consisted of butterfly valves No. 2 and No. 3 set at 30 deg open with the QC gate set at 70 percent open. Both valves remained submerged during this test and throughout most of the two-valve operations. Valve No. 2 became unsubmerged during Test F1-H as indicated by the water-surface elevations in Table 5. The pressures recorded in the valve area were close to atmospheric pressure with the lowest negative pressure being -1.426 ft at transducer P5.

36. Operations involving three butterfly valves were conducted with two valves (No. 1 and No. 3) open to 90 deg while butterfly valve No. 2 was gradually closed for various openings of the QC gate. During these tests, the wet well water-surface elevation did not fluctuate more than 2.0 ft (Plate 15) and the pressures on the No. 2 valve leaf reflected very little change from head pressure with decreasing valve openings.

Valve Area Cavitation

37. In conjunction with the pressure measurements discussed previously, six pressure transducers were used to detect cavitation pressures at the valve seat (PB1 and PB2) and at a point midway between the butterfly valve and the wet well (PV3, PV6, PV9, and PV12), as shown in Plate 3. From the pressure data presented in Table 6 and the water-surface elevation data of Table 5 for these transducer locations, it is shown that during a single-valve operation, severe conditions exist when the water surface in the wet well is lower than the invert elevation of butterfly valve No. 2. The lowest instantaneous negative pressure recorded for the single-valve test conditions was -17.82 ft at transducer PV3 for Test B2-G. The lowest instantaneous negative pressures recorded for a two-valve operation were -17.57 ft at transducer PB2 for Test F2-J and -18.4 ft at PV3 for Test D2-H. No negative pressures were recorded in the valve area for any of the three-valve operation tests.

38. In general, the turbulence in the valve area and the low pressures that exist are the result of the high-velocity unsubmerged flow condition created by the partial opening of the butterfly valve and corresponding large QC gate openings. The pressures appear to be severe along the invert or bottom of the valve area. This is evident from the data of the pressure

transducers located in this area (PV6 and PB2) where the lowest instantaneous negative pressure has been exceeded to the extent that the transducer no longer functions. This happened to transducers PV6 and PB2 during Test B1-G. The transducers were stressed from the instantaneous overranging of the pressure limit during the previous test. These events occurred on the last day of testing and for the most severe conditions that were expected to exist. Therefore, due to the limited time to complete these tests, the damaged transducers were not replaced. Just prior to the time of the loss of the transducers, the pressures in the valve area were at or below 0 ft (atmospheric pressure) with extremely turbulent flow. The lowest negative mean pressure recorded was -6.73 ft at transducer PV3, which also recorded the lowest instantaneous pressure at -17.82 ft during Test B2-G.

39. During these single-valve, high-discharge, and partial butterfly opening tests, a stereo tape recorder and microphone were set up next to butterfly valve No. 2 to record audible sounds of the flow for detection of noises such as sizzling, popping, or loud banging, which would be typically associated with cavitation. The maximum discharge tests were considered to have the conditions where cavitation would most likely occur; however, for the particular valve operating conditions tested, these sounds were not detected. The loudest noise level observed occurred during Test A3-I when the butterfly valve No. 3 was at 45 deg open and the QC gate was 90 percent open. These gate configurations created a severe drop in the water-surface elevation to a level 17 ft below the center-line elevation of the butterfly valve. The noise level at the valve location was too high for detection of distinguishable cavitation noises.

40. The cavitation number c_c is an index used in the study of cavitation phenomena and is defined (Rouse 1950) as

$$c_c = \frac{H_u - H_v}{\frac{V^2}{2g}} \tag{2}$$

where

H_u = mean reference pressure

H_v = vapor pressure of the flowing liquid (estimated to be -33 ft measured relative to the barometric pressure)

V = velocity

g = acceleration due to gravity

Using the value for H_v stated previously, values of H_u from transducer IP4, and the discharges determined for the single-valve tests at a QC gate setting of 70 percent, the cavitation index numbers were computed and plotted relative to the butterfly valve opening. A model study was conducted at Colorado State University (Tullis 1974) to estimate the expected level of cavitation at the butterfly valve for various upstream head conditions. The model data were used to compute cavitation index values for the various head conditions using the following equation:

$$c_i = \frac{H_d - H_v}{\Delta H} \qquad (3)$$

where H_d is the water-surface el 391.0 (from Table 5) and

$$\Delta H = \left(\frac{1}{C_Q^2} - 1 \right) \frac{V^2}{2g} = H_u - H_d$$

where H_u is the upstream head pressure in feet. For comparison with the cavitation index values of the model, this equation was used to compute the cavitation index values using prototype data. The results are listed in Table 7. The differences between the model and prototype values of c_i can be related to the differences in the physical characteristics of the model and prototype butterfly valves, as well as the scale effects that are produced in adjusting the values up to the prototype values. Also, the difference in flow conditions upstream and downstream of the prototype valve created by the upstream bends and the short length of conduit downstream, which were not tested in the model, will affect the cavitation index value.

Butterfly Valve Shaft Torque

41. Data from the butterfly valve shaft strain are presented in Table 8 for the various test conditions. The arrangement of gages used, as illustrated in Figure 6, resulted in automatic temperature compensation for all the

gages and insensitivity to the effects of all strains other than torsional strain (Doebelin 1966). The torsional stress was computed using the following equation (Perry and Lissner 1962):

$$\sigma = \frac{\varepsilon E}{1 + \mu} \tag{4}$$

where

σ = torsional stress, psi

ε = one-fourth of the bridge output, µin./in.

E = the modulus of elasticity, 29×10^6 psi, for stainless steel

μ = Poisson's ratio, 0.30, for stainless steel

The torsional stresses were then used to compute the values of the valve shaft torque using the following equation:

$$T = \frac{\sigma \pi r^3}{2} \tag{5}$$

where

T = valve shaft torque, lb-in.

π = 3.14 radians

r = radius of the valve shaft, in.

42. Table 8 lists the maximum torque values computed from the strain data for the single-valve and combination-valve operations. The material used in the design of the butterfly valve shaft is stainless steel. ASTM A564 type 630 (American Society for Testing and Materials 1988) which is designed for an ultimate stress greater than 75 ksi. The maximum stress value computed from the maximum strain shown in Table 8 is 0.559 ksi and is evidently well below this ultimate stress level.

Butterfly Valve Leaf Vibrations

43. As stated previously, two locations were designated for installation of the accelerometers for measurement of the valve leaf vibrations. The accelerometers were installed with the butterfly valve closed, which oriented the axis of acceleration parallel to the direction of flow. When the valve

was opened to the different valve openings, the axis of acceleration changed accordingly and introduced an offset in the acceleration data, causing the accelerations to appear larger than they actually were. A rotation of the butterfly valve leaf from the closed position to the fully open position created a 1-g offset in the reading of the accelerometers in a no- flow condition. Therefore, at each increment of opening, the accelerometers would experience a slight offset equivalent to the mean value of the acceleration reading. The data were corrected for this offset by removing the mean value. The accelerations for all the tests in which butterfly valve No. 2 was operated are listed in Table 9. The vibration data do not indicate any severe vibrations existing nor do they reveal any flutter of the butterfly valve leaf. The largest acceleration observed was 4.533 g's for Test DO-J in which the butterfly valve was at an opening of 45 deg. In general, the largest acceleration values observed were found to occur during tests when the butterfly valve was at openings $\leq$50 deg.

44. The acceleration data were used to compute the movement of the valve leaf in terms of displacement from the following equation:

$$d = \frac{32.2\ (\text{acceleration})}{(2\pi\ \text{frequency})^2} \tag{6}$$

where

d = peak-to-peak sinusoidal displacement, ft
acceleration = greatest peak-to-peak acceleration, g's
frequency = predominant frequency, Hz

Since the butterfly valves can be considered to be elastic structures, in which many resonant frequencies exist, any one of a number of frequencies could be indicative of the natural frequency of vibration. However, it is generally the lower frequencies that receive the driving power more frequently due to the ease at which they are excited. The transforming of the data from the time domain to the frequency domain was accomplished by a mathematical Fast Fourier Transform (FFT). The peak-to-peak accelerations were taken from the time-history data for each accelerometer. A typical time-history plot of acceleration is shown in Plate 16. Plate 17 illustrates a typical example of an FFT plot of the time-history plots shown in Plate 16. The predominant frequencies of the accelerations were obtained from these types of plots and are listed in Table 9.

45. The data presented in Table 9 show that, in general, movement of the butterfly valve leaf was extremely small. The greatest displacement computed was 6.892×10^{-3} ft for Test B3-E, a single-valve operation at a partial opening. The purpose of placing the accelerometers on the valve leaf was to obtain those vibrations of the leaf most predominant in the low-frequency range to detect movement of the leaf as well as obtain vibrations in the high-frequency range for cavitation analysis. Due to the limitations placed on maximum discharge, the extremely high flows where cavitation would likely be present could not be tested; and therefore the data analysis was limited to the low frequencies. As evidenced from the tests for which the pressure data indicated that a potential for cavitation existed, the corresponding accelerometer frequency analysis did not indicate significant energy or driving force at the higher frequencies (>250 Hz).

Stratified Flow in the Wet Well

46. Thermally stratified flow in the wet well was hypothesized as a possibility during low-flow releases. If the turbulence within the intake conduit and wet well were minimal under low-flow conditions, it was considered possible for the thermal stratification, which occurs in the zone of withdrawal for a given port, to be maintained through the structure. To test this hypothesis, thermistors were positioned above and below each port approximately 2 ft upstream of the connection to the wet well. Although the possibility existed that turbulence due to the inlet, elbow, and butterfly valve could influence the temperature readings, this was the only position accessible in the wet well to attach thermistors.

47. Before the QC gate was opened, thermal stratification downstream of each valve was observed. Stratification was indicated by temperature differences of several degrees between the top and bottom thermistors at each of the three ports. However, the initiation of flow quickly mixed the water downstream of the valve to a uniform temperature within a few minutes. Even at the lowest flow condition tested, stratified flow was not observed at any of the ports. Obviously, similar conclusions could be drawn about stratified flow within the entire wet well.

Comparison of Water Quality Sample Ports to Reservoir Profiles

48. According to the project's water control manual (USAED, Sacramento, 1984), the operation of the ports in the wet well depends upon the desired release temperature. To monitor the reservoir thermal profile, a water quality sampling system was constructed in the wet well. This system consisted of 12 sample ports located at 20-ft intervals beginning at el 230.0 and extending to el 450.0. The individual pipes collected to a sample manifold at el 270.0 in the control structure so that water samples could be taken from discrete elevations in the reservoir. Temperature measurements were made from samples taken from the water quality manifold and compared to the temperature profile taken from a representative station in the reservoir approximately 1,000 ft upstream of the tower. An evaluation of the various temperature measurements relative to the actual release temperature was performed to give an indication of the precision of the sample port system. This comparison, given in Table 10, indicated the water quality sample port temperatures from elevations above 400 ft were below the corresponding reservoir profile temperature. Further, sample port temperatures from elevations below 400 ft were above the corresponding profile temperature. In addition, the deeper sample ports were much warmer, probably a result of the distance the sample water traveled through the pipe system prior to reaching the manifold. The water from the port at el 270 was 14.4° F warmer than at the corresponding profile elevation, probably due to a construction error or a leak in the sample system. In either case, the data collected from this sample port should not be used in making operational decisions. Further, it is recommended that additional comparisons between the sample ports and profiles in the pool be made to identify the precision of these ports in representing the thermal profile.

Multiple Port Operation Tests

49. The primary objective in these water quality tests was to investigate the effects of thermal stratification on flow through the water quality ports. Specifically, the objective involved evaluating whether the buoyancy associated with the water density differences between two ports was greater than the hydraulic losses of each port such that thermal (density) blockage might occur and prevent flow through the upper port. The test conditions for

the water quality measurements are listed in Table 11.

50. The series of tests designed to investigate this phenomenon (Tests 1 through 6, Table 12) began with the minimum flow (5 percent QC gate opening). In the first series of tests, a rating curve for the QC gate, shown in the following tabulation, was constructed based on observed stream gage measurements made immediately downstream in a controlled section of the outlet channel. QC gate openings were curtailed at 50 percent due to potential damage to temporary structures downstream of the project.

QC Gate Opening percent	Discharge cfs
5	28
10	68
20	123
30	181
50	312

51. In the next series of tests, after the wet well was stratified, the No. 3 valve (el 352) and the No. 1 valve (el 431) were fully open (90 deg), and the QC gate was opened 5 percent to release approximately 28 cfs. The release temperature (53° F) indicated that most of the flow came from the No. 3 port (el 352) (Test 8, see Table 10 for a representative thermal profile). The upper valve (No. 1) was then closed to 30 deg with little impact on release temperature (Test 9, Table 12). This was not unexpected since the discharge through this port was negligible. Similar observations were made as the upper valve (No. 1) was closed to 20, 10, and 5 deg (Tests 10, 11, and 12, respectively, Table 12). These observations indicated density blockage occurred between the No. 3 and No. 1 ports for this minimum flow.

52. The next series of tests (Tests 13 through 16, Table 12) involved closing the No. 3 valve by varying amounts to increase local head loss, thereby overcoming the density blockage and allowing flow from the upper port (No. 1 valve). As the No. 3 valve was closed to 60 deg open, the release temperature increased from 53° to 55.8° F. Although the mixing in the wet well above the No. 3 valve was still obvious, the density blockage was overcome. As the valve was closed to 45 deg the temperature increased to 60° F and the mixing zone moved down below the No. 3 valve. Continued increases in release temperature were observed with No. 3 valve openings of 30 and 15 deg, respectively. Plate 18 illustrates these findings.

53. As the discharge from the QC gate was increased from 5 to 10 percent open, density blockage was overcome more quickly. With both No. 1 and No. 3 valves open 90 deg, flow through the top port (No. 1) was indicated by a release temperature of 59° F (Test No. 17), which was an increase of 6° F over the release temperature resulting from the tests with a lower flow rate (Test 8). Restriction of flow from the No. 3 valve, by closing it to 60 deg open (Test 19), increased the release temperature to 60.7° F. Further restriction by closing the lower valve to 45, 30, and 15 deg (Tests 20, 21, and 22, respectively) further increased release temperature similar to the 5 percent QC gate flow series discussed previously. Since density blockage was not observed at the 10 percent gate, the No. 1 valve (el 430) was closed to 10 deg open. The release temperature of 54.7° F (Test 18) indicated that some flow was still coming from the upper port. Release temperatures for the 20 percent (Tests 23-27) and 50 percent (Tests 28 and 29) QC gate openings exhibited similar trends to that of the 10 percent series in increasing upper port flow, resulting ultimately in release temperatures composed of an almost equal blend of water from the No. 1 and No. 3 ports for these larger QC gate settings.

54. A similar series of tests, Tests 30-41, was conducted using the No. 2 and No. 1 ports to investigate the flow distribution under a slightly smaller density difference. The temperature difference between the No. 1 and No. 2 ports (approximately 13° F) was slightly less than that between No. 1 and No. 3 ports (approximately 16° F). In the first test, with both No. 1 and No. 2 valves fully open (90 deg) and the QC gate flow at 5 percent of the gate opening, a release temperature of 61.4° F was observed. This indicated that flow from the upper port (No. 1) was occurring. As the No. 2 valve was closed to 60 and 30 deg, an increase in release temperature was observed (Plate 19), indicating an increase in the portion of flow coming from the No. 1 port.

55. In the next set of tests, Tests 42-44, the blending of water from the deeper portions of the reservoir with epilimnetic water was attempted. This was investigated by operating butterfly valve No. 4, the 30-in. filling valve, with the No. 1 valve (el 430). The 30-in. filling valve inlet is located in the roof of the flood-control tunnel at el 228. Since this is not a normal operating procedure, flows were not allowed to exceed 5 percent QC gate capacity. After the wet well was filled from valve No. 4, the No. 3 and No. 1 valves were opened to allow stratification of the wet well (Test 42); then the No. 3 valve was closed and the QC gate opened 5 percent (Test 43).

The resulting release temperature was 65.5° F, indicating blending between the No. 1 port and the filling valve. The No. 1 (upper) valve was closed to 10 deg open and a corresponding reduction in release temperature (58.0° F) was observed (Test 44).

56. The water from the filling valve, although located much deeper in the hypolimnion than water from the No. 3 port, did not have a temperature any cooler (thus denser) than the water at the No. 3 port. Although density blockage was observed in previous tests using the No. 1 and the No. 3 ports with a 5 percent QC gate opening, density blockage was not observed during operation of the No. 1 and filling valves. This was undoubtedly due to the higher hydraulic losses of the filling system (as compared to those of the No. 3 valve), which caused the density blockage to be overcome more quickly than did the No. 1 and No. 3 valve operation.

57. The results of the simultaneous multilevel port operation (blending) portion of the field study indicated that blending is, indeed, both possible and potentially practical in the operation of this structure. The in-well temperature monitoring results lead to the conclusion that the release water was composed of a combination of flows from multiple ports within the single wet well for many intake/valve combinations. Furthermore, the observed release temperatures indicated that the flow distributions among the ports followed the trends established in prior blending research (Howington 1987). The results also showed that substantial control over the flow distribution could possibly be gained by partial valve closure in the inlet conduits. This was evidenced by the strong functional relationship between release temperature changes and incremental valve setting changes.

58. Since the field data correlated well qualitatively with existing theory, a separate effort was undertaken to quantitatively describe the blending processes at this structure. The observed data from this fieldwork were compared to output from an existing algorithm that describes the general blending process (Howington 1987). The details of the application of the blending algorithm to the Warm Springs data appear in the section, "Blending Analysis."

59. The comparison between the algorithm-predicted and observed release temperatures generally indicated errors of less than 1° F. Plate 20 demonstrates that the larger errors were confined to the 5 percent QC gate (28-cfs) tests. In this range, the flow distribution is much more sensitive to total

discharge and density potential computations than at higher flows. However, the accuracy of the discharge measurement is also poorest at these very low flows. Therefore, these large errors cannot be directly attributed to an insufficiency in the blending algorithm.

60. As indicated previously, thermal blockage was observed during these tests. Tests 8 through 12 (Table 12) demonstrated an essentially blocked structure with the release temperature comparing very closely with that in the lowest intake conduit. As the lower valve was throttled to 60 deg (Test 13, Table 12), the algorithm still predicted a generally blocked state; however, a slight contribution from the upper port, probably due to wet well turbulence, was evident in the observed data. Blockage was easily overcome, both in the prototype and the algorithm predictions, once the lower port had been throttled to 45 deg.

61. Tests 1 and 2 were not blending tests as only one intake was open, but they did reveal an important problem. The field study documentation indicated significant leakage through the lower butterfly valve. For Tests 1 and 2, the only open valve was the upper valve with a temperature in the wet well at the elevation of the upper port of about 71° F. The upper valve settings for these tests were small (15 and 30 deg, respectively, with the QC gate at 5 percent) and the losses were large. This large differential between the wet well water surface and the pool created a driving pressure differential across the lower butterfly valves. At this low flow (28 cfs), the leakage across the lowest valve was significant enough to decrease the expected release temperature by about 11° F to 60° F. The leakage should be considerably less for larger gate settings, thus minimizing the impact of the leakage on temperature predictions. The use of valves 2 and 3 during the blending tests yielded consistently cooler temperatures than were predicted. This can be attributed to the leakage across the lower valve.

62. In general, the results of the comparisons of predicted to observed release temperatures were very good. The head loss coefficients used in the blending predictions should, however, not be used extensively without further evaluation since the method used in their derivation was indirect in the absence of direct port flow measurement. The predicted release temperatures corresponded very well with the observed release temperatures, providing verification of the methods used. The results of this evalution indicate the existing blending algorithm can be used to satisfactorily predict release

temperatures for multilevel port operation in the Warm Springs single wet well structure.

SELECT Model Test

63. The final effort conducted during this investigation was an on-site application of the numerical model SELECT (Davis et al. 1987). This version of SELECT, which was developed prior to the formulation of the blending algorithm, was used to determine the accuracy of the model in predicting flows through ports necessary to result in a given release temperature. An operation was formulated in which 123 cfs of 59.0° F water was to be released. This discharge was well above the critical discharge (below which density blockage was observed). Since this temperature objective could not be achieved by operation of a single port, the required multiport operation was sought using SELECT. The desired release temperature, the thermal profile in the pool, and intake structure configuration were input into the model. The output indicated 86 percent (109 cfs) of the total discharge should come from el 390 (port 2) and 14 percent (17 cfs) from el 352 (port 3) to yield the desired release temperature. Since measurement of the individual discharges through the valves was not accomplished during the field tests reported herein, the following formulas were used to develop rating curves for each valve:

$$Q_3 + Q_2 = Q_{rel} \tag{7}$$

$$T_3Q_3 + T_2Q_2 = T_{rel}Q_{rel}(2) \tag{8}$$

where the subscripts 3 , 2 , and rel represent flow Q and temperature T at port 3, port 2, and release, respectively. This method is dependent upon the thermal stratification under which the ratio of gate opening to flow is observed. Therefore, these rating curves are accurate only under an identical thermal stratification. These curves indicated that a valve opening of 18 deg on valve 1 would result in approximately 17-cfs flow with the No. 2 valve fully open. The release temperature observed (59.0° F) for a prototype test under these same conditions (Test 45, Table 12) indicated that the model was fairly precise in predicting flows necessary for a given release temperature, when the effects of density on the release distribution are known to be minimal.

Withdrawal Angle Tests

64. The Warm Springs outlet structure is somewhat rare in that the structure was constructed inside the north embankment of the reservoir. Not only are the selective withdrawal ports located at different elevations, but the inlet conduits are of varying lengths and the radius of bend of each elbow into its respective valve also varies. This unique orientation afforded the opportunity to compare the observed release temperature from one port with that predicted by the SELECT model under varying withdrawal angles. The withdrawal angle is the effective lateral dimension of withdrawal within which the structure is capable of operating. For example, a structure in the face of a dam might draw water laterally from only 180 deg of the structure, while a structure located in the middle of a pool might draw water from 360 deg. Given that the ports at Warm Springs are located in the hillside, they would not be expected to draw water beyond 180 deg; therefore, angles of 180 deg and smaller were tested. Flow rates through port 1 (el 430) were computed using Equations 7 and 8, and comparisons were made between the observed release temperature from that port and the SELECT predicted release temperature for withdrawal angles of 180, 120, 90, and 45 deg. As indicated in the following tabulation, the smaller withdrawal angles resulted in better accuracy of the predicted release temperature. Although this port is located in the face of the hillside, the dam ties into the hillside very near the port, effectively restricting flows. Therefore the smaller angle of 45 deg represents the best withdrawal angle for port 1. While tests were not conducted on the other two ports, similar conclusions could be drawn regarding the withdrawal angles for these ports.

Port 1 Predicted Discharge cfs	Observed Release Temperature, °F	Predicted Release Temperature, °F, with Withdrawal Angles, deg			
		180	120	90	45
6	71.2	73.0	73.0	73.0	72.8
48	70.7	72.7	72.5	72.1	71.6
103	70.5	72.1	72.0	71.6	70.5
224	69.1	71.2	70.9	70.5	68.9

Blending Analysis

65. The accuracy of the numerical description of single wet well blending has been found to rely largely on an accurate description of the intake losses (Howington 1987). Initially, the wet well pressure data collected during the hydraulic portion of the Warm Springs field study were used to determine the water-surface elevation within the wet well, a purpose for which the data had not been intended. It was hoped that the wet well water surface could then be used in the blending analysis to approximate the energy loss across the uppermost open port. However, the data were found to be unusable in the blending evaluation. The measuring devices provided pressure data that were adequate for the hydraulic analysis, but were not accurate enough to assess the water-surface elevation in the low range of discharges common to most of the blending tests. Therefore, an alternate method of arriving at the head losses through the ports was sought.

66. A technique to derive loss coefficients from the observed temperature data was devised. First, the blending algorithm was assumed to apply, as is, for a small number of tests. The known information was then used to develop head loss coefficients for the individual ports. The remaining tests were then evaluated using these computed loss coefficients to predict flow distribution. The blending algorithm was then used to predict individual port flows assuming the computed loss coefficients to be correct. Subsequently, release temperatures were computed. If the agreement between predicted and observed release temperatures was good for the remaining tests (which were not used to derive the loss coefficients), the assumption that the blending algorithm was applicable would have some validity.

67. The loss coefficients associated with the ports were separated into a "base" k coefficient and a "valve" k coefficient. The base k coefficient was associated with the hydraulic losses incurred through the entrance, the elbow, the exit into the wet well, and skin friction in the intake conduit. The valve k coefficient was used to represent the losses associated with the butterfly valves only.

68. First, an estimated base k coefficient was determined for each of the three ports. An approximate value for each base coefficient was determined from Brater and King (1976) by summing the component loss coefficients for entrance, elbow, exit, and friction. Test 17 (Table 12) was then chosen

at random from the fully open valve tests to derive the total k coefficient for the fully open butterfly valve (90 deg) condition. The release temperature and the individual port entrance temperatures were used to arrive at a flow distribution by mass balance. This assumed no significant gain or loss of heat within the wet well (which is generally appropriate). The upper port (valve 1) required 23.3 cfs and the lower port (valve 3) required 44.7 cfs to produce the observed release temperature (59.5° F) at a total release flow of 68 cfs.

69. The pretest stratification condition was integrated between the elevations of ports 1 and 3 to yield a density potential term of 0.1185 g-ft/ml. The blending algorithm was then solved in reverse using the Test 17 data to compute the total loss coefficients. The individual port flows for this test were known and the necessary head losses to produce these flows were desired. Since the valve k coefficients for both intakes were assumed to be the same (approximately 0.4 from HDC (US Army Corps of Engineers) estimates), the only remaining unknowns within the algorithm were the base k coefficients. The approximate ratio of base k coefficients between the two open ports was then determined from HDC estimates. This reduced the number of unknowns within the blending algorithm to one. The resulting coefficients were 1.8 and 1.67 for ports 1 and 3, respectively. A similar process involving Test 36 produced a coefficient of 1.7 for the middle port (valve 2).

70. As was mentioned, the valve k coefficient should vary with butterfly valve setting, but not with discharge. Therefore, an analysis was performed to estimate the valve k coefficient for various valve settings. Tests 18 through 22 (Table 11) were selected for this evaluation. This represented a single group of tests that included a full range of gate settings. A similar process to the one discussed previously was used to compute the coefficients. The unknowns were now the valve coefficients rather than the base coefficients. The resulting values for total k coefficients were converted to discharge coefficients for comparison to other data on butterfly valves. The resulting graph is shown in Plate 21. The data compared favorably with discharge coefficient data from the design curve suggested in HDC.

71. The remaining prototype water quality tests were then evaluated with these head loss coefficients taken as given information. The blending algorithm was employed to produce the flow distribution between the ports for each of the remaining tests. This flow ratio was then applied to the measured

temperature within the ports at thermistors A2, A9, and B7 located within ports 1, 2, and 3, respectively (Plate 4). This process resulted in a predicted release temperature from the structure. An observed release temperature was obtained by averaging the lowest four thermistors within the wet well. These thermistors were located well beneath the lowest water quality port, port 3, and immediately above the wet well service gate. The predicted release temperatures were very close to the observed release temperatures with most deviations of less than 1° F (Plate 22).

72. Several assumptions were made in this evaluation. The total structure discharge was assumed to be related only to the service gate setting. This is obviously not completely true in that the wet well water surface, which drives the flow through the service gate, is dependent on the butterfly valve settings. However, for the range of tests conducted, this assumption should not cause significant errors. The k coefficients, which were each derived on the basis of one test per valve setting, were assumed to apply for every other test with that particular valve setting at that port. It was initially assumed that the blending theory was applicable at this structure to derive the coefficients. The temperature profile, and thereby the density potential energy terms, were assumed constant during the testing period. The posttesting vertical temperature profile was somewhat different in the epilimnetic region due to wind mixing; however, this impact on the density potential energy terms would have been minimal.

PART V: CONCLUSIONS AND RECOMMENDATIONS

73. The following conclusions and determinations result from literature review, field observations, and analysis of the Warm Springs prototype data:

a. The air demand in the 14-in.-diam low-flow air vent agreed with findings of prior field tests in the occurrence of a peak air flow (78 cfs) at a small gate opening (5 percent) and again at a larger gate opening (90 percent).

b. Discharge rating curves were derived from the piezometric pressure data collected from each of the low-flow intakes and the wet well transition zone elbow. However, this does not imply that a precise calibration of the outlet works has been established. The scope of work described in the test program was not originally intended to provide a calibrated discharge system but to evaluate the use of the elbow piezometers in the intakes as discharge measuring devices. It is recommended that a more complete and detailed discharge calibration of the system be performed with instrumentation that could be permanently installed with provisions made for continuous display of the data at the operator control location.

c. Wet well water-surface elevations recorded for each test indicated that large surges of the water surface (maximum 6.14 ft) occur during single-butterfly-valve operations in which unsubmerged flow conditions exist. Single-butterfly-valve operations involving large QC gate settings and small butterfly valve openings were found to generate the unsubmerged flow conditions. The operation of two butterfly valves at identical small openings was found to produce unsubmerged flow conditions at certain large QC gate settings. Two-butterfly- valve operations in which one valve remained fully open and the other valve was set to various openings did not generate any unsubmerged flow conditions for any of the QC gate openings tested. These same results were found to apply to the tests in which all three butterfly valves were operated where two valves remained fully open and one valve was set to various openings. The unsubmerged flow conditions experienced in the testing were found to be the underlying cause of the extreme values observed in the other measurements recorded. Operation under these conditions is not recommended for long-term releases.

d. Operations of a single butterfly valve in an unsubmerged flow condition were found to produce the most turbulent pressure conditions on the butterfly valve leaf. These turbulent conditions resulted in the lowest pressure (-17.82 ft) recorded in the valve area. Operation of a butterfly valve under these conditions is not recommended for long-term releases. Two-butterfly-valve operations in an unsubmerged flow condition resulted in a low pressure in the valve area of -1.426 ft. No negative pressures were recorded during the operations involving all three butterfly valves.

e. The measured strain values of the butterfly valve shaft for the flow conditions tested did not reveal any significant amount of torque being exerted on the shaft. This is verified also by the acceleration data, which revealed very little movement of the valve leaf resulting from the flow conditions.

f. No cavitation conditions were found to occur for the valve operations tested. However, the potential for its occurrence is greatly increased when the butterfly valves are operated in an unsubmerged condition resulting from partial valve openings. The turbulence created under these conditions was found to be severe enough to overrange several pressure transducers. Long-term operation under these conditions is not recommended unless required under emergency cases.

g. Water quality prototype tests were conducted at Warm Springs Dam to investigate stratified flow and thermal (density) blockage within the wet well and to evaluate methods to predict simultaneous multiple-level port operation to achieve a given release temperature. The prototype tests showed that stratified flow within the wet well does not occur, even under the lowest flow conditions (28 cfs). A comparison was made between the water temperature from the water quality sample manifold located in the wet well and the thermal profile in the reservoir. Results indicate that some difference in temperature between the sample manifold and the reservoir profile occurs, and it is recommended that further study be made of this system to determine the exact cause of the differences.

h. The multiple-port operation tests confirmed that density blockage did occur at the lowest flow condition (28 cfs). However, it was easily overcome by throttling operations of the port valves. Application of the blending algorithm developed from research at WES to the Warm Springs tests indicated that the algorithm satisfactorily predicted release temperatures for multilevel port operations. Selective withdrawal predictive techniques (SELECT), although not coupled with the blending algorithm, proved to be accurate in predicting release flows necessary from two ports to achieve a given release temperature for cases where density has little effect on the flow distribution. Withdrawal angle tests further indicated that adjustment to the SELECT model for withdrawal angles at Warm Springs would improve the predictive techniques. Since these results demonstrate the utility of the blending algorithm and the SELECT model in predicting release temperatures, it is recommended that these two components be combined to provide an operational model for Warm Springs Dam. This model would take into account the effects of density on the flow distribution between ports and the impacts of local topography on the withdrawal zone. When coupled, the model would, for a given reservoir thermal structure, release quantity and objective, and set of head loss coefficients, predict which ports should be operated (including partial valve openings) to meet the given release temperature objective.

REFERENCES

American Society for Testing and Materials. 1988. "Annual Book of ASTM Standards for Iron and Steel Products - Steel Bars, Forgings, Bearings Chain, and Springs," Section 1, Vol 01.05, pp 382-387, Philadelphia, PA.

Brater, E. F., and King, H. W. 1976. Handbook of Hydraulics, McGraw-Hill, New York.

Davis, J. E., Holland, J. P., Schneider, M. L., and Wilhelms, S. C. 1987 (Aug). "SELECT: A Numerical, One-Dimensional Model for Selective Withdrawal," Technical Report EL-87-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Doebelin, E. O. 1966. Measurement Systems: Application and Design, McGraw-Hill, New York.

Hart, E. D., and Pugh, C. A. 1975 (May). "Outlet Works for Beltzville Dam Pohopoco Creek, Pennsylvania, Prototype Tests," Technical Report H-75-10, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Howington, S. E. 1987 (Aug). "Simultaneous Releases from a Stratified Reservoir," Proceedings of the 1987 National Conference on Hydraulic Engineering, American Society of Civil Engineers, Williamsburg, VA, pp 42-47.

Perry, C. C., and Lissner, H. R. 1962. The Strain Gage Primer, McGraw-Hill, New York.

Rouse, H. 1950. Engineering Hydraulics, Wiley, New York.

__________. 1962. Elementary Mechanics of Fluids, Wiley, New York.

Tullis, J. P. 1974. "Predicted Cavitation Performance and Testing Procedures for 60-Inch Butterfly Valves," Model Study Report prepared by Colorado State, Fort Collins, CO, for the US Army Engineer Waterways Experiment Station, Vicksburg, MS.

US Army Corps of Engineers. "Hydraulic Design Criteria," prepared for Office, Chief of Engineers, by US Army Engineer Waterways Experiment Station, Vicksburg, MS, issued serially since 1952.

US Army Engineer District, Sacramento. 1984 (Sep). "Warm Springs Dam and Lake Sonoma Dry Creek, California; Water Control Manual," Appendix II to Master Water Control Manual, Russian River Basin, California, Sacramento, CA.

Vennard, J. K., and Street, R. L. 1975. Elementary Fluid Mechanics, Wiley, New York.

Table 1

Instrumentation

Instrument				
Name	Type	Range	Location	Parameter Measured
IP1	CEC 4-312	50 psia	Intake No. 2 manifold	Static piezometric pressure in intake conduit
IP2			Intake No. 2 manifold	Static piezometric pressure in intake conduit
IP3			Intake No. 2 manifold	Static piezometric pressure in intake conduit
IP4			Intake No. 2 manifold	Static piezometric pressure in intake conduit
PR1			Wet well at el 400.0	Absolute pressure in wet well
PR2		100 psia	Wet well at el 387.5	
PR3		100 psia	Wet well at el 360.0	
PR4		100 psia	Wet well at el 292.0	
PR5		50 psia	D.S. of QC gate el 233.0 (236.0 Plate 1)	
PV3		100 psia	D.S. valve 2 el 391.0	Absolute pressure in valve area
PV9		50 psia	D.S. valve 2 el 391.0	
PV6			D.S. valve 2 el 388.4	
PV12			D.S. valve 2 el 393.5	
PB1			D.S. valve 2 el 388.4	
PB2			D.S. valve 2 el 388.4	
TP8		100 psia	Transition zone elbow, el 241.5	Absolute pressure in transition elbow
TP9		100 psia	Transition zone elbow, el 241.5	Absolute pressure in transition elbow
P1		50 psia	Butterfly valve leaf el 393.0	Absolute pressure on valve leaf

(Continued)

Table 1 (Concluded)

Name	Instrument Type	Instrument Range	Instrument Location	Parameter Measured
P2	CEC 4-312	50 psia	Butterfly valve leaf el 391.0	Absolute pressure on valve leaf
P3	↓	50 psia	Butterfly valve leaf el 391.0	Absolute pressure on valve leaf
P4	↓	50 psia	Butterfly valve leaf el 391.0	Absolute pressure on valve leaf
P5	↓	50 psia	Butterfly valve leaf el 389.0	Absolute pressure on valve leaf
IP5	Validyne DP 15-22	±0.5 psid	Intake No. 2 manifold	Elbow piezometer differential pressure
IP6	Validyne DP 15-22	±0.5 psid	Intake No. 3 manifold	Elbow piezometer differential pressure
IP7	Validyne DP 15-22	±0.5 psid	Intake No. 1 manifold	Elbow piezometer differential pressure
DP1	Validyne DP 15-22	±0.5 psid	14-in.-diam air vent	Air vent differential pressure
A1	Sundstrand QA1100	±20 g	Butterfly valve leaf	Vibrations of valve leaf
A2	Sundstrand QA1100	±20 g	Butterfly valve leaf	Vibrations of valve leaf
E1	Micro	--	Butterfly valve shaft	Butterfly valve shaft strain

Table 2

Test Conditions

Test No.	QC Gate Opening percent	Butterfly Valve Opening,* deg		
		Valve No. 1	Valve No. 2	Valve No. 3
A1-A	10	0	0	15
A1-B	20			15
A1-C	30			15
A2-A	10			30
A2-B	20			
A2-C	30			
A2-D	40			
A2-E	50			
A2-F	60			
A2-G	70			
A3-A	10			45
A3-B	20			
A3-C	30			
A3-D	40			
A3-E	50			
A3-F	60			
A3-G	70			
A3-H	80			
A3-I	90			
E7-A	10	90		90
E7-B	20	90		
E7-C	30	90		
E7-E	50	90		
WQA1-A	5	90		
WQA1-G		30		
WQA1-H		20		
WQA1-I		10		
WQD1-D		90		10
E5-B		70		70
E3-B		45		45
E1-B		15		15
WQA5-I	10	90		90

(Continued)

* 0 = Valve closed during test.

(Sheet 1 of 5)

Table 2 (Continued)

Test No.	QC Gate Opening percent	Butterfly Valve Opening,* deg Valve No. 1	Valve No. 2	Valve No. 3
WQD2-A	10	90	0	60
WQD2-B		90		45
WQD2-C		90		30
WQD2-D		90		15
E5-D		70		70
E3-D		45		45
E1-D		15		15
WQD3-A	20	90		60
WQD3-B		90		45
WQD3-C		90		30
WQD3-D		90		15
E5-F		70		70
E3-F		45		45
E1-F		20		20
WQD4-A	50	90		60
WQD4-C		90		30
E5-H		70		70
E3-H		45		45
E2-H		15		15
WQB1-A	5	90	90	0
WQB1-D	5		60	
WQB1-G	5		30	
WQB5-A	10		90	
WQB5-D	10		60	
WQB5-G	10		30	
WQB7-A	20		90	
WQB7-D	20		60	
WQB7-G	20		30	
WQB9-A	50		90	
WQB9-D			60	
WQB9-G			30	
D5-H		70	70	
D3-H		45	45	
D2-H		30	30	

(Continued)

Table 2 (Continued)

Test No.	QC Gate Opening percent	Butterfly Valve Opening,* deg Valve No. 1	Valve No. 2	Valve No. 3
WQC-1	5	90		0
D7-B		90	90	90
D5-B		70	70	70
D3-B		45	45	45
D1-B		15	15	15
F7-B		0	90	90
F5-B		0	70	70
F3-B		0	45	45
F1-B		0	15	15
D7-D	10	90	90	0
D5-D		70	70	0
D3-D		45	45	0
D1-D		15	15	0
F7-D		0	90	90
F5-D		0	70	70
F3-D		0	45	45
F1-D		0	15	15
D7-F	20	90	90	0
D5-F		70	70	0
D3-F		45	45	0
D1-F		15	15	0
F7-F		0	90	90
F5-F			70	70
F3-F			45	45
F1-F			15	15
F7-H	50		90	90
F5-H	50		70	70
F3-H	50		45	45
F1-H	50		15	15
D7-J	70	90	90	0
D5-J		70	70	
D3-J		45	45	
D2-J		60	60	
D1-J		50	50	
D0-J		45	45	

(Continued)

(Sheet 3 of 5)

Table 2 (Continued)

Test No.	QC Gate Opening percent	Butterfly Valve Opening,* deg		
		Valve No. 1	Valve No. 2	Valve No. 3
E7-J	70	90	0	90
E5-J		70		70
E3-J		60		60
E2-J		50		50
E1-J		45		45
F7-J		0	90	90
F6-J			70	70
F5-J			60	60
F4-J			50	50
F3-J			45	45
F2-J			30	30
B7-A	5		90	0
B1-A	5		15	
B7-B	10		90	
B2-B	10		30	
B1-B	10		15	
B7-C	20		90	
B3-C	20		45	
B2-C	20		30	
B1-C	20		15	
B7-E	50		90	
B4-E	50		60	
B3-E	50		45	
B2-E	50		30	
B7-B	10		90	
B2-B	10		30	
B1-B	10		15	
B7-C	20		90	
B3-C	20		45	
B2-C	20		30	
B1-C	20		15	
B7-E	50		90	
B4-E	50		60	
B3-E	50		45	
B2-E	50		30	

(Continued)

Table 2 (Concluded)

Test No.	QC Gate Opening percent	Butterfly Valve Opening,* deg Valve No. 1	Valve No. 2	Valve No. 3
B7-G	70	0	90	0
B4-G	↓	↓	70	↓
B3-G	↓	↓	60	↓
B2-G	↓	↓	50	↓
B1-G	↓	↓	45	↓
G1-I	10	90	90	90
G1-G	10	90	70	90
G1-D	10	90	45	90
G1-A	10	90	15	90
WQST-1	20	18	90	0
G2-I	↓	90	90	90
G2-G	↓	↓	70	↓
G2-D	↓	↓	45	↓
G2-A	↓	↓	15	↓
G3-I	50	↓	90	↓
G3-G	50	↓	70	↓
G3-D	50	↓	45	↓
G3-A	50	↓	15	↓
G4-I	70	90	90	90
G4-G	70	90	70	90
G4-D	70	90	45	90
G4-A	70	90	15	90
A5-A	10	70	0	0
A3-A	↓	45	↓	0
A1-A	↓	15	↓	0
C7-A	↓	0	↓	90
C5-A	↓	0	↓	70
C3-A	↓	0	↓	45
C1-A	↓	0	↓	15
A5-B	20	70	↓	0
A3-B	↓	45	↓	0
A1-B	↓	15	↓	0
C7-B	↓	0	↓	90
C5-B	↓	0	↓	70
C3-B	↓	0	↓	45
C1-B	↓	0	↓	15

Table 3

Air Discharge Data

QC Gate percent	Single Valve Operating: Valve No.	Valve Opening deg	Air Flow cfs	Multiple Valves Operating: Valve No.	Valve Openings deg	Air Flow cfs
5	2	90	77			
		15	76			
10	2	90	60			
		30	59			
		15	58			
20	2	90	43			
		45	41			
		30	38			
		15	29			
50	2	90	31			
		60	34			
		45	29			
		30	26			
70	2	90	17			
		70	12			
		60	17			
		50	0			
		45	0			
10	1	70	52			
		45	53			
		15	50			
20	1	70	49			
		45	46			
		15	20			
10	3	90	60			
		70	54			
		45	52			
		30	21			
		15	52			
20	1	70	49			
		45	46			
		15	20			
20	3	90	49			
		70	46			
		45	43			
		15	27			

(Continued)

Table 3 (Continued)

QC Gate percent	Single Valve Operating: Valve No.	Single Valve Operating: Valve Opening deg	Single Valve Operating: Air Flow cfs	Multiple Valves Operating: Valve No.	Multiple Valves Operating: Valve Openings deg	Multiple Valves Operating: Air Flow cfs
10	3	15	17			
20			29			
30			0			
10	3	30	21			
20			38			
30			17			
40			12			
50			12			
60			0			
70			0			
10	3	45	52			
20			42			
30			24			
40			21			
50			12			
60			12			
70			24			
80			24			
90			46			
5				1,3	90/90	77
					30/90	78
					20/90	77
					10/90	78
					90/15	76
					70/70	79
					45/45	77
					15/15	75
10				1,3	10/90	29
					90/60	29
					90/45	29
					90/30	29
					90/15	31
					70/70	31
					45/45	31
					15/15	29

(Continued)

Table 3 (Continued)

QC Gate percent	Single Valve Operating Valve No.	Valve Opening deg	Air Flow cfs	Multiple Valves Operating Valve No.	Valve Openings deg	Air Flow cfs
20				1,3	90/60	41
					90/45	41
					90/30	41
					90/15	41
					70/70	43
					45/45	41
					20/20	36
50				1,3	90/60	29
					90/30	31
					70/70	31
					45/45	29
					30/30	26
5				1,2	90/90	78
					90/60	80
					90/30	78
10				1,2	90/90	27
					90/60	27
					90/30	27
20				1,2	90/90	41
					90/60	41
					90/30	41
50				1,2	90/90	29
					90/60	26
					90/30	29
					70/70	26
					45/45	26
					30/30	26
5				1,2	90/90	66
					70/70	68
					45/45	67
					15/15	65
5				2,3	90/90	70
					70/90	69
					45/45	68
					15/15	68
10				1,2	90/90	58
					70/90	57
					45/45	56
					15/15	56

(Continued)

Table 3 (Continued)

QC Gate percent	Single Valve Operating: Valve No.	Single Valve Operating: Valve Opening deg	Single Valve Operating: Air Flow cfs	Multiple Valves Operating: Valve No.	Multiple Valves Operating: Valve Openings deg	Multiple Valves Operating: Air Flow cfs
10				2,3	90/90	56
					70/70	56
					45/45	57
					15/15	56
20				1,2	90/90	44
					18/90	46
					70/70	44
					45/45	39
					15/15	38
20				2,3	90/90	41
					70/70	41
					45/45	41
					15/15	36
50				2,3	90/90	31
					70/70	31
					45/45	29
					15/15	17
70				1,2	90/90	17
					70/70	17
					45/45	0
					60/60	17
					50/50	17
					45/45	12
70				1,3	90/90	17
					70/70	17
					60/60	17
					50/50	12
					45/45	17
70				2,3	90/90	17
					70/70	17
					60/60	17
					50/50	17
					45/45	17
					30/30	17
10				1,2,3	90/90/90	34
					90/70/90	34
					90/45/90	34
					90/15/90	34

(Continued)

Table 3 (Concluded)

QC Gate percent	Single Valve Operating: Valve No.	Valve Opening deg	Air Flow cfs	Multiple Valves Operating: Valve No.	Valve Openings deg	Air Flow cfs
20				1,2,3	90/90/90	44
					90/70/90	43
					90/45/90	41
					90/15/90	44
50				1,2,3	90/90/90	31
					90/70/90	34
					90/45/90	31
					90/15/90	34
70				1,2,3	90/90/90	24
					90/70/90	20
					90/45/90	20
					90/15/90	24

(Sheet 5 of 5)

Table 4

Elbow Meter Data

Test No.	QC Gate Opening percent	Butterfly Valve No. 1 Valve Opening deg	Butterfly Valve No. 1 Elbow Meter Discharge cfs	Butterfly Valve No. 2 Valve Opening deg	Butterfly Valve No. 2 Elbow Meter Discharge cfs	Butterfly Valve No. 3 Valve Opening deg	Butterfly Valve No. 3 Elbow Meter Discharge cfs	Transition Elbow Discharge cfs
A1-A	10	0	0	0	0	15	57	--*
A1-B	20					15	79	--*
A1-C	30					15	80	--*
A2-A	10					30	65	--*
A2-B	20						98	--*
A2-C	30						145	--*
A2-D	40						125	130
A2-E	50						150	195
A2-F	60						200	200
A2-G	70						200	205
A3-A	10					45	76	--*
A3-B	20						110	--*
A3-C	30						170	--*
A3-D	40						175	160
A3-E	50						--**	220
A3-F	60						--**	270
A3-G	70						--**	325
A3-H	80						--**	350
A3-I	90						--**	365
E7-A	10	90	47			90	13	--*
E7-B	20	90	63				62	125
E7-C	30	90	90				90	180
E7-E	50	90	150				165	315
WQA1-A	5	90	24				10	--*
WQA1-G	5	30	24				12	--*
WQA1-H	5	20	24				12	--*
WQA1-I	5	10	24				12	--*
WQD1-D	5	90	25			10	0	--*
E5-B	5	70	24			70	12	--*
E3-B	5	45	24			45	12	--*
E1-B	5	15	34			15	0	--*
WQA5-I	10	90	28			90	39	--*
WQD2-A			43			60	21	--*
WQD2-B			50			45	13	--*
WQD2-C			60			30	0	--*
WQD2-D			68			15	0	--*
E5-D		70	44			70	23	--*
E3-D		45	45			45	19	--*
E1-D		15	48			15	17	--*

(Continued)

Note: 0 = valve closed during test.
* Data not measurable; beyond lower range of pressure transducer.
** Data not measurable; beyond upper range of pressure transducer.

Table 4 (Continued)

Test No.	QC Gate Opening percent	Butterfly Valve No. 1 Valve Opening deg	Butterfly Valve No. 1 Elbow Meter Discharge cfs	Butterfly Valve No. 2 Valve Opening deg	Butterfly Valve No. 2 Elbow Meter Discharge cfs	Butterfly Valve No. 3 Valve Opening deg	Butterfly Valve No. 3 Elbow Meter Discharge cfs	Transition Elbow Discharge cfs
WQD3-A	20	90	80	0	0	60	48	128
WQD3-B		90	92			45	36	128
WQD3-C		90	105			30	21	120
WQD3-D		90	120			15	10	130
E5-F		70	72			70	55	125
E3-F		45	77			45	50	125
E1-F		20	77			20	45	125
WQD4-A	50	90	120			60	160	280
WQD4-C		90	200			30	80	280
E5-H		70	160			70	120	280
E3-H		45	165			45	105	270
E2-H		15	90			15	110	200
WQB1-A	5	90	35	90	27	0	0	--*
WQB1-D	5		38	60	32			--*
WQB1-G	5		38	30	34			--*
WQB5-A	10		45	90	55			85
WQB5-D	10		50	60	52			--*
WQB5-G	10		65	30	30			--*
WQB7-A	20		55	90	85			140
WQB7-D	20		60	60	80			140
WQB7-G	20		110	30	50			160
WQB9-A	50		155	90	150			300
WQB9-D			70	60	140			310
WQB9-G			220	30	90			310
D5-H		70	145	70	155			310
D3-H		45	150	45	150			310
D2-H		30	100	30	150			250
WQC-1	5	90	36	0	0			--*
D7-B		90	24	90	38			--*
D5-B		70	24	70	38			--*
D3-B		45	24	45	38			--*
D1-B		15	26	15	34			--*
F7-B		0	0	90	40	90		--*
F5-B		0	0	70	40	70		--*
F3-B		0	0	45	38	45		--*
F1-B		0	0	15	34	15	6	--*
D7-D	10	90	47	90	60	0	0	--*
D5-D	10	70	47	70	60	0	0	--*
D3-D	10	45	47	45	60	0	0	--*
D1-D	10	15	47	15	60	0	0	--*

(Continued)

* Data not measurable; beyond lower range of pressure transducer.

(Sheet 2 of 4)

Table 4 (Continued)

Test No.	QC Gate Opening percent	Butterfly Valve No. 1 Valve Opening deg	Butterfly Valve No. 1 Elbow Meter Discharge cfs	Butterfly Valve No. 2 Valve Opening deg	Butterfly Valve No. 2 Elbow Meter Discharge cfs	Butterfly Valve No. 3 Valve Opening deg	Butterfly Valve No. 3 Elbow Meter Discharge cfs	Transition Elbow Discharge cfs
F7-D	10	0	0	90	60	90	17	--*
F5-D	10	0	0	70	54	70	19	--*
F3-D	10	0	0	45	52	45	21	--*
F1-D	10	0	0	15	52	15	17	--*
D7-F	20	90	60	90	90	0	0	150
D5-F		70	74	70	90	0	0	100
D3-F		45	65	45	90	0	0	100
D1-F		15	64	15	90	0	0	100
F7-F		0	0	90	80	90	45	125
F5-F				70	80	70	45	125
F3-F				45	80	45	45	125
F1-F				15	80	15	45	125
F7-H	50			90	135	90	115	250
F5-H	50			70	135	70	115	250
F3-H	50			45	120	45	120	240
F1-H	50			15	110	15	80	170
D7-J	70	90	--**	90	--**	0	0	390
D5-J		70	--**	70	--**			390
D3-J		45	--**	45	--**			340
D2-J		60	--**	60	--**			380
D1-J		50	--**	50	--**			360
D0-J		45	--**	45	--**			350
E7-J		90	--**	0	0	90	--**	380
E5-J		70	--**	0	0	70	--**	380
E3-J		60	--**	0	0	60	--**	375
E2-J		50	--**	0	0	50	--**	370
E1-J		45	--**	0	0	45	--**	350
F7-J		0	0	90	--**	90	--**	370
F6-J				70	--**	70	--**	370
F5-J				60	--**	60	--**	370
F4-J				50	--**	50	--**	360
F3-J				45	--**	45	--**	350
F2-J				30	--**	30	--**	300
B7-A	5			90	53	0	0	--*
B1-A	5			15	50			--*
B7-B	10			90	80			--*
B2-B	10			30	80			--*
B1-B	10			15	78			--*
B7-C	20			90	127			130
B3-C	20			45	125			130
B2-C	20			30	125			130
B1-C	20			15	127			130

(Continued)

* Data not measurable; beyond lower range of pressure transducer.
** Data not measurable; beyond upper range of pressure transducer.

Table 4 (Concluded)

Test No.	QC Gate Opening percent	Butterfly Valve No. 1 Valve Opening deg	Butterfly Valve No. 1 Elbow Meter Discharge cfs	Butterfly Valve No. 2 Valve Opening deg	Butterfly Valve No. 2 Elbow Meter Discharge cfs	Butterfly Valve No. 3 Valve Opening deg	Butterfly Valve No. 3 Elbow Meter Discharge cfs	Transition Elbow Discharge cfs
B7-E	50	0	0	90	--**	0	0	310
B4-E	50	↓	↓	60	--**	↓	↓	300
B3-E	50	↓	↓	45	--**	↓	↓	285
B2-E	50	↓	↓	30	--**	↓	↓	245
B7-G	70	↓	↓	90	--**	↓	↓	425
B4-G	70	↓	↓	70	--**	↓	↓	415
B3-G	70	↓	↓	60	--**	↓	↓	400
B2-G	70	↓	↓	50	--**	↓	↓	365
B1-G	70	↓	↓	45	--**	↓	↓	335
G1-I	10	90	23	90	38	90	12	--*
G1-G	10	90	23	70	38	90	12	--*
G1-D	10	90	26	45	40	90	15	--*
G1-A	10	90	32	15	0	90	22	--*
WQST-1	20	18	23	90	117	0	0	150
G2-I	20	90	45	90	59	90	36	150
G2-G	20	90	45	70	59	90	36	150
G2-D	20	90	53	45	49	90	38	150
G2-A	20	90	66	15	27	90	47	150
G3-I	50	90	98	90	107	90	110	315
G3-G	50	90	98	70	107	90	110	315
G3-D	50	90	125	45	75	90	115	315
G3-A	50	90	140	15	35	90	140	315
G4-I	70	90	125	90	180	90	175	430
G4-G	70	90	130	70	175	90	175	430
G4-D	70	90	155	45	130	90	195	430
G4-A	70	90	175	15	85	90	220	430
A5-A	10	70	76	0	0	0	0	--*
A3-A	10	45	76	↓	↓	0	0	--*
A1-A	10	15	60	↓	↓	0	0	--*
C7-A	10	0	0	↓	↓	90	56	--*
C5-A	10	0	0	↓	↓	70	56	--*
C3-A	10	0	0	↓	↓	45	56	--*
C1-A	10	0	0	↓	↓	15	49	--*
A5-B	20	70	130	↓	↓	0	0	150
A3-B	20	45	130	↓	↓	0	0	150
A1-B	20	15	56	↓	↓	0	0	150
C7-B	20	0	0	↓	↓	90	110	160
C5-B	20	0	0	↓	↓	70	110	160
C3-B	20	0	0	↓	↓	45	105	160
C1-B	20	0	0	↓	↓	15	70	135

* Data not measurable; beyond lower range of pressure transducer.
** Data not measurable; beyond upper range of pressure transducer.

Table 5

Wet Well Water-Surface Elevations

Test No.	QC Gate Opening percent	Butterfly Valve Opening, deg Valve No. 1	Valve No. 2	Valve No. 3	Water-Surface Elevation	Discharge cfs
A1-A	10	0	0	15	403.35	57
A1-B	20			15	370.80	79
A1-C	30			15*	325.65	80
A2-A	10			30	435.4	65
A2-B	20			30	426.40	98
A2-C	30			30	409.85	145
A2-D	40			30	386.75	130
A2-E	50			30	362.25	195
A2-F	60			30*	343.55	200
A2-G	70			30*	328.35	205
A3-A	10			45	441.10	76
A3-B	20			45	438.25	110
A3-C	30			45	432.70	170
A3-D	40			45	423.60	160
A3-E	50			45	413.20	220
A3-F	60			45	397.90	270
A3-G	70			45	381.70	325
A3-H	80			45	362.45	350
A3-I	90			45*	338.80	365
E7-A	10	90		90	445.90	63
E7-B	20	90		90	445.00	125
E7-C	30	90		90	444.50	180
E7-E	50	90		90	443.10	315
WQA1-A	5	90		90	446.05	36
WQA1-G	5	30		90	445.20	36
WQA1-H	5	20		90	445.20	36
WQA1-I	5	10		90	445.20	36
WQD1-D	5	90		10	445.20	35
E5-B	5	70		70	445.20	36
E3-B	5	45		45	445.10	36
E1-B	5	15		15	445.10	34
WQA5-I	10	90		90	444.80	67

(Continued)

Note: 0 = Valve closed during test.
* Butterfly valve operating in partially submerged or unsubmerged condition.

Table 5 (Continued)

Test No.	QC Gate Opening percent	Butterfly Valve Opening, deg Valve No. 1	Valve No. 2	Valve No. 3	Water-Surface Elevation	Discharge cfs
WQD2-A	10	90	0	60	444.90	64
WQD2-B	10	90		45	444.80	63
WQD2-C	10	90		30	444.70	60
WQD2-D	10	90		15	444.65	68
E5-D	10	70		70	445.00	63
E3-D	10	45		45	444.65	64
E1-D	10	15		15	438.30	65
WQD3-A	20	90		60	444.55	128
WQD3-B	20	90		45	444.30	128
WQD3-C	20	90		30	444.00	126
WQD3-D	20	90		15	443.35	130
E5-F	20	70		70	444.72	85
E3-F	20	45		45	443.35	85
E1-F	20	20*		20	431.10	70
WQD4-A	50	90		60	442.20	280
WQD4-C	50	90		30	438.30	280
E5-H	50	70		70	442.60	280
E3-H	50	45		45	435.20	265
E2-H	50	15*		15	405.70	200
WQB1-A	5	90	90	0	446.10	62
WQB1-D	5	90	60		445.00	30
WQB1-G	5	90	30		444.90	27
WQB5-A	10	90	90		444.90	66
WQB5-D	10	90	60		444.80	100
WQB5-G	10	90	30		444.70	101
WQB7-A	20	90	90		444.55	125
WQB7-D	20	90	60		444.55	125
WQB7-G	20	90	30		444.00	150
WQB9-A	50	90	90		442.70	310
WQB9-D	50	90	60		442.10	310
WQB9-G	50	90	30		438.95	300
D5-H	50	70	70		442.35	310
D3-H	50	45	45		435.20	310
D2-H	50	30*	30		397.90	250

(Continued)

* Butterfly valve operating in partially submerged or unsubmerged condition.

Table 5 (Continued)

Test No.	QC Gate Opening percent	Butterfly Valve Opening, deg Valve No. 1	Valve No. 2	Valve No. 3	Water-Surface Elevation	Discharge cfs
WQC-1	5	90	0	0	445.80	36
D7-B	5	90	90		445.30	62
D5-B	5	70	70		445.30	62
D3-B	5	45	45		445.20	62
D1-B	5	15	15	↓	444.00	60
F7-B	5	0	90	90	444.82	40
F5-B	5	0	70	70	445.10	40
F3-B	5	0	45	45	445.10	38
F1-B	5	0	15	15	443.80	40
D7-D	10	90	90	0	445.55	107
D5-D	10	70	70	0	445.35	107
D3-D	10	45	45	0	445.00	107
D1-D	10	15	15	0	439.90	107
F7-D	10	0	90	90	444.90	77
F5-D	10	0	70	70	445.30	73
F3-D	10	0	45	45	445.00	73
F1-D	10	0	15	15	439.90	69
D7-F	20	90	90	0	444.90	164
D5-F	20	70	70	0	444.80	164
D3-F	20	45	45	0	443.75	155
D1-F	20	15*	15	0	425.50	154
F7-F	20	0	90	90	444.75	128
F5-F	20		70	70	444.75	131
F3-f	20		45	45	443.90	130
F1-F	20		15	15	425.70	130
F7-H	50		90	90	443.90	250
F5-H	50		70	70	443.75	250
F3-H	50		45	45	436.80	250
F1-H	50	↓	15*	15	357.90	170
D7-J	70	90	90	0	440.45	390
D5-J	70	70	70		439.90	390
D3-J	70	45	45		420.50	340
D2-J	70	60	60		437.25	380
D1-J	70	50*	50		431.00	360
D0-J	70	45*	45	↓	424.10	350

(Continued)

* Butterfly valve operating in partially submerged or unsubmerged condition.

Table 5 (Continued)

Test No.	QC Gate Opening percent	Butterfly Valve Opening, deg Valve No. 1	Valve No. 2	Valve No. 3	Water-Surface Elevation	Discharge cfs
E7-J	70	90	0	90	440.45	380
E5-J	70	70	↓	70	440.00	380
E3-J	70	60		60	437.90	375
E2-J	70	50*		50	432.20	370
E1-J	70	45*		45	425.45	350
F7-J	70	0	90	90	442.10	370
F6-J	70	↓	70	70	441.45	370
F5-J	70		60	60	439.00	370
F4-J	70		50	50	433.25	360
F3-J	70		45	45	428.00	350
F2-J	70		30	30	401.05	300
B7-A	5		90	0	445.65	53
B1-A	5		15	↓	442.20	50
B7-B	10		90		445.45	80
B2-B	10		30		440.90	80
B1-B	10		15		430.70	78
B7-C	20		90		444.40	130
B3-C	20		45		439.80	130
B2-C	20		30		428.55	130
B1-C	20		15*		388.35	130
B7-E	50		90		438.00	310
B4-E	50		60		429.40	300
B3-E	50		45		409.85	285
B2-E	50		30*		355.30	245
B7-G	70		90		430.30	425
B4-G	70		70		426.00	415
B3-G	70		60		413.80	400
B2-G	70		50*		390.80	365
B1-G	70		45*		372.80	335
G1-I	10	90	90	90	446.30	73
G1-G	10	90	70	90	445.90	73
G1-D	10	90	45	90	445.70	81
G1-A	10	90	15	90	445.40	94
WQST-1	20	18	90	0	444.10	150

(Continued)

* Butterfly valve operating in partially submerged or unsubmerged condition.

(Sheet 4 of 5)

Table 5 (Concluded)

Test No.	QC Gate Opening percent	Butterfly Valve Opening, deg Valve No. 1	Valve No. 2	Valve No. 3	Water-Surface Elevation	Discharge cfs
G2-I	20	90	90	90	445.15	150
G2-G	20	90	70	90	445.10	150
G2-D	20	90	45	90	445.00	150
G2-A	20	90	15	90	444.80	150
G3-I	50	90	90	90	444.40	315
G3-G	50	90	70	90	444.35	315
G3-D	50	90	45	90	444.50	315
G3-A	50	90	15	90	443.55	315
G4-I	70	90	90	90	443.85	430
G4-G	70	90	70	90	443.60	430
G4-D	70	90	45	90	442.80	430
G4-A	70	90	15	90	441.60	430
A5-A	10	70	0	0	446.00	76
A3-A	10	45		0	444.00	76
A1-A	10	15*		0	425.65	60
C7-A	10	0		90	444.80	56
C5-A	10	0		70	444.90	56
C3-A	10	0		45	443.60	56
C1-A	10	0		15	424.50	49
A5-B	20	70		0	443.60	150
A3-B	20	45		0	438.45	150
A1-B	20	15*		0	338.20	150
C7-B	20	0		90	443.90	160
C5-B	20	0		70	443.90	160
C3-B	20	0		45	438.50	160
C1-B	20	0		15	376.00	135

* Butterfly valve operating in partially submerged or unsubmerged condition.

(Sheet 5 of 5)

Table 6

Valve Leaf Pressures

Test No.	Transducer	Pressure, ft Mean	Maximum	Minimum
WQB1-A	PV3	54.613	55.736	52.928
	PV6	56.680	57.091	55.960
	PV9	54.322	54.991	53.653
	PV12	51.683	52.506	50.861
	P1	52.385	53.007	51.556
	P2	54.800	55.463	54.042
	P3	54.706	55.648	53.952
	P4	54.800	55.657	54.157
	P5	56.343	57.166	55.703
	PB1	56.973	57.782	55.817
	PB2	56.969	57.671	56.181
WQB1-D	PV3	54.613	55.923	53.115
	PV6	56.783	57.400	56.063
	PV9	54.513	55.182	53.749
	PV12	51.889	52.711	50.964
	P1	51.349	52.178	50.312
	P2	54.421	54.989	53.664
	P3	54.706	55.553	53.952
	P4	54.800	55.657	54.050
	P5	57.348	58.171	56.617
	PB1	56.973	57.782	55.933
	PB2	57.057	57.671	56.268
WQB1-G	PV3	54.800	55.923	53.115
	PV6	56.783	57.400	56.063
	PV9	54.418	55.182	53.749
	PV12	51.786	52.608	51.066
	P1	50.209	51.142	49.483
	P2	53.948	54.516	53.096
	P3	54.612	55.365	53.858
	P4	54.693	55.443	53.836
	P5	57.714	58.445	56.983
	PB1	56.973	58.014	55.933
	PB2	56.969	57.671	56.356
WQB5-A	PV3	54.613	55.923	51.992
	PV6	56.680	57.606	55.754
	PV9	54.418	55.278	53.462
	PV12	51.889	52.711	50.758
	P1	52.178	53.318	51.349
	P2	54.800	55.842	53.853
	P3	54.800	55.930	53.858
	P4	54.907	56.085	54.050
	P5	56.526	57.623	55.612
	PB1	56.858	58.361	54.892
	PB2	56.969	57.671	56.093

(Continued)

Table 6 (Continued)

Test No.	Transducer	Pressure, ft Mean	Maximum	Minimum
WQB5-D	PV3	54.426	55.923	52.741
	PV6	56.577	57.297	55.754
	PV9	54.227	55.182	53.271
	PV12	51.683	52.608	50.655
	P1	50.934	51.867	49.794
	P2	54.137	54.895	53.285
	P3	54.612	55.742	53.764
	P4	54.586	55.657	53.622
	P5	57.074	58.080	56.343
	PB1	56.742	58.361	54.661
	PB2	56.794	57.583	55.918
WQB5-G	PV3	54.426	55.736	52.928
	PV6	56.474	57.297	55.651
	PV9	54.131	55.182	53.175
	PV12	51.580	52.506	50.655
	P1	50.416	51.556	49.483
	P2	53.664	54.516	52.433
	P3	54.423	55.365	53.293
	P4	54.372	55.121	53.408
	P5	57.440	58.445	56.617
	PB1	56.511	58.245	54.892
	PB2	56.619	57.583	55.743
WQB7-A	PV3	54.051	56.110	51.431
	PV6	56.268	57.503	54.828
	PV9	54.035	55.373	52.698
	PV12	51.375	52.711	49.833
	P1	52.074	53.422	50.831
	P2	54.421	55.652	53.001
	P3	54.612	56.024	53.387
	P4	54.693	56.085	53.408
	P5	56.160	57.531	54.698
	PB1	56.164	58.245	54.430
	PB2	56.444	57.758	55.305
WQB7-D	PV3	53.490	55.174	51.618
	PV6	55.857	56.989	54.314
	PV9	53.462	54.800	51.933
	PV12	51.169	52.506	49.627
	P1	50.416	52.074	48.861
	P2	53.096	54.800	51.581
	P3	53.764	55.271	52.351
	P4	53.729	55.335	52.230
	P5	56.252	57.988	54.698
	PB1	55.701	57.436	53.967
	PB2	55.918	57.145	54.341

(Continued)

Table 6 (Continued)

Test No.	Transducer	Pressure, ft		
		Mean	Maximum	Minimum
WQB7-G	PV3	52.928	54.800	51.243
	PV6	55.343	56.577	53.903
	PV9	52.889	54.035	51.455
	PV12	50.450	51.683	49.010
	P1	49.276	50.831	48.032
	P2	52.338	53.474	51.202
	P3	53.199	54.329	51.880
	P4	53.194	54.372	51.909
	P5	56.343	57.623	55.063
	PB1	55.239	57.204	53.273
	PB2	55.480	56.619	54.165
WQB9-A	PV3	51.431	53.864	48.435
	PV6	53.491	55.034	51.845
	PV9	51.551	53.367	49.926
	PV12	49.216	50.655	47.366
	P1	49.691	51.971	48.032
	P2	51.486	52.717	50.066
	P3	52.163	53.293	50.750
	P4	52.230	53.515	50.624
	P5	52.961	54.698	51.407
	PB1	52.811	54.892	50.614
	PB2	53.552	55.042	52.062
WQB9-D	PV3	48.997	51.056	45.628
	PV6	50.919	53.182	47.936
	PV9	48.493	50.882	46.677
	PV12	47.674	49.524	46.132
	P1	45.545	47.410	42.746
	P2	47.225	48.835	45.331
	P3	48.208	50.091	46.512
	P4	47.411	51.159	44.948
	P5	50.310	51.773	48.756
	PB1	50.152	52.464	47.493
	PB2	50.573	52.588	48.207
WQB9-G	PV3	45.066	47.125	42.820
	PV6	48.245	49.891	46.290
	PV9	45.053	46.390	43.428
	PV12	43.151	45.721	41.403
	P1	41.606	42.850	39.533
	P2	44.479	45.615	42.775
	P3	45.476	46.607	44.252
	P4	45.269	46.661	43.984
	P5	48.391	49.762	46.928
	PB1	47.493	48.996	45.643
	PB2	48.119	49.784	43.825

(Continued)

Table 6 (Continued)

Test No.	Transducer	Pressure, ft		
		Mean	Maximum	Minimum
D5-H	PV3	49.933	51.805	47.874
	PV6	51.948	54.005	49.171
	PV9	49.831	52.984	47.824
	PV12	48.394	50.038	46.954
	P1	46.788	48.343	45.337
	P2	48.077	49.876	46.373
	P3	50.091	52.257	47.831
	P4	48.268	49.767	46.661
	P5	49.670	51.407	47.933
	PB1	50.499	52.695	47.955
	PB2	51.361	53.377	49.434
D3-H	PV3	39.076	43.943	35.145
	PV6	41.456	45.982	36.004
	PV9	38.554	42.281	34.636
	PV12	38.627	41.711	36.366
	P1	35.076	37.253	33.107
	P2	37.756	39.650	35.957
	P3	38.696	43.405	34.552
	P4	38.201	40.129	36.166
	P5	40.712	42.540	37.970
	PB1	40.787	42.984	37.665
	PB2	41.372	44.789	36.114
D2-H	PV3	3.509	8.750	-18.393
	PV6	9.567	16.973	-1.542
	PV9	3.674	11.414	-3.398
	PV12	3.983	11.179	-3.213
	P1	1.286	4.085	-1.720
	P2	2.911	5.846	-0.592
	P3	5.263	8.559	1.966
	P4	4.254	9.608	0.291
	P5	6.434	9.999	2.870
	PB1	6.912	19.398	-4.881
	PB2	8.775	17.187	-17.250
D7-B	PV3	52.937	54.241	51.447
	PV6	56.483	57.196	55.668
	PV9	54.042	54.800	53.189
	PV12	50.972	51.789	50.155
	P1	55.363	56.286	54.645
	P2	55.738	56.582	54.988
	P3	54.987	55.919	54.240
	P4	54.906	56.181	54.163
	P5	55.625	56.348	54.631
	PB1	56.634	57.320	55.605
	PB2	56.539	57.233	55.845

(Continued)

Table 6 (Continued)

Test No.	Transducer	Pressure, ft		
		Mean	Maximum	Minimum
D5-B	PV3	53.310	54.986	51.633
	PV6	56.891	57.706	56.076
	PV9	54.326	55.084	53.378
	PV12	51.279	51.994	50.359
	P1	54.748	55.568	54.030
	P2	55.363	56.301	54.988
	P3	54.987	55.919	54.427
	P4	55.012	55.968	54.375
	P5	56.348	57.252	55.716
	PB1	56.520	57.320	55.491
	PB2	56.886	57.494	56.192
D3-B	PV3	53.682	54.986	52.006
	PV6	56.993	57.706	56.178
	PV9	54.326	55.179	53.473
	PV12	51.483	52.300	50.462
	P1	54.235	55.568	53.518
	P2	55.081	56.019	54.425
	P3	54.893	55.826	54.240
	P4	54.906	55.862	54.163
	P5	56.800	57.704	56.167
	PB1	56.520	57.892	55.034
	PB2	56.886	57.580	56.192
D1-B	PV3	52.937	54.055	51.447
	PV6	55.872	56.585	54.853
	PV9	53.378	54.136	52.620
	PV12	50.359	50.972	49.338
	P1	52.697	53.723	51.775
	P2	53.675	54.519	52.830
	P3	53.867	54.613	52.935
	P4	54.163	55.012	53.207
	P5	56.167	57.071	55.354
	PB1	55.034	56.063	53.891
	PB2	55.671	56.279	54.630
F7-B	PV3	54.241	55.359	52.751
	PV6	57.298	58.113	56.483
	PV9	54.705	55.369	53.757
	PV12	51.994	52.606	51.177
	P1	55.568	56.491	54.953
	P2	56.113	56.770	55.363
	P3	55.266	56.013	54.520
	P4	55.225	56.075	54.694
	P5	55.896	56.619	55.083
	PB1	55.034	56.063	53.891
	PB2	55.671	56.279	54.630

(Continued)

Table 6 (Continued)

Test No.	Transducer	Pressure, ft Mean	Maximum	Minimum
F5-B	PV3	54.427	56.290	52.378
	PV6	57.298	58.419	56.381
	PV9	54.705	55.464	53.757
	PV12	51.994	52.709	51.074
	P1	54.850	55.773	54.133
	P2	55.738	56.582	55.081
	P3	55.173	56.106	54.427
	P4	55.225	56.287	54.375
	P5	56.529	57.342	55.896
	PB1	56.634	57.663	55.605
	PB2	57.146	57.841	56.365
F3-B	PV3	54.427	55.731	52.192
	PV6	57.196	58.011	56.279
	PV9	54.610	55.179	53.663
	PV12	51.891	52.709	50.870
	P1	54.235	55.055	53.518
	P2	55.175	56.207	54.519
	P3	54.987	56.013	54.147
	P4	55.119	56.181	54.375
	P5	56.890	57.884	56.258
	PB1	56.520	57.663	55.263
	PB2	57.060	57.754	56.279
F1-B	PV3	52.564	53.682	51.074
	PV6	55.566	56.279	54.751
	PV9	52.904	53.663	51.956
	PV12	50.155	50.972	49.236
	P1	52.185	53.723	51.262
	P2	53.112	53.956	52.362
	P3	53.308	54.054	52.561
	P4	53.313	54.163	52.569
	P5	55.625	56.348	54.902
	PB1	54.805	56.063	53.548
	PB2	55.411	56.018	54.630
D7-D	PV3	54.241	55.731	52.006
	PV6	57.196	58.113	56.178
	PV9	54.610	55.369	53.568
	PV12	51.994	52.913	50.666
	P1	56.080	57.413	55.260
	P2	56.019	57.051	55.175
	P3	55.173	56.386	54.427
	P4	55.225	56.393	54.375
	P5	55.896	56.890	54.993
	PB1	56.520	57.777	54.920
	PB2	57.060	57.927	56.018

(Continued)

Table 6 (Continued)

Test No.	Transducer	Pressure, ft		
		Mean	Maximum	Minimum
D5-D	PV3	54.055	55.359	52.378
	PV6	57.094	58.317	55.872
	PV9	54.516	55.558	53.283
	PV12	51.789	52.913	50.564
	P1	55.055	56.080	54.133
	P2	55.363	56.394	54.331
	P3	54.987	56.106	54.147
	P4	55.012	56.181	54.163
	P5	56.258	57.342	55.354
	PB1	56.406	57.892	54.691
	PB2	56.886	57.841	55.845
D3-D	PV3	53.496	55.173	51.819
	PV6	56.585	57.604	55.668
	PV9	53.947	54.990	52.809
	PV12	51.279	52.402	50.155
	P1	54.030	55.158	53.005
	P2	54.612	55.644	53.675
	P3	54.427	55.453	53.494
	P4	54.588	55.650	53.632
	P5	56.439	57.433	55.535
	PB1	55.834	57.206	54.234
	PB2	56.452	57.320	55.411
D1-D	PV3	48.839	50.329	46.976
	PV6	51.593	52.612	50.167
	PV9	49.018	50.155	47.786
	PV12	46.070	50.237	44.742
	P1	49.007	50.392	47.982
	P2	49.360	50.882	47.954
	P3	49.856	51.082	48.457
	P4	50.020	53.004	48.851
	P5	52.010	50.926	50.926
	PB1	50.576	52.176	48.976
	PB2	51.333	52.461	48.643
F7-D	PV3	54.427	56.104	52.564
	PV6	57.196	58.317	56.178
	PV9	54.610	55.558	53.473
	PV12	51.891	52.913	50.768
	P1	55.978	57.106	55.158
	P2	56.113	57.145	54.519
	P3	55.266	56.292	54.240
	P4	55.331	56.500	54.375
	P5	55.987	56.800	54.993
	PB1	56.520	57.892	54.577
	PB2	57.060	57.927	56.018

(Continued)

Table 6 (Continued)

Test No.	Transducer	Pressure, ft		
		Mean	Maximum	Minimum
F5-D	PV3	54.241	55.731	52.378
	PV6	57.196	58.317	56.178
	PV9	54.610	55.558	53.568
	PV12	51.891	52.811	50.870
	P1	55.260	56.388	54.440
	P2	55.550	56.767	54.612
	P3	55.080	56.106	53.961
	P4	55.119	56.287	54.269
	P5	56.439	57.613	55.535
	PB1	56.520	58.120	54.805
	PB2	57.060	58.014	56.018
F3-D	PV3	53.869	55.359	52.006
	PV6	56.789	57.807	55.872
	PV9	54.136	55.179	53.189
	PV12	51.585	52.402	50.462
	P1	54.338	55.260	53.313
	P2	54.800	55.738	53.956
	P3	54.613	55.826	53.774
	P4	54.694	55.862	53.738
	P5	56.619	57.704	55.716
	PB1	56.063	57.892	54.462
	PB2	56.626	57.580	55.758
F1-D	PV3	48.093	49.398	46.417
	PV6	51.084	52.306	49.862
	PV9	48.354	49.587	46.932
	PV12	45.968	47.295	44.333
	P1	48.289	49.212	47.162
	P2	48.704	49.829	47.485
	P3	48.924	50.043	47.898
	P4	48.958	50.126	47.895
	P5	51.107	52.372	50.022
	PB1	50.233	51.948	48.633
	PB2	50.899	52.287	48.816
D7-F	PV3	53.682	55.731	51.260
	PV6	56.687	58.317	55.464
	PV9	54.136	55.653	52.809
	PV12	51.381	53.117	49.747
	P1	55.773	57.106	54.645
	P2	55.457	56.676	54.237
	P3	54.800	56.199	53.681
	P4	54.906	56.500	53.738
	P5	55.535	56.710	54.270
	PB1	55.834	57.320	54.348
	PB2	56.539	57.754	55.151

(Continued)

Table 6 (Continued)

Test No.	Transducer	Pressure, ft		
		Mean	Maximum	Minimum
D5-F	PV3	53.310	55.173	51.260
	PV6	56.483	58.113	55.057
	PV9	53.852	55.179	52.430
	PV12	51.177	52.709	49.747
	P1	54.748	55.978	53.313
	P2	54.612	55.925	53.299
	P3	54.334	55.733	52.935
	P4	54.375	55.650	52.888
	P5	55.444	56.710	54.089
	PB1	55.377	57.206	53.777
	PB2	56.105	57.494	54.717
D3-F	PV3	51.633	53.310	49.584
	PV6	54.751	56.076	52.918
	PV9	51.956	53.283	50.629
	PV12	49.542	50.768	48.010
	P1	52.390	53.723	50.852
	P2	52.549	53.862	51.236
	P3	52.468	53.867	51.069
	P4	52.569	54.056	51.082
	P5	54.450	55.716	53.095
	PB1	53.777	55.491	52.176
	PB2	54.456	56.018	52.634
D1-F	PV3	32.072	37.661	27.415
	PV6	35.905	40.795	30.200
	PV9	32.714	37.927	28.448
	PV12	30.443	36.775	23.906
	P1	33.527	38.038	29.836
	P2	33.041	37.918	29.384
	P3	34.000	38.757	30.362
	P4	33.661	38.547	30.049
	P5	35.653	40.443	32.038
	PB1	33.888	39.603	29.430
	PB2	35.279	41.874	28.250
F7-F	PV3	54.055	55.918	52.006
	PV6	56.891	58.317	55.668
	PV9	54.326	55.653	52.999
	PV12	51.585	52.913	50.155
	P1	56.183	57.618	54.953
	P2	55.644	57.051	54.519
	P3	54.893	56.479	53.494
	P4	55.119	56.712	53.738
	P5	55.716	56.981	54.179
	PB1	55.948	57.777	54.120
	PB2	56.713	58.014	55.411

(Continued)

Table 6 (Continued)

Test No.	Transducer	Pressure, ft Mean	Maximum	Minimum
F5-F	PV3	53.682	55.359	51.633
	PV6	56.687	58.011	55.363
	PV9	54.136	55.369	52.715
	PV12	51.483	52.811	50.053
	P1	55.260	57.311	54.030
	P2	54.988	56.488	53.487
	P3	54.613	56.292	53.401
	P4	54.588	56.181	53.207
	P5	56.077	57.704	54.631
	PB1	55.834	57.777	53.891
	PB2	56.452	57.754	55.151
F3-F	PV3	52.378	54.055	50.515
	PV6	55.261	56.789	53.529
	PV9	52.620	54.136	51.293
	PV12	50.257	51.789	48.930
	P1	53.210	54.953	52.082
	P2	53.299	54.612	52.080
	P3	53.214	54.520	51.815
	P4	53.313	54.588	51.826
	P5	55.173	56.348	53.727
	PB1	54.577	56.177	52.291
	PB2	55.151	56.452	53.762
F1-F	PV3	31.513	35.984	27.788
	PV6	35.396	40.184	30.812
	PV9	32.240	36.316	29.207
	PV12	30.239	36.163	25.336
	P1	32.912	36.910	30.452
	P2	32.479	36.418	29.852
	P3	33.347	37.264	30.642
	P4	32.917	37.060	30.049
	P5	34.930	38.997	32.219
	PB1	33.888	39.375	28.973
	PB2	35.192	40.746	27.643
F7-H	PV3	52.192	53.869	50.143
	PV6	55.159	56.483	53.325
	PV9	52.620	54.231	50.724
	PV12	49.747	51.074	47.908
	P1	54.645	56.080	53.108
	P2	53.675	55.081	52.268
	P3	53.401	54.707	52.002
	P4	53.525	55.012	51.932
	P5	53.547	55.354	52.101
	PB1	53.548	55.263	51.948
	PB2	54.717	56.105	53.242

(Continued)

Table 6 (Continued)

Test No.	Transducer	Pressure, ft		
		Mean	Maximum	Minimum
F5-H	PV3	51.260	53.123	49.211
	PV6	54.344	56.279	52.510
	PV9	51.767	53.473	50.155
	PV12	49.338	50.768	47.602
	P1	52.903	54.748	51.467
	P2	52.080	53.675	50.486
	P3	52.468	54.054	50.696
	P4	51.613	53.100	50.126
	P5	52.462	54.089	50.835
	PB1	52.748	54.348	50.919
	PB2	53.675	55.151	52.027
F3-H	PV3	43.250	45.672	40.083
	PV6	45.481	50.167	35.701
	PV9	42.857	46.459	38.591
	PV12	42.086	45.048	39.839
	P1	43.676	45.829	41.728
	P2	43.452	45.609	41.670
	P3	43.514	46.032	41.182
	P4	43.115	45.346	41.309
	P5	44.871	46.859	42.973
	PB1	44.975	47.147	42.346
	PB2	45.605	50.465	41.353
F1-H	PV3	-1.647	-0.156	-3.323
	PV6	-2.093	-1.074	-2.908
	PV9	-1.221	-0.368	-2.074
	PV12	4.398	20.740	-2.956
	P1	3.592	6.770	2.055
	P2	0.309	1.529	-0.628
	P3	4.059	26.538	-0.139
	P4	-0.119	0.731	-0.969
	P5	-0.315	2.757	-1.400
	PB1	-1.431	3.027	-4.975
	PB2	-1.426	-0.472	-2.294
D7-J	PV3	47.907	50.143	45.299
	PV6	50.575	52.306	48.639
	PV9	48.733	51.388	45.511
	PV12	46.376	48.725	43.516
	P1	50.442	52.082	48.802
	P2	49.079	50.673	47.203
	P3	49.856	51.256	47.898
	P4	49.807	51.401	47.577
	P5	48.667	51.830	45.503
	PB1	48.062	49.776	46.118
	PB2	50.118	52.374	48.035

(Continued)

Table 6 (Continued)

Test No.	Transducer	Pressure, ft		
		Mean	Maximum	Minimum
D5-J	PV3	44.368	47.348	41.014
	PV6	47.417	50.677	41.610
	PV9	45.131	47.786	41.814
	PV12	44.742	46.887	42.903
	P1	46.136	48.597	43.779
	P2	42.795	46.359	39.700
	P3	45.659	49.110	42.581
	P4	42.159	44.284	39.291
	P5	41.617	44.058	39.268
	PB1	43.832	45.890	40.861
	PB2	45.953	48.382	43.436
D3-J	PV3	16.424	24.807	1.893
	PV6	18.485	32.747	-5.760
	PV9	14.894	25.889	1.054
	PV12	19.106	26.868	13.999
	P1	16.509	21.635	8.206
	P2	14.940	19.630	11.189
	P3	15.625	22.993	10.308
	P4	14.859	20.064	6.042
	P5	15.861	19.567	11.524
	PB1	17.314	23.715	7.713
	PB2	18.445	33.457	-3.509
D2-J	PV3	38.965	43.250	28.719
	PV6	42.221	46.092	36.618
	PV9	39.254	43.710	34.799
	PV12	40.044	41.882	37.797
	P1	40.088	45.316	34.962
	P2	37.262	39.419	33.885
	P3	38.104	42.861	33.347
	P4	36.423	43.328	31.324
	P5	38.454	40.172	36.195
	PB1	38.917	40.975	36.060
	PB2	40.833		34.932
D1-J	PV3	28.347	35.612	19.218
	PV6	34.275	39.573	27.959
	PV9	30.818	37.264	25.889
	PV12	31.260	34.018	28.196
	P1	30.657	35.577	25.633
	P2	28.915	32.010	23.663
	P3	29.616	34.373	22.620
	P4	28.456	32.599	23.888
	P5	30.321	33.484	27.519
	PB1	29.888	34.460	23.144
	PB2	32.069	37.796	25.908

(Continued)

Table 6 (Continued)

Test No.	Transducer	Pressure, ft		
		Mean	Maximum	Minimum
D0-J	PV3	20.895	28.160	-2.019
	PV6	24.088	37.841	3.714
	PV9	20.486	29.870	9.491
	PV12	23.293	30.341	17.472
	P1	21.840	28.504	16.612
	P2	20.005	25.163	16.347
	P3	20.661	28.497	14.039
	P4	19.745	25.482	15.709
	P5	21.193	25.531	17.398
	PB1	22.115	26.344	14.571
	PB2	23.131	35.366	6.470
F7-J	PV3	49.211	51.260	46.231
	PV6	52.816	54.853	50.677
	PV9	50.345	52.715	48.449
	PV12	47.397	49.338	45.661
	P1	52.492	54.440	51.160
	P2	50.955	52.643	49.173
	P3	51.162	52.841	49.763
	P4	51.401	53.313	49.914
	P5	50.926	52.914	48.757
	PB1	50.462	52.176	48.404
	PB2	52.027	53.762	49.771
F6-J	PV3	47.162	49.211	44.927
	PV6	50.778	53.223	47.519
	PV9	48.070	50.914	45.700
	PV12	46.376	47.908	44.538
	P1	49.827	52.082	47.879
	P2	47.766	49.454	45.890
	P3	48.737	51.349	46.405
	P4	47.152	49.064	44.602
	P5	48.034	49.751	46.136
	PB1	48.404	50.690	46.461
	PB2	49.771	51.680	47.862
F5-J	PV3	43.995	47.162	39.524
	PV6	48.130	51.593	42.527
	PV9	44.942	48.165	41.340
	PV12	43.618	45.457	42.086
	P1	46.239	49.007	43.676
	P2	44.577	46.172	42.701
	P3	44.820	47.431	41.182
	P4	43.859	47.046	39.716
	P5	45.865	47.582	43.967
	PB1	45.318	48.290	42.689
	PB2	46.647	48.816	43.436

(Continued)

Table 6 (Continued)

Test No.	Transducer	Pressure, ft Mean	Maximum	Minimum
F4-J	PV3	37.102	40.642	30.396
	PV6	40.388	47.722	29.487
	PV9	37.359	41.719	32.809
	PV12	37.490	40.759	34.937
	P1	38.653	43.676	35.065
	P2	37.543	39.700	35.386
	P3	37.544	42.115	34.559
	P4	37.167	39.185	34.723
	P5	38.997	41.075	36.014
	PB1	39.032	42.575	35.260
	PB2	40.052	47.862	33.283
F3-J	PV3	31.327	38.779	23.317
	PV6	34.275	41.101	25.820
	PV9	30.629	36.316	22.666
	PV12	31.771	36.877	28.502
	P1	32.092	35.782	29.119
	P2	31.259	34.542	28.258
	P3	31.575	36.052	28.310
	P4	31.112	33.661	28.668
	P5	32.671	36.014	29.327
	PB1	33.088	36.517	29.316
	PB2	33.891	41.961	27.383
F2-J	PV3	-1.460	4.874	-10.402
	PV6	5.751	12.475	-6.371
	PV9	0.106	8.258	-6.908
	PV12	0.619	9.301	-6.020
	P1	2.772	6.463	-1.226
	P2	0.685	5.374	-3.161
	P3	2.286	6.390	-1.725
	P4	1.156	6.786	-2.987
	P5	2.848	8.361	-1.219
	PB1	2.569	25.087	-12.861
	PB2	5.602	16.623	-17.567
B7-A	PV3	54.644	56.639	52.649
	PV6	57.102	58.056	55.958
	PV9	54.551	55.448	53.683
	PV12	51.681	52.767	50.532
	P1	54.768	55.872	53.826
	P2	55.947	56.895	55.146
	P3	55.206	56.395	54.077
	P4	55.052	56.211	54.091
	P5	55.402	56.309	54.466
	PB1	56.998	58.144	55.743
	PB2	57.079	58.176	56.009

(Continued)

Table 6 (Continued)

Test No.	Transducer	Pressure, ft		
		Mean	Maximum	Minimum
B1-A	PV3	51.123	52.825	49.305
	PV6	53.320	54.432	51.762
	PV9	50.721	51.649	49.734
	PV12	48.010	49.638	46.860
	P1	48.243	49.314	47.106
	P2	50.373	51.381	49.157
	P3	50.482	51.552	49.621
	P4	50.348	51.275	49.254
	P5	52.282	53.303	51.261
	PB1	52.805	54.023	51.479
	PB2	52.985	54.163	50.898
B7-B	PV3	54.527	56.346	52.590
	PV6	56.816	58.088	55.481
	PV9	54.341	55.508	52.965
	PV12	51.490	52.831	50.213
	P1	54.248	55.612	52.885
	P2	55.561	56.895	54.375
	P3	54.879	56.513	53.750
	P4	54.853	55.946	53.660
	P5	54.948	56.309	53.672
	PB1	56.424	58.108	55.027
	PB2	56.705	58.069	55.340
B2-B	PV3	48.952	51.241	46.899
	PV6	51.698	53.320	49.950
	PV9	48.806	50.302	47.520
	PV12	46.318	48.201	44.721
	P1	47.236	48.697	45.743
	P2	49.276	50.551	47.793
	P3	49.353	50.690	48.106
	P4	49.254	50.745	47.896
	P5	50.892	52.197	49.559
	PB1	51.229	52.769	49.473
	PB2	51.621	53.173	49.106
B1-B	PV3	37.569	41.501	33.932
	PV6	40.764	44.324	37.394
	PV9	37.796	41.117	35.014
	PV12	35.622	40.060	31.759
	P1	36.036	39.672	33.244
	P2	38.157	41.685	35.607
	P3	38.450	41.985	35.835
	P4	38.256	41.701	35.572
	P5	39.971	43.687	37.504
	PB1	40.228	44.456	36.072
	PB2	40.811	44.905	34.416

(Continued)

Table 6 (Continued)

Test No.	Transducer	Pressure, ft Mean	Maximum	Minimum
B7-C	PV3	53.236	55.465	51.299
	PV6	55.513	57.039	53.765
	PV9	53.085	54.730	51.619
	PV12	50.213	51.873	48.457
	P1	52.852	54.476	51.229
	P2	54.049	55.591	52.389
	P3	53.661	55.384	52.116
	P4	53.660	55.151	52.070
	P5	53.303	54.891	51.544
	PB1	54.382	56.173	52.554
	PB2	55.126	56.892	53.467
B3-C	PV3	46.957	49.422	40.562
	PV6	48.901	52.112	41.431
	PV9	46.443	48.866	43.541
	PV12	45.073	47.180	43.093
	P1	44.996	47.301	42.983
	P2	46.933	48.979	45.243
	P3	46.769	49.443	44.540
	P4	46.538	48.459	44.583
	P5	47.715	49.502	45.644
	PB1	48.864	51.229	46.463
	PB2	49.052	51.781	45.520
B2-C	PV3	33.403	38.450	28.123
	PV6	37.617	42.353	31.959
	PV9	33.638	38.185	28.223
	PV12	32.142	39.294	28.438
	P1	31.816	36.166	29.219
	P2	33.947	38.098	31.278
	P3	34.290	38.153	31.617
	P4	34.048	38.057	31.530
	P5	35.433	39.518	32.994
	PB1	36.358	40.945	32.847
	PB2	37.146	42.845	26.389
B1-C	PV3	0.076	9.523	-5.557
	PV6	1.984	23.949	-5.772
	PV9	-0.439	9.075	-5.406
	PV12	0.470	17.583	-11.407
	P1	-2.791	6.624	-7.498
	P2	-0.802	8.745	-4.686
	P3	0.065	9.423	-4.332
	P4	0.058	9.997	-3.950
	P5*	--	--	--
	PB1	2.784	17.833	-8.217
	PB2*	--	--	--

(Continued)

* Pressure transducer inoperative.

Table 6 (Continued)

Test No.	Transducer	Pressure, ft		
		Mean	Maximum	Minimum
B7-E	PV3	45.021	47.896	42.029
	PV6	47.312	49.759	44.197
	PV9	45.276	50.572	39.203
	PV12	42.295	45.456	38.591
	P1	44.217	46.165	41.847
	P2	44.650	46.844	42.308
	P3	46.145	48.046	43.857
	P4	45.941	48.161	43.689
	P5	43.205	49.303	39.830
	PB1	43.560	46.069	40.622
	PB2	45.841	50.096	42.390
B4-E	PV3	30.704	37.745	20.260
	PV6	34.470	40.923	22.868
	PV9	30.646	37.856	19.187
	PV12	31.727	34.856	28.183
	P1	27.920	35.484	22.141
	P2	28.017	31.367	23.125
	P3	28.170	33.518	22.080
	P4	25.965	35.108	19.869
	P5	27.519	30.554	24.144
	PB1	29.622	33.671	21.416
	PB2	31.393	37.199	23.312
B3-E	PV3	9.757	16.857	3.714
	PV6	12.506	21.596	-4.437
	PV9	5.993	14.281	-1.606
	PV12	10.942	16.689	6.249
	P1	4.481	7.987	1.072
	P2	7.085	11.502	2.074
	P3	6.898	11.028	1.372
	P4	7.247	11.587	2.675
	P5	7.040	12.373	2.530
	PB1	11.992	20.556	-0.011
	PB2	12.770	23.018	5.653
B2-E	PV3	-3.093	-0.687	-4.853
	PV6	-4.246	1.444	-5.835
	PV9	-2.144	1.745	-4.269
	PV12	2.131	9.985	-2.786
	P1	-2.369	2.923	-4.609
	P2	-2.344	-0.179	-3.559
	P3	1.461	22.704	-3.708
	P4	-2.625	-1.333	-3.851
	P5*	--	--	--
	PB1	-3.236	15.325	-14.129
	PB2*	--	--	--

(Continued)

* Pressure transducer inoperative.

Table 6 (Continued)

Test No.	Transducer	Pressure, ft Mean	Maximum	Minimum
B7-G	PV3	35.105	39.564	25.658
	PV6	37.776	42.258	25.951
	PV9	35.882	47.699	25.620
	PV12	33.259	39.326	27.960
	P1	34.251	38.211	23.959
	P2	33.413	37.831	25.912
	P3	36.964	41.332	22.080
	P4	36.632	40.939	24.176
	P5	31.292	38.411	24.314
	PB1	31.163	38.293	23.889
	PB2	34.871	42.336	30.349
B4-G	PV3	23.605	33.051	16.564
	PV6	26.746	40.923	3.192
	PV9	24.184	36.929	12.157
	PV12	26.012	33.259	19.275
	P1	21.882	35.484	14.350
	P2	17.492	29.559	7.707
	P3	24.070	36.370	12.573
	P4	15.662	28.218	8.672
	P5	11.663	28.512	5.877
	PB1	19.016	24.999	12.494
	PB2	22.938	35.861	15.687
B3-G	PV3	8.173	19.321	0.076
	PV6	14.031	21.151	6.530
	PV9	7.938	15.866	1.416
	PV12	13.082	17.775	8.101
	P1	4.903	11.948	-1.265
	P2	4.179	9.990	0.443
	P3	3.897	9.126	-2.253
	P4	1.681	7.380	-3.917
	P5	2.700	6.217	-0.335
	PB1	3.464	14.357	-4.777
	PB2	18.576	--	2.951
B2-G	PV3	-6.731	3.948	-17.820
	PV6*	--	--	--
	PV9**	--	--	--
	PV12**	--	--	--
	P1**	--	--	--
	P2**	--	--	--
	P3**	--	--	--
	P4**	--	--	--
	P5**	--	--	--
	PB1**	--	--	--
	PB2*	--	--	--

(Continued)

* Pressure transducer inoperative.
** Pressure transducer overranged.

Table 6 (Continued)

Test No.	Transducer	Pressure, ft Mean	Maximum	Minimum
B1-G	PV3	-7.669	-4.266	-11.131
	PV6*	--	--	--
	PV9**	--	--	--
	PV12	3.152	11.868	-2.435
	P1	-5.778	6.429	-11.004
	P2**	--	--	--
	P3**	--	--	--
	P4	-8.622	-6.269	-11.371
	P5**	--	--	--
	PB1	-9.256	-6.604	-12.087
	PB2*	--	--	--
G1-I	PV3	55.407	56.991	53.529
	PV6*	--	--	--
	PV9	54.700	55.628	53.773
	PV12	51.777	52.959	50.468
	P1	54.735	55.709	53.859
	P2	55.858	56.718	54.731
	P3	55.177	56.305	54.315
	P4	55.019	56.046	54.157
	P5	55.430	56.281	54.409
	PB1	56.818	58.359	55.600
	PB2*	--	--	--
G1-G	PV3	55.113	56.874	53.470
	PV6*	--	--	--
	PV9	54.581	55.478	53.534
	PV12	51.650	52.607	50.532
	P1	54.119	55.385	53.210
	P2	55.561	56.629	54.701
	P3	55.177	56.246	54.285
	P4	55.019	55.980	54.124
	P5	56.054	56.905	55.118
	PB1	56.783	58.180	55.457
	PB2*	--	--	--
G1-D	PV3	55.231	56.756	53.823
	PV6*	--	--	--
	PV9	54.640	55.568	53.653
	PV12	51.681	52.703	50.692
	P1	53.242	54.411	52.171
	P2	55.116	56.095	54.079
	P3	54.998	56.098	53.988
	P4	54.853	55.880	53.826
	P5	56.508	57.444	55.685
	PB1	56.639	58.287	55.457
	PB2*	--	--	--

(Continued)

* Pressure transducer inoperative.
** Pressure transducer overranged.

Table 6 (Continued)

Test No.	Transducer	Pressure, ft Mean	Maximum	Minimum
G1-A	PV3	55.172	56.580	53.646
	PV6*	--	--	--
	PV9	54.670	55.628	53.623
	PV12	51.618	52.575	50.596
	P1	52.917	54.021	51.814
	P2	54.968	56.125	53.931
	P3	55.028	56.068	54.107
	P4	54.919	55.980	53.892
	P5	57.075	57.955	56.168
	PB1	56.783	58.287	55.421
	PB2*	--	--	--
WQST-1	PV3	53.940	55.641	52.180
	PV6*	--	--	--
	PV9	53.444	54.850	51.948
	PV12	50.404	51.713	48.712
	P1	53.080	54.508	51.651
	P2	54.435	55.887	52.922
	P3	53.958	55.384	52.503
	P4	53.760	54.953	52.203
	P5	53.842	55.033	52.537
	PB1	54.919	56.424	53.343
	PB2*	--	--	--
G2-I	PV3	55.172	56.874	53.529
	PV6*	--	--	--
	PV9	54.551	55.867	53.414
	PV12	51.522	52.895	49.989
	P1	54.151	55.515	52.852
	P2	55.680	57.192	54.524
	P3	54.998	56.484	53.750
	P4	54.820	56.311	53.395
	P5	55.288	56.650	53.672
	PB1	56.603	58.037	55.063
	PB2*	--	--	--
G2-G	PV3	54.937	57.050	53.177
	PV6*	--	--	--
	PV9	54.461	55.837	53.174
	PV12	51.490	52.927	50.277
	P1	53.469	54.735	52.008
	P2	55.116	56.391	53.664
	P3	54.850	56.276	53.453
	P4	54.621	55.880	53.296
	P5	55.771	57.019	54.437
	PB1	56.424	57.965	54.776
	PB2*	--	--	--

(Continued)

* Pressure transducer inoperative.

Table 6 (Continued)

Test No.	Transducer	Pressure, ft Mean	Maximum	Minimum
G2-D	PV3	54.820	56.346	53.236
	PV6*	--	--	--
	PV9	54.281	55.478	53.085
	PV12	51.394	52.735	50.053
	P1	53.015	54.378	51.814
	P2	54.790	56.036	53.664
	P3	54.671	55.890	53.513
	P4	54.522	55.748	53.263
	P5	56.253	57.557	54.948
	PB1	56.281	57.822	54.561
	PB2*	--	--	--
G2-A	PV3	54.820	56.991	53.236
	PV6*	--	--	--
	PV9	54.281	55.688	52.815
	PV12	51.266	52.990	49.766
	P1	52.430	53.859	50.970
	P2	54.494	56.243	52.804
	P3	54.642	56.216	53.424
	P4	54.555	56.013	53.097
	P5	56.536	57.983	55.061
	PB1	56.388	58.717	54.633
	PB2*	--	--	--
G3-I	PV3	54.292	56.170	52.062
	PV6*	--	--	--
	PV9	53.743	55.209	52.337
	PV12	50.756	52.033	49.000
	P1	53.339	54.930	51.943
	P2	54.820	56.510	53.456
	P3	54.315	55.741	52.919
	P4	54.191	55.847	52.733
	P5	54.296	55.856	52.877
	PB1	55.313	56.962	53.522
	PB2*	--	--	--
G3-G	PV3	53.764	55.583	51.769
	PV6*	--	--	--
	PV9	53.234	55.059	51.649
	PV12	50.628	52.512	49.032
	P1	52.073	53.859	50.580
	P2	53.575	55.650	51.944
	P3	53.691	55.355	51.790
	P4	53.064	54.555	51.308
	P5	53.842	55.345	52.452
	PB1	54.812	56.639	53.235
	PB2*	--	--	--

(Continued)

* Pressure transducer inoperative.

Table 6 (Continued)

Test No.	Transducer	Pressure, ft Mean	Maximum	Minimum
G3-D	PV3	53.470	55.348	51.417
	PV6*	--	--	--
	PV9	52.606	54.521	50.990
	PV12	50.021	51.681	48.106
	P1	50.385	52.008	48.632
	P2	52.448	54.108	50.728
	P3	52.295	53.899	50.661
	P4	52.070	53.826	50.414
	P5	53.842	55.402	52.367
	PB1	54.167	56.138	52.304
	PB2*	--	--	--
G3-A	PV3	53.177	55.172	50.771
	PV6*	--	--	--
	PV9	52.456	54.192	50.751
	PV12	49.319	51.011	47.722
	P1	50.450	52.073	48.502
	P2	52.537	54.197	50.639
	P3	52.651	54.285	50.869
	P4	52.733	54.555	50.745
	P5	54.664	56.224	53.019
	PB1	54.274	56.102	52.339
	PB2*	--	--	--
G4-I	PV3	53.118	55.289	50.126
	PV6*	--	--	--
	PV9	52.486	53.952	50.452
	PV12	49.702	51.426	47.595
	P1	52.203	53.599	50.775
	P2	53.426	54.850	51.855
	P3	53.156	54.612	51.760
	P4	53.031	54.588	51.607
	P5	52.735	54.381	51.204
	PB1	53.701	55.493	51.874
	PB2*	--	--	--
G4-G	PV3	51.652	53.940	49.657
	PV6*	--	--	--
	PV9	51.260	53.115	49.704
	PV12	49.000	50.851	46.988
	P1	50.418	52.008	48.794
	P2	51.440	53.456	49.750
	P3	51.998	53.869	50.304
	P4	50.745	52.302	48.989
	P5	51.090	52.679	49.502
	PB1	52.411	54.274	50.440
	PB2*	--	--	--

(Continued)

* Pressure transducer inoperative.

Table 6 (Concluded)

Test No.	Transducer	Pressure, ft		
		Mean	Maximum	Minimum
G4-D	PV3	50.185	52.473	47.544
	PV6*	--	--	--
	PV9	49.674	51.679	47.849
	PV12	47.435	49.351	45.392
	P1	48.210	49.833	46.392
	P2	50.165	52.329	48.445
	P3	50.096	51.760	48.492
	P4	49.784	51.308	47.929
	P5	51.317	53.133	49.445
	PB1	51.587	53.665	49.688
	PB2*	--	--	--
G4-A	PV3	50.595	53.001	48.190
	PV6*	--	--	--
	PV9	49.854	51.978	48.118
	PV12	46.892	49.159	44.945
	P1	47.885	49.801	46.327
	P2	50.017	51.855	48.238
	P3	50.156	51.998	48.670
	P4	50.248	52.004	48.658
	P5	52.026	53.785	50.239
	PB1	51.802	53.737	49.867
	PB2*	--	--	--

* Pressure transducer inoperative.

Table 7

Cavitation Index Values

Valve Opening deg	C_Q	V fps	H_u ft	H_v ft	ΔH ft	H_d ft	Prototype c_i	Model c_i
90	1.30	21.60	44.9	-33.0	5.60	39.30	12.90	16.6
70	0.90	20.80	45.04		10.00	35.00	6.80	9.3
60	0.60	20.30	45.71		23.70	22.00	2.37	6.7
50	0.45	18.30	47.27		47.30	0.00	0.70	4.4
45	0.30	17.00	49.60		68.60	-19.00	0.20	--*
40	0.17	6.70	--*		--*	--*	--*	2.6

* Data not available for this valve opening.

Table 8

Valve Shaft Torque Data

QC Gate Opening percent	Butterfly Valve Opening deg	Single Valve: Maximum Strain μin./in.	Single Valve: Maximum Torque in.-lb	Multiple Valves: Maximum Strain μin./in.	Multiple Valves: Maximum Torque in.-lb
5	90	22.83	8,575	18.75	7,043
	70	--	--	6.79	2,551
	45	--	--	6.79	2,551
	15	11.682	6,063	12.76	4,793
10	90	23.10	8,676	21.90	11,365
	70	--	--	13.54	7,027
	45	--	--	12.75	4,785
	15	17.52	6,581	10.75	4,038
20	90	24.16	9,074	22.70	8,526
	70	--	--	13.67	5,135
	45	32.92	12,365	13.27	4,984
	15	30.28	11,375	10.89	4,090
50	90	25.48	9,570	23.50	8,827
	70	--	--	16.59	6,231
	45	78.19	29,368	17.25	6,479
	15	65.98	24,782	12.35	4,639
70	90	31.86	11,967	23.36	8,774
	70	88.15	33,110	21.11	7,929
	45	100.36	37,696	21.77	8,177
	15	--	--	13.81	5,187

Table 9

Butterfly Valve Leaf Accelerations

	Accelerometer A1			Accelerometer A2		
Test No.	Accel P-P g's	Freq Hz	d 10^{-3} ft	Accel P-P g's	Freq Hz	d 10^{-3} ft
WQB1-A	0.045	80	0.006	0.049	80	0.006
WQB1-D	0.046	80	0.006	0.058	80	0.007
WQB1-G	0.058	80	0.007	0.058	80	0.007
WQB5-A	0.052	80	0.007	0.062	80	0.008
WQB5-D	0.068	80	0.009	0.068	80	0.009
WQB5-G	0.097	55	0.026	0.075	55	0.020
WQB7-A	0.052	48	0.018	0.075	48	0.027
WQB7-D	0.094	58	0.023	0.087	58	0.021
WQB7-G	0.133	75	0.019	0.119	75	0.017
WQB9-G	0.051	82	0.006	0.061	80	0.008
WQB9-D	0.100	80	0.013	0.104	80	0.013
WQB9-G	0.153	82	0.019	0.132	82	0.016
D5-H	0.075	80	0.010	0.078	80	0.010
D3-H	0.084	52	0.025	0.071	52	0.021
D1-H	0.917	65	0.177	1.087	65	0.210
D7-B	0.075	40	0.038	0.087	90	0.009
D5-B	0.084	45	0.034	0.064	45	0.026
D3-B	0.081	78	0.011	0.061	78	0.008
D1-B	0.071	84	0.008	0.078	84	0.009
F7-B	0.068	78	0.009	0.072	78	0.010
F5-B	0.071	65	0.014	0.061	78	0.008
F3-B	0.097	78	0.013	0.072	78	0.010
F1-B	0.104	84	0.012	0.103	84	0.012
D7-D	0.065	120	0.004	0.071	120	0.004
D5-D	0.057	89	0.009	0.081	89	0.008
D3-D	0.113	85	0.013	0.097	68	0.017
D1-D	0.197	85	0.022	0.184	84	0.021
F7-D	0.071	48	0.025	0.071	48	0.025
F5-D	0.087	88	0.009	0.090	88	0.010
F3-D	0.116	84	0.013	0.097	84	0.011
F1-D	0.182	84	0.021	0.177	84	0.020

(Continued)

Note: Accel P-P = greatest peak-to-peak acceleration; Freq = predominant frequency; d = displacement.

Table 9 (Continued)

	Accelerometer A1			Accelerometer A2		
Test No.	Accel P-P g's	Freq Hz	d 10^{-3} ft	Accel P-P g's	Freq Hz	d 10^{-3} ft
D7-F	0.075	47	0.028	0.081	47	0.030
D5-F	0.084	120	0.005	0.090	70	0.015
D3-F	0.136	70	0.023	0.133	70	0.022
D1-F	1.457	51	0.456	1.302	51	0.408
F7-F	0.091	58	0.022	0.090	47	0.033
F5-F	0.127	58	0.031	0.129	58	0.031
F3-F	0.195	58	0.047	0.165	58	0.040
F1-F	0.837	75	0.121	2.850	75	0.413
F7-H	0.084	47	0.031	0.090	47	0.033
F5-H	0.129	68	0.023	0.107	68	0.019
F3-H	0.278	79	0.036	0.174	79	0.023
F1-H	0.706	57	0.261	0.588	79	0.077
D7-J	0.078	50	0.025	0.087	50	0.028
D5-J	0.119	48	0.042	0.110	48	0.039
D3-J	2.000	50	0.652	1.900	50	0.620
D2-J	0.197	48	0.070	0.178	48	0.063
D1-J	1.113	50	0.363	3.312	50	1.081
D0-J	2.240	32	1.784	4.533	32	3.608
F7-J	0.078	50	0.025	0.084	50	0.027
F6-J	0.126	48	0.045	0.123	48	0.044
F5-J	0.178	48	0.063	0.171	48	0.060
F4-J	0.434	49	0.147	0.307	49	0.949
F3-J	1.246	50	0.406	2.911	50	0.950
F2-J	2.224	48	0.783	3.651	48	1.292
B7-A	0.051	47	0.019	0.052	47	0.019
B1-A	0.071	47	0.026	0.070	47	0.026
B7-B	0.059	78	0.008	0.062	78	0.008
B2-B	0.166	76	0.023	0.129	76	0.018
B1-B	0.174	82	0.021	0.170	82	0.021
B7-C	0.073	47	0.027	0.076	47	0.036
B3-C	0.160	78	0.021	0.140	78	0.019
B2-C	0.231	83	0.027	0.201	83	0.024
B1-C	1.075	53	0.312	0.922	53	0.268
B7-E	0.095	45	0.038	0.089	45	0.036
B4-E	0.830	45	0.334	2.580	45	1.039
B3-E	2.332	30	2.113	4.090	22	6.892
B2-E	0.894	54	0.250	0.762	54	0.213

(Continued)

Table 9 (Concluded)

Test No.	Accelerometer A1 Accel P-P g's	Freq Hz	d 10^{-3} ft	Accelerometer A2 Accel P-P g's	Freq Hz	d 10^{-3} ft
B7-G	0.371	45	0.149	0.464	45	0.187
B4-G	1.579	19	3.567	4.120	30	3.734
B3-G	2.521	18	6.346	3.817	49	1.297
B2-G	1.630	49	0.554	2.840	49	0.964
B1-G	1.860	49	0.632	1.830	49	0.622
G1-I	0.063	48	0.022	0.053	48	0.019
G1-G	0.074	78	0.010	0.073	78	0.010
G1-D	0.091	58	0.022	0.083	58	0.020
G1-A	0.102	58	0.025	0.090	58	0.022
WQST-1	0.060	78	0.008	0.063	78	0.008
G2-I	0.074	45	0.030	0.072	45	0.029
G2-G	0.074	78	0.010	0.073	78	0.010
G2-D	0.109	58	0.026	0.117	58	0.028
G2-A	0.129	46	0.050	0.109	41	0.053
G3-I	0.075	78	0.010	0.069	46	0.027
G3-G	0.096	78	0.013	0.079	78	0.010
G3-D	0.126	41	0.061	0.098	41	0.048
G3-A	0.148	78	0.020	0.129	78	0.017
G4-I	0.056	45	0.023	0.061	45	0.025
G4-G	0.083	45	0.033	0.072	45	0.029
G4-D	0.121	45	0.049	0.110	45	0.044
G4-A	0.146	45	0.059	0.140	45	0.056

(Sheet 3 of 3)

Table 10

Warm Springs Sample Port Temperature Comparison to Reservoir Temperature Profile and Water Quality Intake Temperature

El	Sample Port Temper-ature °F	Δt_p , °F*	Pool Profile °F	Δt_i , °F*	Intake Temper-ature °F
430.0	70.5	-0.2	70.7	0.5	71.2
410.0	61.2	-1.0	62.2		
390.0	57.4	0.6	56.8	0.2	57.0
370.0	54.4	0.7	53.8		
350.0	54.1	1.6	52.5	0.7	53.2
330.0	54.0	1.7	52.3		
310.0	53.8	1.6	52.2		
290.0	54.1	2.3	51.8		
270.0	66.0	14.4	51.6		
255.0	52.9	1.3	51.6		
230.0	52.5	0.9	51.6		

* Δt = Difference between sample port temperature (subscript p) or intake temperature (subscript i) and pool profile.

Table 11

Water Quality Measurement Test Conditions

Test No.	Butterfly Valve Opening, deg 1	2	3	4*	QC Valve Opening percent
1	15	0	0	0	5
2	30	0	0	0	5
3	90	0	90	0	10
4	90	0	90	0	20
5	90	0	90	0	30
6	90	0	90	0	50
7	90	0	90	0	0
8	90	0	90	0	5
9	30	0	90	0	5
10	20	0	90	0	5
11	10	0	90	0	5
12	5	0	90	0	5
13	90	0	60	0	5
14	90	0	45	0	5
15	90	0	30	0	5
16	90	0	15	0	5
17	90	0	90	0	10
18	10	0	90	0	10
19	90	0	60	0	10
20	90	0	45	0	10
21	90	0	30	0	10
22	90	0	15	0	10
23	90	0	90	0	20
24	90	0	60	0	20
25	90	0	45	0	20
26	90	0	30	0	20
27	90	0	15	0	20
28	90	0	60	0	50
29	90	0	30	0	50
30	90	90	0	0	5
31	90	60	0	0	5
32	90	30	0	0	5
33	90	90	0	0	10
34	90	60	0	0	10
35	90	30	0	0	10

(Continued)

* Butterfly valve 4 refers to the 30-in.-diam wet well filling valve at el 272.0

Table 11 (Concluded)

Test No.	Butterfly Valve Opening, deg 1	2	3	4	QC Valve Opening percent
36	90	90	0	0	20
37	90	60	0	0	20
38	90	30	0	0	20
39	90	90	0	0	50
40	90	60	0	0	50
41	90	30	0	0	50
42	90	0	90	0	0
43	90	0	0	0	5
44	10	0	0	90	5
45	18	90	0	0	20

Table 12

Water Quality Temperature Tests

Thermistor Location	Temperature, °F				
	Test 1	Test 2	Test 3	Test 4	Test 5
A-2	72.0	72.2	72.1	72.1	72.0
A-3	77.0	77.2	77.1	77.1	77.0
A-4	71.9	72.2	72.0	72.0	71.8
A-5	71.8	72.0	71.8	71.8	71.7
A-6	71.7	72.0	71.9	71.9	71.8
A-7	71.5	72.4	72.2	72.2	72.0
A-8	64.8	71.7	71.7	71.8	71.7
A-9	67.3	71.9	71.9	71.9	71.7
A-10	70.8	72.0	71.9	71.9	71.8
A-11	71.1	72.1	72.0	72.0	71.9
A-12	70.7	72.0	71.9	71.9	71.8
B-1	69.9	72.0	71.9	71.9	71.8
B-2	71.0	71.9	71.9	71.8	71.7
B-3	70.9	71.9	71.8	71.8	71.8
B-4	53.6	72.0	71.9	71.9	71.8
B-5	53.8	72.0	71.9	71.9	71.9
B-6	53.6	53.7	53.8	53.7	53.7
B-7	53.9	53.9	53.9	53.9	53.8
C-1	60.5	60.3	60.2	62.5	62.0
C-2	59.5	59.8	59.8	61.0	61.2
C-3	60.5	60.0	60.2	62.5	63.2
C-4	59.4	59.8	59.4	61.0	60.5
C-5	60.0	60.4	60.2	61.8	62.3
C-6	59.5	59.9	60.0	61.0	60.3
C-7	60.5	60.8	60.2	62.5	63.0
C-8	60.3	59.8	60.4	61.0	62.0
C-9	59.8	60.5	60.2	61.3	62.5
C-10	60.1	60.0	60.1	61.2	61.5
C-11	59.8	59.8	60.2	61.7	60.5
C-12	59.5	59.5	60.1	61.2	62.0

(Continued)

Note: See Table 11 for test conditions. See Plate 4 for thermistor location.

Table 12 (Continued)

Thermistor Location	Temperature, °F				
	Test 6	Test 7	Test 8	Test 9	Test 10
A-2	71.8	70.9	71.2	71.3	71.3
A-3	76.8	68.5	71.0	71.1	71.1
A-4	71.7	73.4	76.1	76.2	76.2
A-5	71.6	66.5	70.7	70.8	70.8
A-6	71.7	64.8	71.0	71.0	71.0
A-7	71.8	61.4	71.0	71.0	71.0
A-8	71.6	60.0	70.4	70.5	70.5
A-9	71.6	58.5	71.1	71.2	71.2
A-10	71.7	56.7	68.9	69.1	69.5
A-11	71.8	55.5	70.6	70.7	70.8
A-12	71.7	55.7	70.7	70.7	70.8
B-1	71.7	55.3	70.8	70.7	70.8
B-2	71.6	55.6	70.5	70.6	70.7
B-3	71.6	55.4	70.0	70.1	69.8
B-4	71.7	55.0	56.0	56.0	56.0
B-5	71.7	55.2	58.0	57.0	57.0
B-6	53.9	55.5	53.4	53.4	53.4
B-7	53.8	54.0	53.4	53.4	53.4
C-1	62.0	54.0	53.8	53.8	53.5
C-2	62.8	54.2	53.6	53.8	53.7
C-3	62.5	54.2	63.6	53.8	53.8
C-4	61.5	54.3	53.5	53.7	53.7
C-5	62.0	54.0	53.4	53.4	53.2
C-6	60.5	53.7	52.8	52.8	52.8
C-7	62.3	54.9	53.9	54.0	53.9
C-8	61.2	54.2	53.7	53.8	53.6
C-9	61.9	54.8	53.8	53.9	53.9
C-10	61.5	54.2	53.6	53.7	53.5
C-11	62.0	54.6	53.5	53.5	53.4
C-12	61.5	53.9	53.3	53.4	53.2

(Continued)

Table 12 (Continued)

Thermistor Location	Temperature, °F				
	Test 11	Test 12	Test 13	Test 14	Test 15
A-2	71.2	71.2	71.2	71.2	71.3
A-3	71.2	71.2	71.2	71.1	71.3
A-4	76.2	76.2	76.3	76.3	76.5
A-5	70.9	70.9	71.1	71.1	71.2
A-6	71.0	71.0	71.1	71.1	71.2
A-7	71.1	71.0	71.2	71.2	71.3
A-8	70.6	70.6	70.8	70.9	71.1
A-9	71.1	71.2	71.2	71.0	71.0
A-10	69.6	69.7	69.3	70.9	71.1
A-11	70.7	70.8	70.9	71.1	71.2
A-12	76.8	70.8	71.0	71.2	71.3
B-1	70.7	70.8	71.1	71.2	71.3
B-2	70.7	70.7	70.9	71.1	71.2
B-3	70.2	70.2	70.4	70.7	70.9
B-4	53.3	55.0	68.8	71.1	71.3
B-5	53.4	57.0	68.3	71.1	71.3
B-6	53.5	53.3	53.7	53.1	53.2
B-7	53.9	53.4	53.6	53.7	53.7
C-1	53.9	53.3	56.1	61.0	64.0
C-2	53.4	53.5	56.1	60.5	64.5
C-3	53.8	53.5	56.2	60.8	64.0
C-4	53.7	53.5	56.0	60.5	64.0
C-5	53.2	53.2	56.0	60.7	63.5
C-6	52.8	52.5	56.1	59.6	63.2
C-7	53.9	53.8	56.2	61.0	64.0
C-8	53.6	53.5	56.0	60.4	64.5
C-9	53.9	53.8	56.1	60.5	64.2
C-10	53.5	53.4	56.0	60.8	64.1
C-11	53.4	53.2	55.9	60.2	64.0
C-12	53.2	53.0	55.7	60.0	64.0

(Continued)

Table 12 (Continued)

Thermistor Location	Temperature, °F				
	Test 16	Test 17	Test 18	Test 19	Test 20
A-2	71.3	71.3	71.3	71.3	71.3
A-3	71.1	71.3	71.4	71.3	71.3
A-4	76.1	76.5	76.5	76.5	76.5
A-5	70.8	71.3	71.3	71.2	71.3
A-6	70.9	71.2	71.3	71.2	71.3
A-7	70.9	71.3	71.3	71.2	71.3
A-8	70.8	71.2	71.1	71.2	71.2
A-9	70.9	71.2	71.2	71.1	71.2
A-10	70.9	71.2	71.2	71.2	71.3
A-11	70.8	71.3	71.3	71.3	71.3
A-12	70.9	71.3	71.3	71.3	71.4
B-1	70.9	71.3	71.3	71.3	71.3
B-2	70.8	71.2	71.2	71.2	71.3
B-3	70.6	71.0	70.9	71.0	71.1
B-4	70.9	71.3	63.0	71.2	71.3
B-5	70.8	71.3	64.0	71.2	71.3
B-6	54.1	53.3	53.6	53.1	53.1
B-7	67.0	53.5	53.6	53.4	53.5
C-1	67.0	60.0	54.3	61.0	63.5
C-2	69.0	59.0	54.8	60.8	64.0
C-3	68.5	60.1	54.8	61.5	63.0
C-4	68.7	60.0	54.9	61.0	63.5
C-5	66.3	59.2	54.1	61.0	64.0
C-6	68.5	58.2	53.8	60.0	62.5
C-7	68.0	59.3	54.9	61.1	64.0
C-8	68.0	59.0	54.8	60.9	63.0
C-9	68.0	60.1	54.9	61.0	63.0
C-10	67.8	59.1	54.7	61.0	63.5
C-11	68.0	59.6	54.9	60.7	62.5
C-12	68.0	59.0	54.5	60.7	63.5

(Continued)

Table 12 (Continued)

Thermistor Location	Temperature, °F				
	Test 21	Test 22	Test 23	Test 24	Test 25
A-2	71.3	71.3	71.5	71.5	71.5
A-3	71.0	71.0	76.6	71.6	71.5
A-4	76.1	75.9	71.4	76.7	76.7
A-5	70.8	71.5	71.4	71.5	71.5
A-6	70.8	70.5	71.4	71.4	71.4
A-7	70.9	70.6	71.5	71.5	71.4
A-8	70.8	70.6	71.3	71.5	71.5
A-9	70.9	70.6	71.4	71.4	71.4
A-10	70.9	70.6	71.5	71.4	71.5
A-11	70.8	70.6	71.5	71.5	71.5
A-12	70.9	70.7	71.5	71.6	71.5
B-1	70.8	70.7	71.5	71.5	71.5
B-2	70.8	70.6	71.2	71.5	71.5
B-3	70.6	70.4	71.5	71.3	71.2
B-4	70.8	70.6	71.5	71.5	71.4
B-5	70.9	70.6	53.5	71.5	71.4
B-6	53.1	53.7	53.6	53.4	53.3
B-7	53.5	56.8	62.0	53.7	53.7
C-1	66.0	68.0	61.0	62.0	64.0
C-2	65.5	68.0	62.5	62.5	64.0
C-3	66.0	69.9	60.8	61.5	64.5
C-4	66.0	67.0	61.2	62.0	64.0
C-5	66.0	69.5	60.0	62.5	65.0
C-6	65.0	66.0	61.6	61.5	63.0
C-7	66.8	69.4	60.2	62.8	64.5
C-8	65.2	68.0	61.3	62.3	63.0
C-9	66.3	68.5	61.3	62.8	64.0
C-10	66.0	68.0	61.2	62.0	64.5
C-11	65.5	69.0	61.0	62.0	63.8
C-12	65.8	68.5	61.1	62.0	64.0

(Continued)

Table 12 (Continued)

Thermistor Location	Temperature, °F				
	Test 26	Test 27	Test 28	Test 29	Test 30
A-2	71.0	71.3	71.4	70.6	71.3
A-3	76.2	70.9	71.5	68.0	70.8
A-4	70.8	76.0	76.6	74.8	76.2
A-5	70.7	70.7	71.4	69.2	70.9
A-6	70.7	70.6	71.4	69.1	70.8
A-7	70.8	70.7	71.4	69.1	70.7
A-8	70.7	70.8	71.5	69.3	70.8
A-9	70.7	70.5	71.3	69.1	57.2
A-10	70.7	70.5	71.4	69.1	57.1
A-11	70.8	70.5	71.4	69.2	58.8
A-12	70.7	70.6	71.5	69.3	62.8
B-1	70.7	70.6	71.4	69.1	59.5
B-2	70.5	70.5	71.4	69.1	61.5
B-3	70.7	70.4	71.2	69.0	60.3
B-4	70.7	70.6	71.4	69.1	60.8
B-5	53.3	70.6	71.4	69.2	61.5
B-6	53.7	53.7	53.4	54.3	60.7
B-7	66.0	56.0	53.7	53.9	60.9
C-1	66.5	69.5	62.0	65.0	61.8
C-2	67.5	67.5	63.5	65.0	62.0
C-3	65.5	69.0	63.0	65.0	61.9
C-4	65.5	66.9	63.0	65.5	61.8
C-5	64.8	69.9	62.1	65.8	61.9
C-6	66.5	66.5	61.8	64.0	61.0
C-7	66.0	69.7	62.5	66.0	62.0
C-8	66.2	68.1	63.0	65.1	61.8
C-9	66.2	68.2	62.5	65.0	61.8
C-10	65.8	68.5	62.5	65.2	61.9
C-11	66.0	68.5	62.0	65.0	61.5
C-12	66.0	68.5	62.5	65.0	61.4

(Continued)

Table 12 (Continued)

Thermistor Location	Temperature, °F				
	Test 31	Test 32	Test 33	Test 34	Test 35
A-2	71.5	71.4	71.4	71.3	71.2
A-3	71.2	71.1	71.3	71.0	70.7
A-4	76.4	76.5	76.5	76.1	75.8
A-5	71.2	71.2	71.3	70.8	70.3
A-6	71.1	71.1	71.2	70.8	70.4
A-7	71.1	71.2	71.3	70.8	70.3
A-8	71.2	71.3	71.4	70.9	70.4
A-9	57.2	57.2	57.3	57.2	57.2
A-10	57.1	57.0	57.0	56.9	57.0
A-11	61.3	65.9	61.0	63.0	67.0
A-12	63.4	67.0	65.0	64.0	67.2
B-1	61.8	64.8	61.8	63.0	66.0
B-2	63.3	68.0	65.0	64.5	67.9
B-3	62.3	65.8	62.0	63.5	66.1
B-4	62.0	65.5	62.3	63.0	66.1
B-5	63.2	67.0	64.8	64.2	68.0
B-6	61.6	65.6	63.3	64.3	66.9
B-7	62.2	66.2	63.1	64.3	66.8
C-1	61.9	66.5	62.8	64.9	67.0
C-2	62.5	67.0	63.0	63.9	66.5
C-3	62.0	66.6	63.0	63.7	66.8
C-4	62.0	66.2	63.0	63.8	66.9
C-5	62.0	66.5	62.4	63.6	66.0
C-6	61.2	65.7	62.0	63.0	66.0
C-7	62.3	66.9	63.0	64.0	66.9
C-8	62.3	66.7	63.0	63.2	67.0
C-9	62.0	66.6	63.1	63.9	66.8
C-10	62.0	66.5	63.0	63.2	66.6
C-11	62.0	66.2	63.0	63.6	66.6
C-12	62.0	66.0	62.6	63.3	66.2

(Continued)

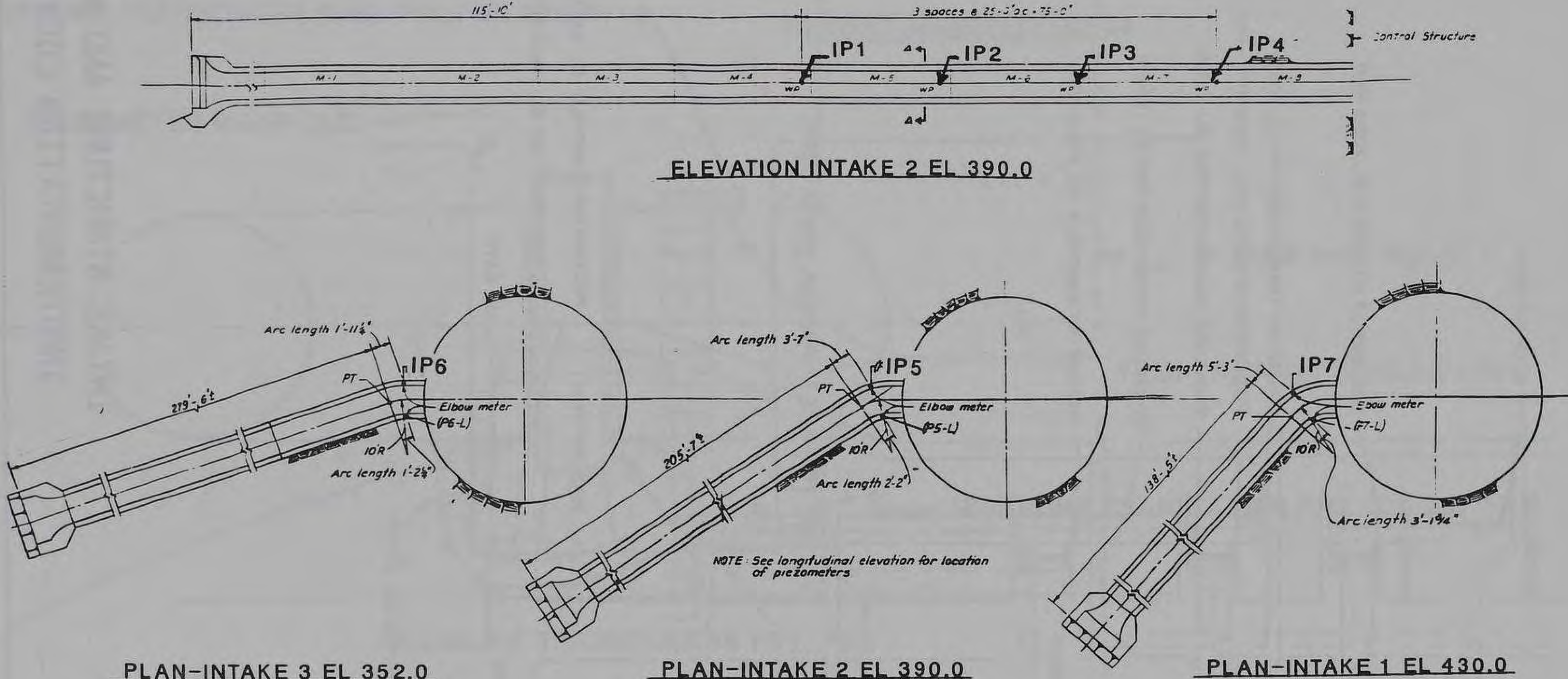
Table 12 (Continued)

Thermistor Location	Temperature, °F				
	Test 36	Test 37	Test 38	Test 39	Test 40
A-2	71.9	71.3	71.2	71.3	71.3
A-3	71.1	71.0	70.7	71.0	70.9
A-4	76.1	75.9	75.8	76.0	76.0
A-5	71.0	60.7	70.4	70.8	70.6
A-6	70.8	70.6	70.4	70.6	70.6
A-7	70.8	70.6	70.4	70.7	70.5
A-8	70.9	70.7	70.4	70.8	70.6
A-9	57.3	57.2	57.3	57.4	57.2
A-10	57.1	57.2	57.1	57.3	57.4
A-11	62.0	64.5	66.0	62.5	65.8
A-12	65.0	63.5	67.3	64.0	63.0
B-1	61.6	64.0	66.5	63.6	64.6
B-2	66.0	64.5	67.3	64.0	64.0
B-3	61.8	63.3	66.3	61.8	63.6
B-4	61.5	63.0	66.3	64.6	63.8
B-5	64.0	65.1	68.3	64.2	65.5
B-6	63.5	64.7	67.3	63.6	64.6
B-7	63.5	64.9	67.1	63.6	64.6
C-1	63.0	64.2	67.0	63.0	64.1
C-2	63.5	63.5	66.8	63.2	64.0
C-3	63.4	64.1	67.2	63.6	64.1
C-4	63.0	64.2	66.8	63.5	64.1
C-5	63.0	64.0	66.2	63.0	64.1
C-6	63.0	63.1	65.9	63.0	63.2
C-7	63.0	64.1	66.8	63.2	64.2
C-8	63.5	63.5	67.0	63.8	64.1
C-9	63.5	64.1	67.0	63.3	64.2
C-10	63.0	64.0	67.0	63.0	64.1
C-11	63.1	63.9	66.5	63.1	64.0
C-12	62.9	63.7	66.1	63.0	64.0

(Continued)

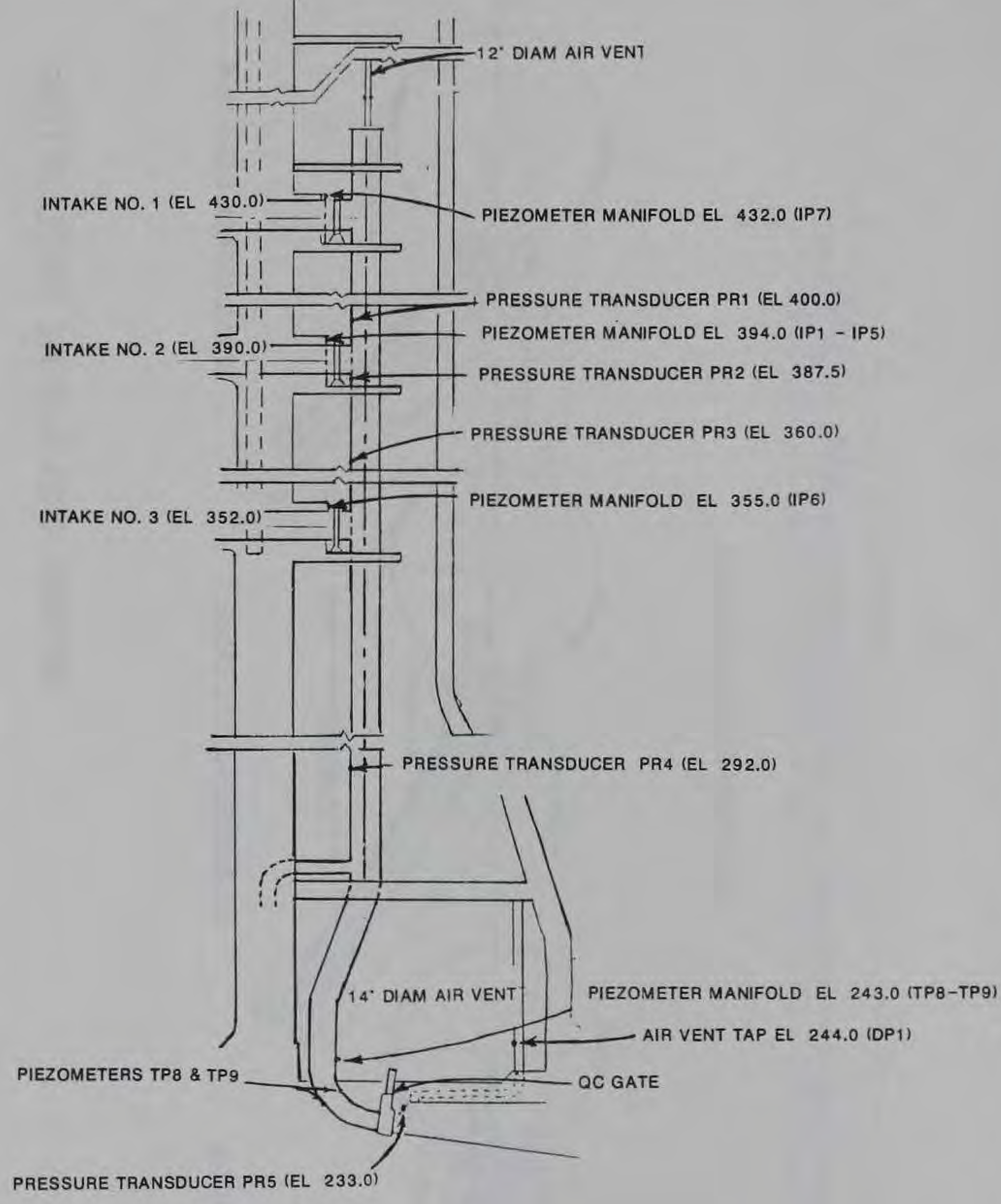
Table 12 (Concluded)

Thermistor Location	Temperature, °F				
	Test 41	Test 42	Test 43	Test 44	Test 45
A-2	71.2	70.8	71.0	71.0	71.5
A-3	70.9	69.2	71.3	71.5	71.6
A-4	75.8	73.0	76.2	76.5	76.6
A-5	70.4	65.7	70.7	70.9	71.5
A-6	70.4	64.5	70.8	71.0	71.3
A-7	70.4	62.5	71.4	71.6	72.4
A-8	70.5	60.1	70.4	70.4	71.5
A-9	57.3	58.9	69.4	70.1	57.7
A-10	57.2	57.1	70.1	70.6	57.6
A-11	67.1	55.3	70.7	70.8	58.8
A-12	66.6	55.5	70.7	70.7	60.2
B-1	67.0	55.1	70.8	70.8	59.2
B-2	67.1	55.4	70.6	70.6	59.8
B-3	66.5	55.2	70.3	70.2	59.7
B-4	66.1	55.0	70.7	70.7	59.2
B-5	67.7	55.1	70.8	70.7	59.3
B-6	67.1	55.2	66.2	68.9	59.2
B-7	67.3	53.9	68.1	69.3	59.4
C-1	66.0	54.0	70.9	70.6	59.0
C-2	66.9	54.2	70.8	70.6	59.0
C-3	67.0	54.4	70.8	70.7	59.1
C-4	67.2	54.2	70.6	70.4	59.1
C-5	66.2	53.9	70.6	70.3	59.1
C-6	66.0	53.7	69.7	69.6	59.1
C-7	66.5	55.0	70.6	70.0	59.1
C-8	66.5	54.4	70.8	69.0	59.0
C-9	67.0	55.0	66.0	58.8	59.2
C-10	66.8	54.4	67.0	58.3	59.0
C-11	66.8	54.9	66.0	58.3	59.0
C-12	66.5	54.0	65.5	58.0	59.0

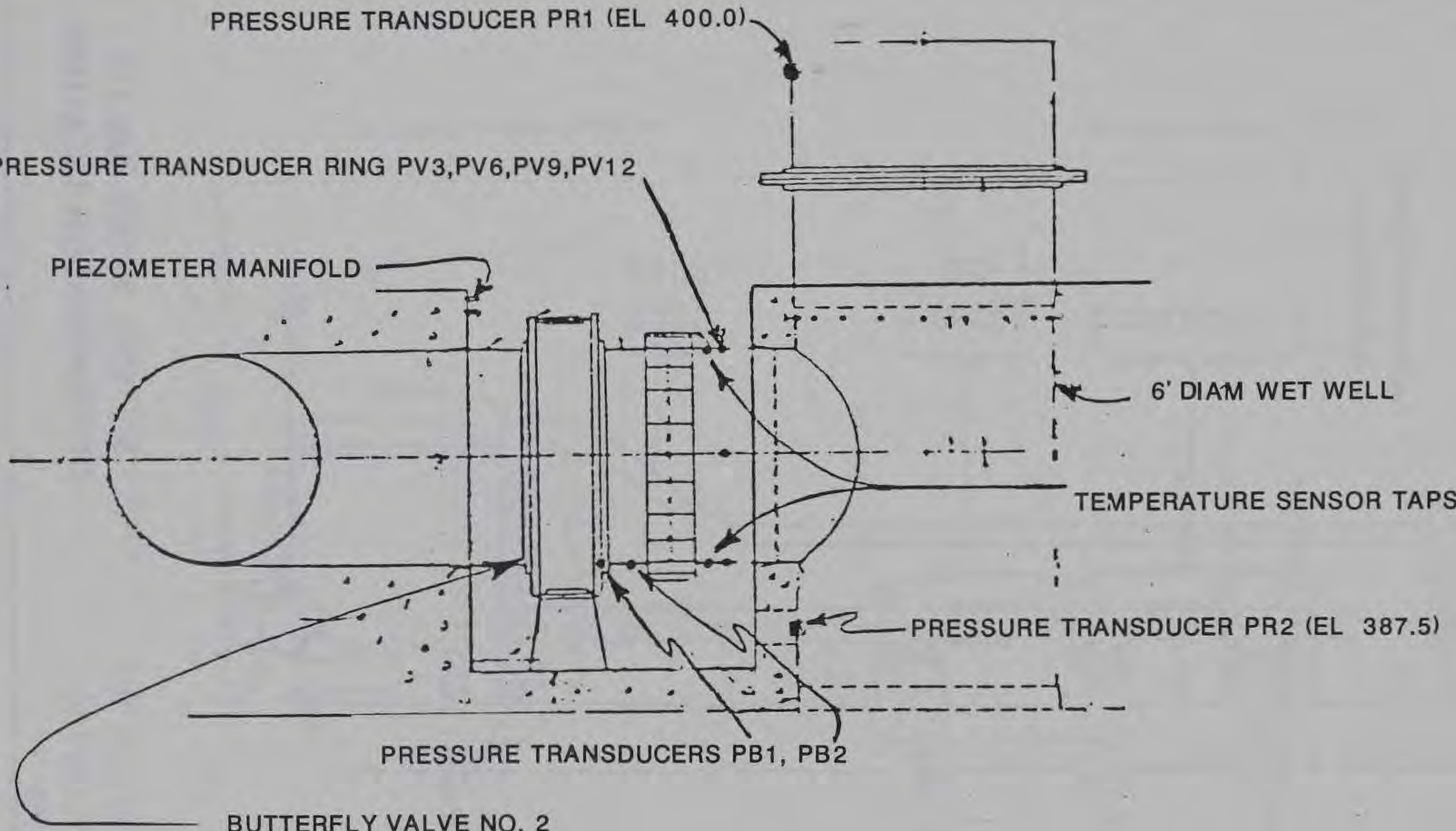


INTAKE AND ELBOW PIEZOMETERS

PLATE 1

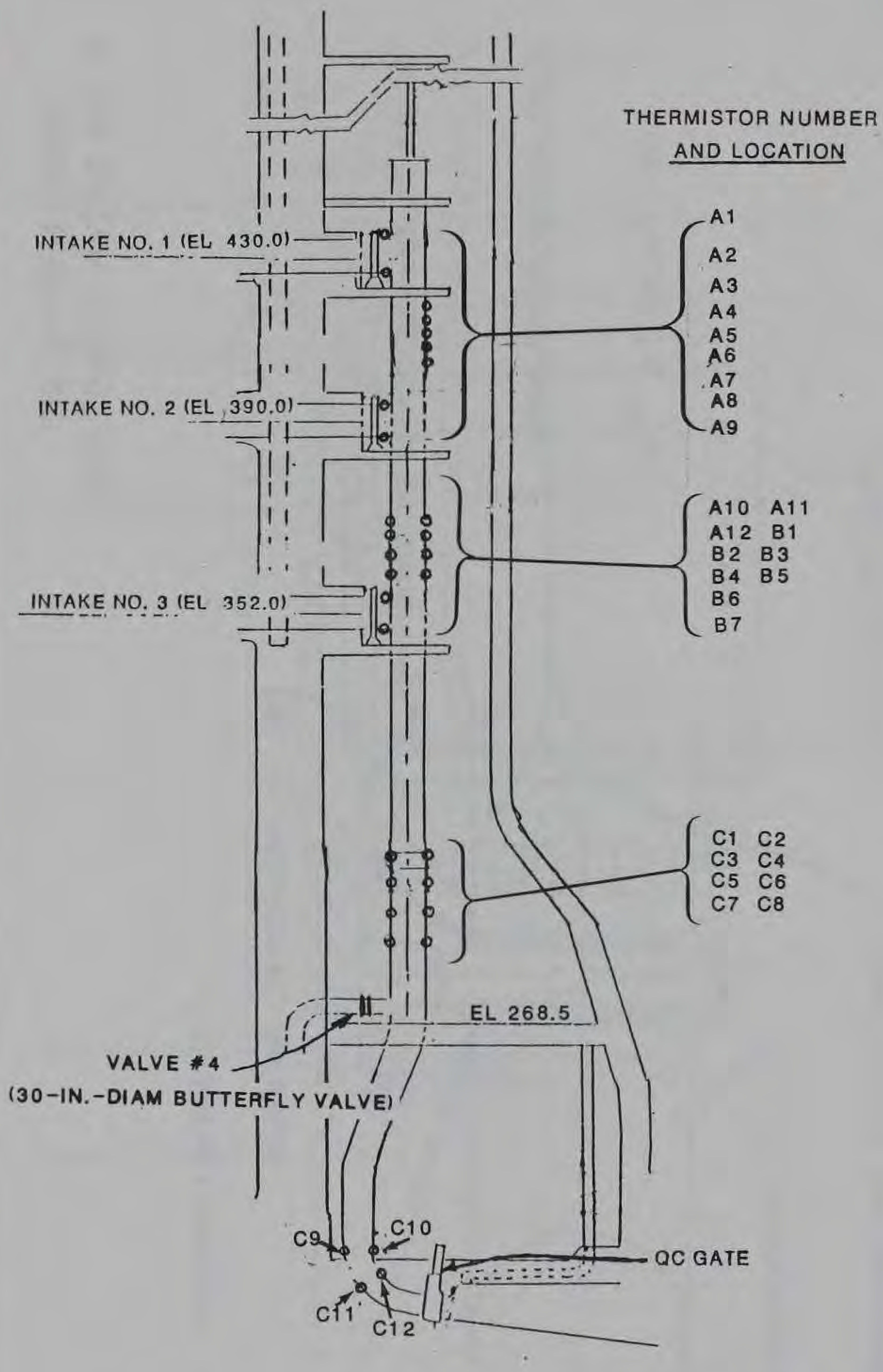


INTAKE STRUCTURE AND WET WELL
INSTRUMENTATION LOCATIONS



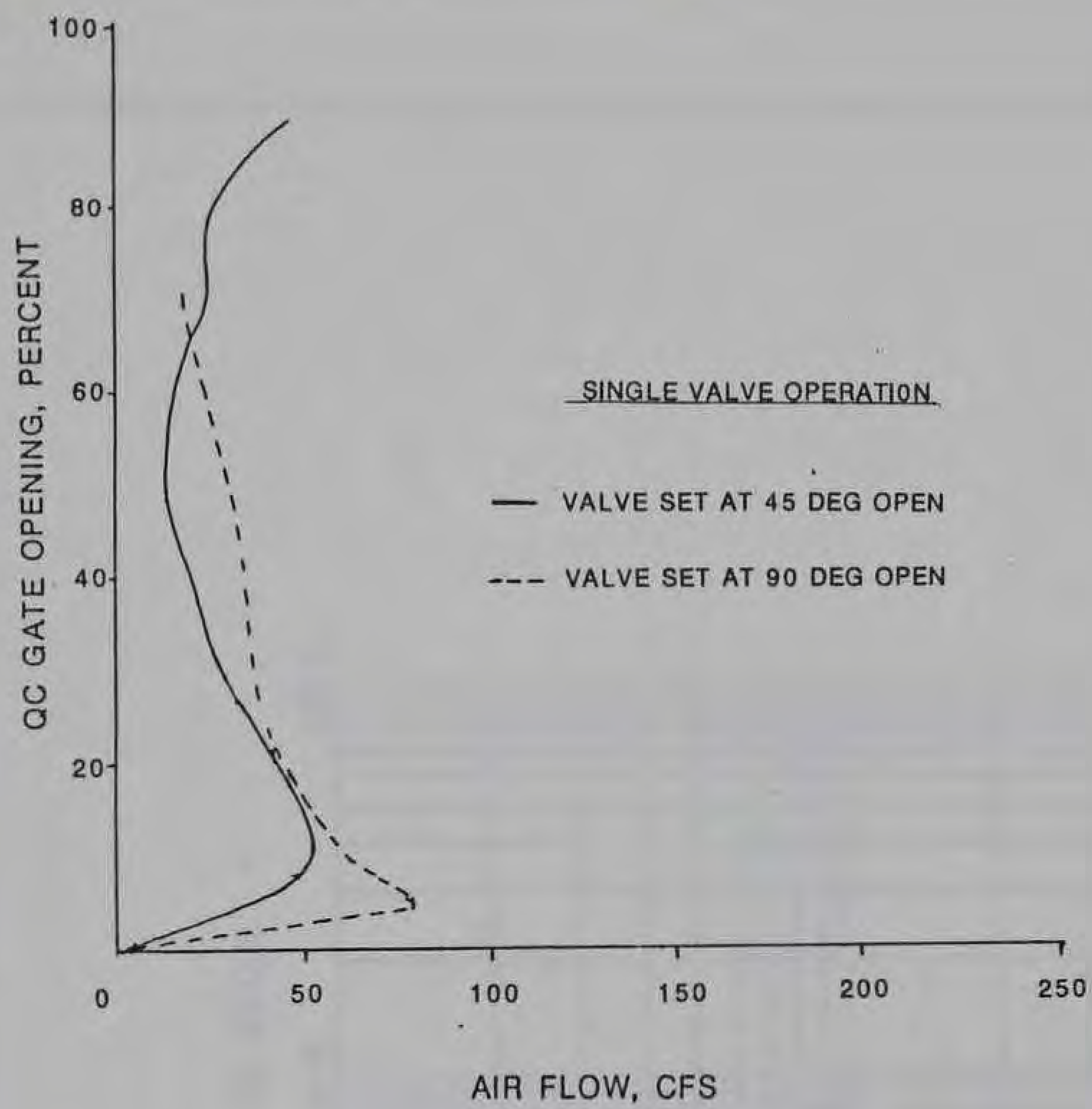
BUTTERFLY VALVE NO. 2
INSTRUMENTATION

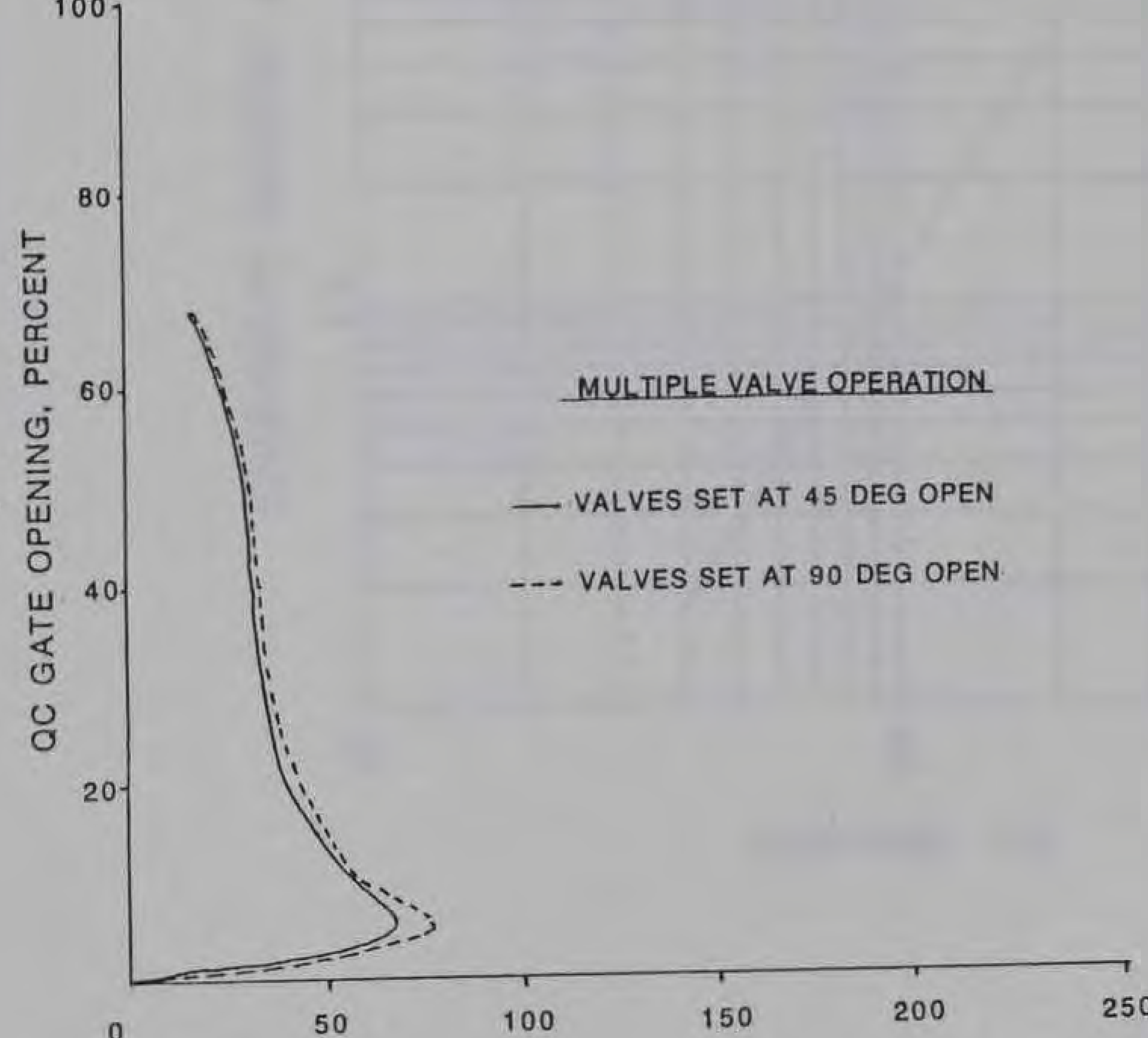
PLATE 3



WET WELL WATER QUALITY INSTRUMENTATION LOCATIONS

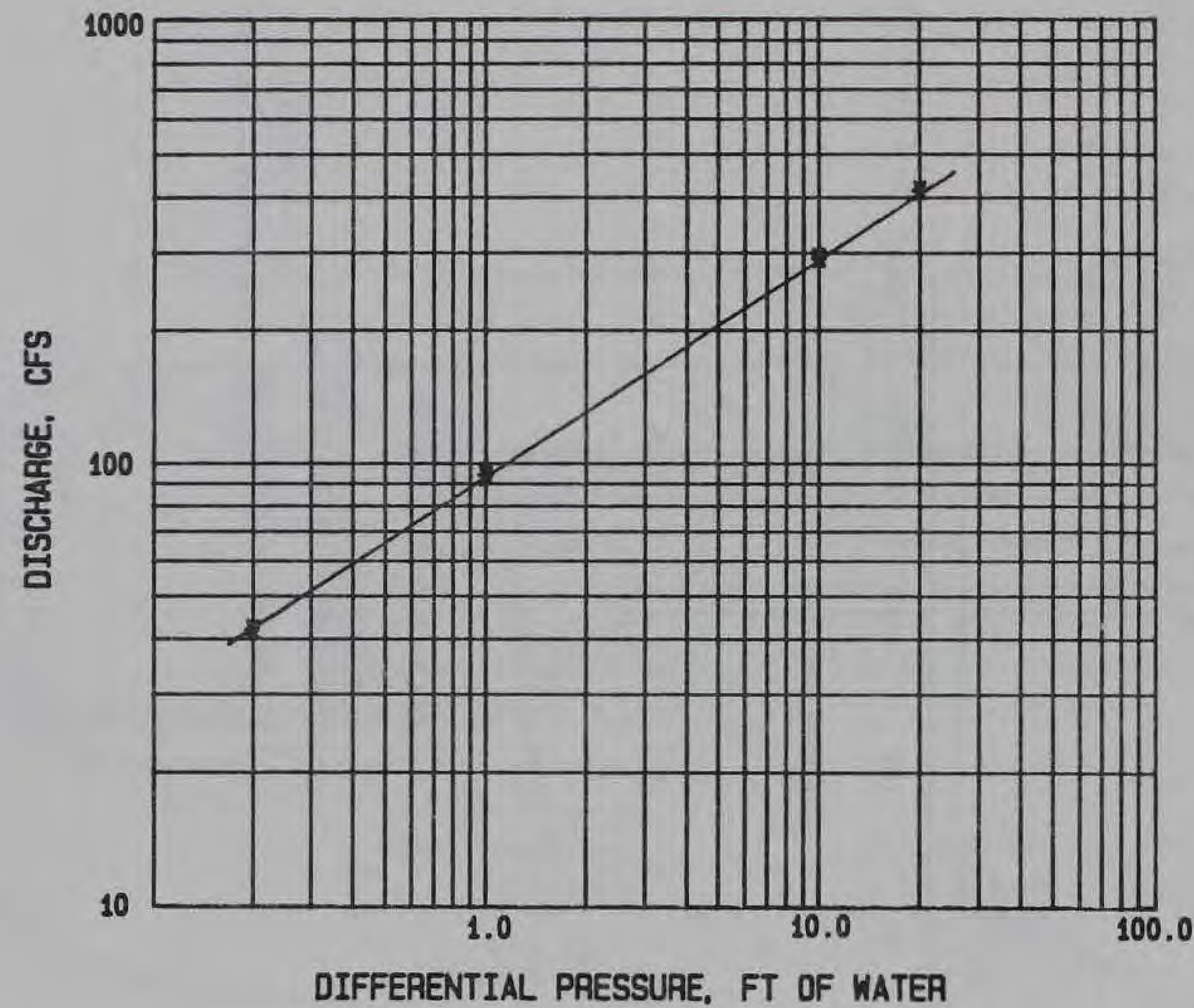
PLATE 4





AIR FLOW VERSUS GATE OPENING

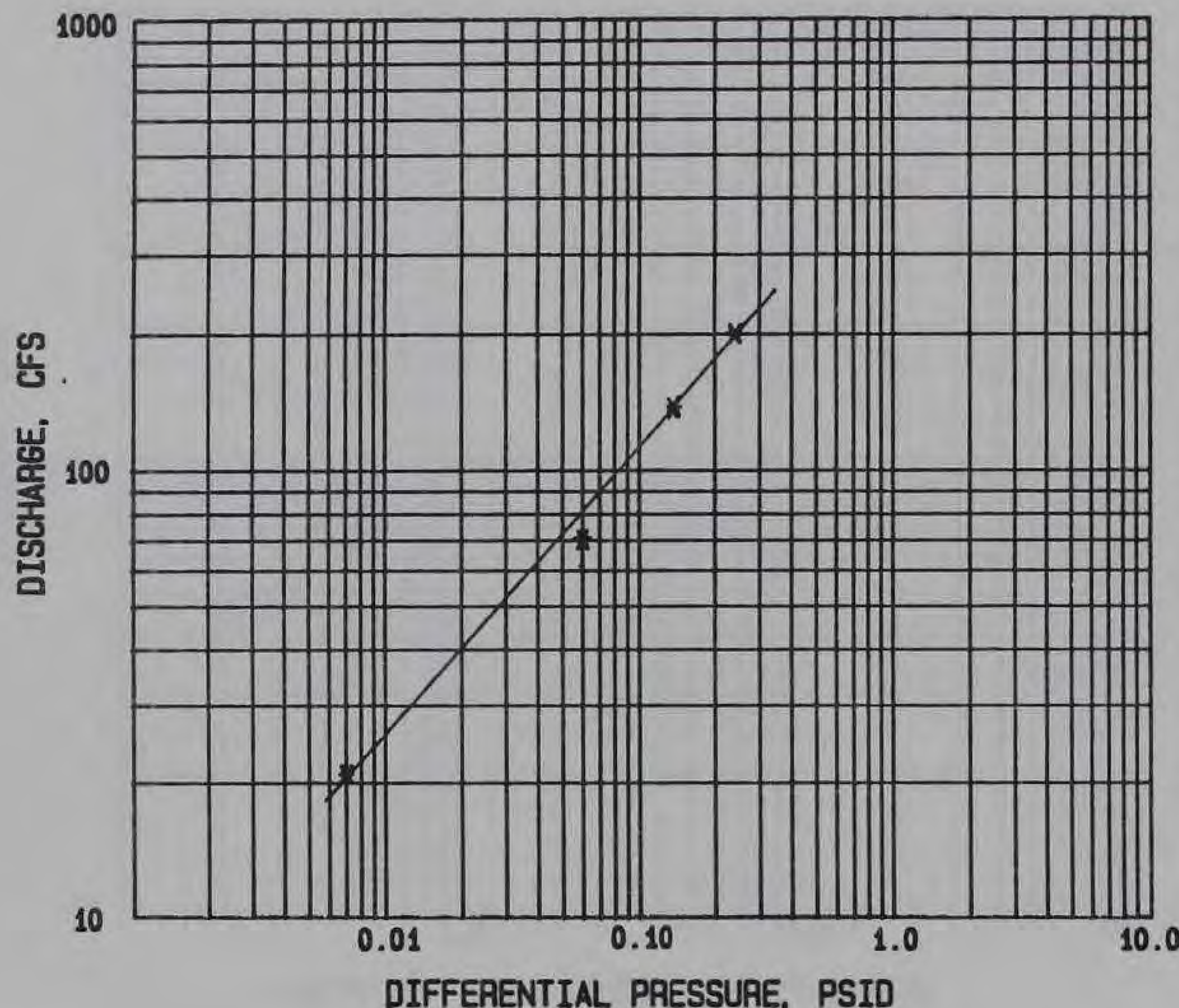
14" AIR VENT



TRANSITION ZONE ELBOW METER CALIBRATION

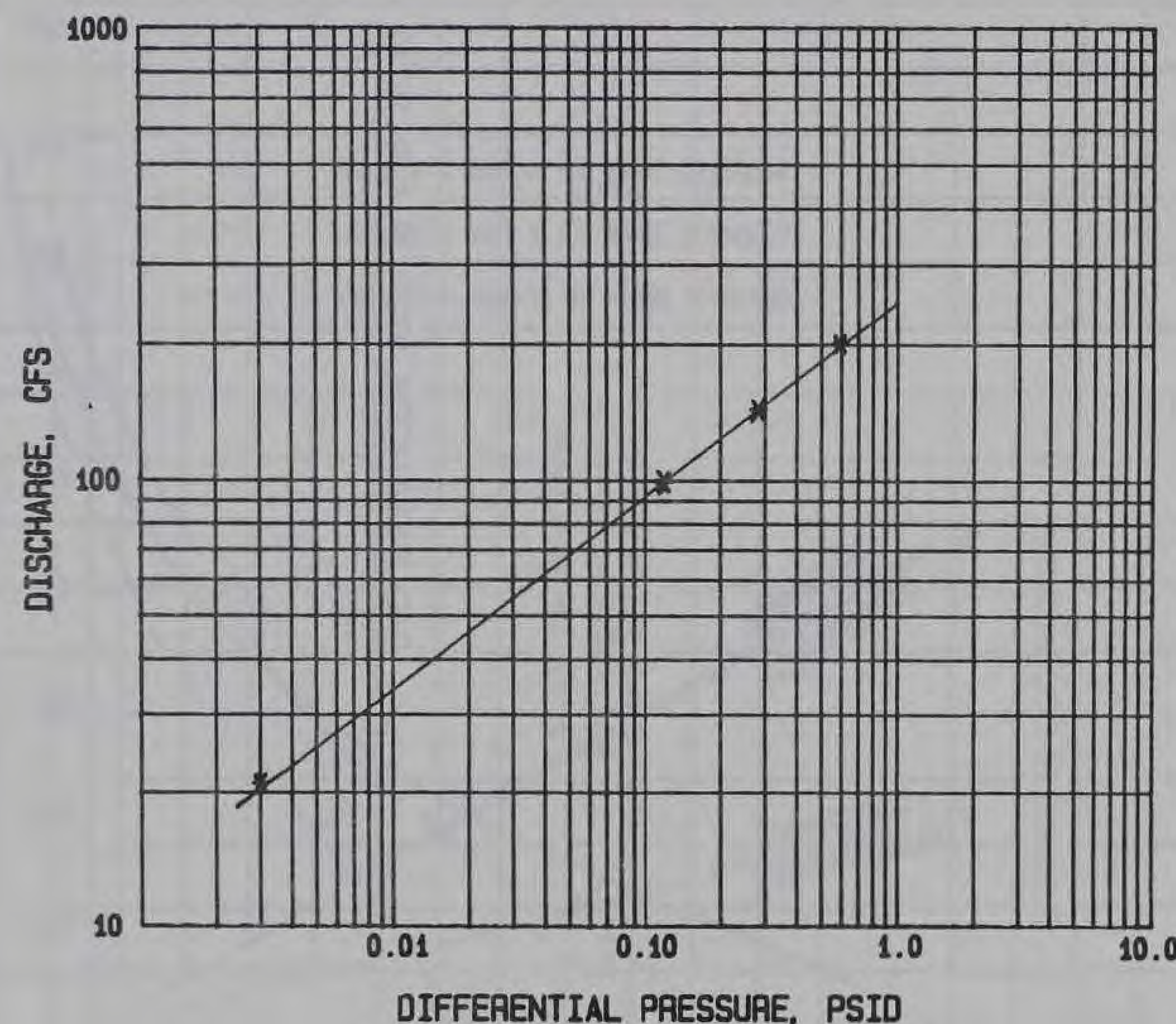
WET WELL PIEZOMETERS TP8 AND TP9

PLATE 8

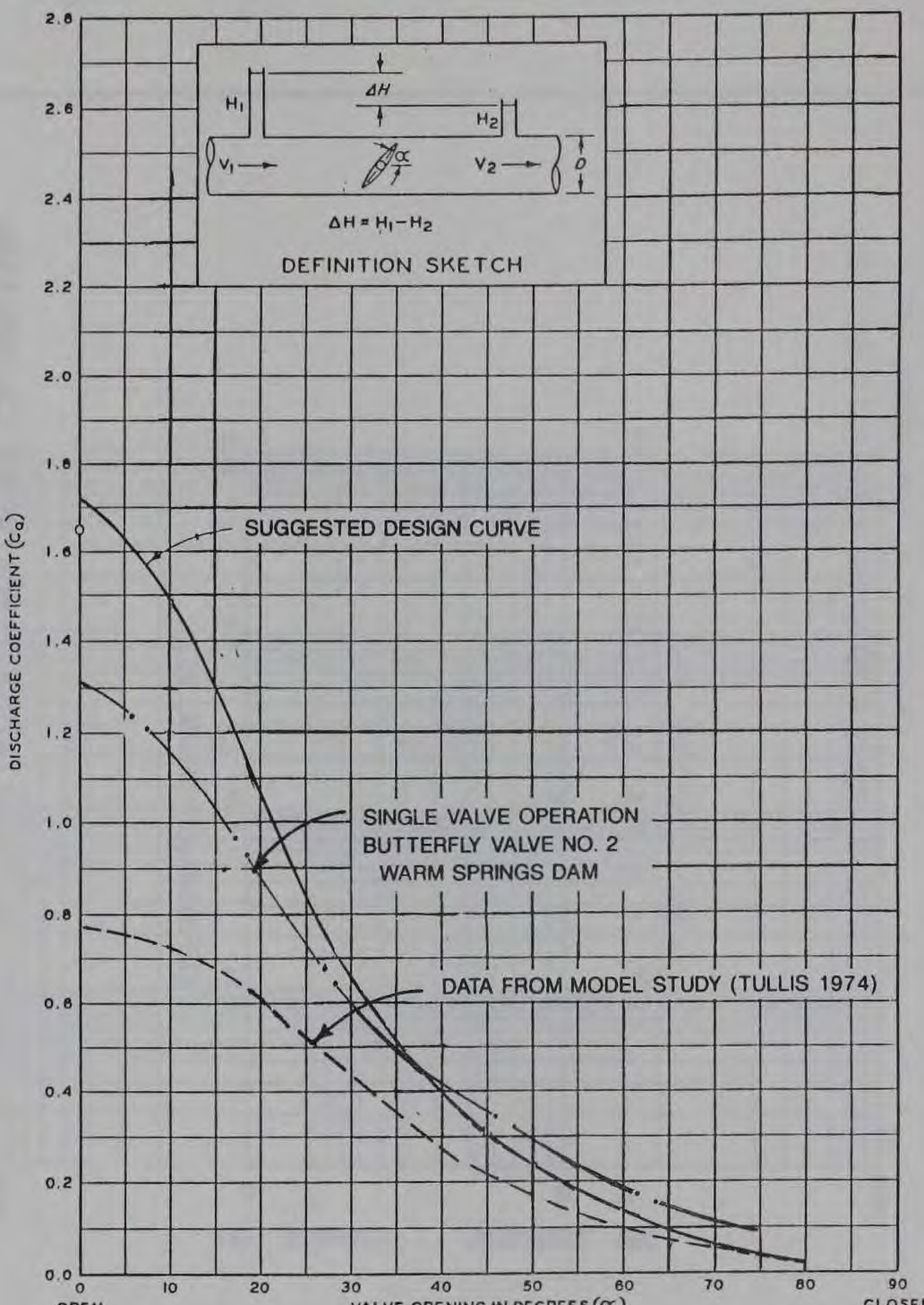


INTAKE ELBOW METER CALIBRATION

INTAKE NO. 3, PIEZOMETER IP6



INTAKE ELBOW METER CALIBRATION
INTAKE NO. 1, PIEZOMETER IP7



BASIC EQUATION

$$Q = C_Q D^2 \sqrt{g}\sqrt{\Delta H}$$

WHERE:

- Q = DISCHARGE IN CFS
- C_Q = DISCHARGE COEFFICIENT
- D = VALVE DIAMETER IN FT
- g = GRAVITY CONSTANT = 32.2 FT/SEC^2
- ΔH = PRESSURE DROP ACROSS THE VALVE IN FT OF WATER

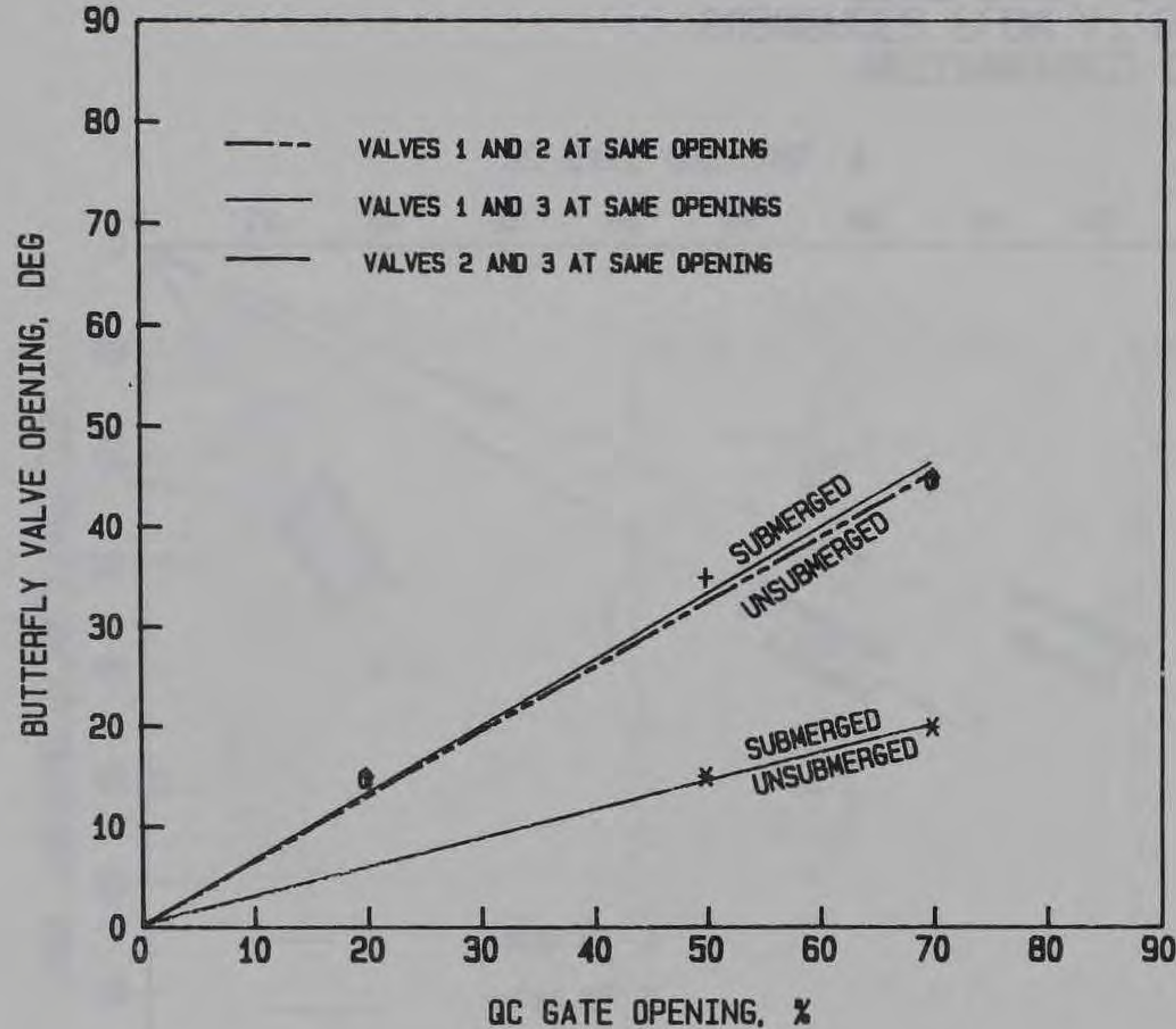
BUTTERFLY VALVES

DISCHARGE COEFFICIENTS

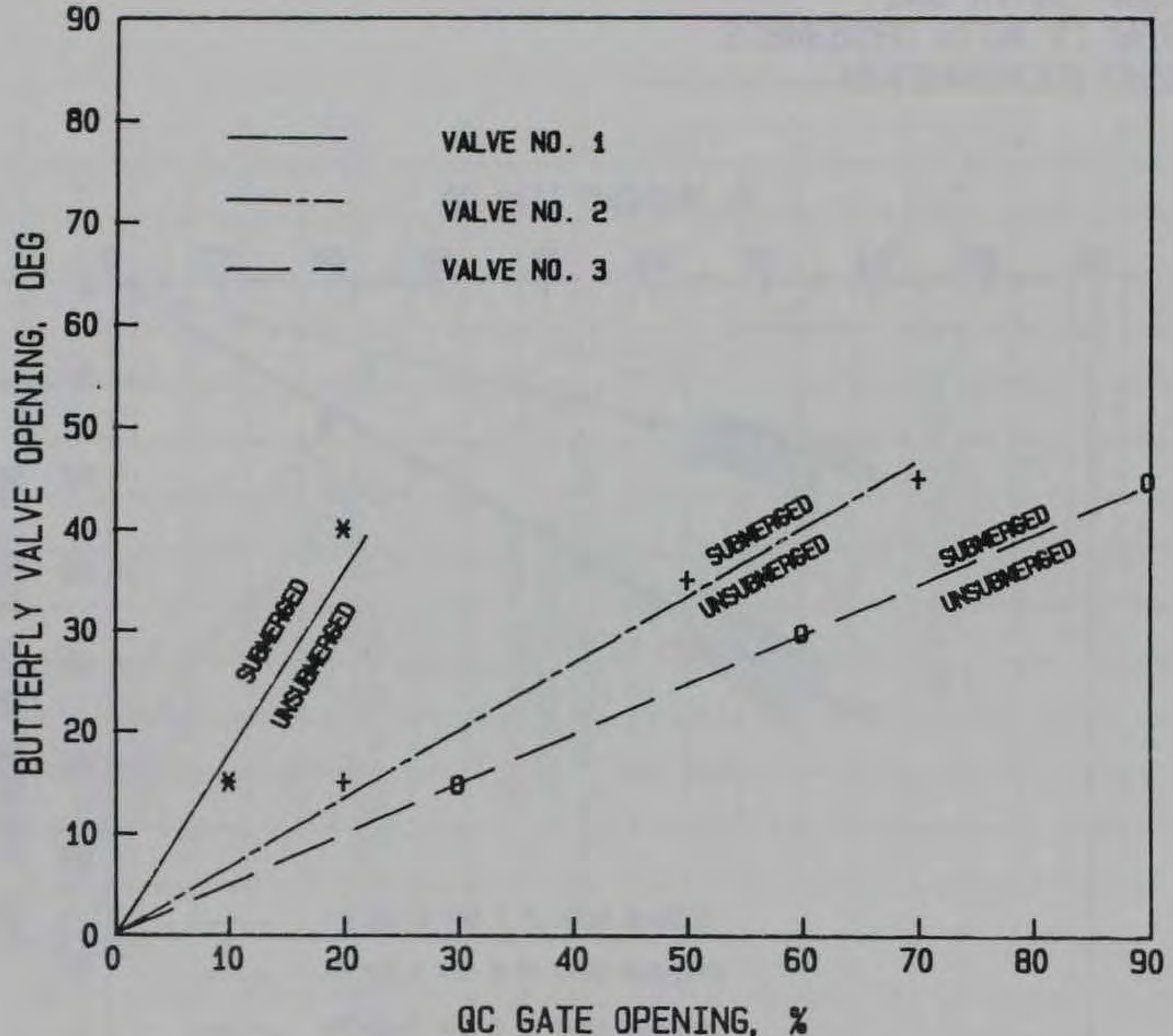
VALVE IN PIPE

HYDRAULIC DESIGN CHART 331-1

WES 8-58

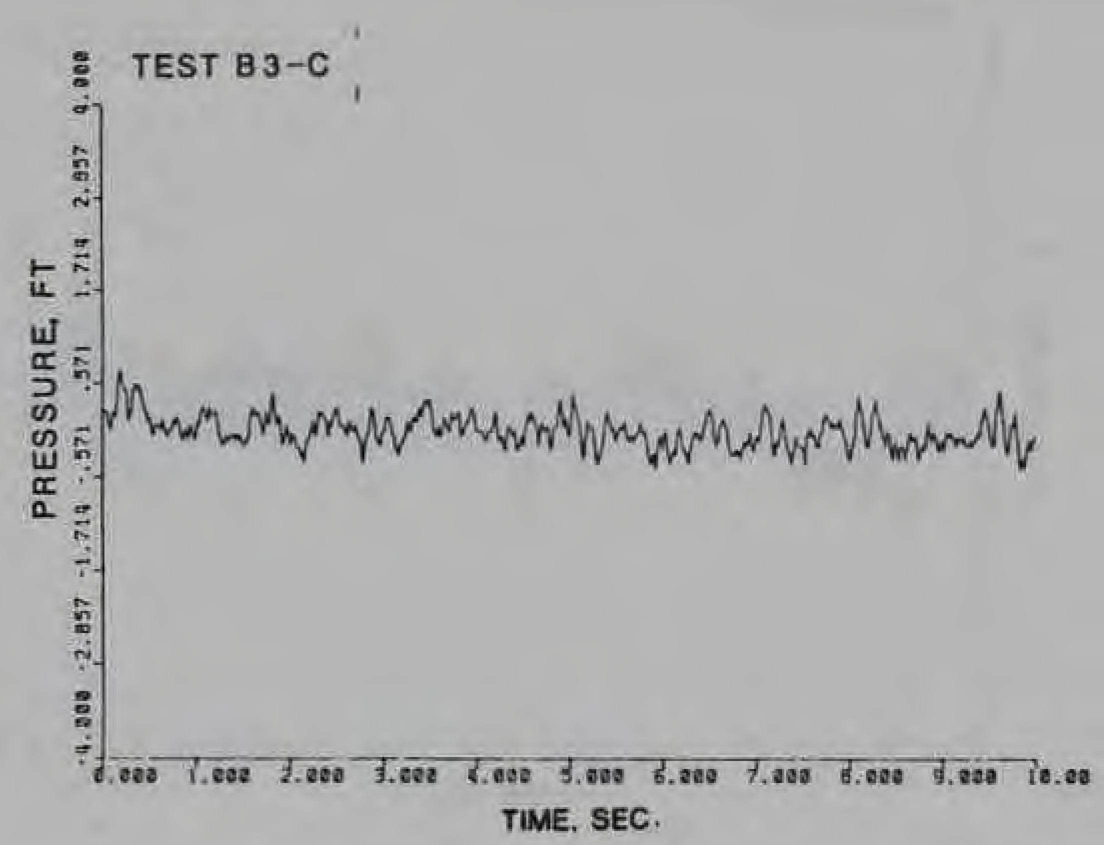


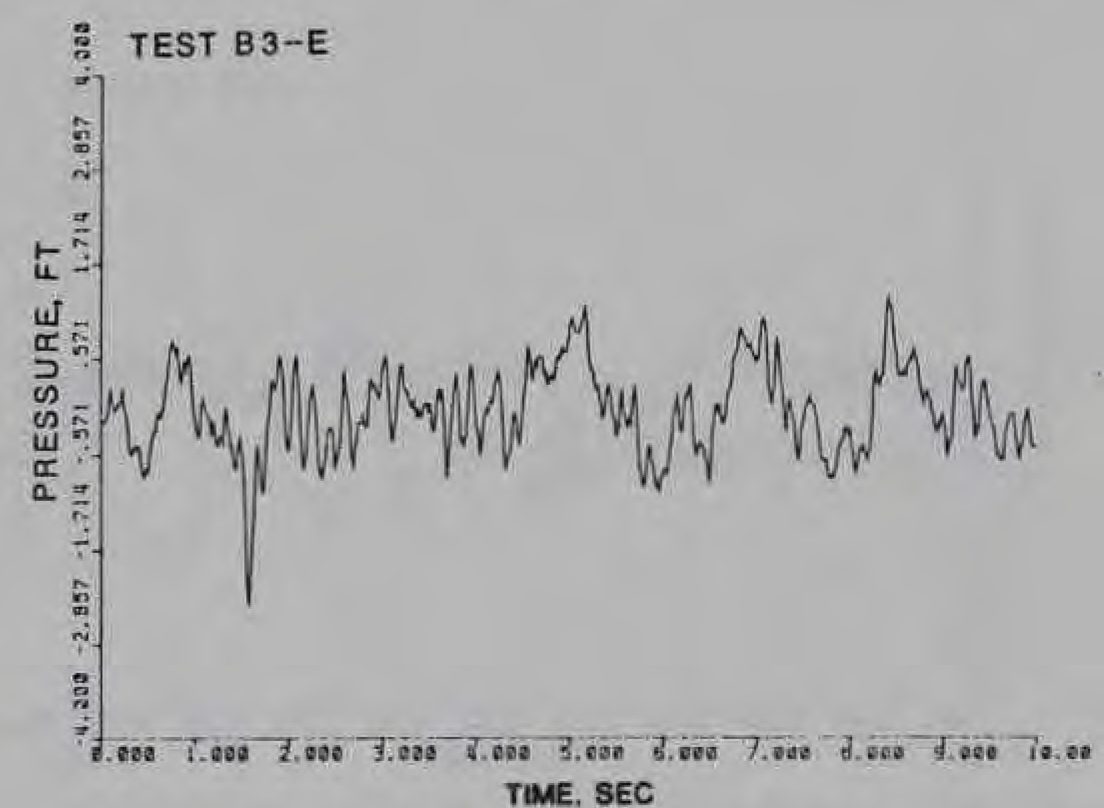
RECOMMENDED OPERATION
SUBMERGED FLOW AT BUTTERFLY VALVES
TWO-VALVE OPERATION



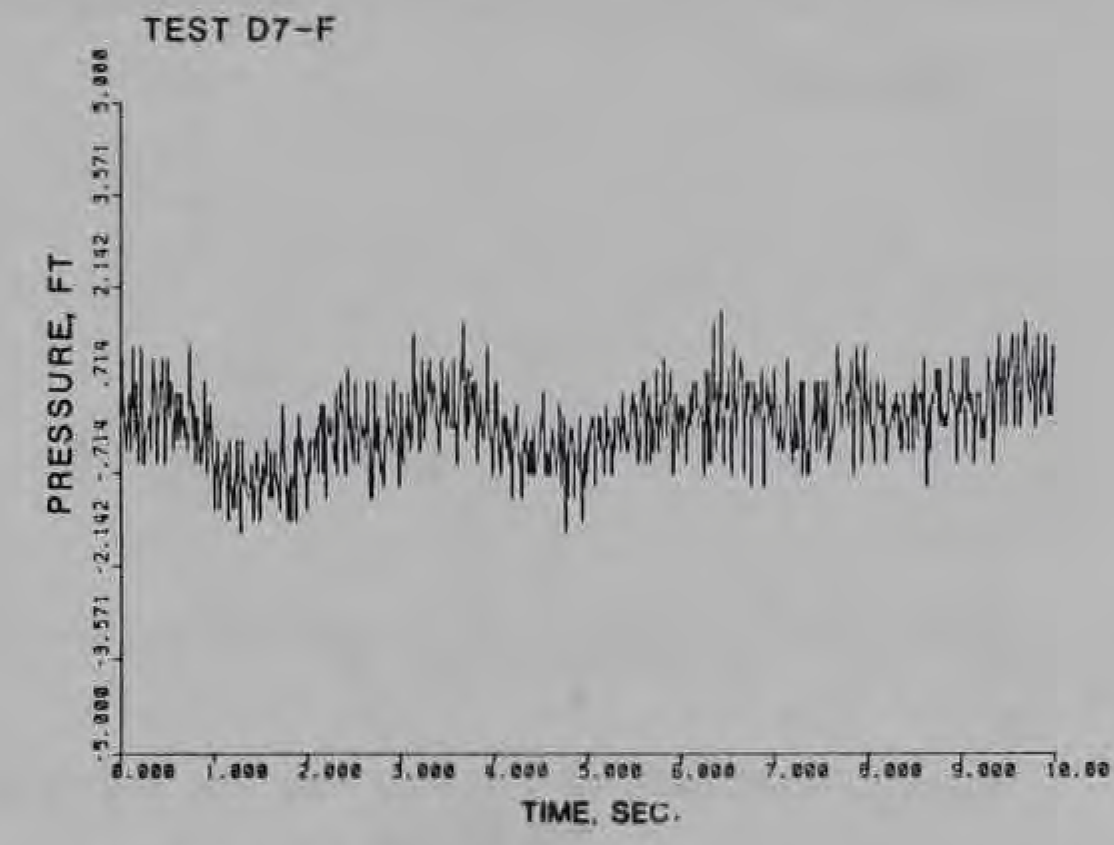
RECOMMENDED OPERATION
SUBMERGED FLOW AT BUTTERFLY VALVES
SINGLE-VALVE OPERATION

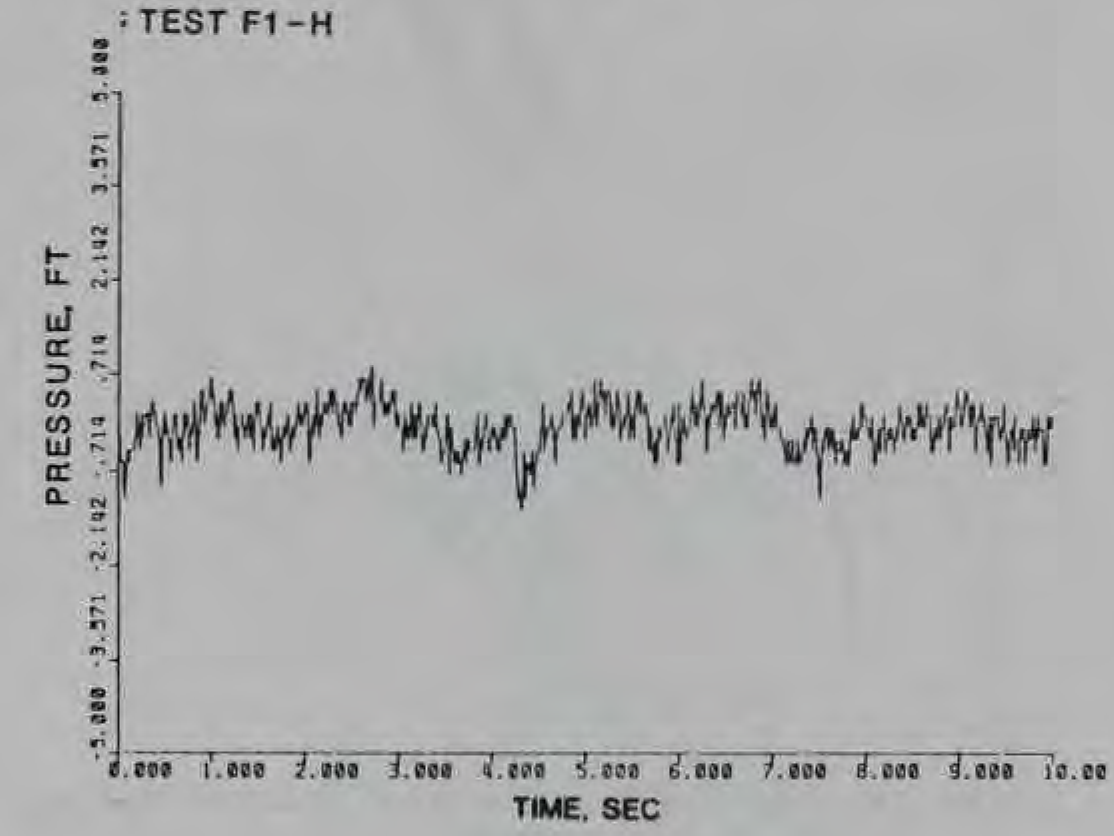
PLATE 12

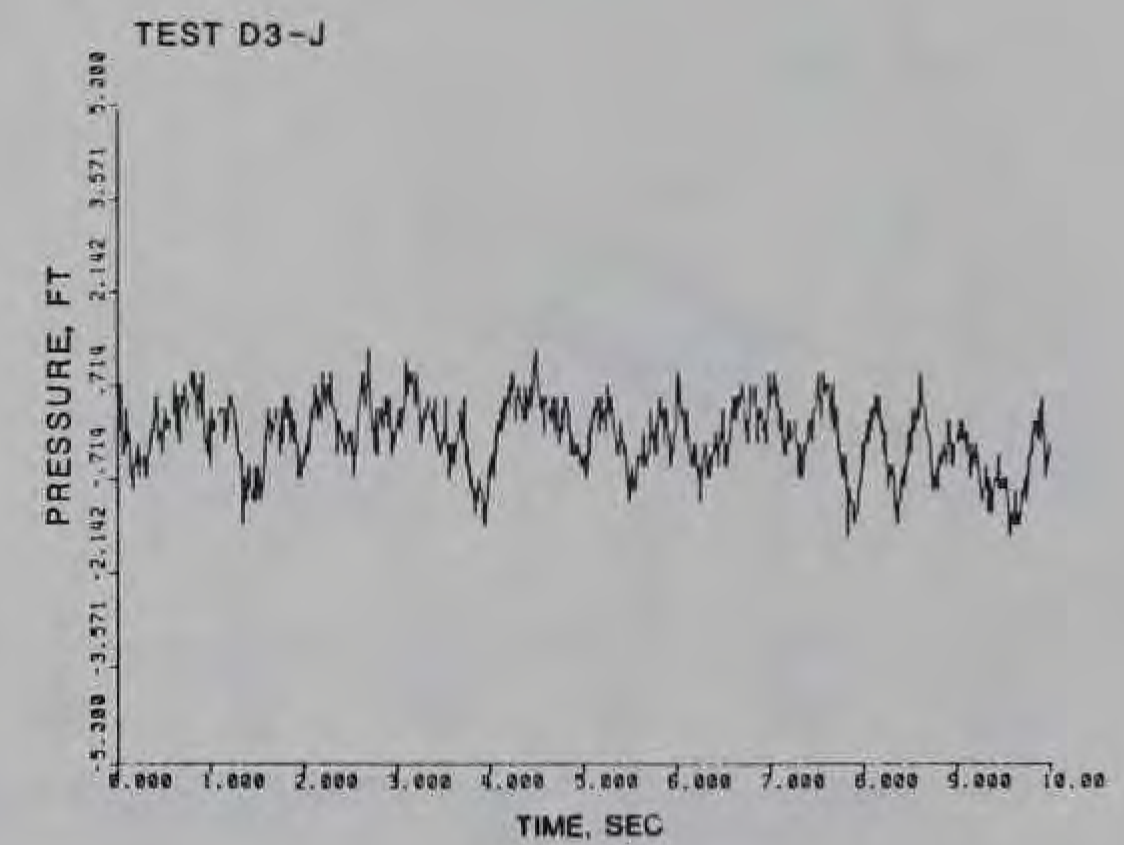




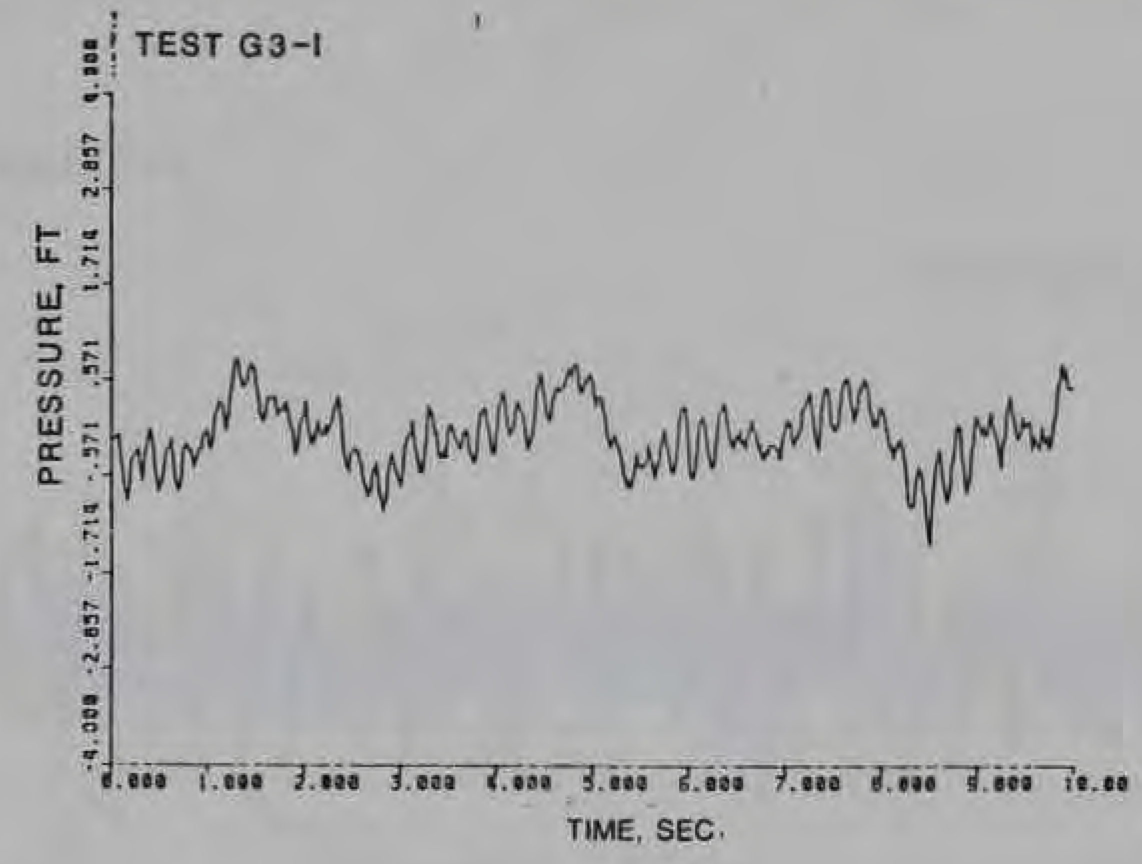
WET WELL
WATER-SURFACE ELEVATION FLUCTUATIONS
SINGLE-BUTTERFLY VALVE OPERATION
PRESSURE TRANSDUCER PR3

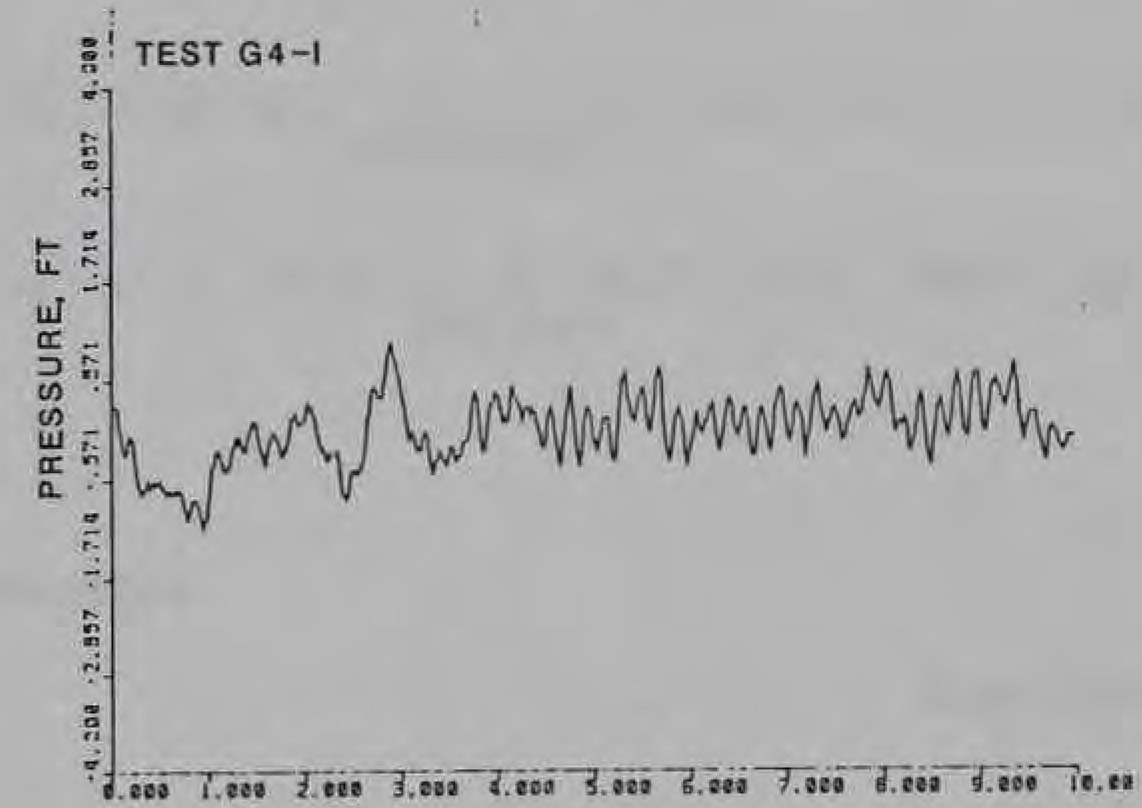


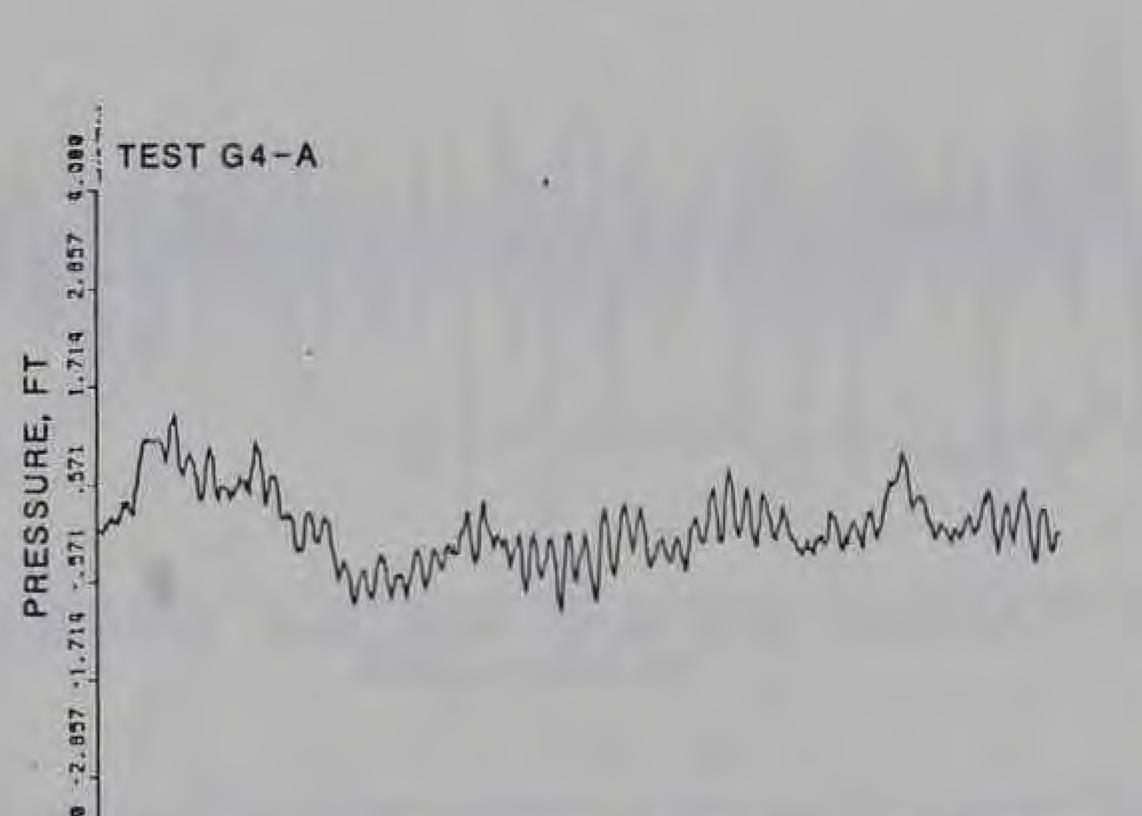




WET WELL
WATER-SURFACE ELEVATION FLUCTUATIONS
TWO-BUTTERFLY-VALVE OPERATION
PRESSURE TRANSDUCER PR3





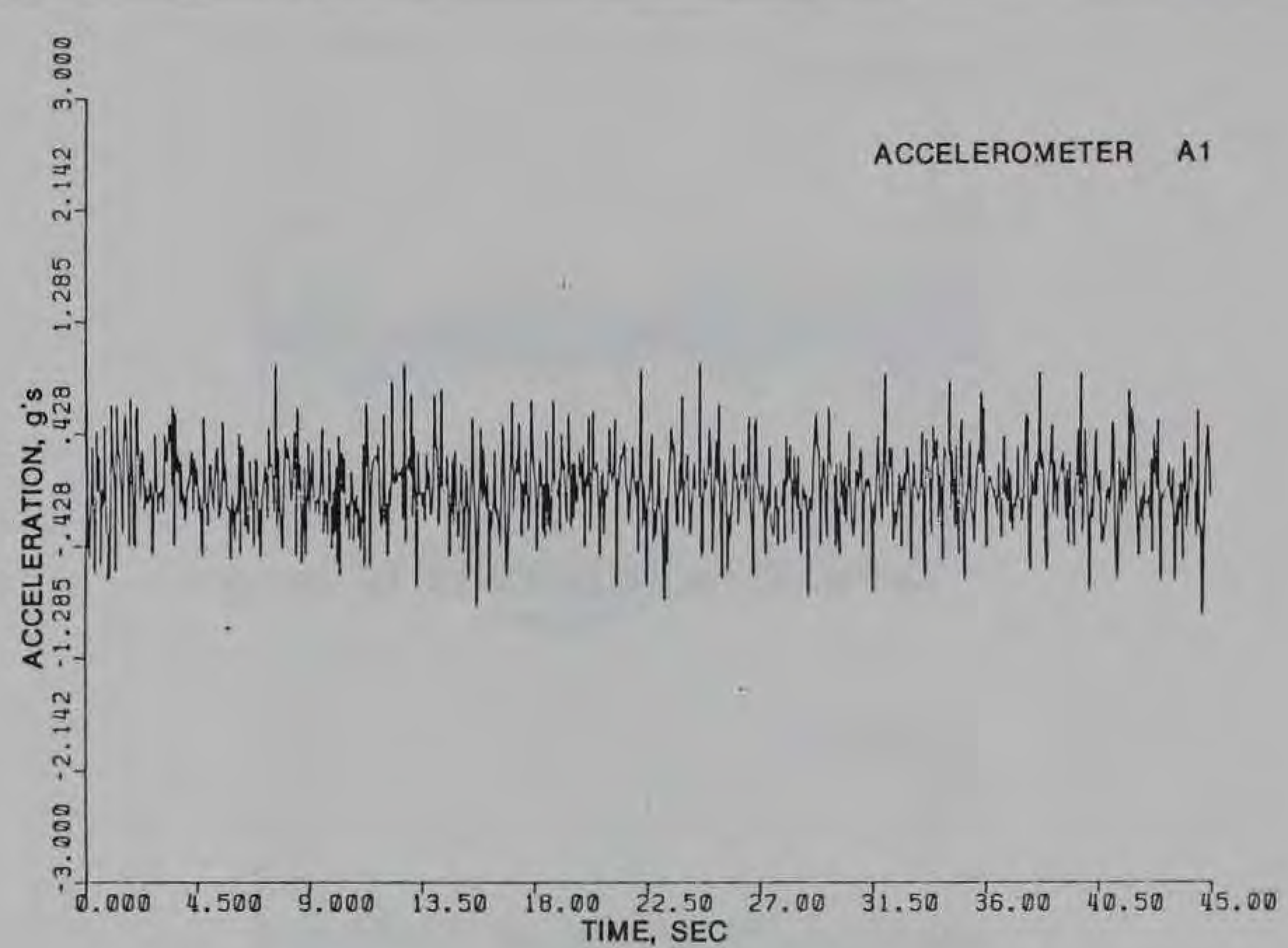


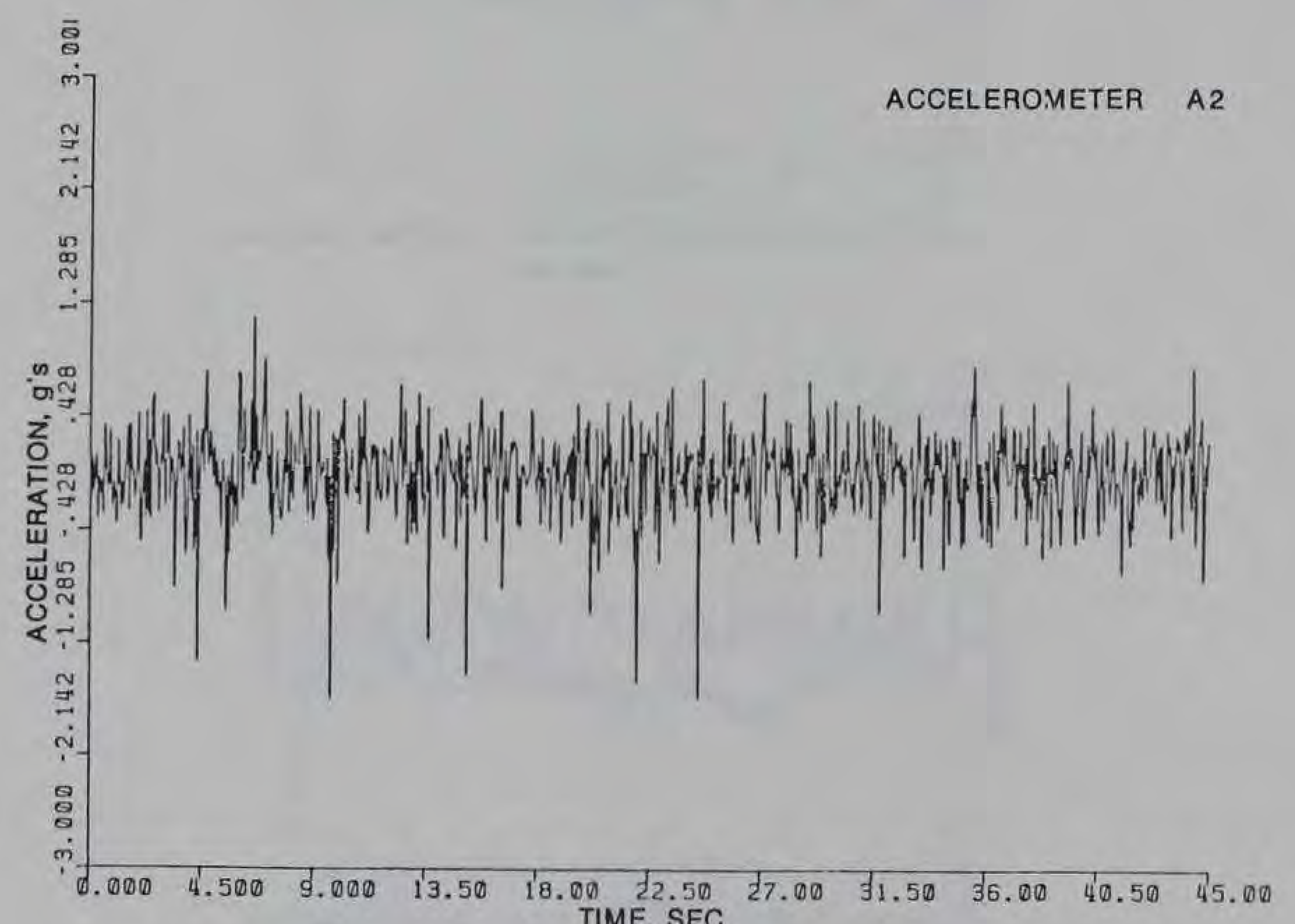
WET WELL

WATER-SURFACE ELEVATION FLUCTUATIONS

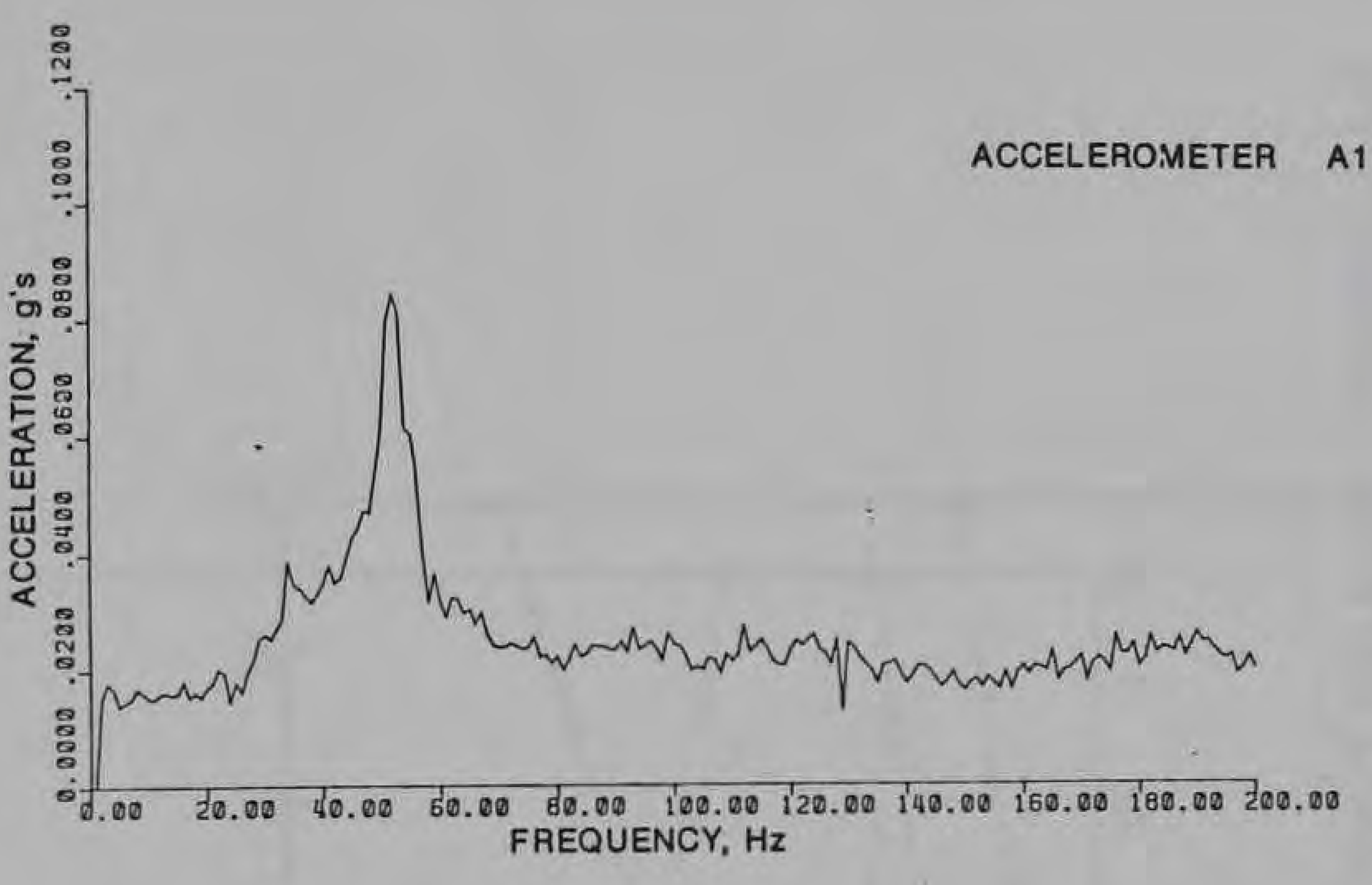
THREE-BUTTERFLY-VALVE OPERATION

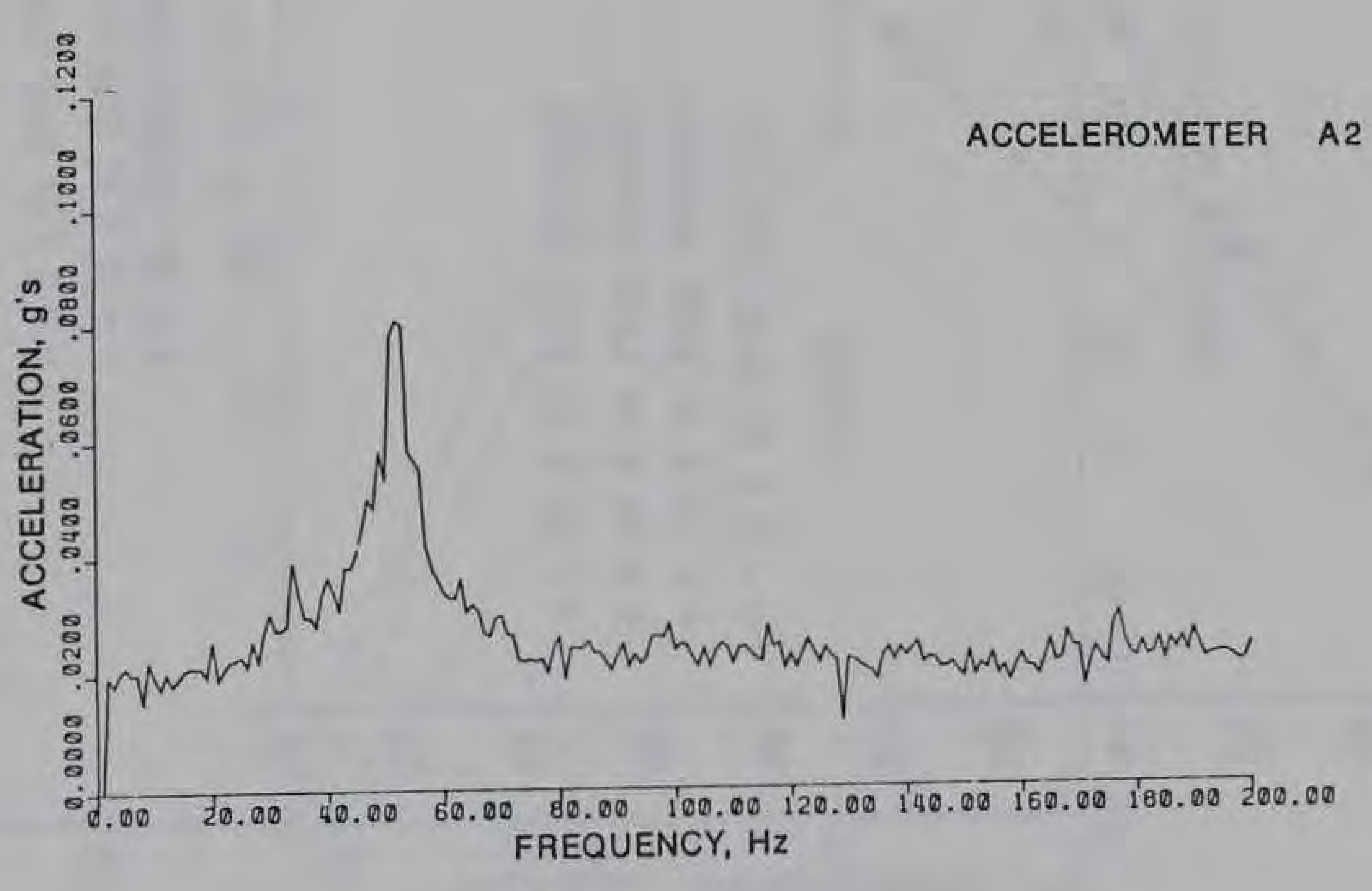
PRESSURE TRANSDUCER PR3





TIME-HISTORY
VALVE LEAF VIBRATIONS
VALVE NO. 2, TEST B2-G

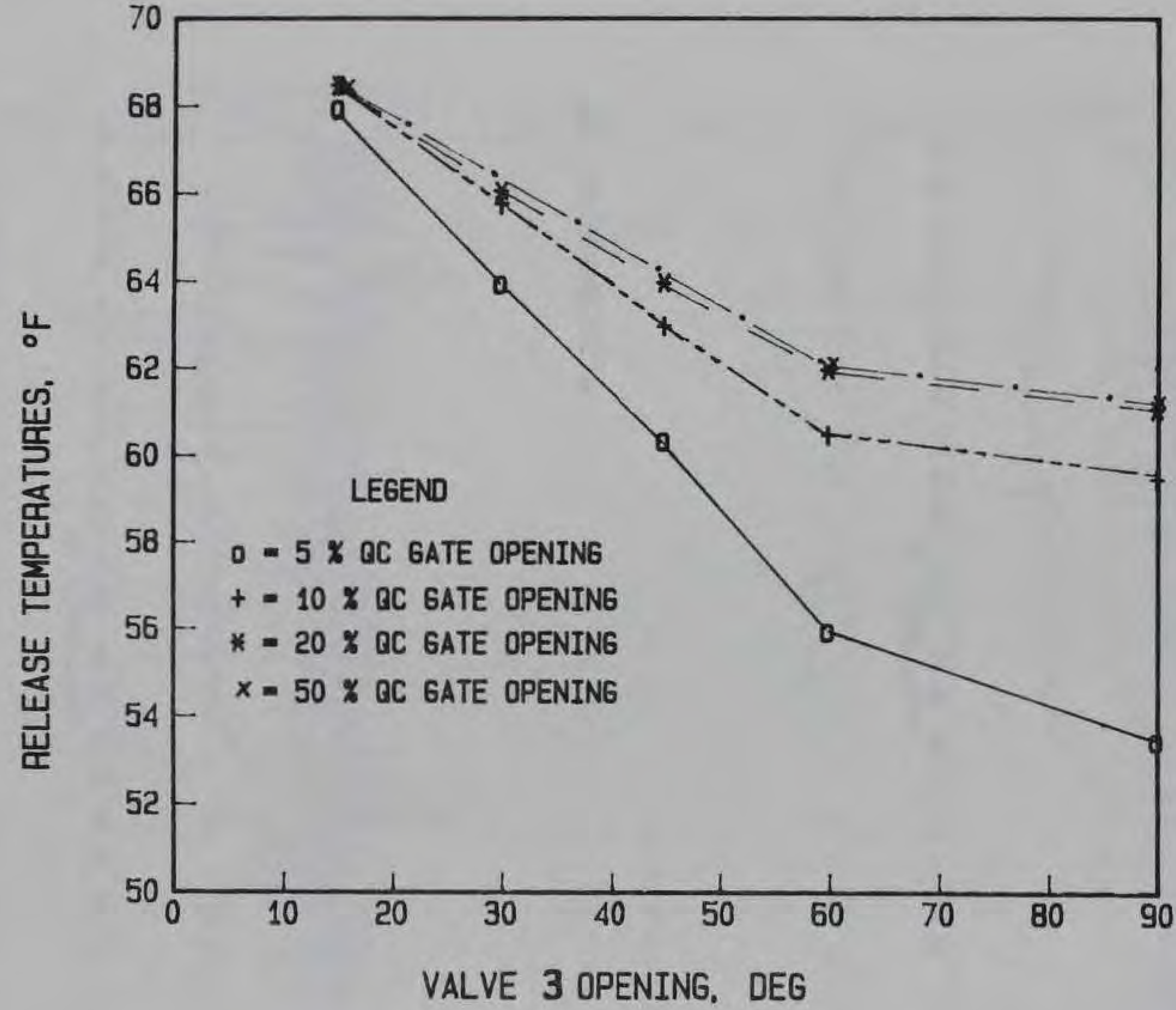




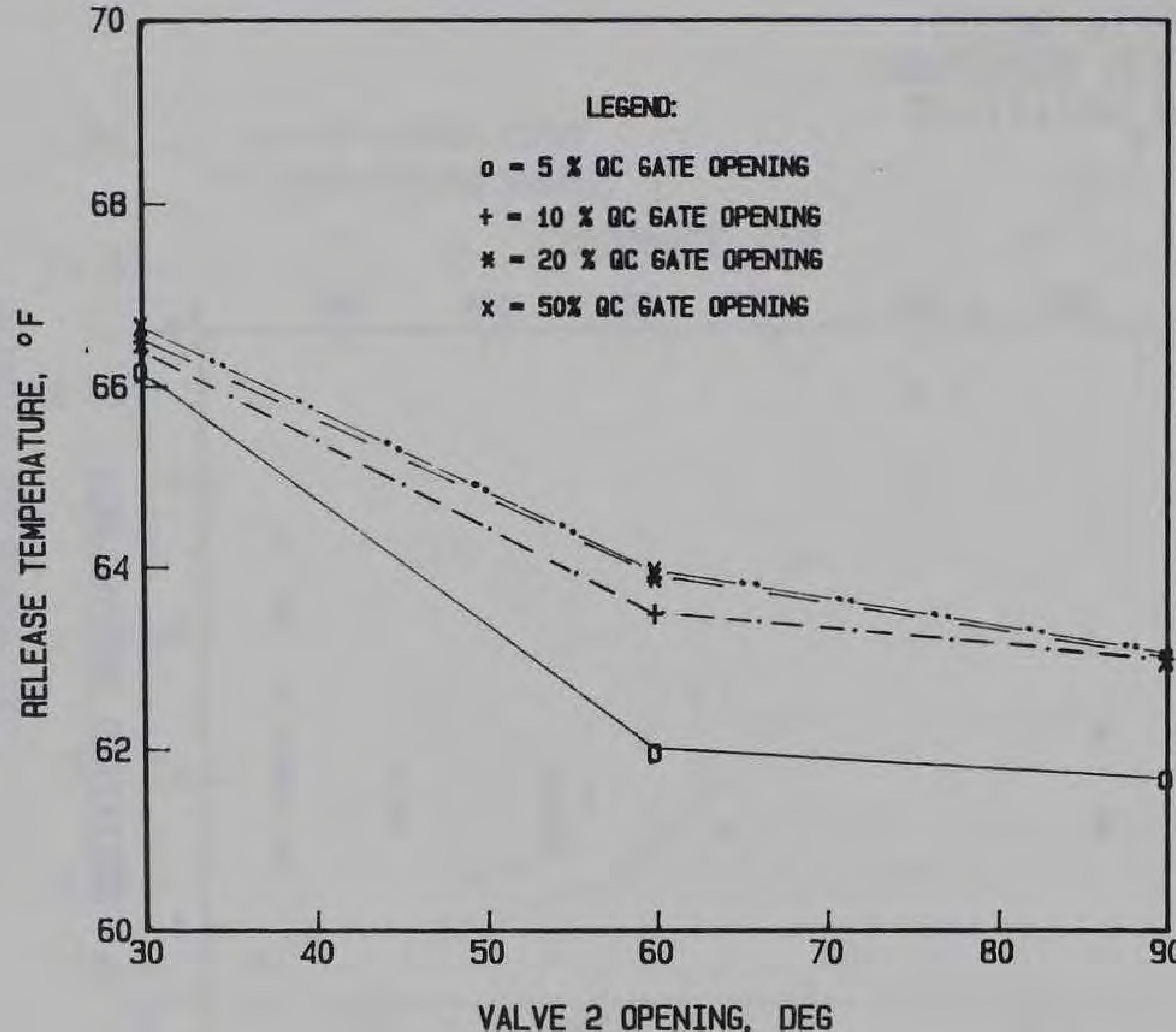
FAST FOURIER TRANSFORMS

VALVE LEAF VIBRATIONS

VALVE NO. 2, TEST B2-G

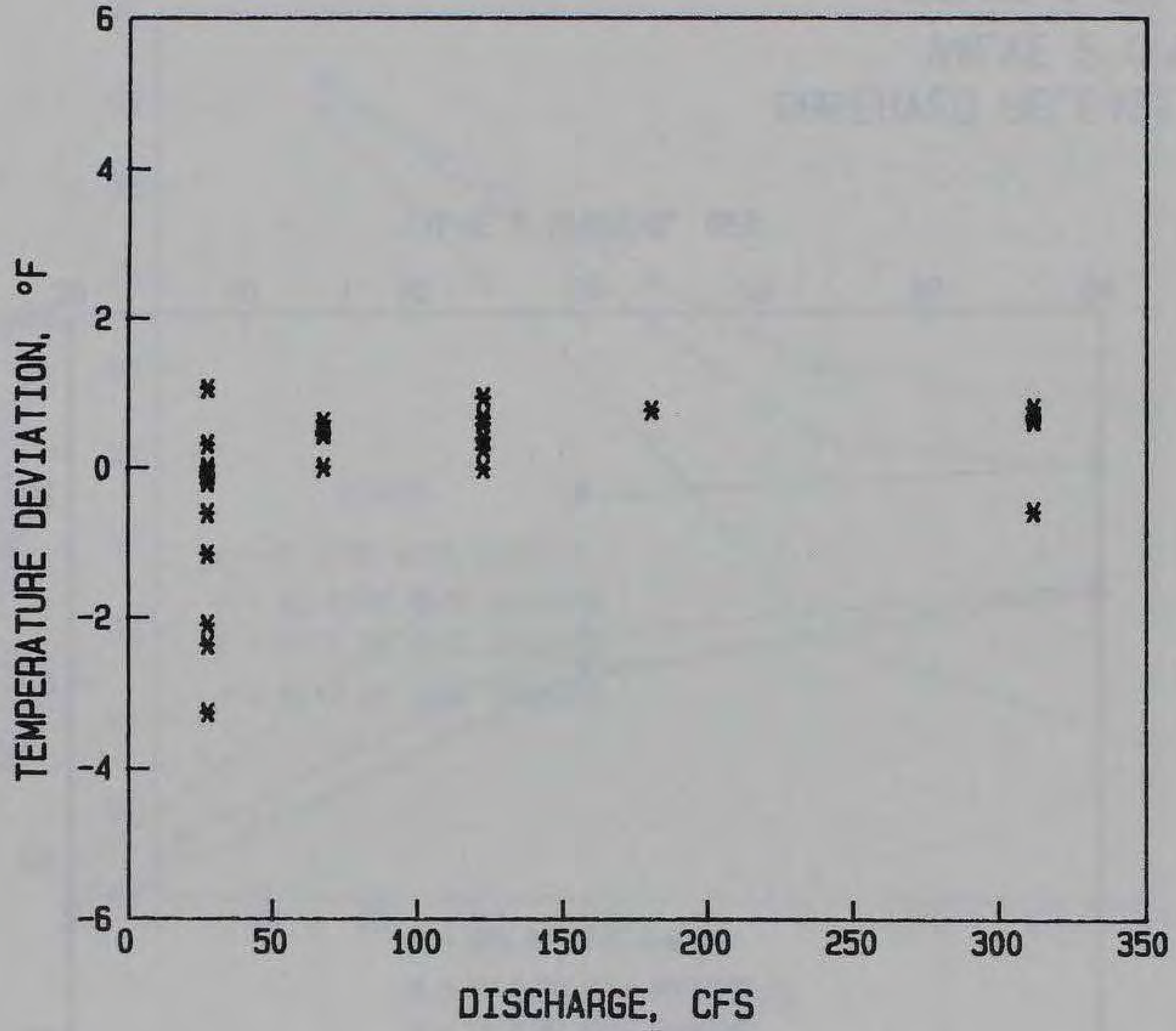


OBSERVED RELEASE TEMPERATURE
VALVE 3 OPENINGS
VALVE 1 FULLY OPEN

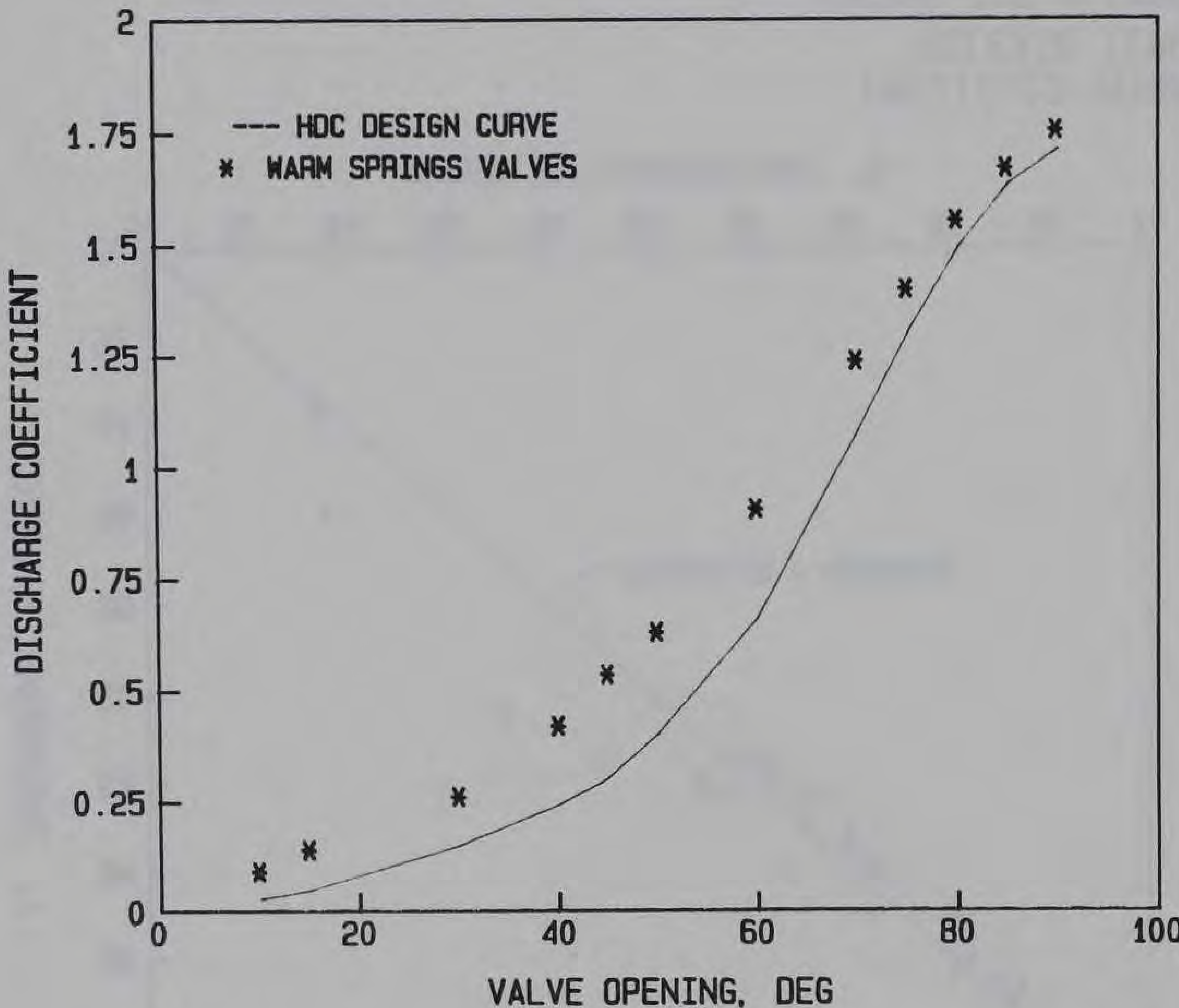


OBSERVED RELEASE TEMPERATURE
VALVE 2 OPENINGS
VALVE 1 FULLY OPEN

PLATE 20

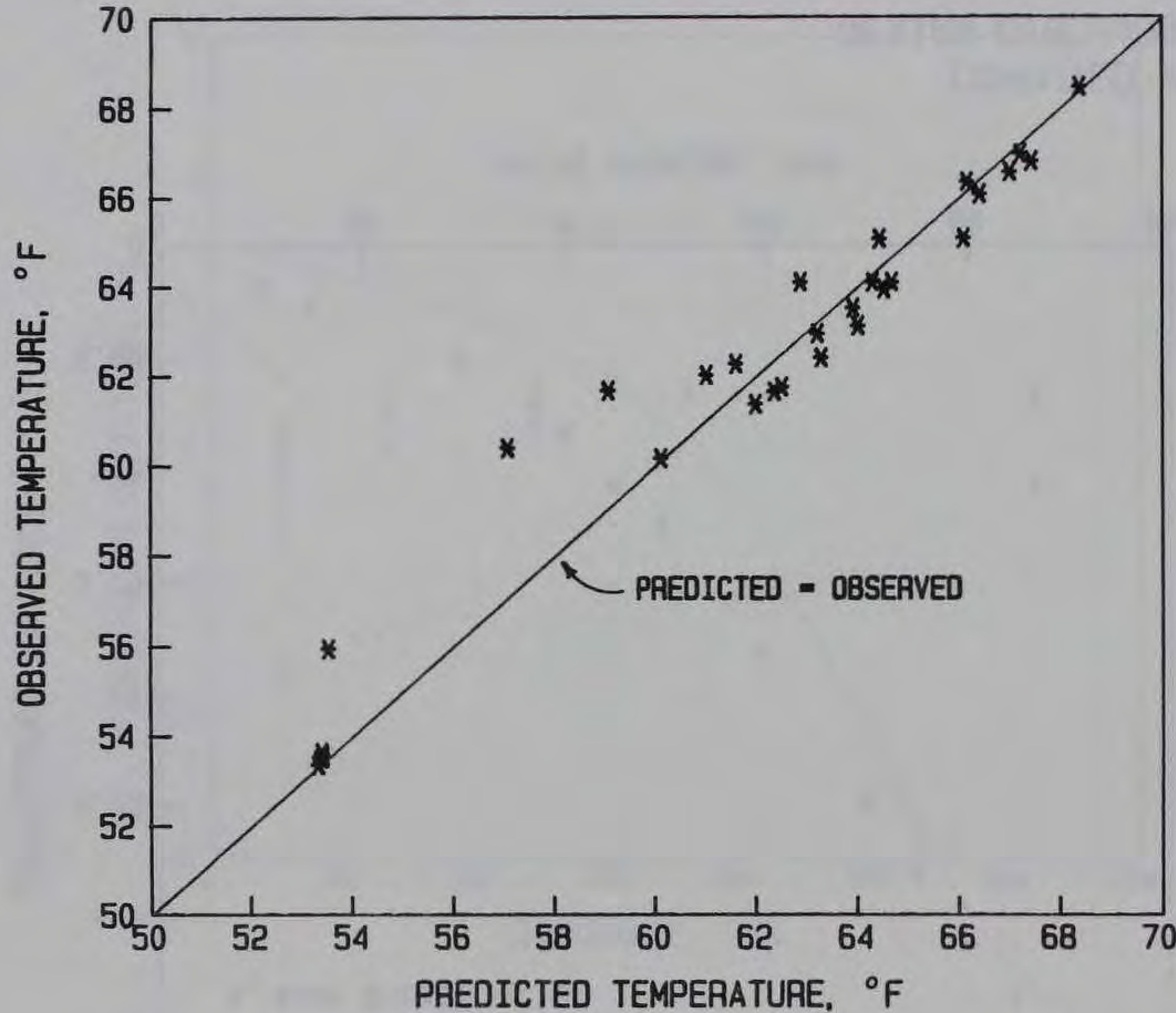


DEVIATION OF PREDICTED FROM
OBSERVED RELEASE TEMPERATURES
(USING BLENDING ALGORITHM)
VERSUS DISCHARGE



COMPUTED VERSUS HDC
DESIGN DISCHARGE COEFFICIENTS

PLATE 22



PREDICTED VERSUS OBSERVED
RELEASE TEMPERATURES
(USING THE BLENDING ALGORITHM)