my Corps
gineers

HYDRAULICS
LABORATORY

TECHNICAL REPORT HL-84-7

FIXED-CONE VALVE PROTOTYPE TESTS, FINAL SERIES NEW MELONES DAM, CALIFORNIA

by

Timothy L. Fagerburg

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631
Vicksburg, Mississippi 39180-0631

August 1984
Final Report

Prepared for

US Army Engineer District, Sacramento
Sacramento, California 95814

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report HL-84-7	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) FIXED-CONE VALVE PROTOTYPE TESTS, FINAL SERIES, NEW MELONES DAM, CALIFORNIA		5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Timothy L. Fagerburg		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Engineer Waterways Experiment Station Hydraulics Laboratory PO Box 631, Vicksburg, Mississippi 39180-0631		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Engineer District, Sacramento 650 Capitol Mall Sacramento, California 95814		12. REPORT DATE August 1984 13. NUMBER OF PAGES 54
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fixed-cone valve (WES)
Hydraulics (LC)
New Melones Dam (Calif.) (LC)
Pressure (LC)
Valves--Testing (LC)

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

The report presents the results of tests conducted subsequent to those discussed in US Army Engineer Waterways Experiment Station Technical Report HL-83-2 dated February 1983. The purpose of the tests was to obtain data at a higher pool elevation to: (a) determine the dynamic response of the 78-in.-diam fixed-cone valve and 18-ft-diam hood, (b) determine the probability of valve fatigue-type failure under prolonged operation, and (c) compare results with those of the earlier (basic) tests and model tests.

(Continued)

20. ABSTRACT (Continued).

Results of the data reduction include information on discharge characteristics of the fixed-cone valve, evaluations of pressure fluctuations in the valve and hood, vibration responses of the valve and hood, and strain measurements on the valve test vane.

The acceleration data revealed no significant changes due to the increase in pool elevation. Mean pressure values in the valve and hood increased as a result of the increase in total head. No negative pressures were recorded. Imposed limitation of the total sleeve travel to a maximum of 28.1 in. prevented the occurrence of a flow control shift.

PREFACE

The prototype investigation reported herein is a continuation of testing of the New Melones Dam fixed-cone valves which was initiated by the District Engineer, US Army Engineer District, Sacramento, in a letter to the Director, US Army Engineer Waterways Experiment Station (WES), dated 16 December 1977. Results of the initial (basic) investigation are reported in WES Technical Report HL-83-2, February 1983. The additional tests, designated as the "final" tests, were conducted during the period 19 and 20 July 1982.

Tests were conducted under the general supervision of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and M. B. Boyd, Chief of the Hydraulic Analysis Division, by T. L. Fagerburg with the assistance of E. D. Hart. This report was prepared by Mr. Fagerburg under the supervision of Mr. Hart, Chief of the Prototype Evaluation Branch, with assistance from Dr. F. M. Neilson, Hydraulic Engineering Information Analysis Center. Instrumentation support was obtained from Messrs. L. M. Duke, Chief of the Operations Branch, Instrumentation Services Division, J. L. Pickens, J. C. Ables, and D. M. Galbreath.

Acknowledgment is made to individuals of the Sacramento District and the US Department of the Interior, Bureau of Reclamation, Mid Pacific Region, for their assistance in the investigation.

Commander and Director of WES during the conduct of the tests and the preparation and publication of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, US CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

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

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
Fahrenheit degrees	*	Celsius degrees or Kelvins
feet	0.3048	metres
feet per second per second	0.3048	metres per second per second
inches	25.4	millimetres
pounds (force) per square inch	6894.757	pascals
pounds (mass) per square foot	4.882428	kilograms per square metre
square feet	0.09290304	square metres

* 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: $K = (5/9)(F - 32) + 273.15$.

FIXED-CONE VALVE PROTOTYPE TESTS, FINAL SERIES
NEW MELONES DAM, CALIFORNIA

PART I: INTRODUCTION

1. Prototype tests of the New Melones Dam, California, were conducted to determine the performance of the fixed-cone valve and hood at different pool elevations. Initially, the 78-in.-diam* Flood Control and Irrigation (FC&I) valve was tested at a pool elevation of 804.0 ft NGVD** in conjunction with tests on the smaller 66-in.-diam low level (LL) valves. These were part of a planned series of tests to be performed on the valves at various pool elevations up to the maximum pool elevation of 1055.0. Because of legal problems with filling of the reservoir and the time required to fill it once the problems were resolved, it was determined that a final test series would be conducted at a pool elevation near 1014.0.

2. A report of the results of the first test series was prepared (Fagerburg 1983) prior to completion of the final FC&I valve tests at pool elevation 1014.0 ft. The purposes of these tests were identical with those for the initial set: (a) determine the dynamic response of the FC&I valve, vane, and hood, (b) determine the probability of fatigue-type failure under prolonged operation, and (c) compare the prototype results with previous physical model predictions (Maynord 1981).

3. The initial tests conducted in connection with the study referred to in paragraph 1 and the report presenting the results of those tests are referred to herein as the basic tests and the basic report, respectively. This report, which constitutes a supplement to the basic report, presents the results of the final tests (Maynord 1981).

4. FC&I valve and hood instrument locations are identical with those of the basic tests. Some minor modifications were made to the valve transducer mounts in order to utilize a larger range pressure transducer necessitated by the significant increase in static head (Table 1).

---

* A table of factors for converting US customary units of measurements to metric (SI) units is presented on page 3.

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

5. Major modifications to the FC&I hood were implemented following the basic tests (Maynord 1981). Plate 1 illustrates the type and location of the modifications. A 3/4-in.-thick plate steel ring was welded to the upstream edge of the hood as shown. This was done in an attempt to increase the stiffness and thereby increase the natural frequency of the hood. Another modification was the addition of a pair of deflector plates. The purpose of the deflector plates is to alter the flow pattern in the hood and to direct the jet downward into the stilling basin for improved energy dissipation. It is difficult to ascertain the effects of these modifications on the pressure and vibration responses of the hood. A more accurate determination would have resulted from a comparison of data from pre- and postmodification tests at the same static head conditions.

PART II: TEST FACILITIES, EQUIPMENT, AND PROCEDURES

6. Location of the FC&I valve instrumentation is described in the basic report (pp 10-14) and shown in Plate 2. Specifications for the various transducers are listed in Table 1.

7. The tests of the FC&I valve were conducted in the following sequence: (a) stepped opening and closing valve operation and (b) individual sleeve openings. The stepped operation consisted of opening the valve sleeve to the desired increment, holding that position for one full minute, and then proceeding to the next desired opening, while simultaneously recording the data on magnetic tape. The same procedure was also followed for the sleeve closing increments. For the individual sleeve opening tests, the sleeve was held at the desired opening for approximately 8 to 10 min.

8. The first 5 to 7 min of the individual tests were to allow the flow in the valve and hood to stabilize and to make adjustments to the recording system. The remaining minimum of 3 min was used for recording the dynamic response data for the existing conditions. The recorders were then switched off, the sleeve opening was increased to the next increment, and the procedures were repeated. The following tabulation lists the test conditions.

Date July 82	Test No.	Duration of Test min	Sleeve Travel in.	Valve Opening* %	Discharge cfs**	Pool El, ft	Temperature Air °F	Temperature Water °F
19	1	19	S_v†	--	--	1014.95	94	49
20	2	10	11.3	25	1688	1014.60	82	
	3	9	16.6	40	2428	1014.59	83	
	4	9	20.1	50	2853		84	
	5	8	23.6	60	3222		84	
	6	10	27.2	70	3664		84	
	7	8	28.1	72	3664		85	
	8	16	S_v	--	--	1014.56	85	

* These values of valve openings are used to maintain a consistency with the notation used in the model study.

** Methods of computing discharge follow.

† S_v - Stepped opening and closing.

PART III: TEST RESULTS

Mean Pressures

9. The following tabulation lists the mean pressures at all pressure transducer locations in the valve and conduit as a function of sleeve opening. The accuracy of the pressures (scaled from oscillograms) is ±3.5 ft. These values may be compared with those of Table 3 of the basic report:

Gage	Mean Pressure, Feet of Water Valve Opening, %/Sleeve Travel, in.					
Location*	25/11.3	40/16.6	50/20.1	60/23.6	70/27.2	72/28.1
PC1	455	422	383	353	325	325
PC2	461	423	389	363	325	325
PC3	484	430	398	387	333	333
PC4	461	423	395	367	329	329
PUB	442	374	342	298	241	241
PUD	441	375	343	298	240	240
PLD	436	373	341	299	240	240

* See Table 1 and Plate 2.

10. Plate 3 is used to illustrate the effect of the increased pool elevation on the mean pressures measured in the conduit and on the test vane of the FC&I valve. Using the mean pressures for transducers PC4 and PUB, in the conduit and vane, respectively, a comparison is made between the basic FC&I valve tests (1979) and those recently completed. The mean conduit pressures were found to have increased as a result of the higher pool elevation by a factor of approximately 1.65 while the mean vane pressures increased by 1.79.

Discharge equations

11. The discharge values listed in paragraph 8 were obtained using a procedure described in the following paragraphs. It is identical with that used in the basic report (paragraphs 24-28). The following equations assume steady-state flow through the FC&I conduit:

a. Valve rating curve (Neilson 1971)

$$Q = C_D A \sqrt{2gH_{net}} \quad (1)$$

in which

Q = discharge, cfs, through one valve*

C_D = valve discharge coefficient

A = cross-sectional area of flow passage at valve intake; $A = 33.2\ ft^2$ for the 78-in. FC&I valve

g = acceleration due to gravity (32.2 ft/sec^2)

H_{net} = net total head, ft, at valve intake referenced to datum at the valve center line

b. Definition of H_{net} (Neilson 1971)

$$H_{net} = h_R + \frac{Q^2}{2gA_R^2} \tag{2}$$

in which

$h_R = h_4$ = piezometric head, ft, in the conduit immediately upstream from the valve at transducer PC4 (referenced to datum at the valve center line)

A_R = flow-passage cross-sectional area at the station corresponding to h_R ($A_R = 39.0\ ft^2$ for the FC&I valve at transducer ring PC1 - PC2 - PC3 - PC4).

c. Combining Equations 1 and 2

$$Q = C_D A \sqrt{\frac{2gh_R}{1 - \left(\frac{C_D A}{A_R}\right)^2}} \tag{3}$$

d. Head loss in the upstream conduit

$$H_L = H_T - H_{net} \tag{4}$$

in which

H_L = head loss, ft

H_T = total head at conduit intake, ft; i.e. pool elevation minus the elevation of the valve center line

e. Upstream conduit loss coefficient (definition)

---

* For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix A).

$$k = \frac{H_L}{\frac{Q^2}{2gA^2}} \quad (5)$$

in which k equals loss coefficient (form plus hydraulic friction) for the upstream conduit.

f. Transducer PC4 rating curve

$$Q = C_{EU}\sqrt{\Delta h_4} = C_{ED}\sqrt{h_4} \quad (6)$$

in which

C_{EU} = flow coefficient for the flow passage upstream of PC4 (i.e. independent of valve opening), $ft^{5/2}/sec$

Δh_4 = piezometric head drop, ft, between pool and transducer PC4

C_{ED} = flow coefficient for the flow passage downstream from PC4 (i.e., essentially independent of flow acceleration but dependent on valve opening), $ft^{5/2}/sec$

h_4 = piezometric head, ft, at transducer PC4

Calibration of transducer PC4

12. In order to have consistent accuracy in discharge determination, the model test C_D value at 50 percent valve opening was used to initially calibrate pressure transducer PC4 (see tabulation in paragraph 9) as a discharge measurement device. This information was then used to establish discharges at other valve openings. The model C_D value (Maynord and Grace 1981) was 0.49 at 50 percent valve opening and h_4 was 395 ft. These values and the defined equations from paragraph 11 were used to make the following tabulations:

Valve	C_D	h_4 ft	Δh_4* ft	Eqn 3 Q cfs	Eqn 2 H_{net} ft	Eqn 4 H_L ft	Eqn 5 k	Eqn 6 C_{EU} $ft^{5/2}/sec$
FC&I	0.49	395	101.6	285.3	478.2	18.4	0.16	283

* $\Delta h_4 = H_T - h_4$ where H_T = pool el - el of PC4 = 496.6.

A similar evaluation for all other gate openings resulted in only a small variation in the values of C_{EU}. The value 283 was therefore used in computing the remaining data.

Discharges

13. The above results and equations from paragraph 11 were used in computing the following values:

Valve Opening %	Sleeve Travel in.	h_4 ft	Δh_4 ft	Eqn 6 $Q = 283\sqrt{\Delta h_4}$ cfs	$\frac{Q^2}{2gA^2}$ ft*	$\frac{Q^2}{2gA_R^2}$ ft**	Eqn 2 H_{net} ft	Eqn 3 C_D
25	11.3	461	35.6	1688	40.20	29.10	490.10	0.29
40	16.6	423	73.6	2428	83.10	60.20	483.30	0.41
50	20.1	395	101.6	2853	114.70	83.10	478.20	0.49
60	23.6	367	129.6	3224	146.40	106.10	473.10	0.56
70	27.2	329	167.6	3664	189.10	137.30	466.30	0.64
72	28.1	329	167.6	3664	189.10	137.30	466.30	0.64

* Velocity head at valve.
** Velocity head at ring.

The results of the average pressure measurements and the discharge computations are indicators of the general valve performance and of the general agreement with the valve rating curve. Note that discharge was not measured and a precise rating cannot be obtained uniquely from these data. The computed discharges for both the 1979 and 1982 prototype tests are shown in Plate 4 for comparison with the project rating curves computed by the US Army Engineer District, Sacramento (based on model C_D values and estimated head loss (H_L) values). The total head (H_T) is the value of the pool elevation minus the elevation of the center line of the valve (518.0). The plot illustrates that some difference exists between the computed discharges and the project rating curves, but the differences (a maximum of 200 cfs) were consistent between the two tests.

Discharge coefficients

14. The discharge coefficients (C_D) at other than 50 percent valve openings were determined using the computed discharges. The following tabulation lists the coefficients from the model study (Maynord 1981) and those computed from the 1979 test data for comparison with the 1982 computed values.

Data	Discharge Coefficient, CD — Valve Opening, %/Sleeve Travel, in. 25/11.3	40/16.6	50/20.1	60/23.6	70/27.2
1982 tests	0.29	0.41	0.49	0.56	0.64
1979 tests	0.26	0.42	0.49	0.56	0.64
Model tests	0.26	0.41	0.49	0.57	0.66

Discharge coefficients determined from the 1979 and 1982 test data are plotted in Figure 1 to show (a) their general agreement with the Hydraulic Design Criteria (HDC) curve for a six-vane valve and (b) that for a given valve opening the coefficients are essentially constant and independent of pool elevation.

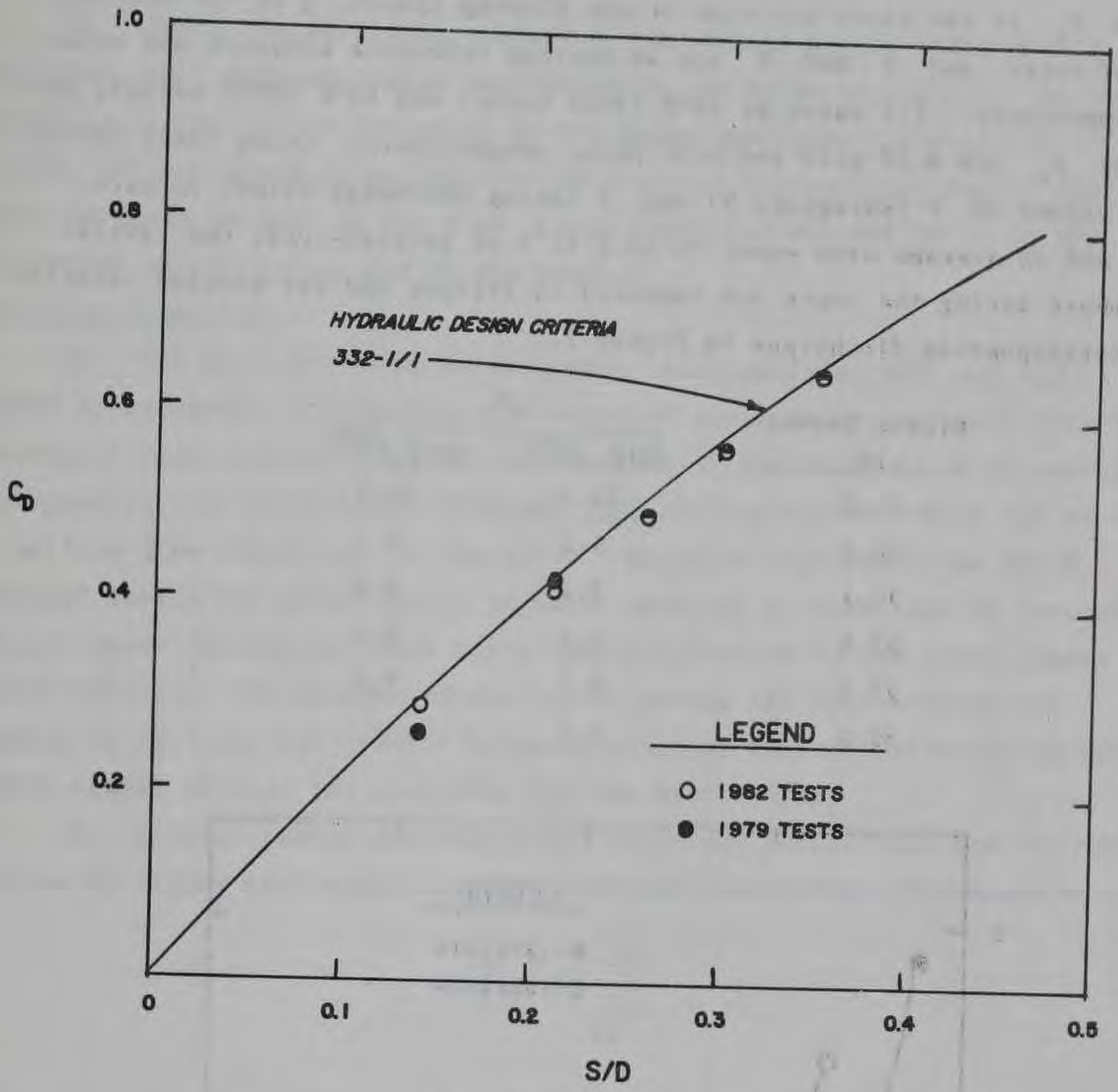


Figure 1. FC&I valve discharge coefficients

Close agreement found between the model and 1982 prototype C_D values supports the use of the C_{EU} value of 283. The values of C_D represent the coefficients of discharge and S/D the values of the ratio of the sleeve travel to the valve diameter.

Cavitation

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

$$\sigma_c = \frac{\frac{P}{\gamma} - \frac{P_v}{\gamma}}{\frac{V^2}{2g}} \tag{7}$$

in which P_v is the vapor pressure of the flowing liquid, γ is the specific weight of water, and P and V are an average reference pressure and velocity, respectively. For water at 49°F (1982 tests) and 65°F (1979 tests), the values of P_v are 0.17 psia and 0.31 psia, respectively. Using these values and the values of P (paragraph 9) and V (using discharge values in paragraph 8 and an average area equal to 33.2 ft^2) at location PC4, the cavitation numbers during the tests are computed as follows and are plotted relative to the corresponding discharges in Figure 2.

Sleeve Travel	σ_c	
in.	July 1979	July 1982
11.3	14.1	11.5
16.6	5.0	5.1
20.1	3.4	3.4
23.6	2.5	2.5
27.2	1.7	1.7
32.4	1.1	--

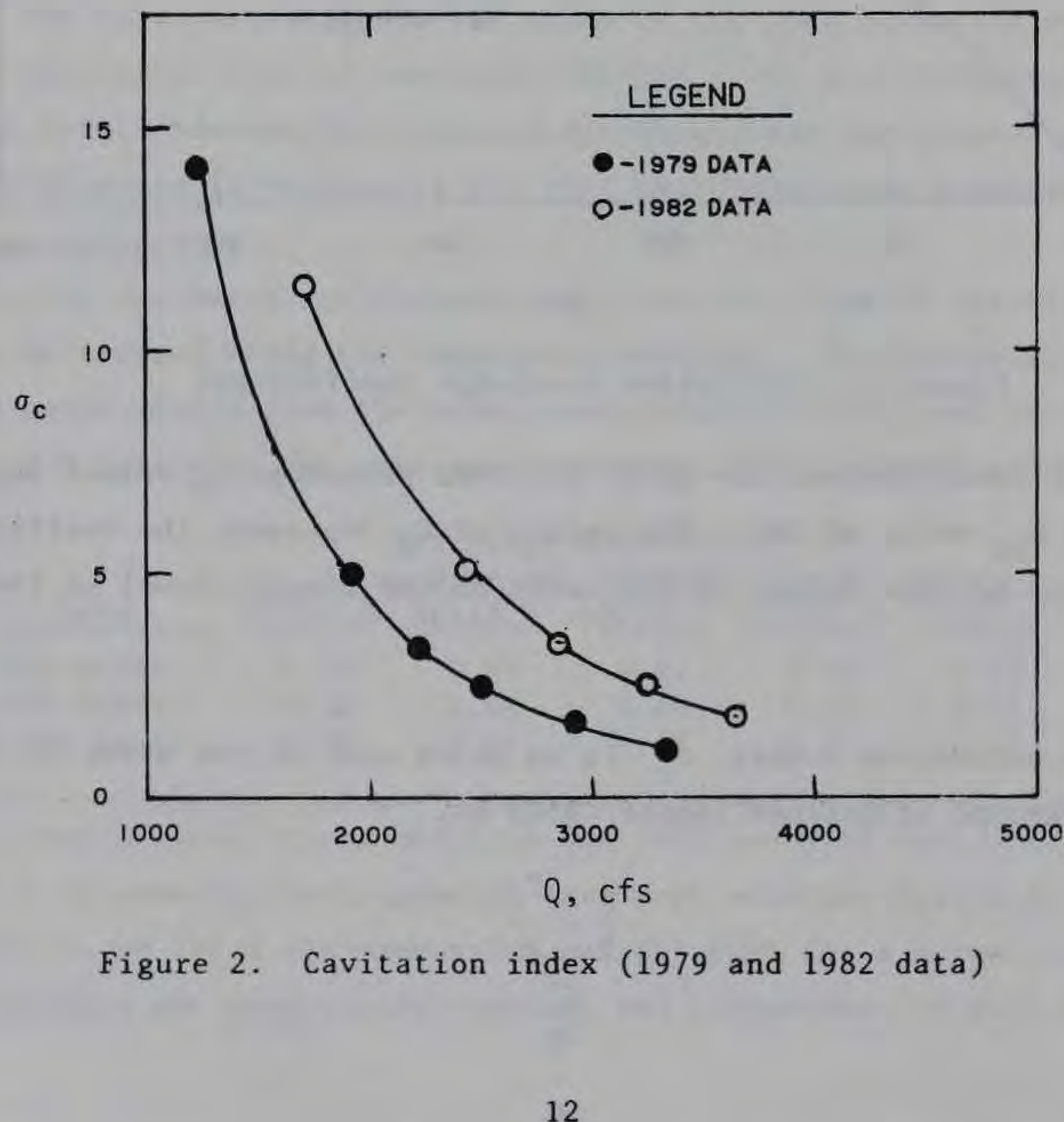


Figure 2. Cavitation index (1979 and 1982 data)

16. Since the cavitation index σ_c decreases as the valve opening increases, the tendency toward cavitation in the valve increases. The consequences of cavitation occurring in the valve immediately downstream of the reducer section would be an increase in pressure fluctuations due to large vapor cavities created in the flow. This condition did not occur to any measurable extent during any of the testing.

Mean vane pressures

17. The mean pressures at each vane location (PUB, PUD, and PLD) listed in paragraph 9 illustrate the expected decrease in magnitude with increasing sleeve opening. The net differences of the mean static pressures for opposing vane transducers (PUD and PLD) are negligible, which may be due to uniform flow conditions in the valve. Negative vane pressures which occurred during the basic tests, at valve openings greater than 85 percent, did not occur during the final tests due to reduction in the total sleeve travel allowed. The maximum sleeve travel during the recent tests was limited to 28.1 in. (72 percent valve opening) as compared with the maximum sleeve travel of 35.0 in. available for the basic tests.

18. A relationship used for model-prototype comparisons and for extrapolation to higher pool elavations for confined steady-flow circumstances is

$$\mathbb{E} = \frac{\Delta h}{\frac{V^2}{2g}} \qquad (8)$$

in which $\mathbb{E}$ is the Euler number and is expected to be influenced by geometric flow pattern changes, and Δh is a piezometric head differential (transducer PC4 minus the particular vane transducer head of interest) referenced to the valve center-line elevation (518.0) as a datum. The Reynolds number is large (10^7) for all the valve openings tested and the flow is enclosed by solid boundaries along the length of conduit from the reservoir to the fixed-cone valve. Because of this, the value of $\mathbb{E}$ will be constant (Rouse 1946) unless the flow pattern changes because of cavitation or a change in the boundary geometry. Plates 5 and 6 present comparisons of the prototype and model values of $\mathbb{E}$ for the FC&I valve for different pool elevations. The prototype Euler numbers plotted in Plate 5 are nearly constant and indicate that any localized cavitation is not sufficient to alter the discharge rating curve discussed in paragraph 13. Changes in the magnitudes of $\mathbb{E}$

(prototype) for the different pool elevations are relatively small indicating that no significant changes occurred in the conduit geometry due to internal pressure loading of the FC&I valve.

19. The values of $\mathbb{E}$ for all valve openings for both the model and the 1982 prototype test are summarized below.

Valve Opening %	Sleeve Travel in.	Model (M) or Prototype (P)	Velocity fps	Values of $\mathbb{E} = \frac{\Delta h}{V^2/2g}$ *U - Surface PUB	*U - Surface PUD	*L - Surface PLD
25	11.3	P	50.8	0.54	0.57	0.69
	11.3	M	47.8	3.30	3.00	2.80
40	16.6	P	73.2	0.62	0.61	0.63
	16.6	M	73.1	1.40	1.20	1.00
50	20.1	P	86.0	0.48	0.48	0.49
	20.1	M	**	**	**	**
60	23.6	P	97.0	0.49	0.49	0.49
	23.6	M	103.3	1.00	0.80	0.60
70	27.2	P	110.3	0.48	0.48	0.48
	27.2	M	**	**	**	**
85	32.4	P	**	**	**	**
	32.4	M	136.5	0.80	0.60	0.40

* Looking downstream at the test vane (6:00 position) U - surface corresponds to the left side of the vane. L - surface corresponds to the right side of the vane.

** No data available.

The relatively small variation in prototype $\mathbb{E}$ values with valve opening, as indicated in the above tabulation and in Plate 5, is comparable to that observed in the basic report (paragraph 32). The model valve supplied by the manufacturer was not typical of those commonly constructed and tested by WES. The model was not framed or fabricated of elastically similar material and components. It was considered "very stiff" relative to the prototype, and significant correlation of model and prototype E values was not expected. It appears that both the model and prototype valves are "stiff" with S/D openings equal to or greater than 0.3 (see Plates 5 and 6).

Flow control

20. A phenomenon that is characteristic of most fixed-cone valves is a flow-control shift. This is described in detail in paragraph 33 of the basic report. The occurrence of this situation in the basic tests resulted in

periods of intense vibrations and pressure fluctuations. For the basic tests (maximum sleeve travel 35.0 in.), a flow-control shift occurred at an opening of 31.0 in. The model tests showed that the flow-control shift occurred at sleeve travels of about 30.9 in. in the FC&I valves and at 27.7 in. in the low-level valves. During the final test period, the total sleeve travel was limited to 28.1 in., and a shift did not occur. This implies that the sleeve opening restriction is sufficient to prevent the flow-control shift and the corresponding intense vibrations and pressure fluctuations, at least to the tested pool elevation.

Dynamic Pressures

Overview

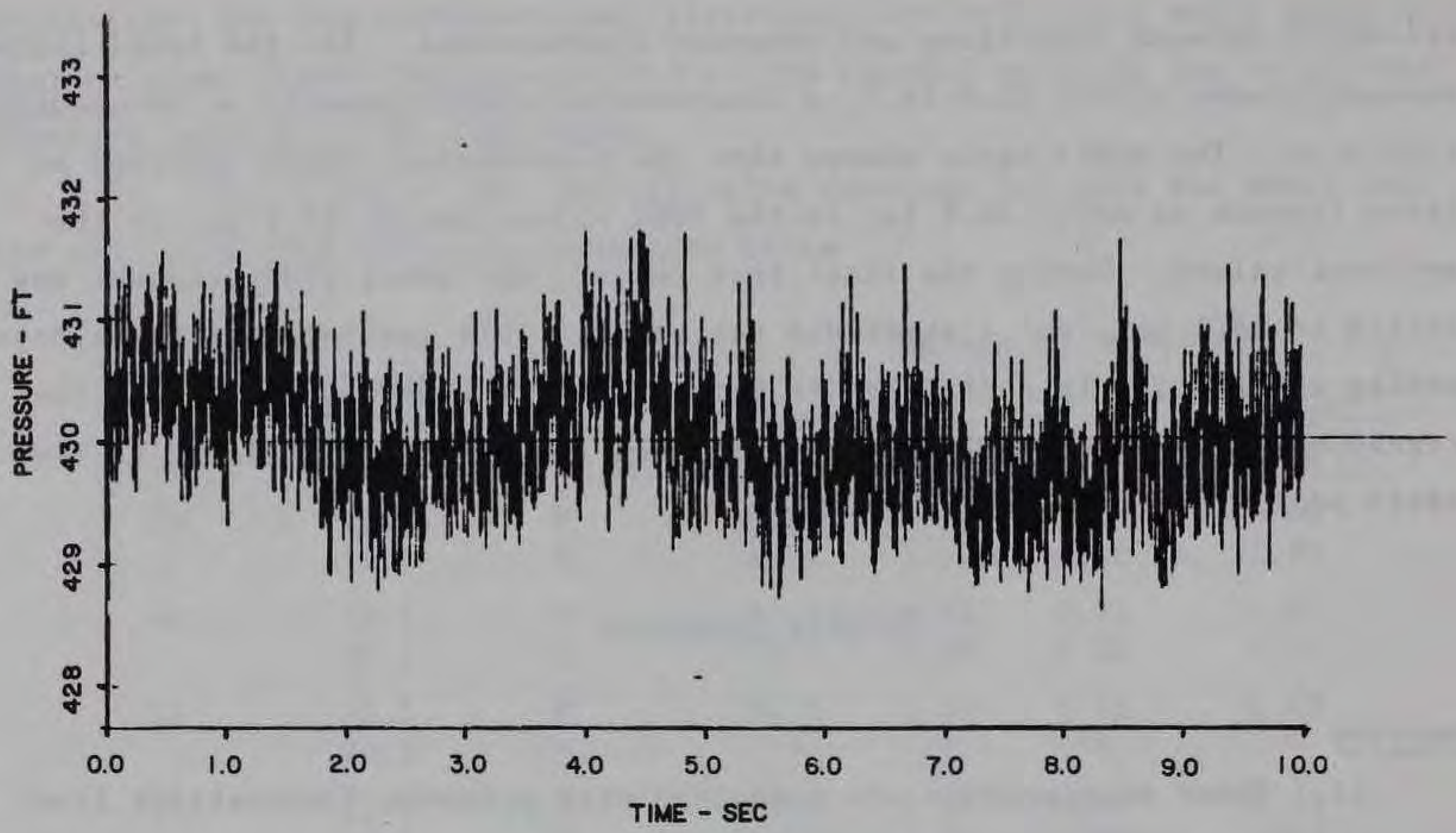
21. These measurements are concerned with pressure fluctuations from four transducers (PC1-PC4) in the valve reducer, three transducers (PUB, PUD, PLD) in the test vane, and eight transducers (PH6-PH13) in the FC&I hood. The reduction and analysis of the pressure data included digitizing the data from the magnetic tape and producing time-history plots and Fast Fourier Transform (FFT) plots. Table 2 is a compilation of the highest instantaneous pressures, lowest instantaneous pressure, and the greatest instantaneous peak-to-peak amplitude of pressure fluctuation observed at each transducer for each increment of sleeve opening tested.

22. A comparison of the data from Table 2 with those of the basic report indicates that:

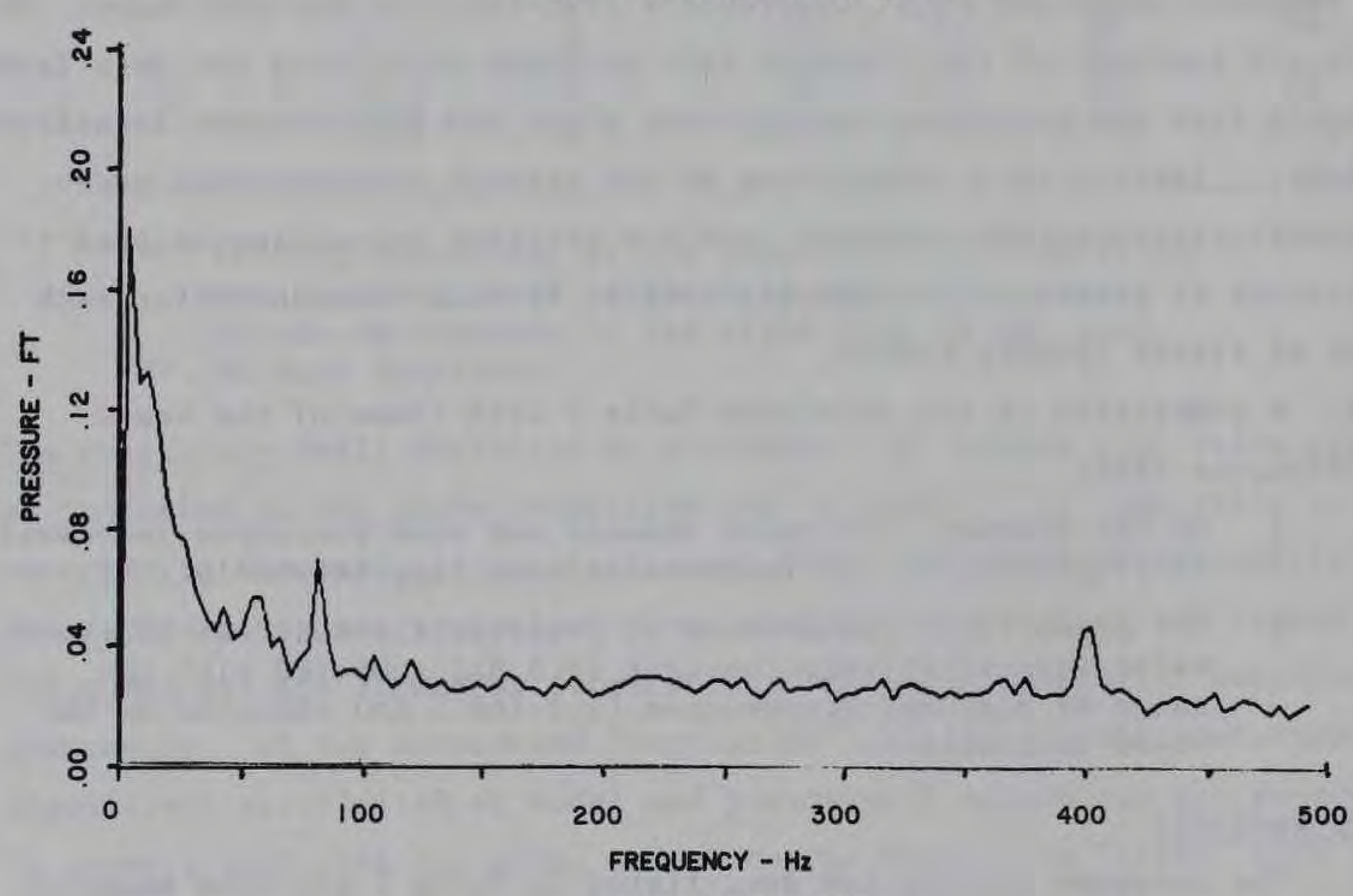
- a. On the average, the valve reducer and vane pressures increased in proportion to the increase in head (approximately 1.7).
- b. The predominant frequencies of pressure fluctuations in the valve were relatively constant (7.8 Hz) compared with the range of dominant frequencies (5.7-166.5 Hz) observed in the basic test data.

Frequency analysis

23. The pressure fluctuation data listed in Table 2 are from magnetic tape analog records digitized at a rate of 2,000 samples per second. A 10-sec digital time-history and FFT plot were made for each data channel for each test. An example is shown in Figure 3. A qualitative evaluation of the FFT plots is presented in Table 3. The descriptive symbols used in the tables are described below.



a. Time-history plot



b. FFT plot

Figure 3. Example of a 10-sec digital time-history and FFT plot for transducer PC3 at a 40 percent valve opening

a. Because of the dominance of low frequency turbulence and limited sample length most plots contain large amplitude components in the range 0 to 20 Hz. This is denoted by "<20 Hz" (Figure 4a).

b. The hood transducer FFT plots normally show large variations in amplitude; the overall trend in amplitude is to become less at higher frequencies and is denoted by "Irr" (Figure 4b).

c. Plots showing a general trend toward constant or increasing amplitude with increasing frequency are denoted by "Noise (u)" (Figure 4c).

d. Distinct peaks at frequencies greater than 20 Hz are included only when they are clearly discernible in the record and are obviously not electrical noise. The symbol "+" denotes plots that contain multiple but not clearly discernible separate peaks of significant amplitude at these higher frequencies; the symbol "--" denotes plots with no separate peaks.

24. The overall results of the FFT overview are summarized as follows. The vane transducer dominant frequencies, as listed in Table 3, are in very close agreement with those determined from the basic test data. Because transducers PUD (basic tests) and PLB (final tests) were inoperative, only two comparisons were available, PUB and PLD. No consistent peaks appeared at frequencies greater than 20 Hz that were apparently flow-dependent. The vane transducer FFT data for the final tests (PUB, PUD, and PLD) did contain some peaks at high frequencies; however, the larger peaks are usually in the less than 20-Hz frequency range. During the final test series, transducers PC1, PC2, and PC3 recorded dominant frequencies less than 20 Hz. Transducer PC4 recorded significant amplitudes at frequencies greater than 20 Hz. In the basic tests, PC2 was inoperative and PC4 amplitudes increased with frequency. In the majority of the tests, transducer PC3 recorded similar frequencies in both test series. The valve piezometer ring (PC1, PC2, PC3, and PC4) FFT data contain some peaks that extend to high frequencies which are likely caused by mechanical vibration of the valve. However, the highest peaks for these transducers commonly occur at frequencies less than 20 Hz. The 400-Hz frequency that occurred for hood transducers PH6, PH7, and PH8 is likely due to mechanical vibrations and reverberation of the hood rather than pressure fluctuations.

25. The maximum amplitudes of all pressure fluctuations are listed in Table 2. The hood pressures are discussed in a subsequent section--this discussion pertains only to the reducer and vane pressures. These latter values are presented in Table 4 in the form

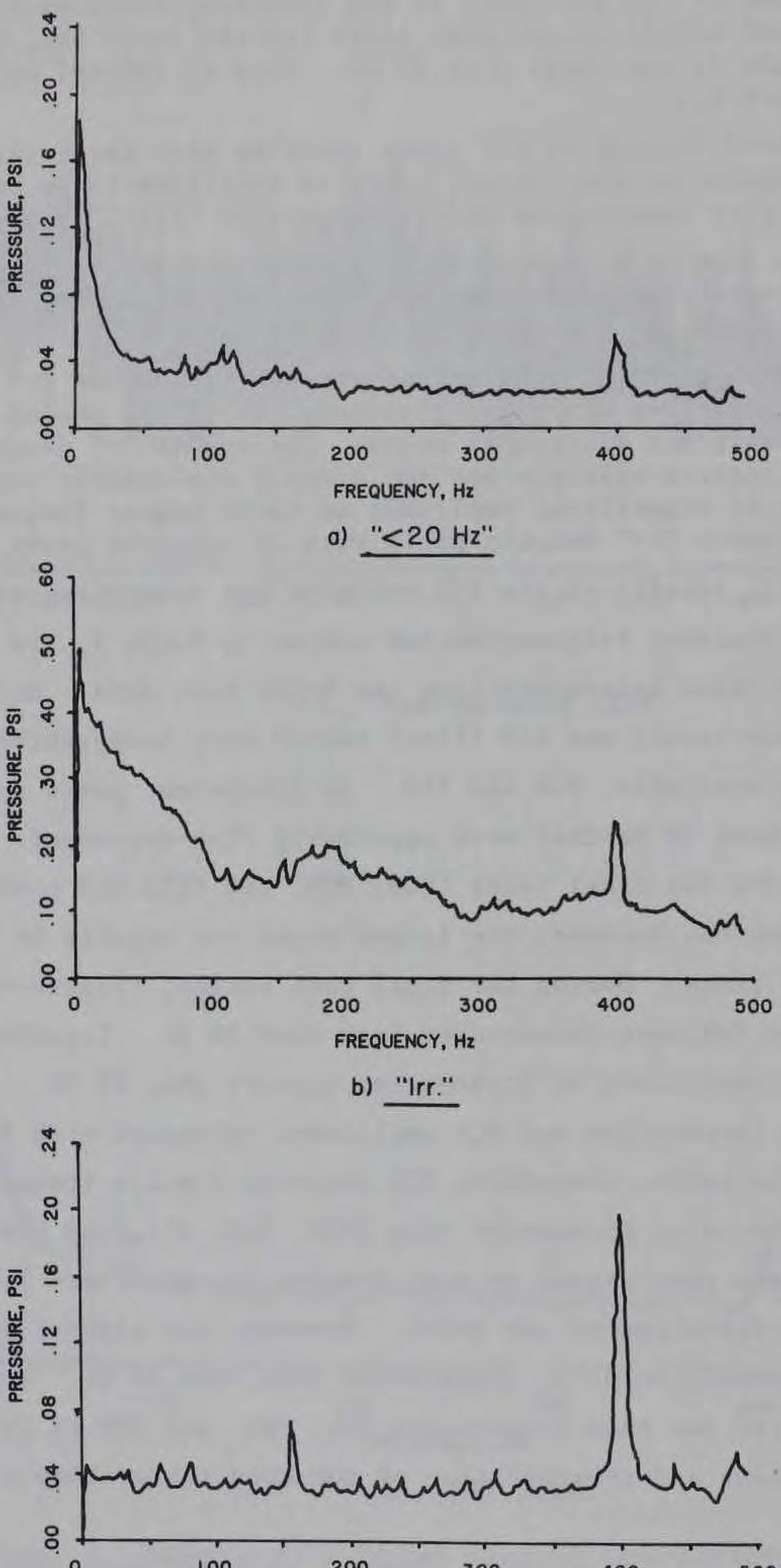


Figure 4. Examples of FFT plots and the descriptive symbols

$$\frac{P_{max} - P_{min}}{\frac{Q^2}{2gA^2}}$$

where

P_{max} and P_{min} = maximum and minimum peak amplitudes expressed in feet of water

Q = discharge, cfs

A = is the cross-sectional area of the valve, ft^2

This gives a dimensionless value for comparison.

26. The following listing considers particular groupings of the transducers. The data are vane and reducer pressure fluctuations in the 50, 60, and 70 percent open circumstance. Listed values are the maximum amplitude (from Table 4), rounded to the nearest 10 percentile; unrounded values in parentheses are average values. For the purpose of comparison, the values of a similar discussion presented in the basic report (paragraph 43, page 34) are also listed.

Transducer Group	Values of $\frac{(P_{max} - P_{min})}{Q^2/2gA^2}$ 1982 Tests		1979 Tests	
Reducer	0.10	(0.10)	0.20	(0.12)
Vanes (D, upstream)	0.10	(0.09)	0.10	(0.06)
(B, downstream)	0.10		0.10	
Vanes (U, left surface)	0.10		0.10	
(L, right surface)	0.10		0.10	

27. The above values indicate:

a. The extreme fluctuation ratios are not significantly different at upstream or downstream, or left or right surface, locations on the vanes.

b. The fluctuation ratios in the valve reducer and on the vane for both test series are not significantly different.

Pressure loading on the vanes

28. As stated previously, the vane pressures are listed in Table 4. The location of each transducer is shown in Plate 2. Upstream and downstream pressure transducer locations are designated by the letters D and B, respectively. The test vane is oriented vertically and the left and right surfaces

of the vane (looking in a downstream direction) are designated by the letters U and L, respectively.

29. Digitized data at each valve opening test were scanned to find the maximum instantaneous pressure for each vane pressure transducer. The largest of these maximum pressures was then used as the point for net vane pressure determination as illustrated in Figure 5. In the illustrated case, pressure from the right vane surface (PLD) was subtracted from that of the left vane surface (PUD) to give the net vane pressure. Figure 6 shows the maximum instantaneous net vane pressures determined for each test. A comparison was made between the maximum net vane pressures obtained from the model study and those from the final prototype tests as shown in Figure 6. The primary direction of the differential vane pressure is also illustrated in the figure. The apparent variation between the model and prototype data can be attributed to the differences in the elastic response of the vanes to changes in pressure as well as the greater heads and sleeve openings tested in the model. The prototype valve is more flexible than the model valve. It was known that fluid-structure interaction due to elasticity of the prototype valve and materials would not be simulated in the "stiff" hydraulic model valve supplied WES for the model study. As no attempt was requested to address elasticity effects in the model, prototype tests were planned to define fluid-structure interactions recognized as significantly pertinent and usually addressed in WES model studies of appurtenances for hydraulic structures.

30. Pressure loadings on the vanes of the valves are expressed in terms of a differential pressure existing over the entire vane. Design differential pressure given for the FC&I valve is 129 ft. Therefore maximum instantaneous net vane pressures were used as a form of expressing the pressure loading conditions on the vanes. Comparison of the design pressure with the prototype values shown in Figure 6 revealed that the measured pressures are well below the design loading value. For example, the maximum differential vane pressure recorded was 11.8 ft at 70 percent valve opening.

31. Due to the loss of transducer PUD during the basic tests and installation difficulties with transducer PLB prior to the final tests, no comparison of net vane pressures for transducers PUD-PLD for the two test series was possible and similarly for transducers PUB-PLB. Therefore the only data available for comparison of vane pressure loading were PUD-PLD for the final test data and PUB-PLB from the basic test data. The following tabulation

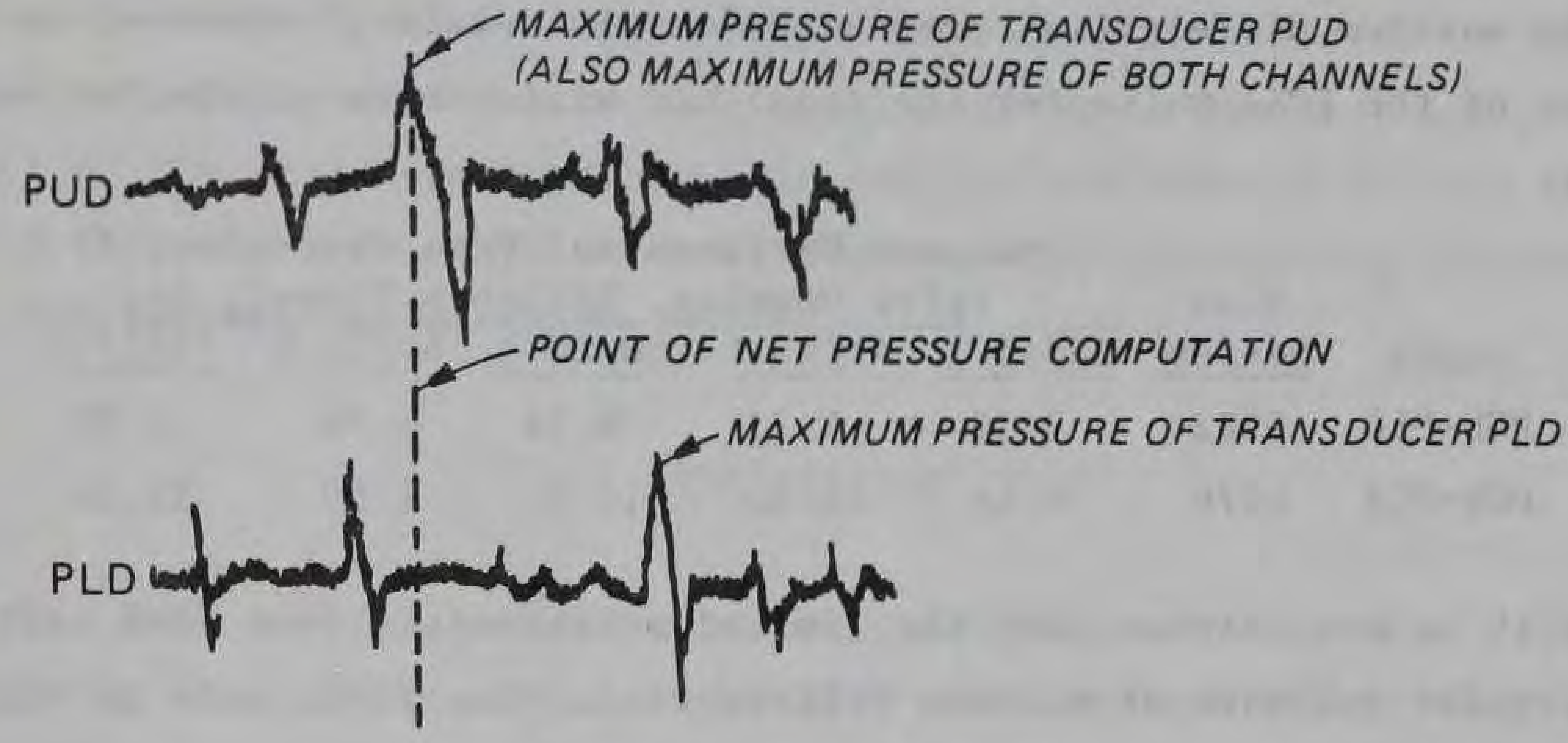


Figure 5. Determination of net pressures

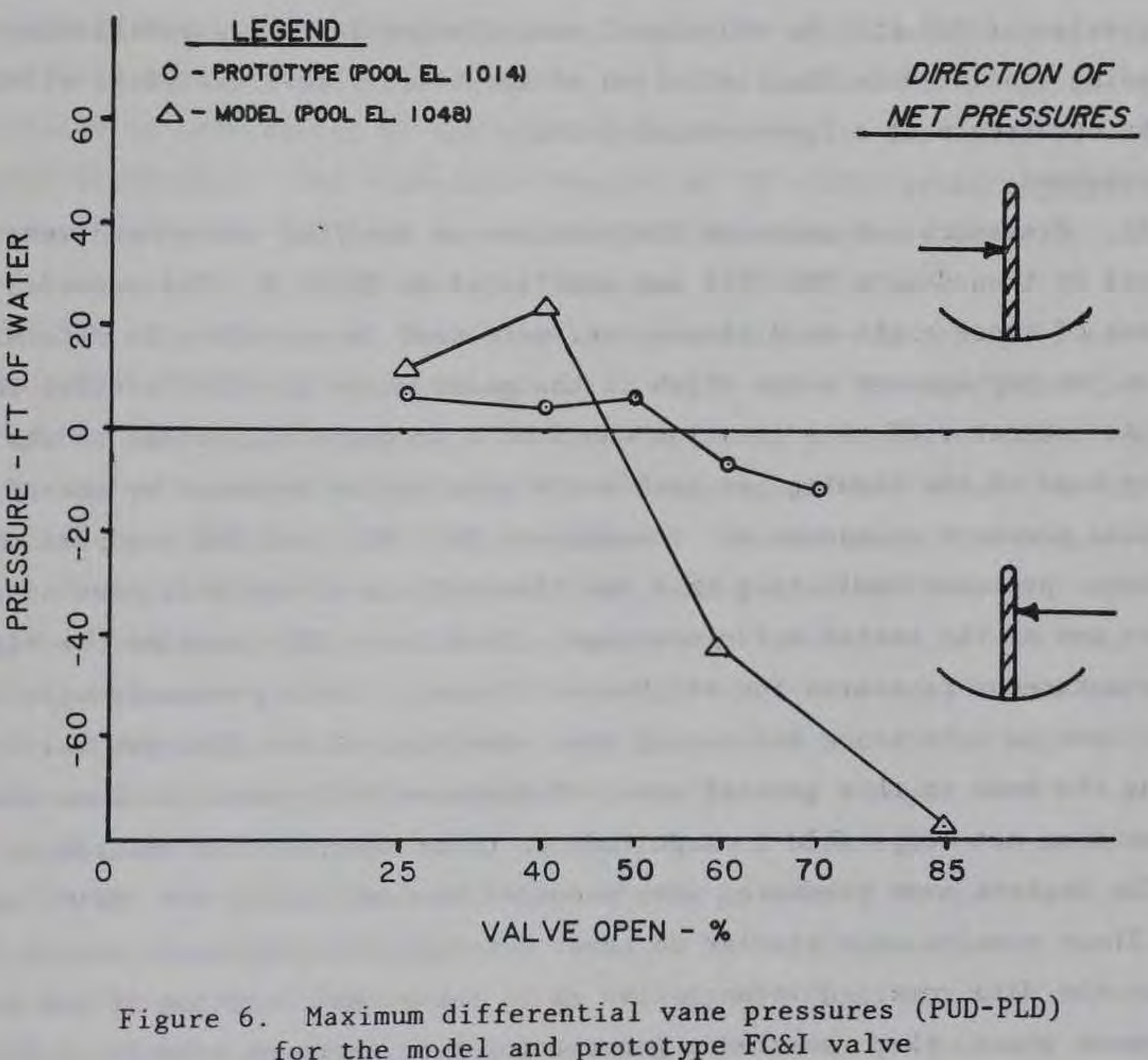


Figure 6. Maximum differential vane pressures (PUD-PLD) for the model and prototype FC&I valve

lists the maximum differential pressures (absolute values) observed on the test vane of the FC&I valve for the final and basic tests at similar valve openings:

Gages	Test Series	Maximum Differential Vane Pressures, ft Valve Opening, %/Sleeve Travel, in. 25/11.3	40/16.6	50/20.1	60/23.6	70/27.2
PUD-PLD	1982	7.15	5.21	6.34	6.76	11.83
PUB-PLB	1979	4.58	10.30	10.81	8.68	25.16

Although it is not certain that the limited measurements from each test provide a precise estimate of maximum differentials, the difference in the net vane loading values between the two test series listed above is small and implies that at the maximum pool elevation (1055.0) the maximum loading condition that would occur is likely to be considerably lower than the design loading value of 129 ft. An additional contributing factor in restricting the loading condition is the limitation of the total sleeve travel to eliminate the occurrence of a flow-control shift.

Hood pressures

32. Pressures and pressure fluctuations on the FC&I valve hood were monitored by transducers PH6-PH13 and are listed in Table 2. The recorded pressures of these eight hood transducers were used in an effort to determine the flow jet impingement point which is the point where the flow strikes the hood. An indicator of this location would be a pressure equivalent to the velocity head of the issuing jet that would possibly be recorded by one of the eight hood pressure transducers. Transducers PH6, PH7, and PH8 recorded only atmospheric pressure indicating that the flow did not strike this part of the hood for any of the tested valve openings. Transducer PH9 recorded the highest instantaneous pressures for all tests. However, these pressures were intermittent in occurrence indicating that some part of the flow jet was striking the hood in this general area. Transducer PH10 pressures were also high but were not comparable in magnitude to those observed for transducer PH9. The highest mean pressures were recorded by transducers PH9, PH10, and PH11. These results were similar to those determined in the basic report. Although the data remained inconclusive as to the actual location of the jet impingement point, they revealed a general location (between transducer PH9 and PH11) that is consistent with the computed-theoretical location presented in the basic report. Direct comparison of hood pressures between the original

1:12-scale model and the prototype FC&I valve hoods as modified to improve energy dissipation could not be made quantitatively. However, hydraulic performance of the prototype hoods is satisfactory and similar to that indicated by the 1:24-scale model used to develop the energy dissipating deflector plates for the FC&I valve hoods.

Acceleration

33. Both the final and basic test series measurements were made at two locations on the valve and one on the hood as shown in Plate 2. Four transducers (accelerometers) were used. Transducers denoted by "V" (AVC and AVP) measured vertical acceleration normal to the flow through the valve. The sign convention is: the measurement is positive when the valve is accelerated in the upward direction. Transducers denoted by "T" (ATC) measured horizontal acceleration normal to the flow direction. The measurement is positive when the valve is accelerated to the right (when looking at the valve in a downstream direction). The transducer denoted by "H" (AHA) measured vertical hood movement normal to the flow direction. The measurement is positive when the hood is accelerated in an upward direction.

34. The basic test series was performed at a reservoir pool elevation of 804.1 ft NGVD and indicated generally small valve and hood vibrations, the exception occurring during the flow-control shift referred to in paragraph 20. The calculated peak-to-peak valve displacements were less than 0.02 in. with dominant frequencies (f_D) of 80 Hz or less. The exception was transducer AVP which recorded higher frequencies. Though hood accelerations were relatively large, the peak-to-peak hood displacements were small, being less than 0.01 in. with f_D values of 145 to 160 Hz. Recommendations were made in the basic report to conduct additional tests at higher elevation to determine if the sleeve opening limitation was sufficient to prevent a flow-control shift.

35. Transducers AVC, ATC, and AVP, for the final tests were unbonded strain-gage accelerometers with range of ± 15 g, natural frequency (f_n) of 700 Hz, and damping about 70 percent of critical. Transducer AHA was an unbonded strain-gage accelerometer with a range of ± 25 g, natural frequency of 900 Hz, and damping of about 70 percent of critical. The primary calibrations for the accelerometers were electronic steps made prior to and following each day's tests. All accelerometers were tilted prior to installation in order to

verify the sign convention noted previously and to provide a rough check on the calibrations.

36. Prior to analysis the data were digitized at a rate of 2,000 samples per second. Four sets of 10-sec digital time-histories are shown in Plates 7-10. The maximum peak-to-peak accelerations for the final test series were tabulated and are listed in Table 5. For comparison the acceleration data of the basic tests are also tabulated.

Acceleration analysis

37. Data in Table 5 show that valve accelerations in the vertical direction varied in dominant frequency from 43 to 117 Hz. The maximum peak-to-peak vertical accelerations varied from 0.78 to 2.20 g with displacements,* varying from 1.76×10^{-3} in. to 11.63×10^{-3} in. In the horizontal direction, the dominant frequency varied from 43 to 324 Hz, maximum peak-to-peak valve accelerations varied from 0.33 to 1.53 g, and displacements varied from 0.07×10^{-3} in. to 8.09×10^{-3} in. The higher displacements all occurred at 70 percent valve opening. These data also show that hood accelerations varied in dominant frequency from 164 to 330 Hz, maximum peak-to-peak accelerations ranged from 9.90 to 26.40 g, and displacements ranged from 0.89×10^{-3} in. to 9.60×10^{-3} in., generally increasing with valve opening.

38. Using the FFT results, a survey was made of the data to determine if the valve and hood vibrated at a specific frequency or range of frequencies and if any significant trends in peak frequency existed that would indicate some type of flow dependence. Two sets of typical FFT's are shown in Plates 11 and 12 for Tests 3 (40 percent valve opening) and 4 (50 percent valve opening), respectively. A qualitative evaluation of the acceleration FFT data was performed and is presented in Table 6. Note that the dominant frequency for each accelerometer is repeated from Table 5 as well as other well-defined peaks. The FFT evaluation in Table 6 of accelerometers AVC, AVP, ATC, and AHA illustrates with some exceptions a specific range of frequencies at which the hood and valve vibrated. In general:

- a. The accelerometers at the center of the valve, AVC and ATC, recorded an average dominant frequency of 43 Hz with the exception of AVC at 25 percent valve opening and ATC at 60 percent valve opening.

---

* $$\text{Displacement} = \frac{(386)(A_{pk-pk})}{(2\pi\ f_D)^2}$$

A_{pk-pk} = maximum peak-to-peak acceleration, g

f_D = dominant frequency

b. The accelerometer on the valve periphery, AVP, recorded an average dominant frequency of 60 Hz. Other secondary peaks ranged from 43 to 309 Hz with 43 and 288 Hz occurring with some regularity.

c. The accelerometer on the hood, AHA, recorded a constant dominant frequency of 164 Hz except for f_D of 330 Hz at 25 percent valve opening. Other secondary peaks ranged from 224 to 336 Hz.

Comparison with previous tests

39. The valve vibration frequency data listed in Table 6 are considered a reasonably accurate representation of the natural frequency of the fundamental mode of vibration of the FC&I valve (estimated by the valve manufacturer to be approximately 55 Hz) referred to in paragraph 51 of the basic report. The data, as presented in Plates 11 and 12, show well-defined low frequency peaks as well as a broad band of high frequency peaks, similar to that which existed during the basic tests (Plates 13 and 14). The implication is that the increase in pool elevation did not significantly alter the valve vibration frequencies.

40. A comparison of the data of the final tests with those obtained during the basic (see Table 5) tests is as follows.

a. For valve openings of 25 and 40 percent, the maximum peak-to-peak valve acceleration amplitudes were greater than those observed in the basic tests. The opposite was true for the hood.

b. For valve openings of 50 percent and greater, the maximum peak-to-peak valve acceleration amplitudes were less than those observed in the basic tests. The opposite was true for the hood.

c. The dominant frequencies of the valve vibrations were approximately equal to or less than those frequencies observed from the basic test data with the exception of AVC at 25 percent valve opening and ATC at 60 percent valve opening.

d. The dominant frequency of the hood accelerometer, AHA, increased from an average value of 149 Hz during the basic tests to 164 Hz for the final tests. This excludes the f_D value of 330 Hz at a valve opening of 25 percent. This general, slight increase in frequency may be the result of the addition of the hood liner stiffener ring, described in paragraph 5, and the increase in discharge.

e. The values of the equivalent peak-to-peak displacements for the two test periods were generally random and not a distinct indication of response to the pool elevation differences.

Valve failure criteria

41. In the basic report, safety parameters, referred to as parametric values, were used to designate a serious situation involving potential valve failure that is closely associated with a critical velocity. The maximum discharge through the valve was used in the computations.

42. It has been determined that valves with a computed parametric value below 0.115 have operated successfully and those with values greater than 0.130 have failed (Mercer 1970). These criteria were developed from the operating records of over 20 examples of similar fixed-cone valves. The equation used for determining a parametric value $\left(\frac{\pi}{4}\frac{S}{D}\right)$ which can be associated with valve failure is

$$\left(\frac{\pi}{4}\frac{S}{D}\right) = \frac{Q}{C_v T_v D} \div \sqrt{\frac{E}{\rho}} \tag{9}$$

where

S/D = dimensionless distance traveled by the flow (where S = sleeve travel, in.)

Q = discharge, cfs (using the maximum discharge experienced)

C_v = dimensionless coefficient dependent upon the ratio of shell thickness to vane thickness (T_s/T_v) and the number of vanes

T_s = thickness of the shell, ft

T_v = thickness of the vane, ft

D = diameter of the valve, ft

E = Young's modulus of elasticity, 4.176×10^9 lb/ft^2

ρ = mass per unit volume, 15.22 lb-sec^2/ft^4 for A-514 steel

Because the same valve was used in both test series, the values used in this computation remained unchanged except for discharge. Due to the restricted maximum sleeve travel of 28.1 in., the maximum discharge for the final tests was 3,664 cfs which is only slightly greater than the discharge of 3,340 cfs attained at full sleeve travel (35.0 in.) for the basic valve tests. The computed parametric values at the maximum discharges are 0.056 and 0.060 for the final and basic tests, respectively, and are indicative of values associated with safe operation of the valve.

Strain

43. The measurement of strain (ε) on the test vane (at the 6:00

location) of the FC&I valve was made at the calculated point of maximum stress concentration. A strain gage arrangement similar to that described in the basic report was used. A particular set of gages monitored a specific axis of strain (axial or bending) while eliminating any opposite strain signals that were present. For example, one strain gage arrangement measured only axial strain (strain having a primary axis parallel to the valve radius) while any accompanying bending strain (strain having a primary axis perpendicular to the valve radius) was nullified. The strain data listed in Table 7 were obtained from the magnetic tape records. A digital time-history and FFT plot were made for each valve opening.

44. The FFT plots of the strain data were reviewed to determine the significant strain fluctuation frequencies. The dominant frequency (f_D) of the axial strain fluctuation was found to be 7.8 Hz (Table 7) for all values of FC&I sleeve opening which compares favorably with the frequency range of 0 to 20 Hz for the basic test data. The bending strain f_D value was found to be 40.2 Hz. Other frequencies were present, having values ranging from 15 to 296 Hz, but were less significant than the dominant frequency. Loss of data due to gage malfunction during the basic tests precludes a similar comparison being made of the bending strain data.

45. For determining how the strain measurements relate to the possibility of fatigue failure, it is necessary to refer to the strain measurements in terms of maximum alternating stress components (Crandal, Dahl, and Lardner 1972). Stress, σ, and strain, ε, are related by Hooke's Law, $\sigma = E(\varepsilon)$, where E is Young's modulus of elasticity (Roark 1965). The measured peak-to-peak strain fluctuations presented in Table 7 were converted into stress fluctuations by means of this equation and are listed in the following tabulation.

Date of Test	σ Stress	Maximum Peak-to-Peak Stress Fluctuations, psi — Valve Opening, %/Sleeve Travel, in. 25/11.3	40/16.6	50/20.1	60/23.6	70/27.2	72/28.1
1982	Axial	1125	1050	1305	980	905	1195
1982	Bending	1160	1195	1415	1160	1270	1305
1979	Axial	380	461	667	1151	423	--*

* No data available.

The values listed above show that the axial stresses increased with the higher head, except at the 60 percent valve opening. The increase in discharge and the associated increase in flow velocity at the test vane are likely the cause of the increase in stress fluctuation amplitudes. It is assumed that a similar increase occurred in the bending stresses. Using the endurance limit stress described in the basic report (40,000 psi) as the critical value for alternating stress, it is evident that the maximum values of alternating stresses are well below the critical value.

Summary of Results

46. The following paragraphs are a compilation of the results of the FC&I valve prototype tests as presented in this report. Whenever applicable, comparisons were made with the model and/or the basic report data.

Hydraulic performance characteristics

47. The following determinations pertain to discharges through the FC&I valve:

- a. The computed discharges (Q) for the basic tests and the tests reported herein are in close agreement with the project rating for the total head conditions.
- b. The discharge coefficients are in close agreement with those determined from the model data, basic test data, and the Hydraulic Design Criteria curve 332-1/1.
- c. As a result of the increase in total head, the mean conduit and valve pressures were found to have increased proportionately (approximately 1.7 times).

Flow conditions in the FC&I valve and hood

48. The following findings pertain to flow within the valve and the hood:

- a. If cavitation is occurring at the vanes, it is not significant enough to appreciably alter the pressure conditions existing in the valve.
- b. The net differences of the mean static pressures for the opposing vane transducers (PUD and PLD) are negligible which may be the result of uniform flow conditions within the FC&I valve.
- c. No negative valve pressures were recorded for this series of tests.
- d. No significant changes between the two test series occurred in the internal pressure loading as indicated by Euler number ($\mathbb{E}$) computations.

e. No flow-control shift was recorded for these prototype tests due to the reduction of the total sleeve travel from 35.0 to 28.1 in.

f. The final test series dynamic pressure measurements and associated pressure fluctuations in the FC&I valve and hood revealed the following when compared with the basic test data:

   (1) A general increase in valve and hood pressures over those observed in the basic tests.

   (2) A constant frequency (7.8 Hz) of valve pressure fluctuation was observed, compared with a frequency range of 5.7 to 166.5 Hz observed for the basic tests.

   (3) The hood transducers (PH6-PH8) pressure fluctuation frequencies of 400 Hz can likely be attributed to mechanical vibrations of the hood for both series of tests.

g. The final test series vane and valve reducer pressure fluctuations (actual and nondimensional) were slightly higher, in almost all cases, than those of the basic tests.

h. Though a direct comparison could not be made, the difference in the net vane loading values between the final and basic test series is small; the maximum value of net pressure loading is well below the design value of 129 ft.

i. Although the data from the hood transducers were inconclusive in the actual determination of the jet impingement point, they did indicate a general location (between transducers PH9 and PH11) that is consistent with the computed-theoretical location presented in the basic report.

Acceleration responses
of the FC&I valve and hood

49. The following determinations pertain to the vibrations caused by flow through the valve and hood:

a. The maximum peak-to-peak valve acceleration of 2.20 g occurred for transducer AVC at a valve opening of 70 percent; the dominant frequencies of valve accelerations ranged from 43 to 324 Hz.

b. The maximum peak-to-peak hood accelerations of 26.4 g occurred at a valve opening of 60 percent; the dominant frequencies of acceleration ranged from 164 to 330 Hz.

c. In comparison with data from the basic report, the valve accelerations increased for valve openings of 25 and 40 percent but were reduced for valve openings of 50 percent and greater.

d. The peak-to-peak hood acceleration amplitudes increased over the basic test values for valve openings of 50 percent and greater and decreased for valve openings of 25 and 40 percent.

e. The dominant frequencies of valve vibrations were generally less than those observed in the basic test data.

f. In general, the dominant frequency of the hood vibrations increased slightly over that observed for the basic tests. Increased discharge through the hood and the addition of the stiffener ring may have contributed to the slight increase.

g. The FC&I valve safety parameter of 0.056, referred to as a parametric value, was found to be almost identical with the value determined from the basic test data (0.060) and is indicative of values associated with safe operation of the valve.

Strain

50. The following determinations pertain to the measurements of strain on the FC&I valve test vane:

a. The dominant frequency of axial strain fluctuation was 7.8 Hz and this compares favorably with the results presented in the basic report.

b. The peak-to-peak axial stress fluctuations increased over those of the basic tests probably due to the increased discharges and associated flow velocities at the vane.

c. The maximum values of alternating stresses on the vane are well below the critical value (40,000-psi endurance limit stress) as described in the basic report.

REFERENCES

Crandal, S. H., Dahl, N. C., and Lardner, T. J. 1972. An Introduction to the Mechanics of Solids, 2nd ed., McGraw-Hill, New York.

Fagerburg, T. L. 1983 (Feb). "Fixed-Cone Valve Prototype Test, New Melones Dam, California," Technical Report HL-83-2, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Maynord, S. T., and Grace, J. L., Jr. 1981 (Apr). "Fixed-Cone Valves, New Melones Dam, California; Hydraulic Model Investigation," Technical Report HL-81-4, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Maynord, S. T. 1981 (Sep). "Flood Control and Irrigation Outlet Works and Tailrace Channel for New Melones Dam, Stanislaus River, California; Hydraulic Model Investigation," Technical Report HL-81-6, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Mercer, A. G. 1970. "Vane Failures of Hollow-Cone Valves," IAHR-AIRH Symposium, Stockholm.

Neilson, F. M. 1971 (Sep). "Howell-Bunger Valve Vibration, Summersville Dam Prototype Test," Technical Report H-71-6, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Roark, R. J. 1965. Formulas for Stress and Strain, 4th ed., McGraw-Hill, New York.

Rouse, H. 1946. Elementary Mechanics of Fluids, Wiley, New York.

________. 1950. Engineering Hydraulics, Wiley, New York.

Table 1

Test Instrumentation

Measurement	Location	Station*	Elev*	Transducer	Code**	Range
Pressure	Conduit	3+98.5	521.3	Unbonded press. gage	PC1	250 psia
			518.0		PC2	
			514.8		PC3	
			518.0		PC4	
	Vane	4+05.7	515.3		PUD	
		4+05.7			PLD	
		4+09.2			PUB	
		4+09.2			PLB†	
	Hood	4+15.3	522.5		PH6	100 psia
		4+16.2	523.4		PH7	
		4+17.1	524.3		PH8	
		4+18.0	525.1		PH9	
		4+18.9	526.0		PH10	
		4+20.8	527.0		PH11	
		4+21.8	527.0		PH12	
		4+22.8	527.0		PH13	
Strain	Vane	4+10.0	514.8	Foil-type bonded strain gage	εA	--
Strain	Vane	4+10.0	514.8	Foil-type bonded strain gage	εB	--
Vibration	Valve	4+11.5	518.0	Accelerometer	AVC	±15 g
	Valve	4+11.5	518.0		ATC	±15 g
	Valve	4+14.5	518.0		AVP	±15 g
	Hood	4+13.5	524.0		AHA	±25 g

* Rounded to nearest 0.1 ft.

** See Plate 2.

† Transducer location PLB was not used due to installation difficulties.

Table 2

FC&I Valve and Hood Pressures

Pressure Transducer	Item	Valve Opening, %/Sleeve Travel, in. 25/11.3	40/16.6	50/20.1	60/23.6	70/27.2	72/28.1
PC1	H	457.5	427.1	390.2	363.6	338.2	336.6
	L	452.8	417.6	377.5	344.7	316.4	316.0
	P/P	3.5	7.7	8.9	13.3	15.0	16.1
	f_D	7.8	7.8	7.8	7.8	7.8	7.8
PC2	H	462.8	427.1	394.5	369.1	333.9	334.7
	L	458.6	419.7	384.9	357.5	318.2	318.9
	P/P	3.1	5.0	7.5	8.9	11.0	14.1
	f_D	7.8	7.8	7.8	7.8	7.8	7.8
PC3	H	486.6	434.0	405.1	394.0	341.2	341.9
	L	482.3	426.7	393.2	380.8	326.1	325.6
	P/P	3.2	5.3	8.1	9.5	11.8	12.7
	f_D	7.8	7.8	7.8	7.8	7.8	7.8
PC4	H	466.7	428.4	401.2	372.4	334.9	334.8
	L	458.5	418.4	389.2	361.8	323.2	323.1
	P/P	6.3	8.1	8.9	8.6	8.2	8.9
	f_D	402.0	402.0	402.0	402.0	402.0	7.8
PUB	H	444.8	378.2	346.8	304.6	248.5	249.1
	L	439.6	369.5	336.5	293.0	234.0	234.1
	P/P	3.7	4.9	7.9	8.8	9.2	12.4
	f_D	7.8	7.8	7.8	7.8	7.8	7.8
PUD	H	443.5	378.4	347.8	304.2	249.5	252.6
	L	438.7	371.3	338.6	292.4	231.5	231.0
	P/P	3.2	3.5	5.5	8.6	15.0	16.7
	f_D	7.8	7.8	7.8	7.8	7.8	7.8
PLD	H	438.4	377.2	346.1	304.8	249.5	249.5
	L	432.8	368.9	335.2	292.6	231.3	231.3
	P/P	3.1	4.2	6.6	8.1	9.8	10.4
	f_D	7.8	7.8	7.8	7.8	7.8	7.8
PH6		Atmospheric					
PH7		Atmospheric					
PH8		Atmospheric					
PH9	H	142.6	261.8	206.9	174.7	178.8	152.5
	M	4.5	2.8	-3.5	4.2	6.7	4.4
	L	-0.6	-16.6	-16.7	-16.4	-13.4	-19.1
	P/P	138.4	242.2	188.2	172.5	172.5	147.0
	f_D	7.8	7.8	7.8	7.8	7.8	7.8

(Continued)

Note: All pressures are in feet of water. H = highest instantaneous pressure; M = mean pressure; L = lowest instantaneous pressure; P/P = greatest instantaneous peak-to-peak pressure; f_D = predominant frequency, Hz.

Table 2 (Concluded)

Pressure Transducer	Item	Valve Opening, %/Sleeve Travel, in. 25/11.3	40/16.6	50/20.1	60/23.6	70/27.2	72/28.1
PH10*	H	94.9	119.4	104.0	91.8	105.6	107.1
	M	6.1	6.1	6.1	7.6	9.2	9.2
	L	-7.6	-16.8	-26.8	-27.5	-29.1	-23.0
	P/P	93.6	95.3	95.3	114.5	95.3	101.6
	f_D	7.8	7.8	7.8	11.7	7.8	7.8
PH11*	H	94.3	72.7	88.1	103.8	116.2	114.1
	M	8.3	9.3	12.4	13.5	13.0	15.5
	L	-23.6	-20.8	-21.7	-20.8	-30.1	-25.9
	P/P	115.3	91.7	91.7	114.5	114.5	114.5
	f_D	7.8	7.8	7.8	7.8	7.8	7.8
PH12	H	41.2	52.0	87.2	88.3	77.8	67.6
	M	-1.9	-1.5	-1.4	1.2	2.1	3.0
	P/P	61.7	62.0	78.6	71.9	65.4	78.6
	f_D	31.2	15.6	7.8	7.8	15.6	7.8
PH13	H	43.8	46.6	64.2	74.3	71.0	88.1
	M	1.4	-1.4	1.2	0.7	2.3	2.0
	L	-14.2	-14.8	-14.0	-14.8	-10.6	-16.6
	P/P	55.4	48.3	64.0	69.5	74.8	90.6
	f_D	7.8	11.7	11.7	7.8	7.8	7.8

* Data obtained from oscillograph records.

Table 3

Overview of FC&I Valve and Hood Pressure Transducer FFT Data

	Valve Opening, %/Sleeve Travel, in.											
	25/11.3		40/16.6		50/20.1		60/23.6		70/27.2		72/28.1	
Transducer	f_D Dominant Frequency Hz	Other Peaks Hz	f_D Dominant Frequency Hz	Other Peaks Hz	f_D Dominant Frequency Hz	Other Peaks Hz	f_D Dominant Frequency Hz	Other Peaks Hz	f_D Dominant Frequency Hz	Other Peaks Hz	f_D Dominant Frequency Hz	Other Peaks Hz
PC1	<20	55, 81, 400	<20	83, 400	<20	55, 81	<20	--	<20	--	<20	--
PC2	<20	55, 81, 400	<20	83	<20	55, 81, 400	<20	--	<20	--	<20	--
PC3	<20	55, 81 400	<20	83	<20	81, 400	<20	--	<20	--	<20	--
PC4	402	156	402	7.8, 156	402	7.8, 156	402	7.8, 156	402	--	<20	400
PUB	<20	106, 156, 400	<20	81, 109, 400	<20	400	<20	400	<20	--	<20	400
PUD	<20	58, 81, 106, 181, 400	<20	58, 81, 181, 400	<20	59, 82, 181, 400	<20	58, 181, 400	Noise (u)	--	Noise (u)	--
PLD	<20	55, 81, 105 119, 400, 481	<20	82, 400, 481	<20	82, 400, 481	<20	81, 106	<20	--	<20	--
PH6	Noise (u)	155, 400	Noise (u)	400	Noise (u)	400	Noise (u)	400	Noise (u)	400	Noise (u)	400
PH7	Noise (u)	7.8, 400	Noise (u)	7.8, 400	Noise (u)	400	Noise (u)	400	Noise (u)	400	Noise (u)	400
PH8	Noise (u)	7.8, 400	Noise (u)	400	Irr	400	Irr	400	Irr	400	Irr	400
PH9	Irr	+	Irr	7.8, 55	Irr	7.8	Irr	--	Irr	--	Irr	--
PH10	Irr	--	Irr	--	Noise (u)	+	Irr	--	Irr	--	Irr	--
PH11	Irr	--	Irr	--	Irr	+	Irr	--	Irr	--	Irr	--
PH12	Noise (u)	+	Irr	--	Irr	+	Irr	--	Irr	--	Irr	--
PH13	Irr	--	Irr	+	Irr	--	Irr	--	Irr	--	Irr	--

Table 4

Nondimensional Valve Pressure Fluctuations

Valve Opening, %	Q/A fps	$Q^2/2gA^2$ ft	$\frac{P_{max} - P_{min}}{Q^2/2gA^2}$ PUB	PUD	PLD	PC1	PC2	PC3	PC4
25	50.8	40.2	0.13	0.12	0.14	0.12	0.10	0.11	0.20
40	73.2	83.1	0.10	0.09	0.10	0.11	0.09	0.09	0.12
50	86.0	114.7	0.09	0.08	0.09	0.11	0.08	0.10	0.10
60	97.0	146.4	0.08	0.08	0.08	0.13	0.08	0.09	0.07
70	110.4	189.1	0.08	0.10	0.10	0.12	0.08	0.08	0.06
72	110.4	189.1	0.08	0.11	0.10	0.11	0.08	0.09	0.06

Table 5

FC&I Valve and Hood Acceleration Data for 1979 and 1982 Tests

Accelerometer	Valve Opening %	1982 Test Series: f_D Dominant Frequency Hz	1982: Accel Maximum Peak-to-Peak g	1982: Equivalent* Peak-to-Peak Displacement 10^{-3} in.	1979 Test Series: f_D Dominant Frequency Hz	1979: Accel Maximum Peak-to-Peak g	1979: Equivalent Peak-to-Peak Displacement 10^{-3} in.
AVC	25	117	1.29	0.92	66	0.52	1.20
ATC	↓	43	0.33	1.73	42	0.18	1.00
AVP	↓	66	0.78	1.76	70	0.70	1.40
AHA	↓	330	9.91	0.89	145	16.00	7.20
AVC	40	43	1.24	6.56	66	0.81	1.80
ATC	↓	43	0.43	2.26	43	0.30	1.60
AVP	↓	62	0.86	2.19	69	0.45	0.90
AHA	↓	164	16.20	5.89	145	17.00	7.70
AVC	50	43	0.82	4.34	75	3.40	5.90
ATC	↓	43	0.50	2.64	44	1.70	8.50
AVP	↓	62	1.03	2.62	67	2.66	5.80
AHA	↓	164	21.10	7.67	159	17.00	6.50
AVC	60	43	0.84	4.44	74	2.90	5.20
ATC	↓	324	0.71	0.07	65	2.40	5.60
AVP	↓	59	1.23	3.46	135	7.43	4.00
AHA	↓	164	26.40	9.60	148	16.00	7.40
AVC	70	43	2.20	11.63	80	4.80	7.30
ATC	↓	43	1.53	8.09	45	2.70	13.00
AVP	↓	58	1.50	4.36	135	12.73	7.00
AHA	↓	164	20.98	7.63	148	10.00	4.40

* Equivalent Peak-to-Peak Displacement = $\frac{(386\ \text{in./sec}^2/\text{g})(\text{Accel})}{(2\pi f_D)^2}$

Accel = maximum peak-to-peak acceleration, g

f_D = dominant frequency, Hz

Table 6

Overview of FC&I Valve and Hood Acceleration FFT Data

	Valve Opening, %/Sleeve Travel, in.					
	25/11.3		40/16.6		50/20.1	
Transducer	f_D Dominant Frequency Hz	Other Frequencies Hz	f_D Dominant Frequency Hz	Other Frequencies Hz	f_D Dominant Frequency Hz	Other Frequencies Hz
AVC	117	43	43	--	43	--
ATC	43	139, 309	43	144, 288	43	144, 315
AVP	66	43, 288, 309	62	43, 288	62	43, 288
AHA	330	165, 260	164	250, 330	164	260, 330

	Valve Opening, %/Sleeve Travel, in.					
	60/23.6		70/27.2		72/28.1	
Transducer	f_D Dominant Frequency Hz	Other Frequencies Hz	f_D Dominant Frequency Hz	Other Frequencies Hz	f_D Dominant Frequency Hz	Other Frequencies Hz
AVC	43	315	43	270, 475	43	270
ATC	324	37, 272	43	273	43	371
AVP	59	43, 283	58	43, 288	48	288
AHA	164	230, 325	164	230, 336	164	224, 330

Table 7

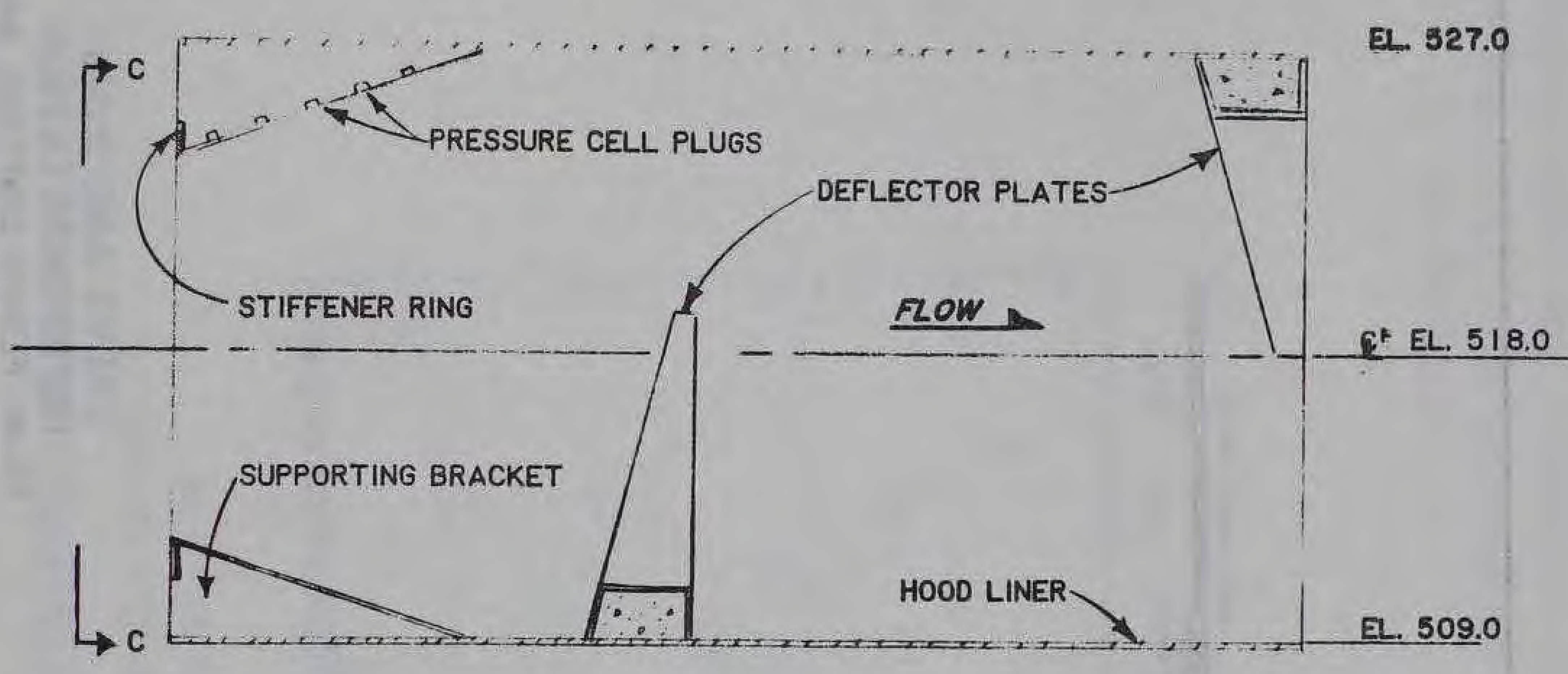
FC&I Valve Strain Measurements

Strain Gage	Item*	Valve Opening, %/Sleeve Travel, in. 25/11.3	40/16.6	50/20.1	60/23.6	70/27.2	72/28.1
				1982 Tests			
ε_1**	P/P	38.8	36.2	45.0	33.8	31.2	41.2
	f_D	7.8	7.8	7.8	7.8	7.8	7.8
ε_2†	P/P	40.0	41.2	48.8	40.0	43.8	45.0
	f_D	40.2	40.2	40.2	40.2	40.2	40.2
				1979 Tests			
ε_1	P/P	13.1	15.9	23.0	39.7	14.6	--
	f_D	<20.0	<20.0	<20.0	<20.0	<20.0	--
ε_2	P/P			Gage destroyed, no data obtained			
	f_D						

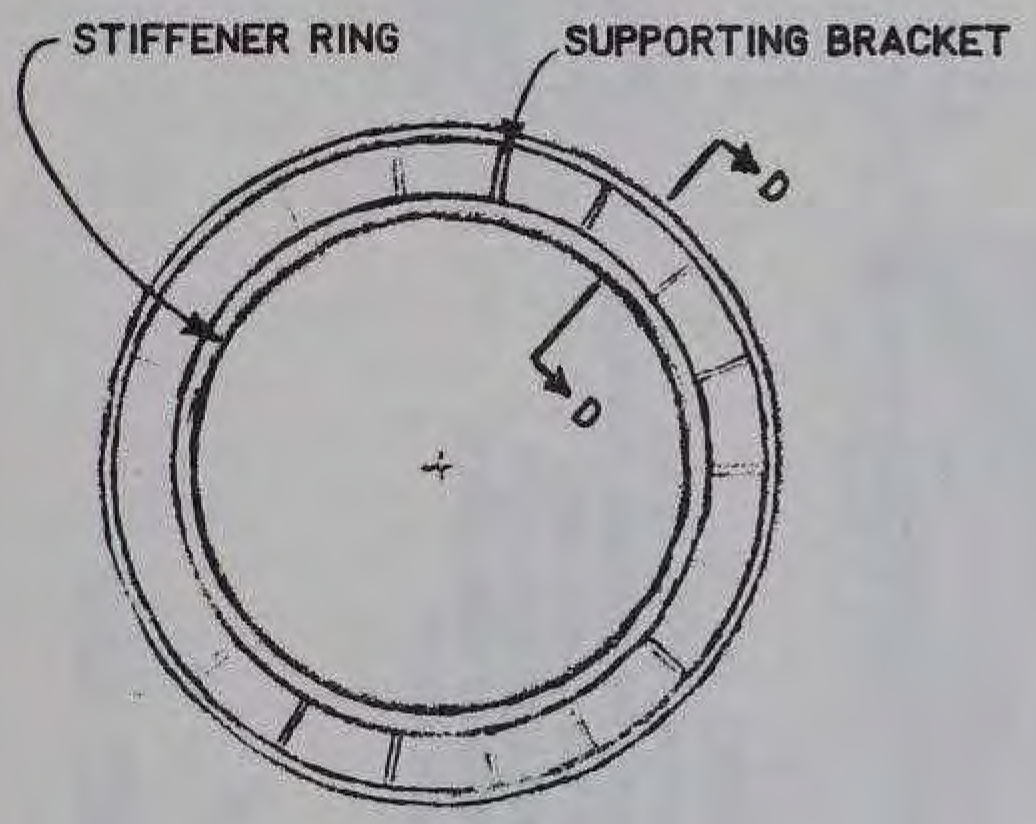
* P/P = greatest instantaneous peak-to-peak strain value, μin./in.; f_D = dominant frequency.

** ε_1 = axial strain, μin./in.; (strain with primary axis parallel to valve radius)

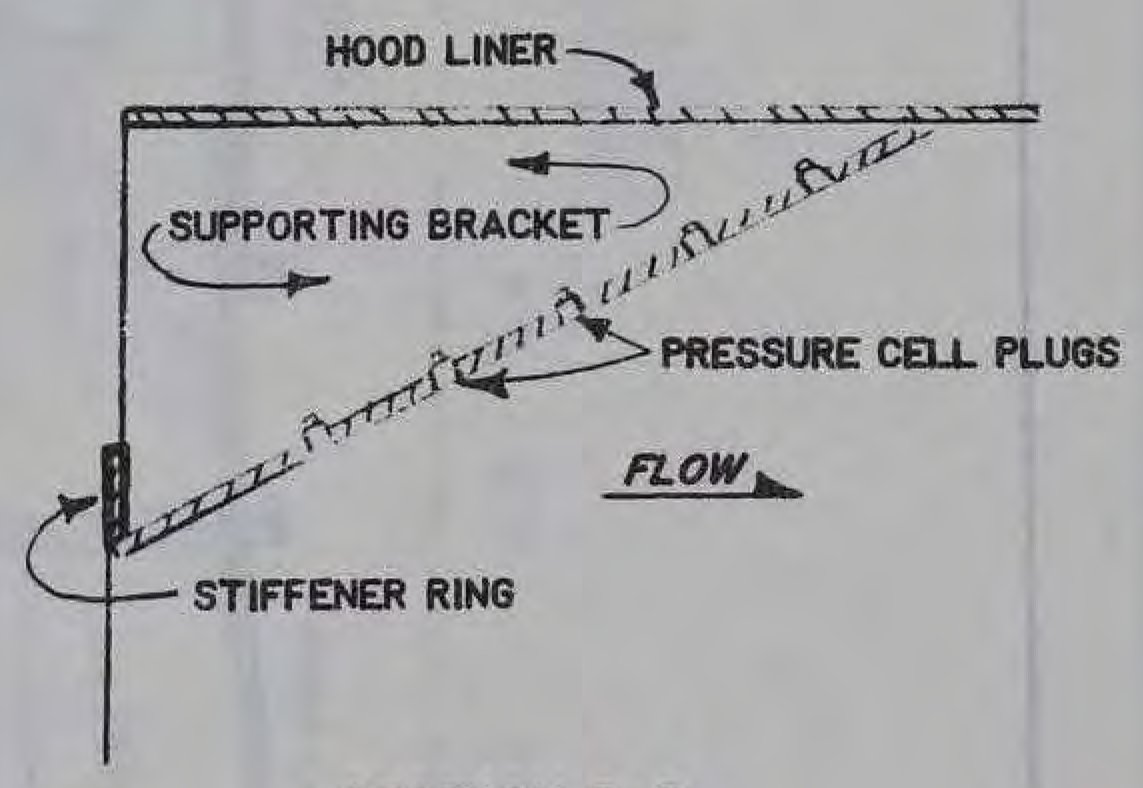
† ε_2 = bending strain, μin./in.; (strain with primary axis perpendicular to valve radius)



SECTION THROUGH CENTER OF HOOD
NO SCALE

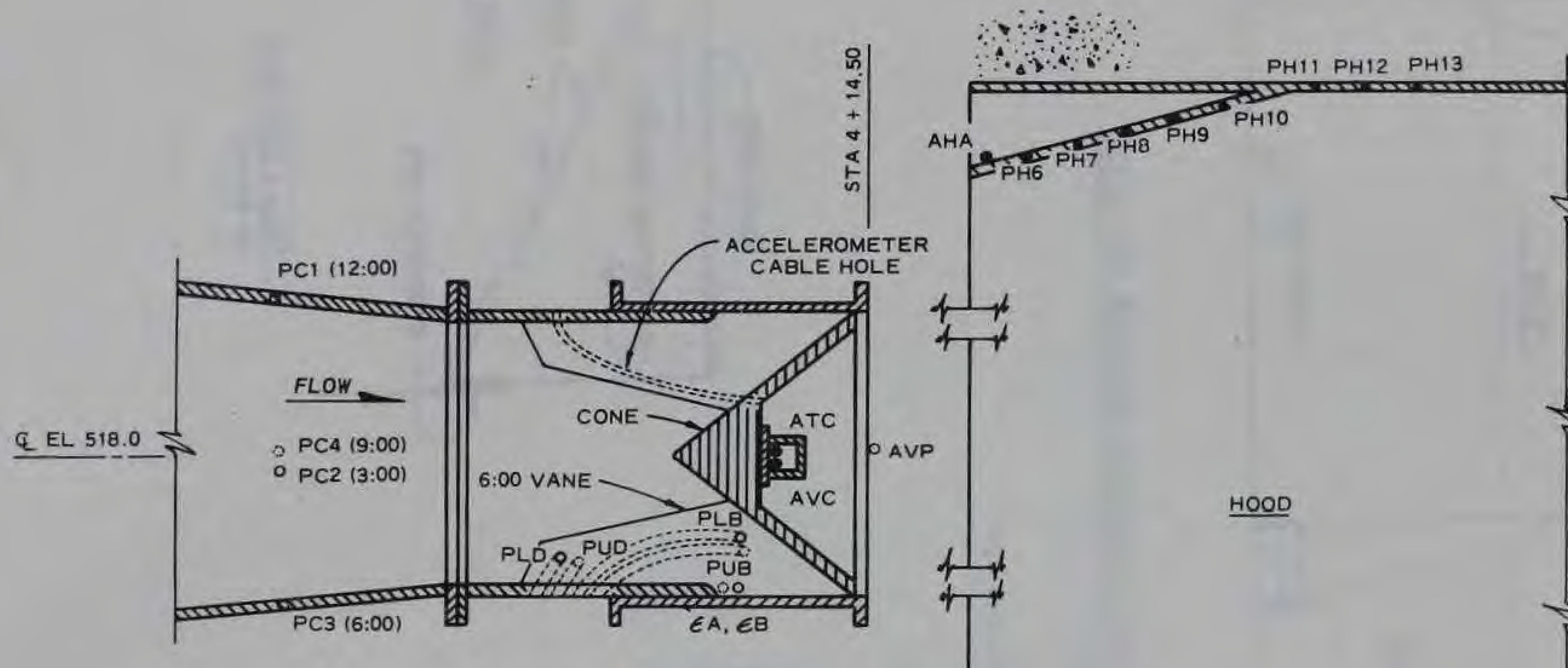


SECTION C-C
NO SCALE



SECTION D-D
NO SCALE

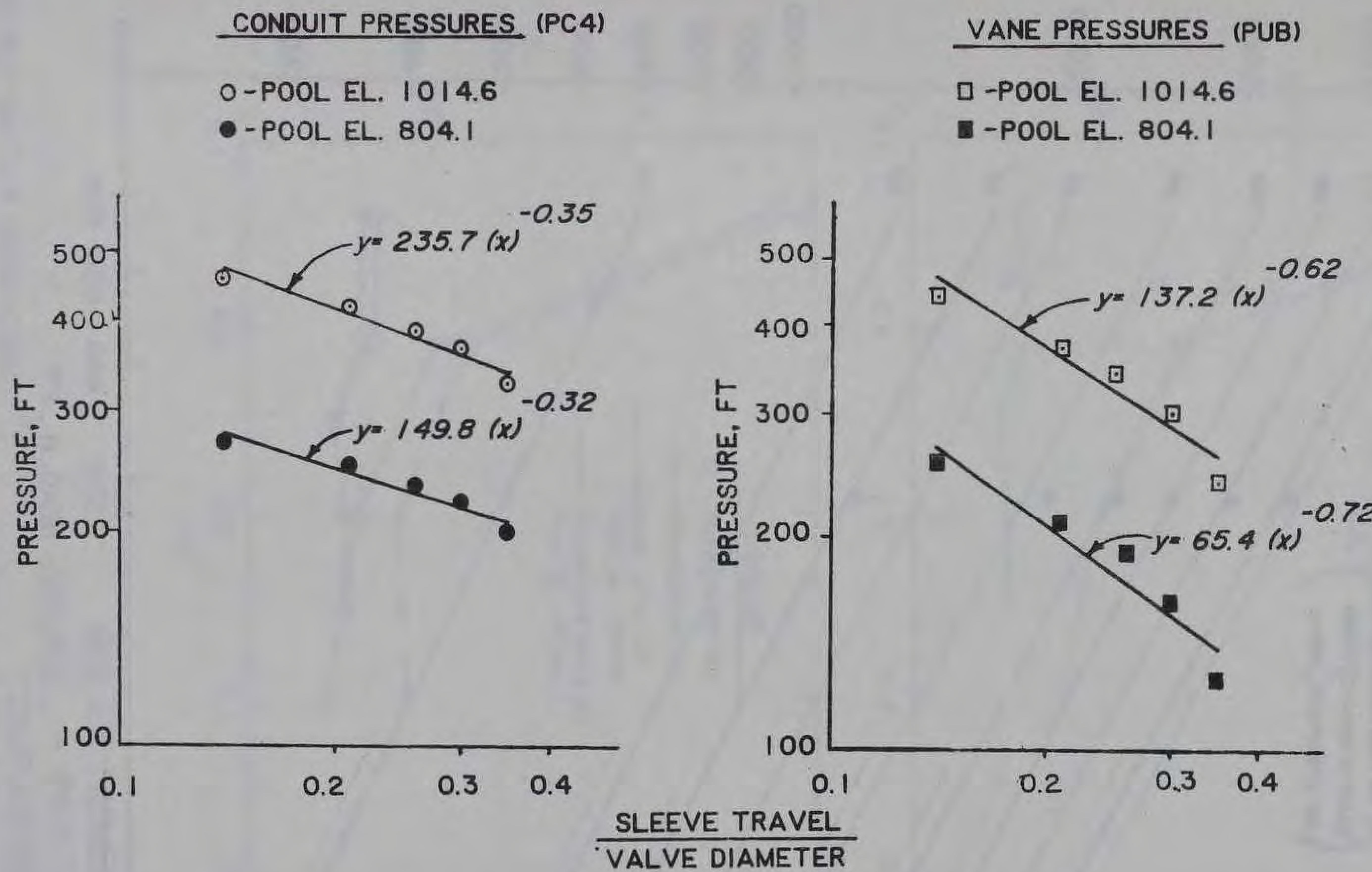
FC&I HOOD MODIFICATIONS



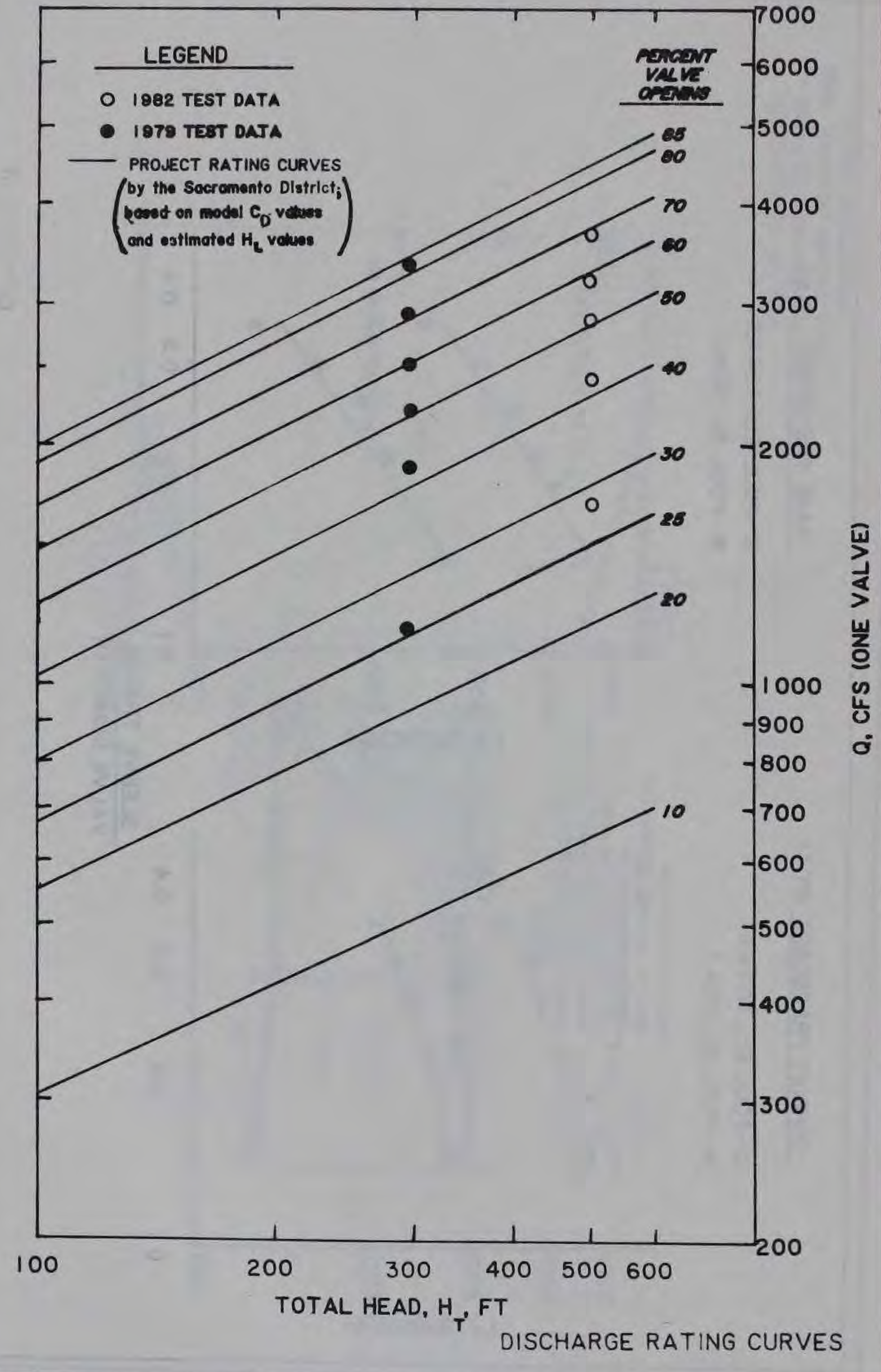
LEGEND

PC1 - PC4	-	CONDUIT PRESSURE TRANSDUCERS
PUD, PLD – PUB, PLB	-	VANE PRESSURE TRANSDUCERS (6:00 VANE)
εA, εB	-	VANE STRAIN GAGES (6:00 VANE)
ATC, AVC, AVP	-	VALVE ACCELEROMETERS
PH6 - PH13	-	HOOD JET PRESSURE TRANSDUCERS
AHA	-	HOOD ACCELEROMETER

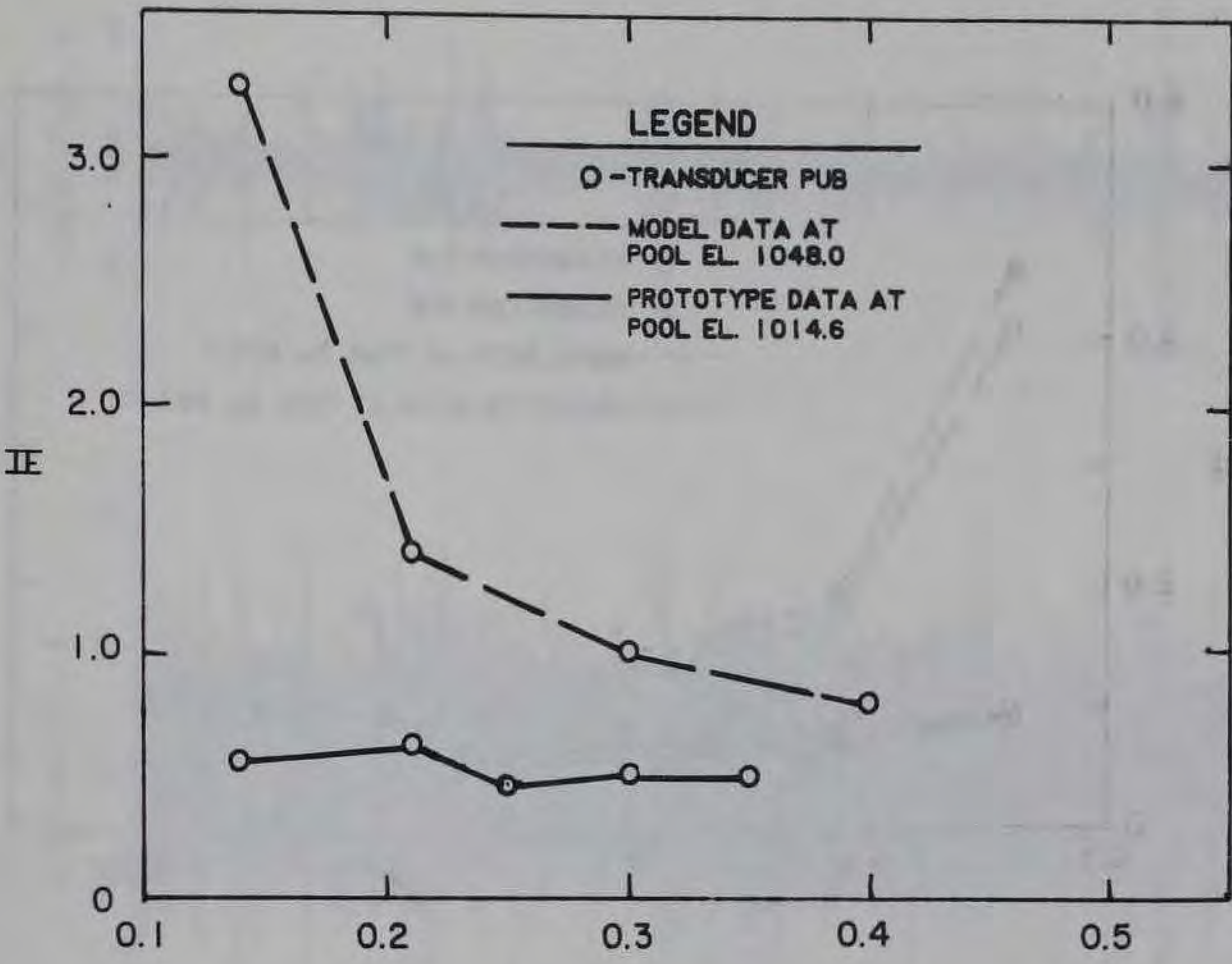
VALVE AND HOOD INSTRUMENTATION
78-IN. FLOOD CONTROL AND IRRIGATION VALVE

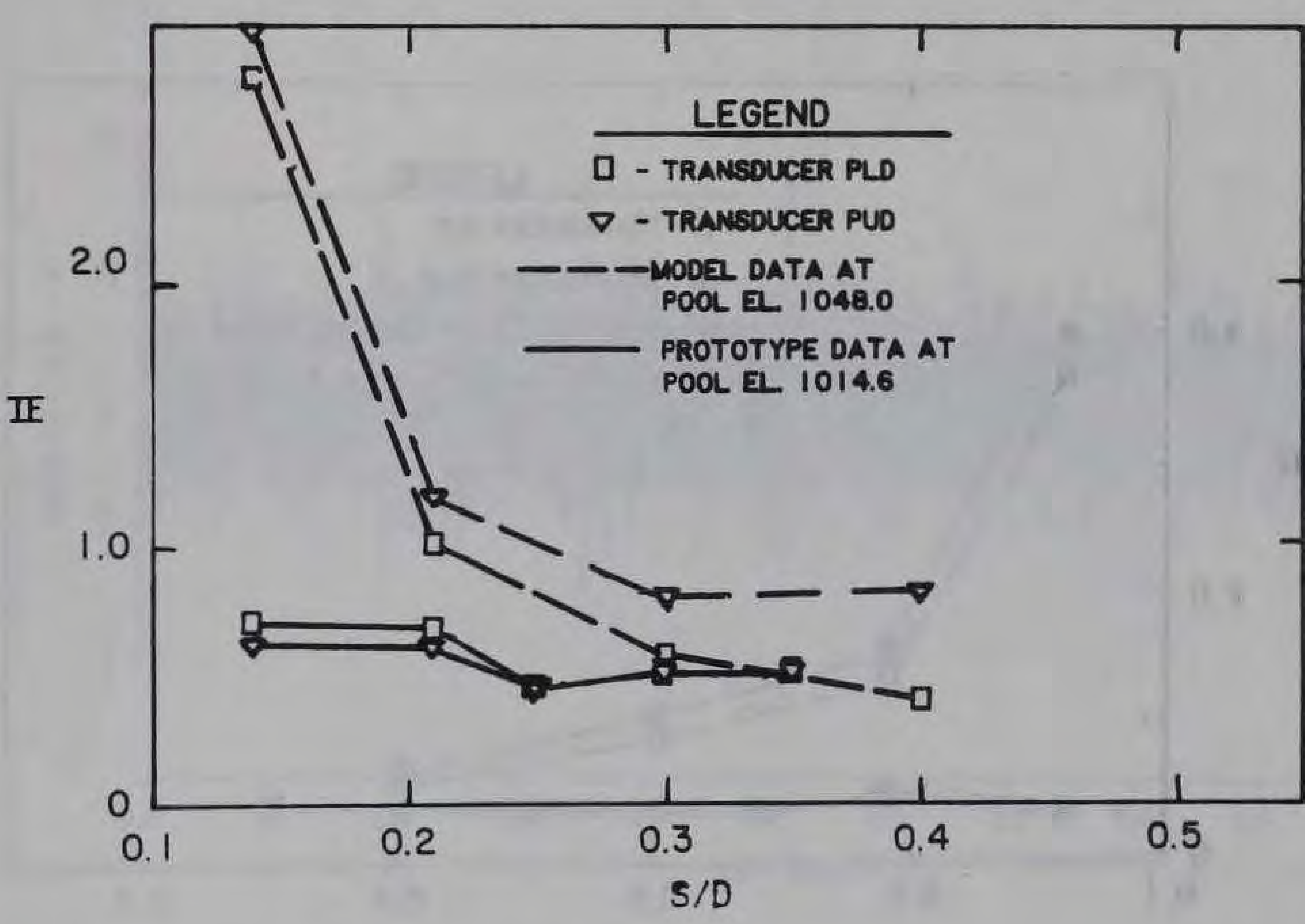


EFFECTS OF
INCREASING POOL ELEVATION ON
MEAN CONDUIT AND VANE PRESSURES

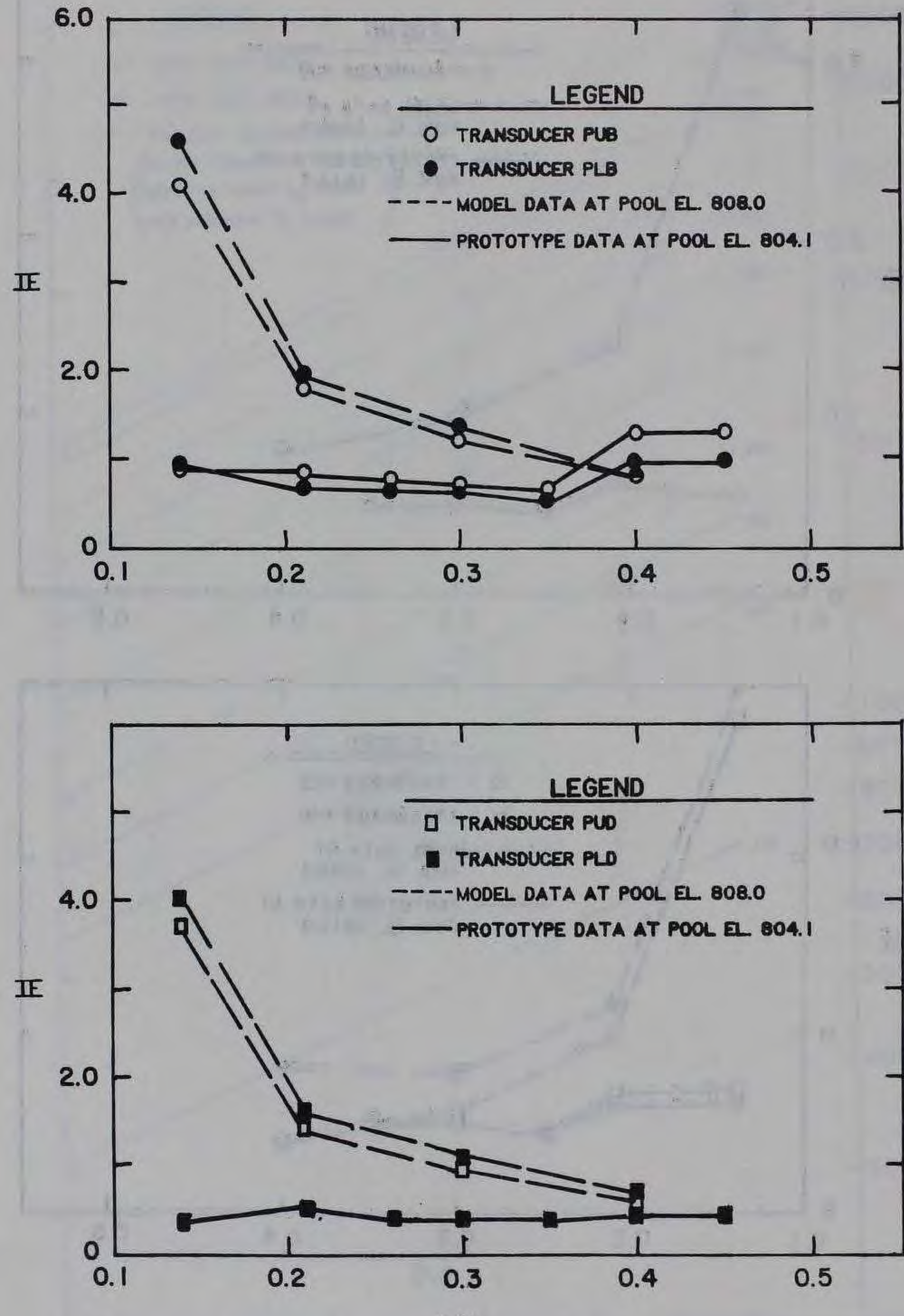


DISCHARGE RATING CURVES

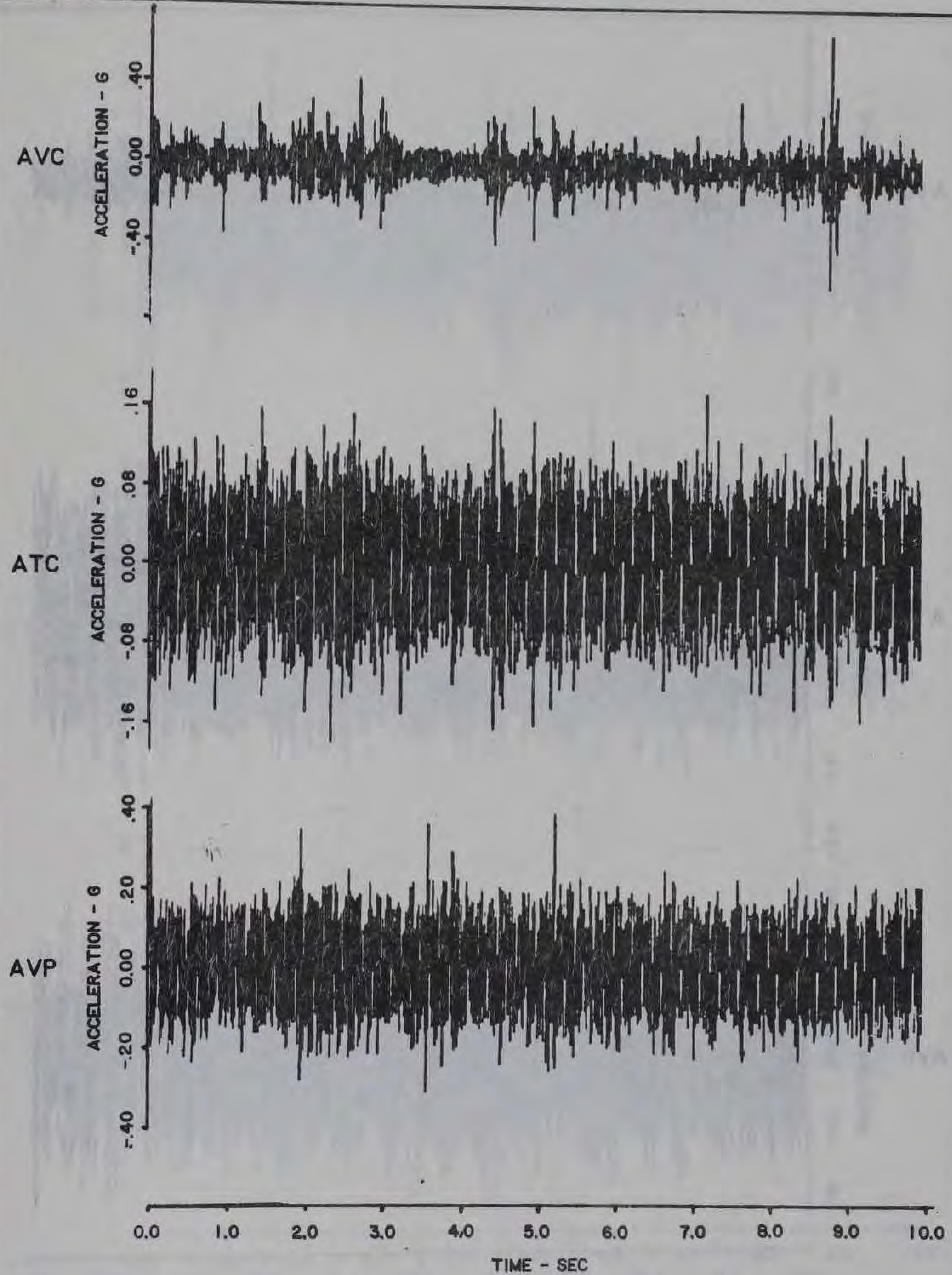




EULER NUMBERS
MODEL - PROTOTYPE
COMPARISON
POOL EL: MODEL 1048.0; PROTOTYPE 1014.6



EULER NUMBERS
MODEL - PROTOTYPE
COMPARISON
POOL EL: MODEL 808.0; PROTOTYPE 804.1



TIME-HISTORY
FC&I VALVE VIBRATIONS
25% VALVE OPENING

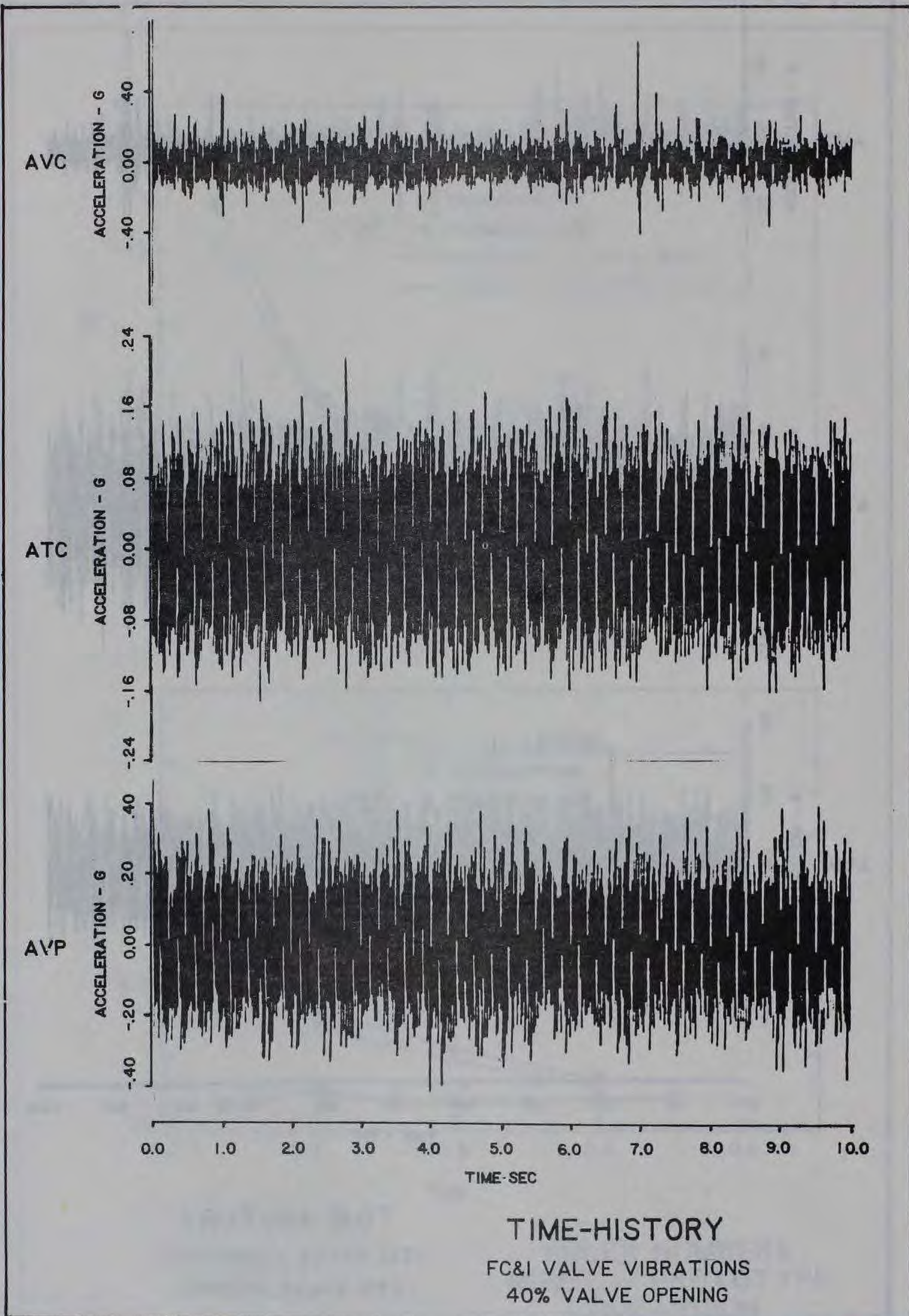
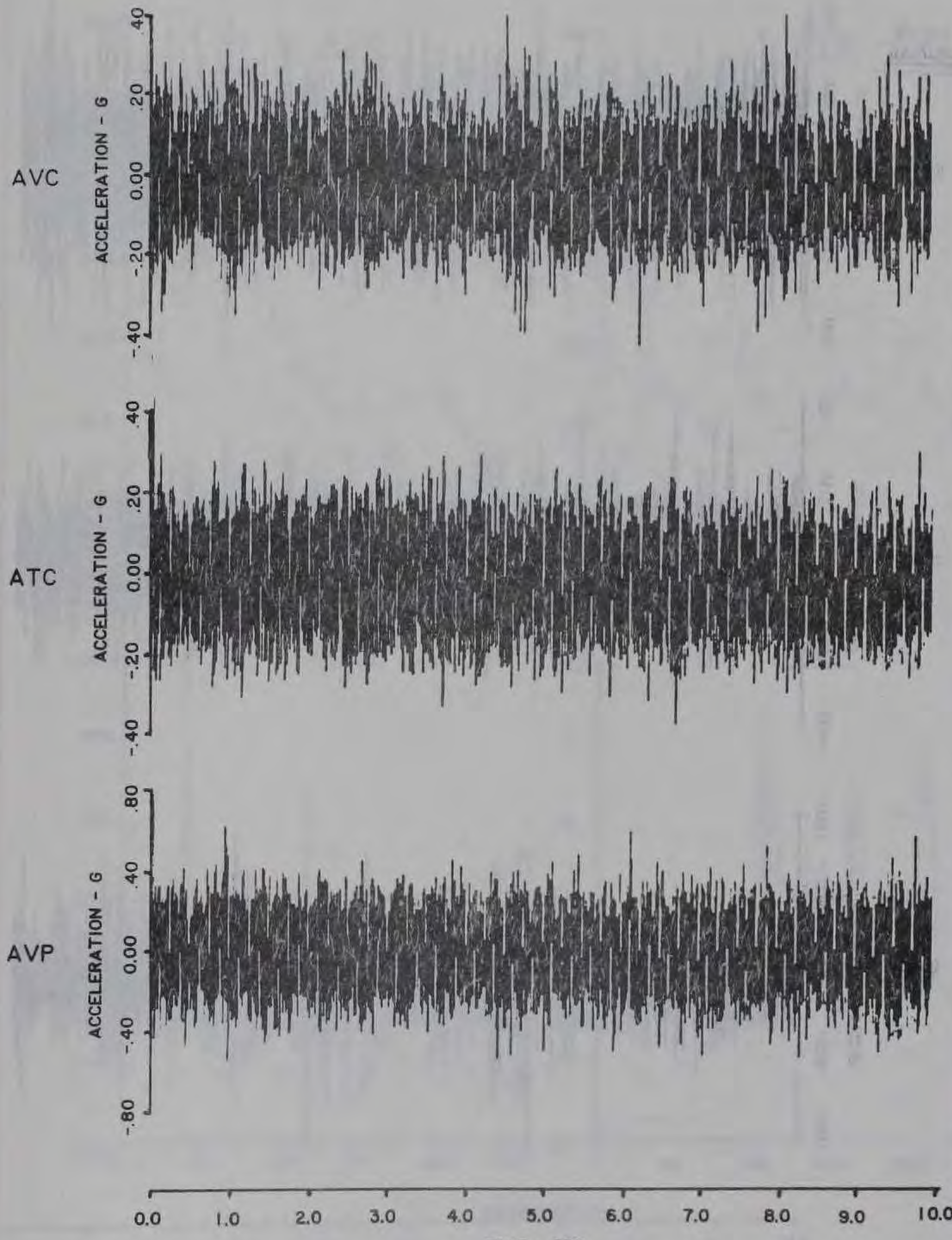
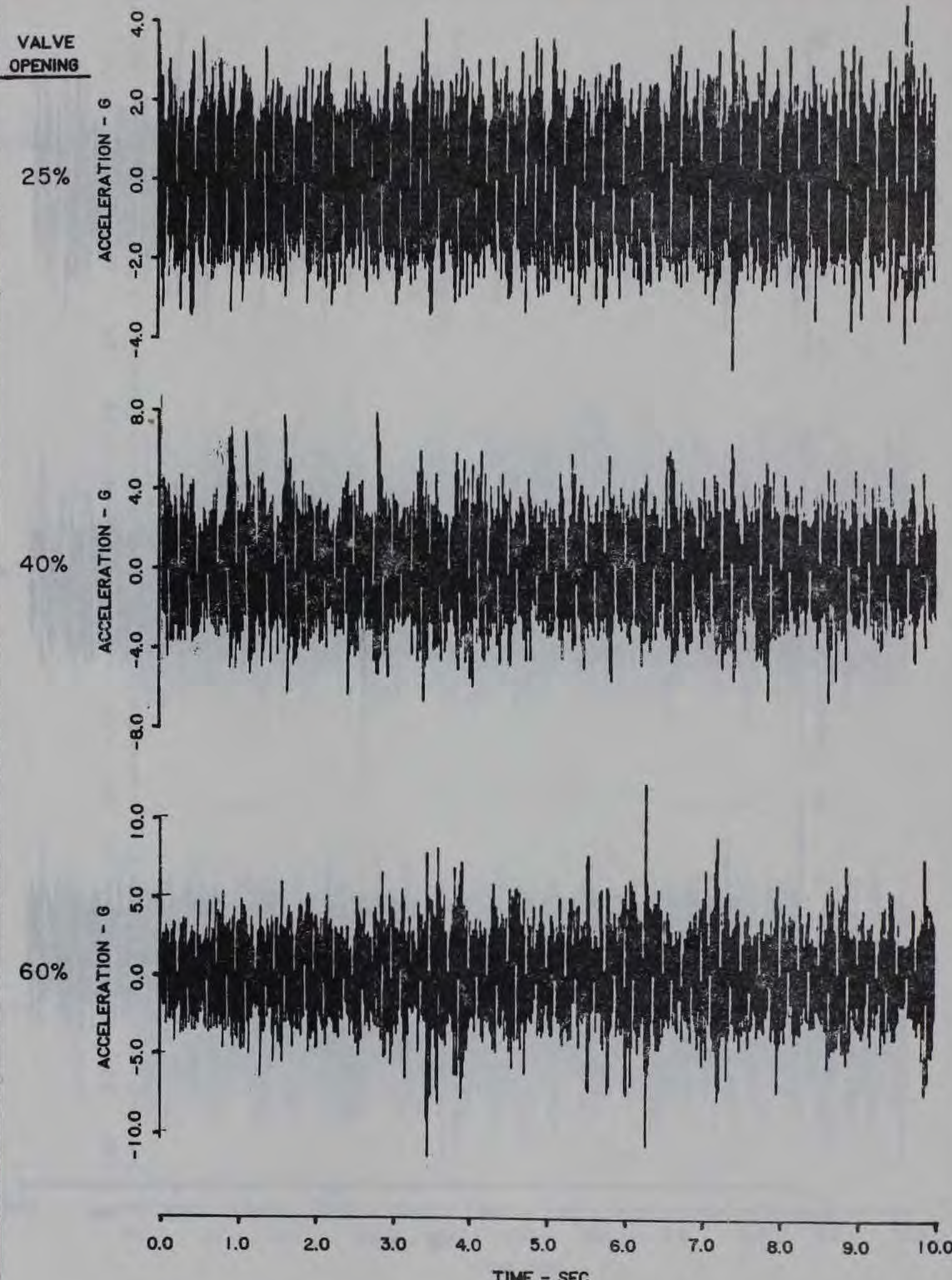

AVC
ACCELERATION - G
.40
0.00
-.40
ATC
ACCELERATION - G
.24
.16
.08
0.00
-.08
-.16
-.24
AVP
ACCELERATION - G
.40
.20
0.00
-.20
-.40
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
TIME-SEC
TIME-HISTORY
FC&I VALVE VIBRATIONS
40% VALVE OPENING

PLATE 8



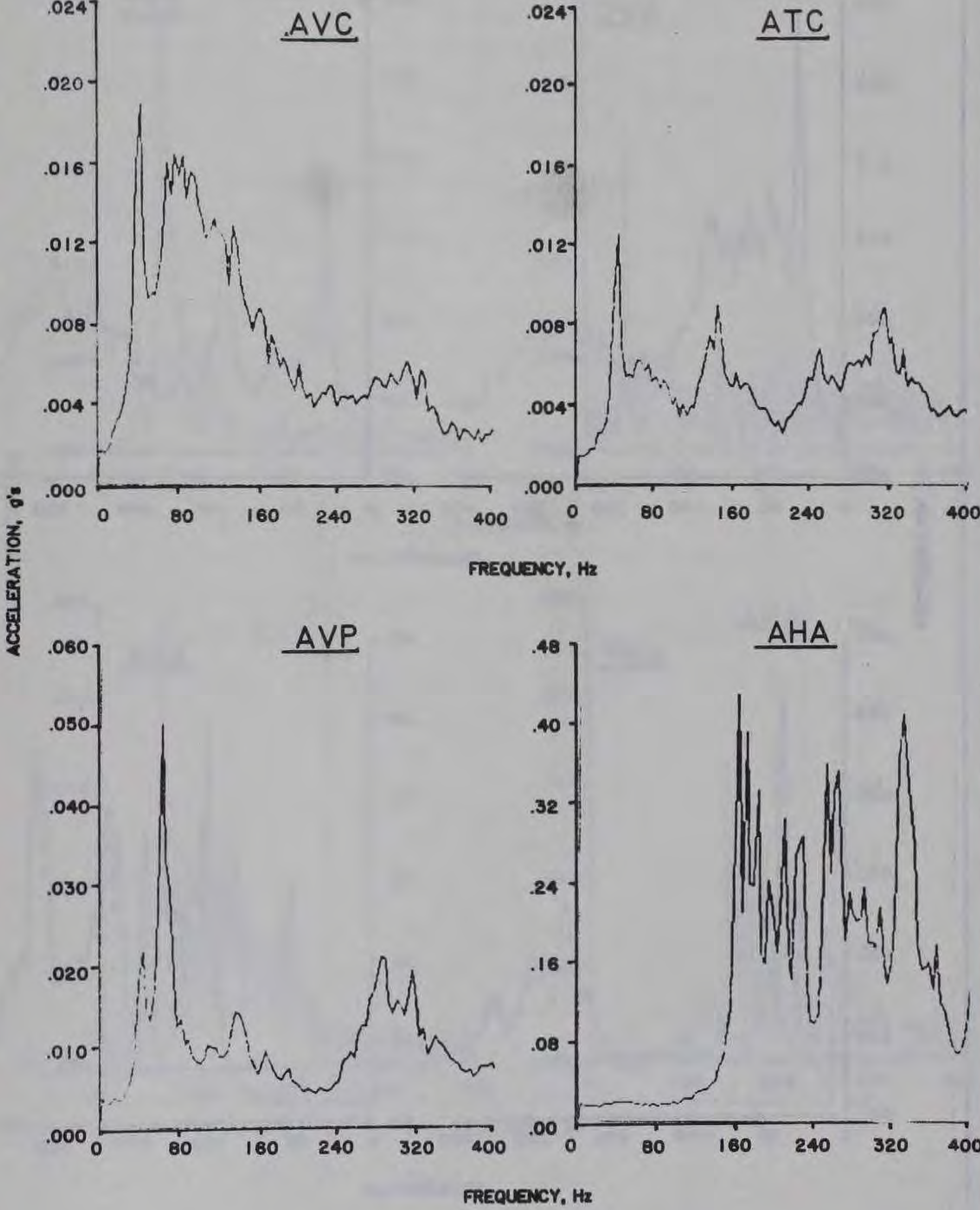
TIME-HISTORY

FC&I VALVE VIBRATIONS
60% VALVE OPENING



TIME-HISTORY

FC&I HOOD VIBRATIONS
ACCELEROMETER AHA

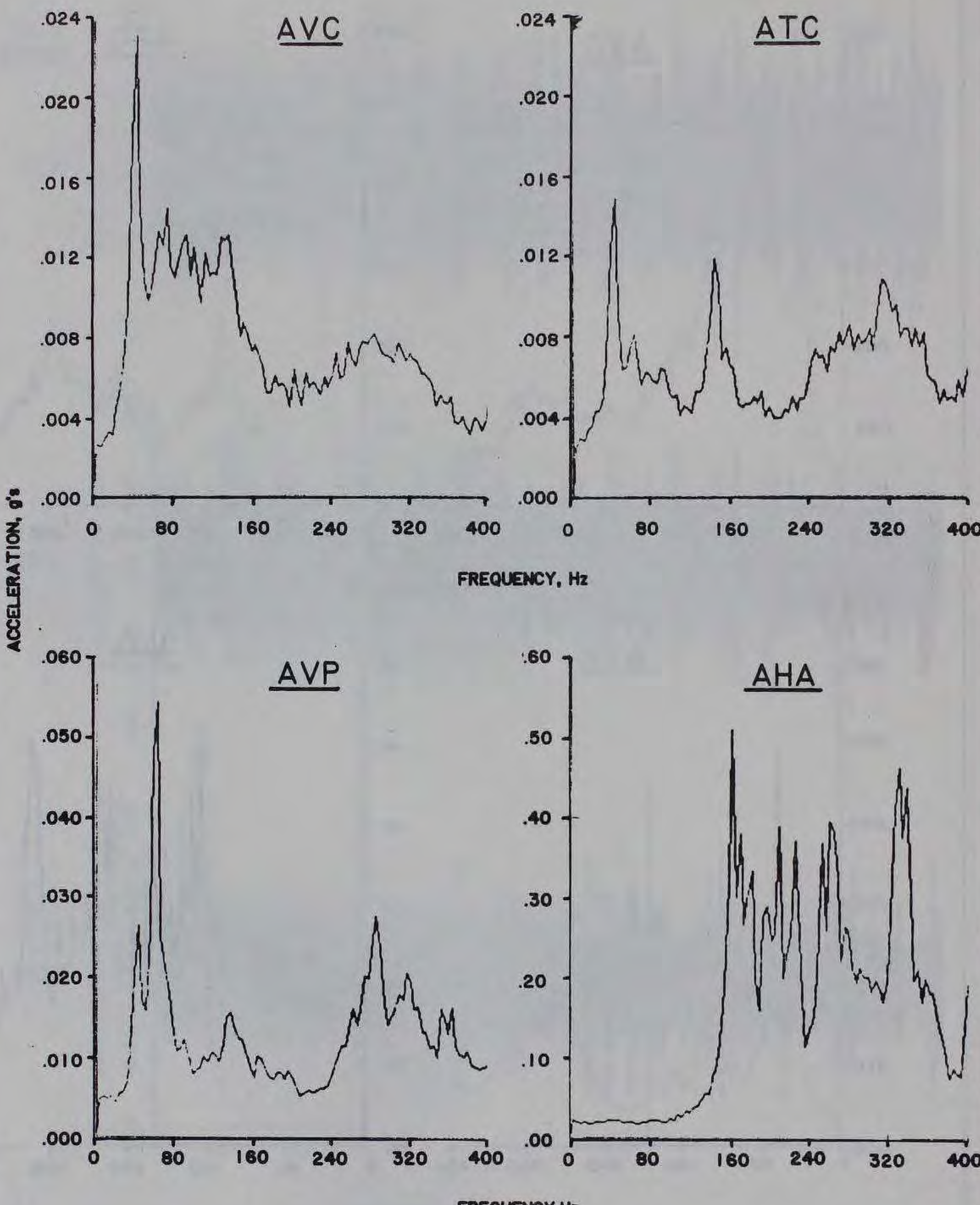


FAST FOURIER TRANSFORMS

1982 TESTS, 40% VALVE OPENING

FC&I HOOD AND VALVE

PLATE 11

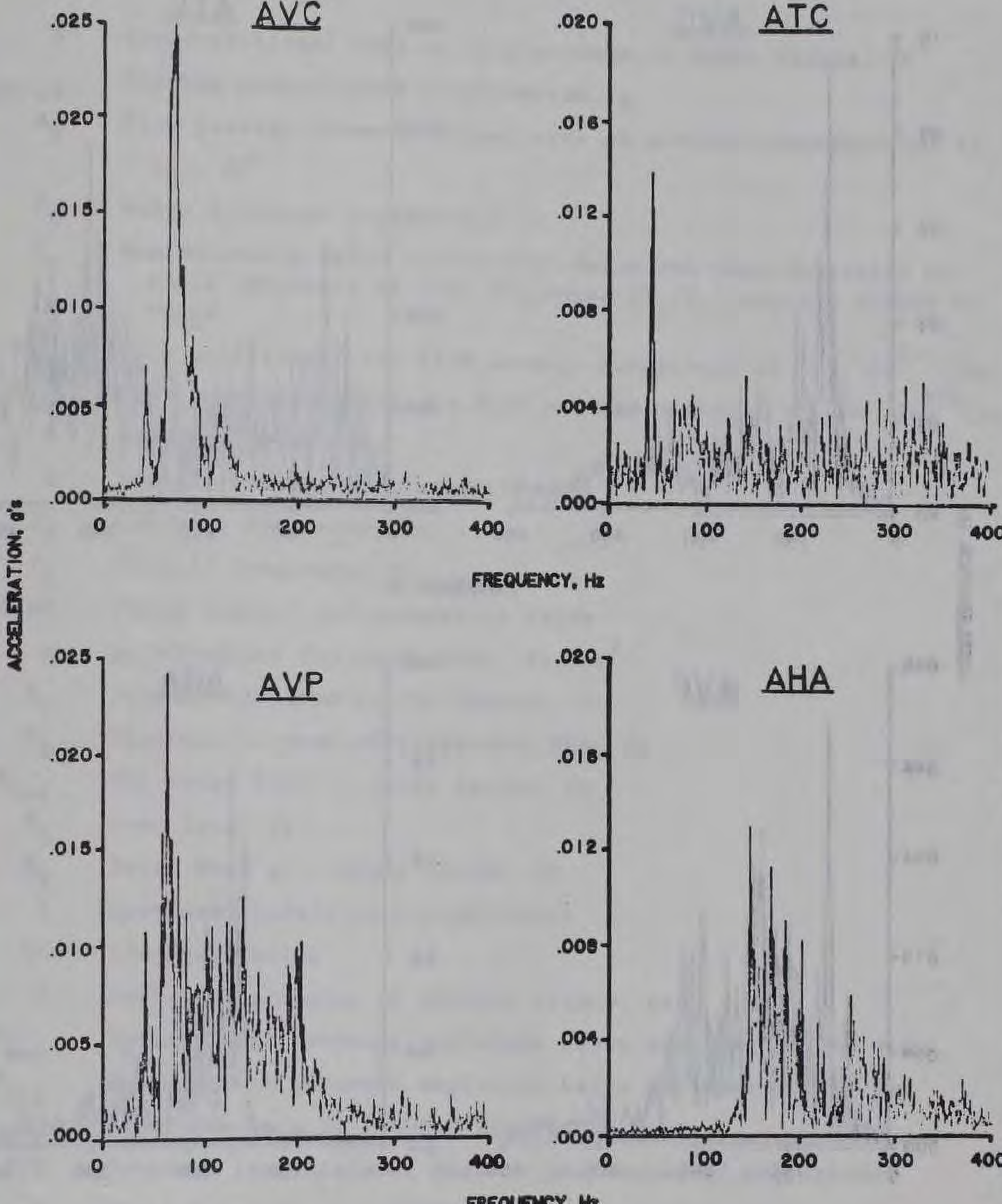


FAST FOURIER TRANSFORMS

1982 TESTS, 50% VALVE OPENING

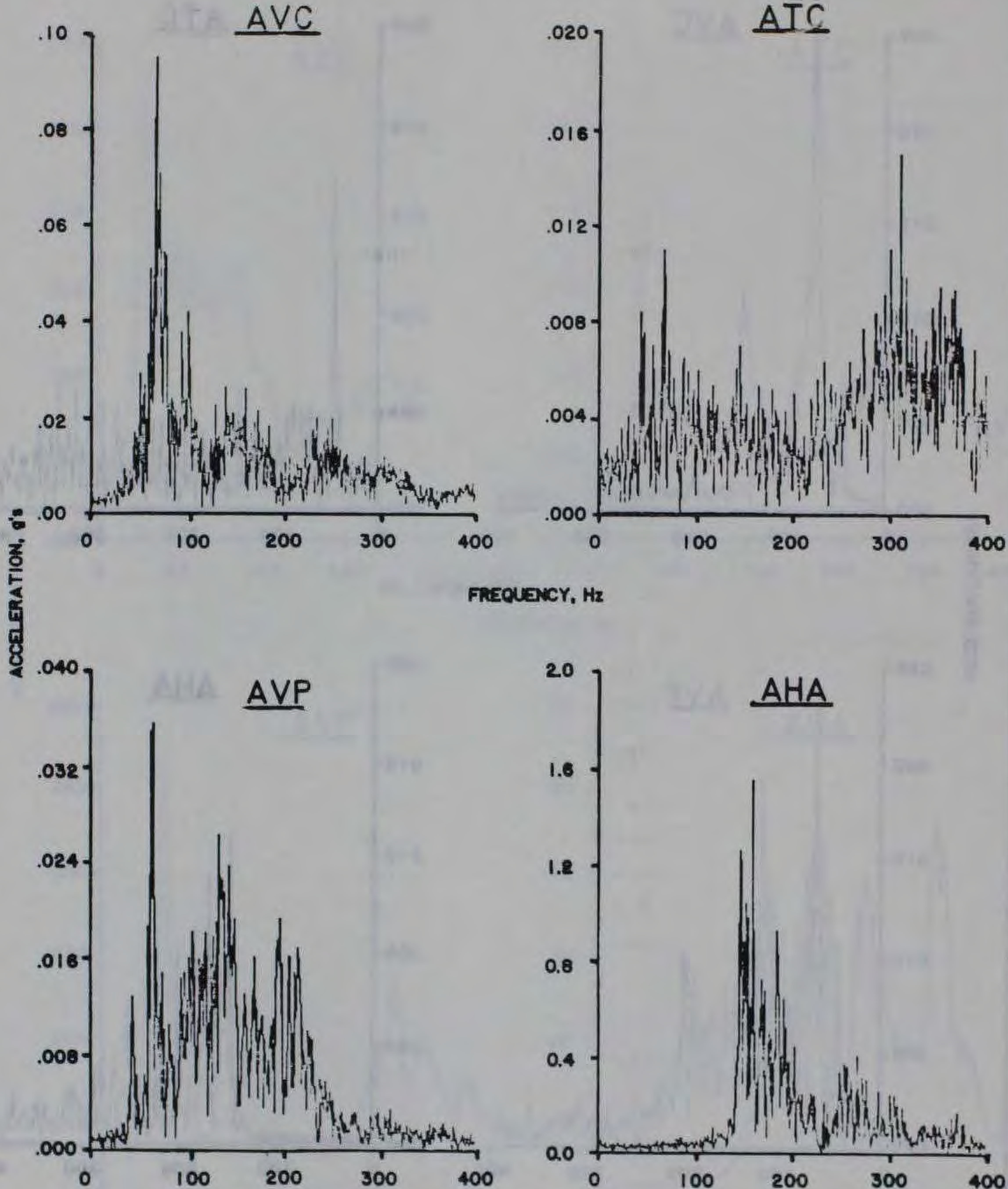
FC&I HOOD AND VALVE

PLATE 12



FAST FOURIER TRANSFORMS

1979 TESTS, 40% VALVE OPENING
FC&I HOOD AND VALVE



FAST FOURIER TRANSFORMS

1979 TESTS, 50% VALVE OPENING

FC&I HOOD AND VALVE

APPENDIX A: NOTATION

A	Cross-sectional area of flow passage at valve intake, ft^2
A_{pk-pk}	Maximum peak-to-peak acceleration, g
A_R	Flow passage cross-sectional area at station corresponding to h_R , ft^2
C_D	Valve discharge coefficient
C_v	Dimensionless valve coefficient dependent upon the ratio of shell thickness to vane thickness (T_s/T_v) and the number of vanes
C_{ED}	Flow coefficient for flow passage downstream of PC4, $ft^{5/2}/sec$
C_{EU}	Flow coefficient for the flow passage upstream of PC4, $ft^{5/2}/sec$
D	Valve diameter, in.
E	Young's modulus of elasticity, psi
f_D	Dominant frequency, Hz
f_n	Natural frequency, Hz
FC&I	Flood control and irrigation valve
g	Acceleration due to gravity, ft/sec^2
h_r	Piezometric head in the conduit, ft
h_4	Piezometric head at transducer PC4, ft
H_{net}	Net total head at valve intake, ft
H_L	Head loss, ft
H_T	Total head at conduit intake, ft
k	Upstream conduit loss coefficient
LL	Low-level valve
P	Reference pressure of flowing liquid, psi
P_{max}	Maximum peak pressure amplitude above the mean value, psi
P_{min}	Minimum peak pressure amplitude below the mean value, psi
P_v	Vapor pressure of flowing liquid, psia
P/P	Greatest instantaneous peak-to-peak value of measurement
Q	Discharge, cfs
S	Sleeve travel, in.
S/D	Dimensionless distance traveled by the sleeve
T_s	Thickness of the shell, ft
T_v	Thickness of the vane, ft
V	Reference velocity of flowing liquid, fps

γ	Specific weight of the flowing liquid, lb/ft^3
Δh	Piezometric head differential, ft
Δh_4	Piezometric head drop between pool and transducer PC4, ft
ε	Strain, μin./in.
ε_1	Axial strain, μin./in.
ε_2	Bending strain, μin./in.
ρ	Mass per unit volume, $lb\text{-}sec^2/ft^4$
σ	Mean stress value, psi
σ_c	Cavitation index number
$\mathbb{E}$	Euler number