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LABORATORY AND FIELD EVALUATION OF ACOUSTIC VELOCITY METERS AT HOOVER, DAVIS, AND PARKER DAMS

by

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INTRODUCTION

The material for this paper is part of a study requested by Reclamation's (U.S. Bureau of Reclamation) Lower Colorado Regional Office. The purpose of the study was to improve the flow measurement at the major dams along the lower Colorado River, namely Hoover, Davis, and Parker Dams. This study is only one of many being conducted in support of the LCRAS (Lower Colorado River Accounting System) program. LCRAS is a water management computer program which will allow Reclamation to better utilize water resources in the Lower Colorado River basin. LCRAS will be used to estimate water consumption by tracking consumptive use by: crops and phreatophytes, reservoir evaporation, municipal and industrial users, and groundwater recharge.

In an effort to improve the accuracy of flow measurement at Hoover, Davis, and Parker Dams, a two-stage study was initiated. The first stage was to evaluate the existing flow measurement system which consists of AVMs (acoustic velocity meters) with four or eight acoustic paths. A field survey was conducted to determine if all 27 AVM installations conformed to ANSI/ASME standards and ASME's Performance Test Code for hydraulic turbines performance tests. The second stage was to determine if the AVM installations were performing to manufacturer's specified accuracies of ± 0.5 percent of the true discharge. A published error analysis by the AVM manufacturer (Lowell and Hirschfeld, 1979) does not adequately address the error related to the integration of an asymmetrical velocity distribution. To verify the flowmeters integration techniques, when applied to an asymmetrical velocity distribution, physical models were used to determine the penstock velocity distributions at the AVM measurement sections. Model study results were used to

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establish overall uncertainty bounds on discharge measurements and develop modifications which will reduce the discharge errors.

Model Study Conclusions - For the Power O&M Workshop I will not go into the details of the model studies, but I will include the model study results. If further information is needed I can be contacted at (303) 236-2000 extension 451. A report for this study will be available by the end of fiscal year 1995.

Davis Penstock No. 5 - An asymmetrical velocity distribution was identified for Davis Penstock No. 5 for all discharges tested. A combined bend just upstream of the AVM measurement cross section creates a secondary current which results in a reduced velocity along the inside of the bend. Data analysis showed that, for this asymmetrical velocity distribution, velocities measured along the four acoustic paths are considerably different depending on acoustic path orientation. Discharge measurement errors as large as 2 percent were measured. An analysis to determine the optimum path orientation showed the existing condition, horizontal acoustic paths, is optimum. For the prototype path orientation, errors in Gaussian quadrature integration of asymmetric velocity distributions for tests 2 through 4 were found to be -0.31, -0.44, and -0.75 percent, respectively (see figure 1).

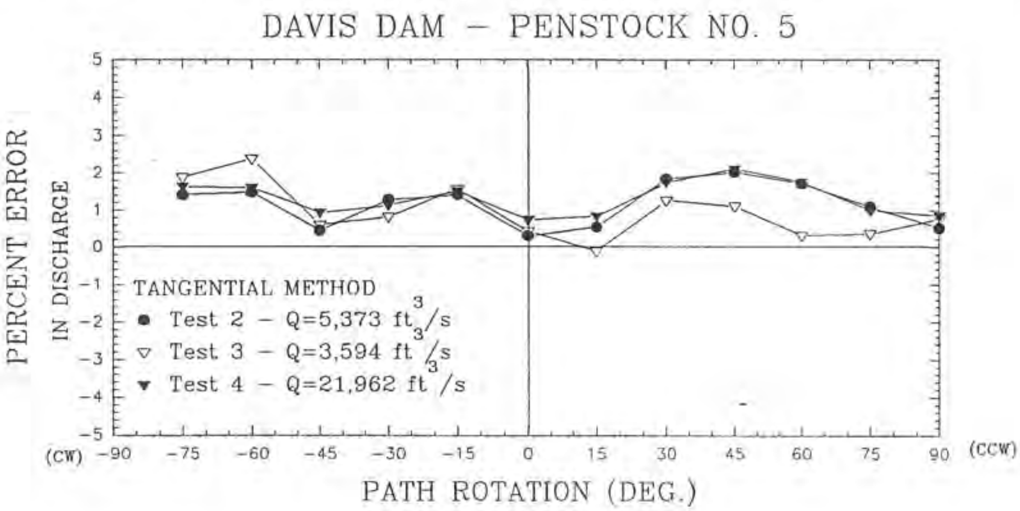


Figure 1. Percent error in discharge measurement as a function of path rotation. This plot indicates the best transducer configuration is the existing, horizontal acoustic paths.

Parker Penstock No. 1 - A nearly symmetrical velocity distribution was identified for Parker penstock No. 1 for all discharges tested. A combined bend upstream of the AVM measurement cross section creates a slightly skewed velocity distribution. Data analysis showed that for this particular velocity distribution, velocities measured along the four acoustic paths are very similar and path velocities are essentially independent of path orientation.

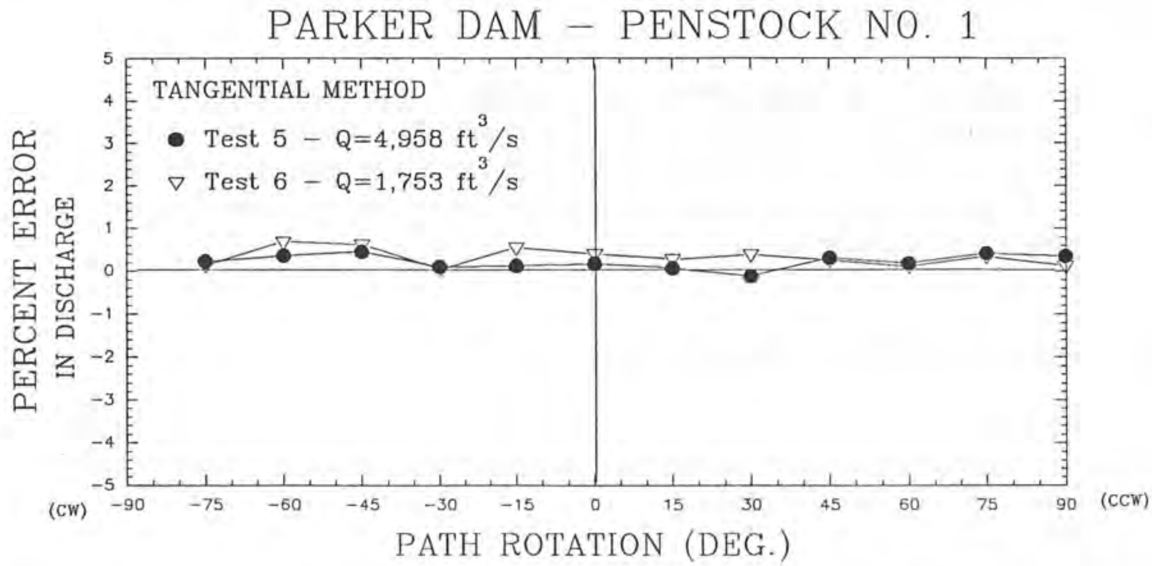


Figure 2. Percent error in discharge measurement as a function of path rotation. This plot indicates the best transducer configuration is for a 30° clockwise rotation, but the existing horizontal acoustic paths are also very accurate.

Errors in Gaussian quadrature integration of the velocity distributions for tests 5 and 6 were found to be +0.18 and +0.41 percent, respectively (see figure 2). Therefore, the prototype AVM installation on Parker penstock No. 1 should perform to the manufacturer's specified accuracy of ±0.50 percent, provided other errors related to AVM installation and setup are also within manufacturer's specifications.

Integration errors for penstocks No. 2 through No. 4 are probably smaller than penstock No. 1 because of there is more straight pipe downstream of the combined bend.

Field Study Conclusions

AVM installations at Davis and Parker Dams are nonstandard because they do not meet the ANSI/ASME standard concerning the required length of straight pipe upstream and downstream from the AVM measurement section.

AVM installations at Davis and Parker Dams do not meet the requirement in ASME's PTC 18 which states: "The intersection of crossed acoustic planes shall be in the same plane as the upstream bend to minimize the effects of the cross flow components on the accuracy of the measurement."

Cross flow errors were identified at Davis penstock No. 5 and Parker penstock No. 1 and were measured to be ±0.5 and ±1.8 percent, respectively. These errors are compensated for by using crossed acoustic planes. Therefore, all penstocks with single plane AVMs are likely to have cross flow errors.

Crossed plane AVMs are recommended on all penstocks at Davis and Parker Dams, except for Parker penstock No. 4. Analysis of path velocity data from Parker Penstock No. 3 indicate a minimal cross flow error. Parker penstock No. 4 has better flow conditions than penstock No. 3, so it is safe to conclude that crossed plane AVMs are not necessary for accurate discharge measurements.

BASIC AVM OPERATION AND THEORY

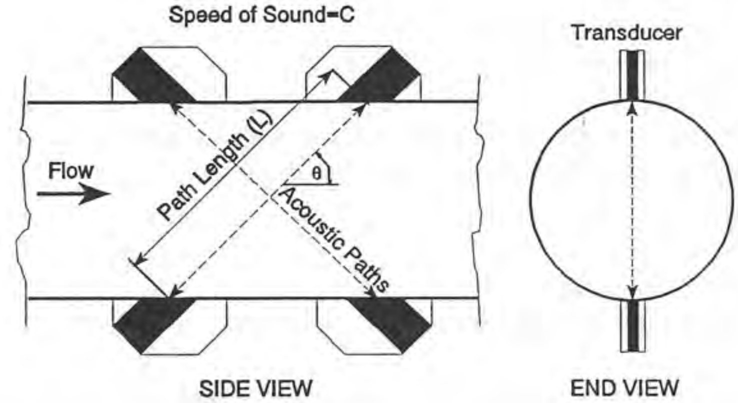
Operation of AVMs has been thoroughly described in ANSI/ASME standard MFC-5M-1985. The following section will provide an overview of transit-time acoustic velocity meters so that the reader may understand this paper.

Transit-Time Acoustic Velocity Meters. - Transit-time acoustic velocity meters are based on the principle that transit time of an acoustic signal along a known path is altered by the fluid velocity. An acoustic signal sent upstream travels slower than a signal traveling downstream. By accurately measuring the transit times of signals sent in both directions along a diagonal path, the average path velocity can be calculated. Then using the known path length and path angle, with respect to the direction of flow, the average axial velocity can be computed (equation 1).

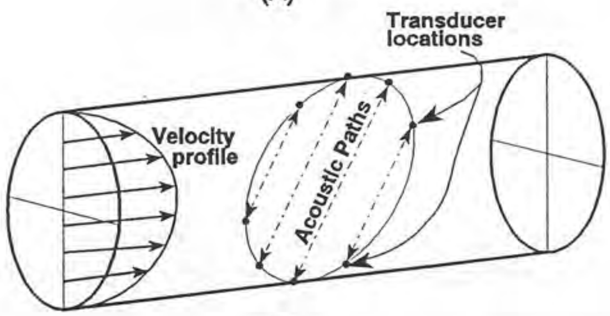
Theory - Discharge measurements are based on determining the average axial velocity in a full-flowing pipe. Knowing this velocity and the cross sectional area of the measurement section, discharge can be calculated. The difference in transit times of acoustic signals traveling in opposite directions through the water can be related to water velocity (see figure 3a). In the downstream direction the velocity of the flowing water (V_w) adds to the speed of sound (C) to give the effective speed of the acoustic pulse, $C + V_w$. In the upstream direction, the velocity delays the arrival of the pulse resulting in an effective pulse speed of $C - V_w$. Taking the difference in these velocities eliminates C from the calculations and results in Δt. When Δt is known, the average axial velocity component can be obtained from the formula:

$$V_{axial} = \frac{L}{2\ COS\theta}\left(\frac{1}{t_d} - \frac{1}{t_u}\right) \equiv \frac{L}{2\ COS\theta}\ \frac{\Delta t}{t_u\ t_d} \qquad (1)$$

where: V_{axial} = axial component of the velocity measured along the acoustic path
t_u = upstream travel time of the acoustic signal
t_d = downstream travel time of the acoustic signal
Δt = difference in upstream and downstream travel times
θ = angle between the acoustic path and the pipe's longitudinal axis
L = acoustic path length between the transducer faces



(A)



(B)

Figure 3. Transit-time acoustic flowmeters. (a) crossed, diametral path configuration and (b) single plane chordal path configuration. fn=acoust1.wpg

AVM transducers are placed in pairs on opposite walls inside the pipe, one transducer downstream of the other. Chordal path meters usually have four transducer pairs, each pair defining an acoustic path and they are oriented at a fixed angle (θ), usually between 45° and 65° to the pipe axis (see figure 3b). Path angles vary depending on the available space and accuracy requirements. The AVM processing electronics consist of a transceiver and a processor. The transceiver sends and receives signals from the transducers, first upstream then in the downstream direction. The difference in travel time in the two directions is a measure of the axial flow velocity component projected along the acoustic path. The processor converts the transit time differences into velocities, then integrates them in the direction perpendicular to the acoustic plane using Gaussian quadrature, equation 2, to calculate discharge.

$$Q = \int_{-R}^{+R} V(y)\ L(y)\ \tan\theta\ dy \quad \approx SD \sum_{i=1}^{n} W_i\ V_i\ L_i\ \tan\theta_i \tag{2}$$

where Q =discharge, ft^3/s
n =number of acoustic paths
V_i =velocity calculated along path i, ft/sec
L_i =path length for path i, ft
θ_i =angle between path and pipe axis for path i, degrees
W_i =Gaussian weighting factors, for 4-path meters
$W_1=W_4=0.1739$
$W_2=W_3=0.3261$
D =pipe inside diameter, ft
S =integration correction factor for a circular cross section

The Gaussian quadrature method requires that the acoustic paths be positioned at exact locations. For paths one and four the relative distance from the conduit center to the path (y/R) is ± 0.809. For paths two and three the relative distance from the conduit center to the path (y/R) is ± 0.309.

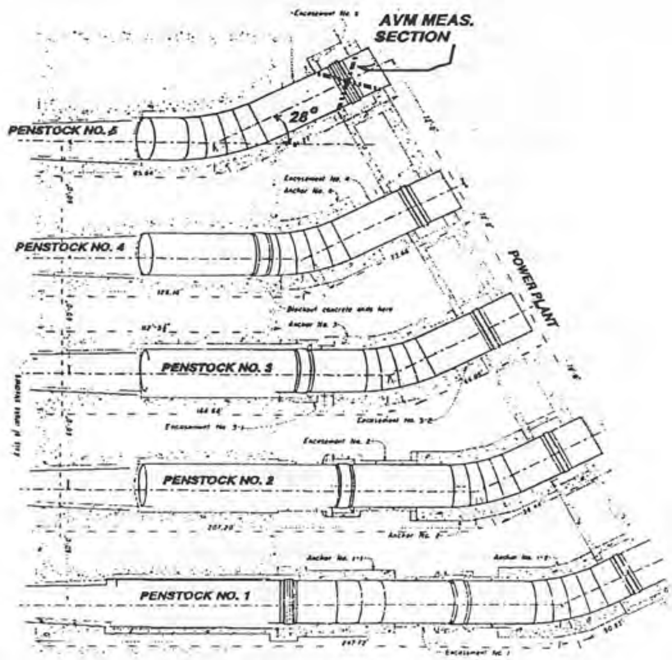
AVM FIELD EVALUATIONS

National Standards - To determine the accuracy of flow measurement at Hoover, Davis, and Parker Dams field surveys were conducted in September 1992 to document and review: AVM equipment, AVM system parameters, as-built drawings, and perceived system performance. Each of the 27 AVM sites and installations was evaluated using ANSI/ASME Standard MFC-5M-1985, entitled *Measurement of Liquid Flow in Closed Conduits using Transit-Time Ultrasonic Flowmeters*. Likewise, ASME's Performance Test Code for Hydraulic Turbines (PTC 18-1992) was used in evaluations because it is the standard procedure for performing turbine performance tests and is in some instances more stringent than the ANSI/ASME standard.

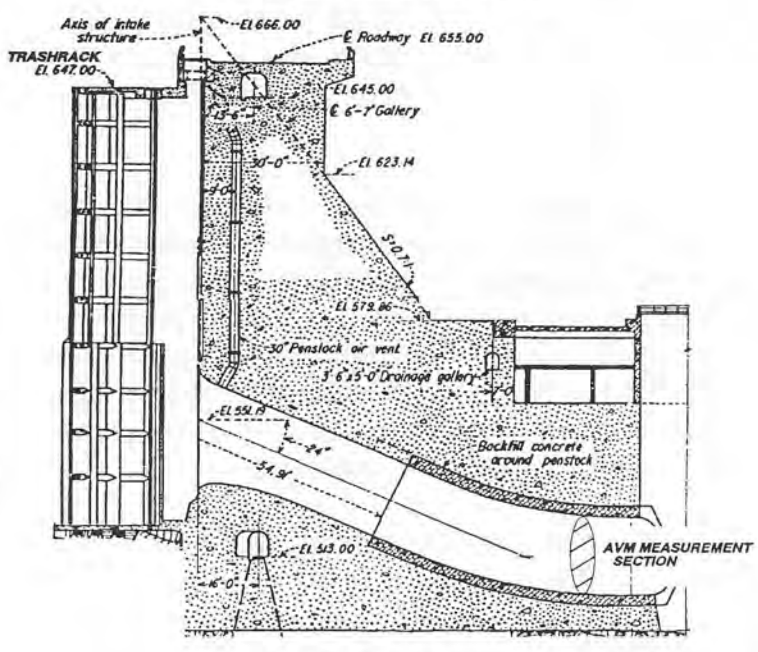
Standard and Non-standard Installations - Surveys at Hoover, Davis, and Parker Dams resulted in a large amount of site-specific data and personal opinions as to how the AVM systems were performing. Survey information is summarized as follows:

Hoover Dam - Eighteen AVMs at Hoover Dam were installed over the period of 1989 to 1991. A review of AVM equipment, system parameters, and as-built drawings at Hoover Dam revealed that all AVM installations were according to ANSI/ASME standards and were configured properly. On average there are 30 pipe diameters upstream and 4 pipe diameters downstream of the AVM measurement sections. The only exception to ASME's PTC 18 is that not all penstocks are equipped with crossed acoustic planes. This was done because cross flow information for a penstock with crossed acoustic planes could be measured and applied to the adjacent penstock with only one acoustic plane.

Davis Dam - Five AVMs were installed in 1989. A review of AVM equipment, system parameters, and as-built drawings for Davis Dam revealed that all five AVM installations were nonstandard because of inadequate length of straight pipe upstream and downstream of the meter



PLAN - POWER PENSTOCKS



SECTION - PENSTOCK NO. 5 WITH TRASHRACK

Figure 4. Plan and section of penstock No. 5 at Davis Dam. The AVM measurement section is shown at the end of the penstock. The combined bend has a 24° vertical and a 28°horizontal angle.

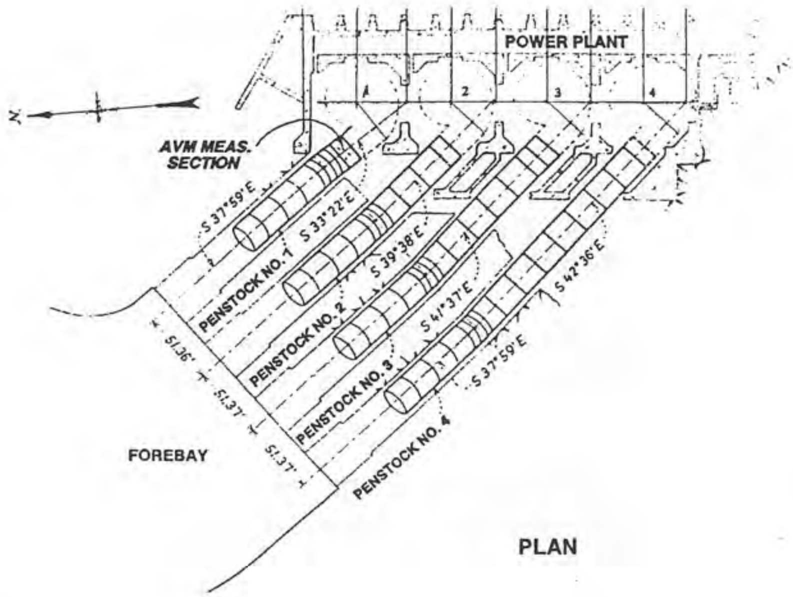
section - 10 and 3 pipe diameters are the recommended minimum upstream and downstream lengths, respectively, as required in the ASME's PTC 18. The amount of straight pipe upstream from the meter section ranged from ½ to 1-½ diameters, for each of the five, 22-ft-diameter penstocks (see figure 4). However, these AVM locations could not be avoided because of short penstocks. All AVMs were installed just upstream of the turbine scroll cases to maximize the length of straight pipe upstream. Because of short penstock lengths and bends upstream, cross flows (flows with nonaxial velocity components) were anticipated. Crossed plane AVMs are used in difficult installations to eliminate cross flow errors. The shortest of the five penstocks was fitted with a crossed path AVM system. It should be noted that ASME's PTC 18 requires installation of two, four-path measurement planes, and that the intersection of the two planes shall be in the plane of the upstream bend. The crossed plane AVM installation at Davis Dam does not meet the above criteria.

Parker Dam - Four AVMs were installed at Parker Dam in 1989. A review of AVM equipment, system parameters, and as-built drawings at Parker Dam revealed that all four AVM installations were nonstandard because of an inadequate length of straight pipe upstream and downstream of the meter section. The length of straight pipe upstream from the meter section ranged from ½ to 6 pipe diameters, for each of the four, 22-ft-diameter penstocks (see figure 5). However, these lengths could not be avoided because of short penstocks. Like at Davis, all AVMs were installed just upstream of the turbine scroll cases to maximize the length of straight pipe upstream of the meter section. Two of the four penstocks (No. 1 and No. 3) were fitted with crossed plane AVM systems, including the shortest penstock. The crossed path AVM installations at Parker do not meet ASME's PTC 18-1992 requirement on acoustic path orientation with respect to the upstream bend.

General Findings - AVM system operators felt their systems were operating satisfactorily. However, interviews indicated that there was a disparity in knowledge levels among AVM system operators. There were varying degrees of expertise in system testing and troubleshooting depending on the AVM maintenance history. To alleviate this problem it is recommended that a training course be given to all AVM system operators. It was also apparent that an experienced electronics technician is necessary to effectively operate and maintain an AVM system. We also recommended developing a database to log maintenance and repair data, as well as keeping records of system parameters and error logs.

AVM Data Analysis - Individual path velocities and discharge values were collected for the crossed path AVMs at Davis and Parker Dams to determine the errors associated with cross flows. Figure 6a contains a typical sample (~120 measurements taken over 2 minutes) of path velocity data collected from Davis penstock No. 5 for an 80 percent gate opening. This penstock is equipped with a crossed path AVM, so a total of eight path velocities and two discharges were measured. Paths 1 and 4 are the upper and lowermost acoustic paths. Paths 2 and 3 are located in between paths 1 and 4.

Davis Dam Acoustic Velocity Meter Evaluation - Field tests were conducted to collect real-time data from the Accusonic Model 7410 acoustic velocity meters. Path velocities (Vel-n) and



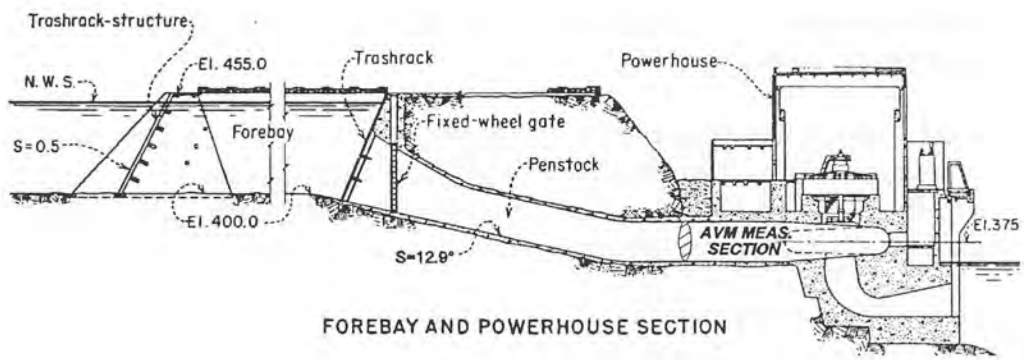


Figure 5 Plan and Section of Penstock and Powerhouse at Parker Dam. For Penstock No. 1, the bend is immediately upstream from the AVM transducer section and has a 12.9° vertical and a 4.6° horizontal angle.

discharge (Flow-n) data were collected for a wide range of wicket gate openings. Of the five penstocks at Davis Dam, only No. 5 has a crossed plane AVM. Penstock No. 5 was chosen for the crossed plane installation because it is the shortest penstock. However, it also has the longest section of straight pipe upstream from the measurement section (see figure 4). As a result, penstocks one through four may have velocity distributions which are worse than No. 5.

AVM data were analyzed to identify problems with the data collection, AVM setup, or cross flow, and skewed velocity distributions. A summary of the data analysis is as follows:

Penstock No. 1 - This penstock has less than 1 pipe diameter of straight pipe upstream from the AVM measurement section. The combined bend is a vertical curve of 20° and a horizontal curve of 28°. In addition, four pipe diameters upstream of the combined bend there is a 20° vertical bend. Analysis of AVM data collected for a 65 percent wicket gate opening at reservoir elevation of 637 ft resulted in the following observations:

- The velocity profile is skewed with path 2 velocities less than the other 3 paths (see figures 6a and 6c). Skewness is caused by the combined bend upstream of the measurement section.
- No diameters of straight pipe upstream of the measurement section and two upstream bends are likely to generate a discharge measurement error because of cross flows.
- There are no crossed acoustic planes for this penstock. As a result, an estimate of cross flow error could not be established.
- To attain accuracies on the order of $\pm$ 0.5 percent, it is necessary to make cross plane measurements on this penstock.

Penstock No. 2 - This penstock has less than 1 pipe diameter of straight pipe upstream form the AVM measurement section. The combined bend is a vertical curve of 10° and a horizontal curve of 28°. Analysis of AVM data collected for a 65 percent wicket gate opening at reservoir elevation of 637 ft resulted in the following observations:

- The velocity profile is skewed toward the pipe invert with path 2 velocities less than the other three paths (see figures 6a and 6c).
- One pipe diameter of straight pipe upstream of the measurement section and an upstream bend will likely generate a discharge measurement error because of cross flows.
- There are no crossed acoustic planes for this penstock. As a result, an estimate of cross flow error could not be established.
- To attain accuracies on the order of $\pm$ 0.5 percent, it is necessary to make cross plane measurements on this penstock.

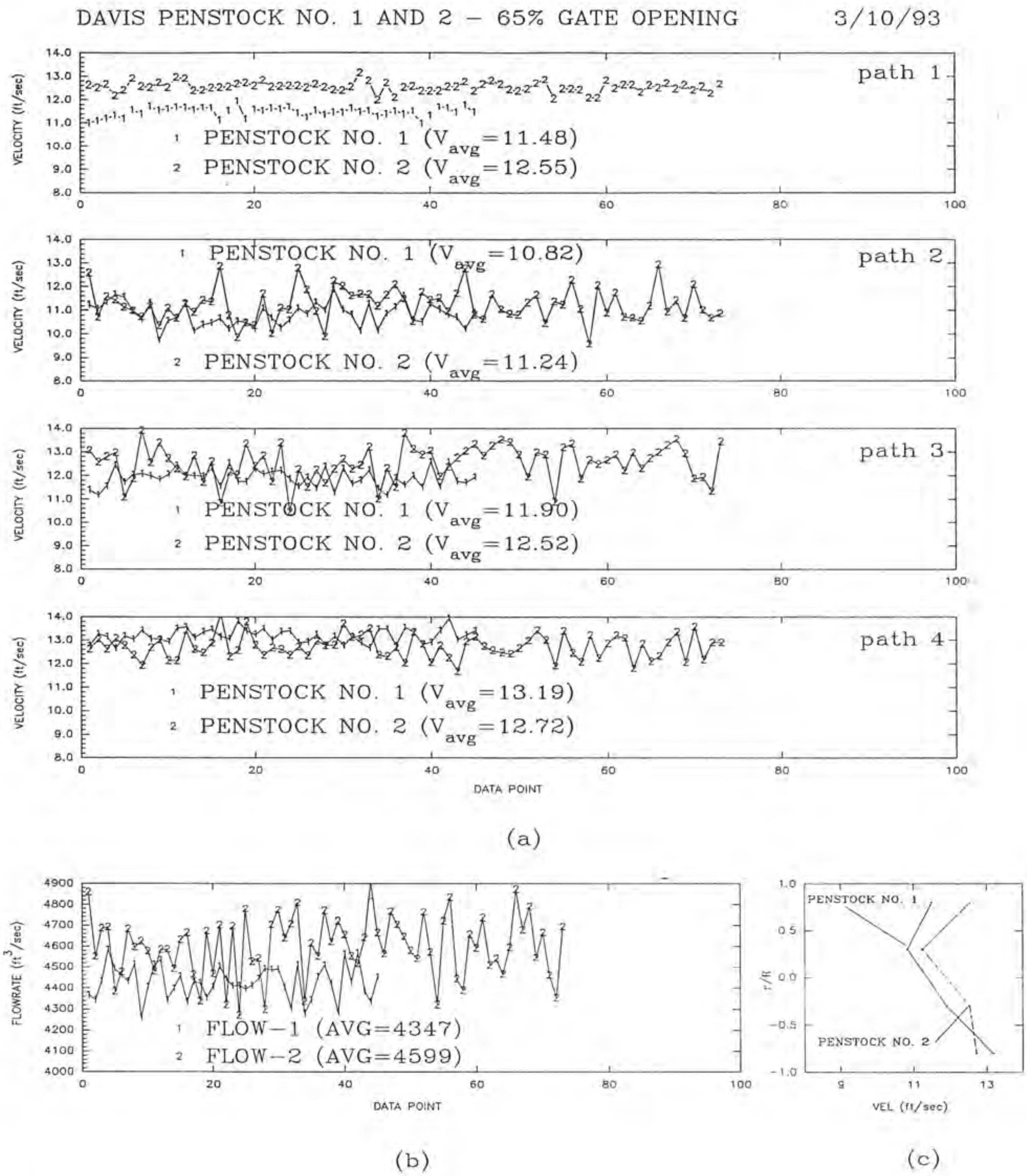


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Figure 6. (a) Instantaneous path velocities for Davis penstocks No. 1 and 2. Single acoustic plane data for each penstock. (b) Instantaneous flowrates for penstock No. 1 and 2. (c) Average velocity profiles for penstock No. 1 and 2.

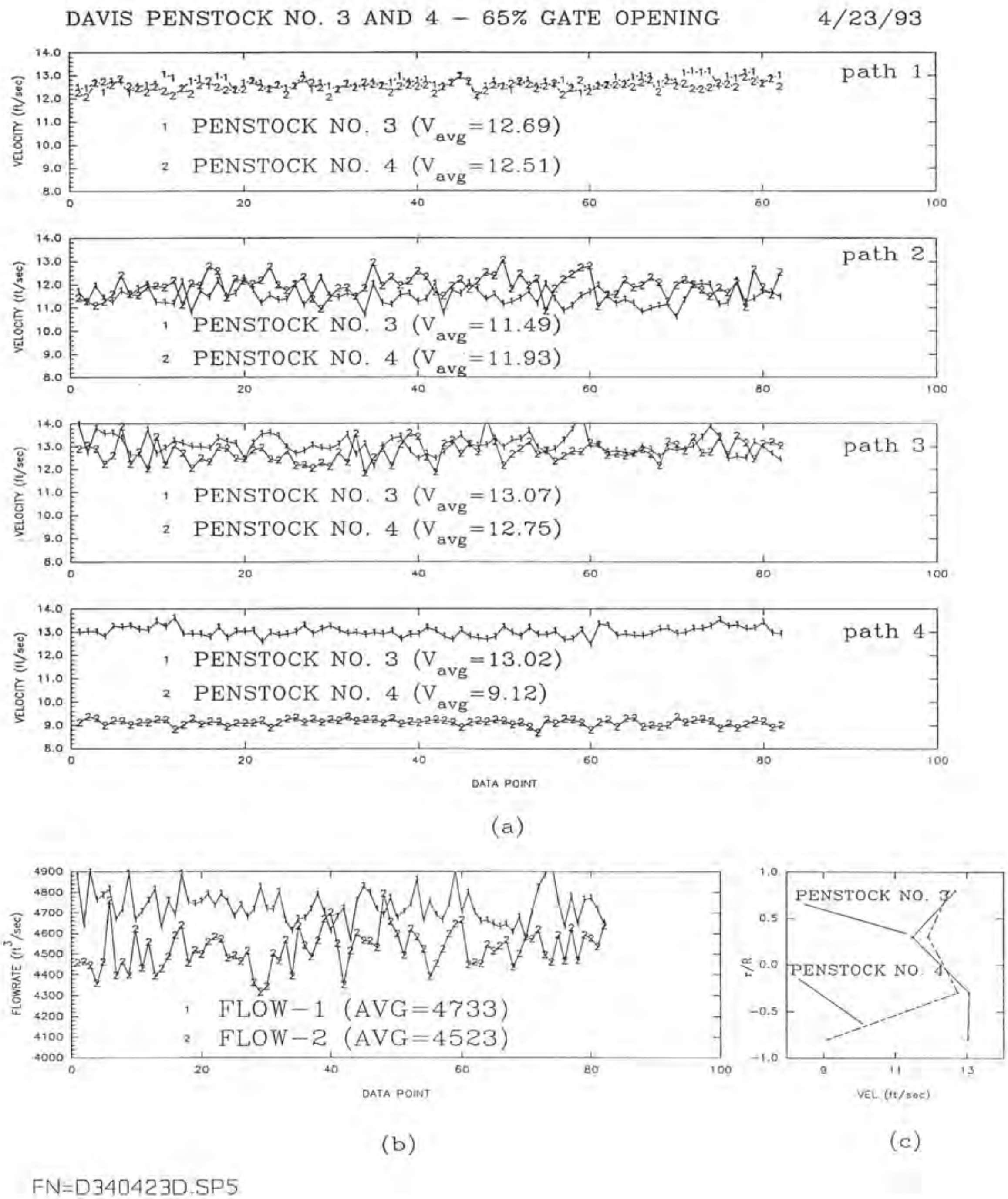

Figure 7. (a) Instantaneous path velocities for Davis penstocks No. 3 and 4. Single acoustic plane data for each penstock. (b) Instantaneous flowrates for penstock No. 3 and 4. (c) Average velocity profiles for penstock No. 3 and 4.

Penstock No. 3 - This penstock has about 1 pipe diameter of straight pipe upstream from the AVM measurement section. The combined bend is a vertical curve of 12.5° and a horizontal curve of 28°. Analysis of AVM data collected for a 65 percent wicket gate opening at reservoir elevation of 637 ft resulted in the following observations:

- The velocity profile is skewed toward the pipe invert with path 2 velocities less than the other three paths (see figure 7a).
- There are no crossed acoustic planes for this penstock. As a result, an estimate of cross flow error could not be established, but because of the proximity of the upstream bend it probably exists.
- To attain accuracies on the order of ± 0.5 percent, it is necessary to make cross plane measurements on this penstock.

Penstock No. 4 - This penstock has about 1.5 pipe diameters of straight pipe upstream from the AVM measurement section. The combined bend is a vertical curve of 16.5° and a horizontal curve of 28°. Analysis of AVM data collected for a 65 percent wicket gate opening at reservoir elevation of 637 ft resulted in the following observations:

- For several data sets collected on different days, acoustic path 4 was consistently 30 percent lower than path 3 velocities. These low velocities are not consistent with path 4 velocity measurements on penstock No. 3 or No. 5 (see figures 7a and 7c). Because penstock No. 4's geometry is similar to penstocks No. 3 and No. 5, it is not probable to have this radical disturbance in the velocity distribution, unless the penstock is damaged. As a result, it is recommended that this transducer be evaluated for electrical or installation errors. If this analysis does not identify the problem, the penstock and transducer mount should be inspected for an offset or other source of a flow disturbance.
- There are no crossed acoustic planes for this penstock. As a result, an estimate of cross flow error could not be established, but because of the proximity of the upstream bend and the very low velocities measured on path 4, cross flow probably exists. Therefore, crossed plane measurements should be taken to assure high accuracy (± 0.5%) in AVM discharge measurements

Penstock No. 5 - This penstock has 1.5 diameters of straight pipe upstream from the measurement section. The combined bend is a vertical curve of 24° and a horizontal curve of 28°. Analysis of AVM data collected for many gate openings (11, 20, 30, 40, 50, 60, and 64 percent) at reservoir elevation of 630.8 ft resulted in the following observations:

- Velocity data indicate close agreement between the two acoustic planes (see figure 8a), but the average velocity profiles are skewed and have different shapes (see figure 8c)

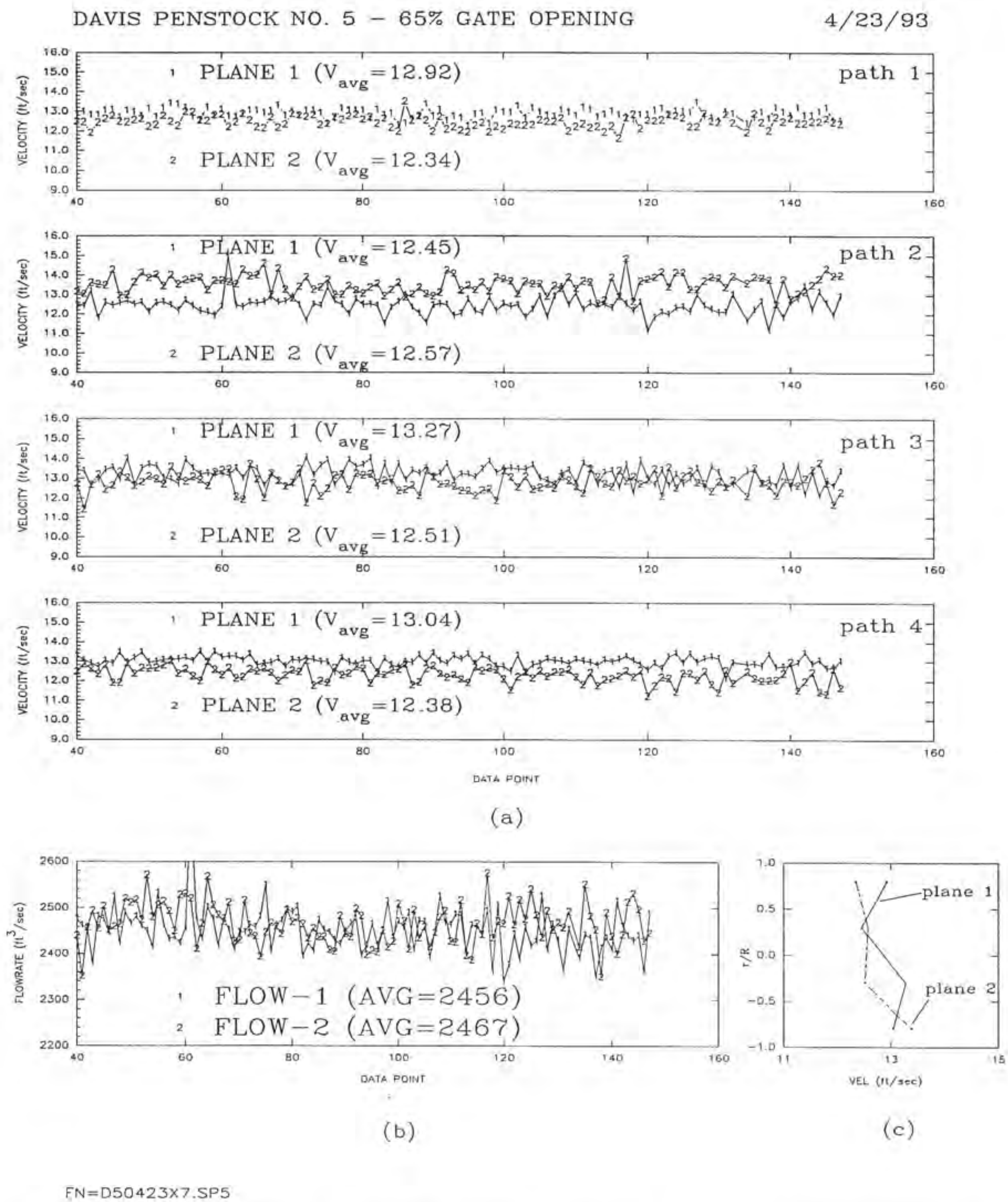

Figure 8. (a) Instantaneous path velocities for-Davis penstocks no. 5. (a) Crossed acoustic plane data for this penstock. (b) Instantaneous flowrates for acoustic planes 1 and 2. (c) Average velocity profiles for planes 1 and 2.

which indicates poor flow conditions caused by the short penstock and combined bend upstream.

- For all wicket gate opening tested, the two crossed acoustic planes produce discharge measurements which are offset by an average of -1.06 percent (see table 1), which is a systematic error in the AVM discharge measurement. This offset is because of a cross flow velocity component through the measurement section.

- Given the similar geometry of penstocks No. 1 through 4 to penstock No. 5, it is probable that cross flows are also occurring those penstocks.

- It is necessary to make cross plane measurements for this penstock, the average of Flow-1 and Flow-2 is a discharge value corrected for cross flow. For the wide range of wicket gate openings tested Flow-2 values were consistently 1.07 percent higher than Flow-1 values. Therefore, if one plane of transducers should fail a correction should be made as follows: increase Flow-1 value by +0.53 percent or decrease Flow-2 value -0.53 percent.

Table 1. Comparison of cross plane discharge measurements for Davis penstock No. 5 over a range of wicket gate openings. Flow-1 and Flow-2 are divided by 2 so when summed they correct for cross flow errors. The percent difference between Flow-1 and Flow-2 is an indication of cross flow error.

Wicket Gate Opening (%)	AVM Flow-1 (ft^3/s)	AVM Flow-2 (ft^3/s)	Percent Difference (%)
11	427.1	433.8	-1.53
20	726.5	733.1	-0.89
30	1140.2	1159.3	-1.64
40	1418.1	1439.7	-1.50
50	1909.9	1928.4	-0.95
60	2319.9	2322.0	-0.09
64	2467.6	2487.5	-0.80

Parker Dam Acoustic Velocity Meter Evaluation - Field tests were conducted to collect real-time data from the Accusonic Model 7410 acoustic velocity meters. Path velocities (Vel-n) and discharge (Flow-n) data were collected for a wide range of wicket gate openings (see table 2). Of the four penstocks at Parker Dam, penstocks No. 1 and No. 3 have crossed plane AVMs. Penstock No. 1 was chosen for the crossed plane installation because it is the shortest penstock, with no diameters of straight pipe upstream of the AVM measurement section. Both crossed plane AVMs were installed for use in turbine performance testing.

Several AVM data sets were analyzed to identify problems with the data collection, AVM setup, or cross flow, and skewed velocity distributions. A summary of the data analysis is as follows:

Table 2. Comparison of cross plane discharge measurements for Parker Penstock No. 1 over a range of wicket gate openings. Flow-1 and Flow-2 are averaged to correct for cross flow errors in Parker penstock No. 1. The percent difference between Flow-1 and Flow-2 is an indication of cross flow error.

Wicket Gate Opening (%)	AVM Flow-1 (ft^3/s)	AVM Flow-2 (ft^3/s)	Percent Difference (%)
15	846.9	814.8	3.79
25	1458.8	1405.6	3.64
35	2033.5	1954.5	3.88
50	3179.0	3058.0	3.80
60	3974.0	3814.0	4.00
70	4690.0	4510.0	3.84
80	5135.0	4940.0	3.79

Penstock No. 1 - This penstock has less than 1 pipe diameter of straight pipe upstream from the AVM measurement section. The combined bend is a vertical curve of 13° and a horizontal curve of 4.6°. Analysis of this AVM data collected for many wicket gate openings (15, 25, 35, 50, 60, 70, and 80 percent) at reservoir elevation of 446.6 ft resulted in the following observations:

- The velocity profile is skewed with path 2 velocities greater than path 3 (see figure 9a). The degree of skewness escalates with increasing gate opening. Skewness is caused by the combined bend located directly upstream of the AVM measurement section.

- The crossed acoustic planes produce discharge measurements which are consistently offset by an average of +3.8 percent (see table 2 and figure 9b), which indicates the cross flow component in the AVM measurement section is significant for the tested range of wicket gate openings.

- Field observations of a vortex near the intake for penstock No. 1 could also be contributing to the development of cross flows. Vortices were not observed in the model.

- It is necessary to make cross plane measurements for accurate flow measurement in this penstock. The average of Flow-1 and Flow-2 is the discharge value corrected for cross flow. If one plane of transducers should fail, a correction should be made as follows: reduce Flow-1 value by -1.9 percent if plane 2 fails, or increase the Flow-2 value +1.9 percent if plane 1 fails. This correction will give a good estimate of the true discharge.

Penstock No. 2 - This penstock has about 2 pipe diameters of straight pipe upstream from the AVM measurement section. The combined bend is a vertical curve of 13° and a horizontal curve of 1.6°. Only one data file was collected for this penstock, analysis of AVM data

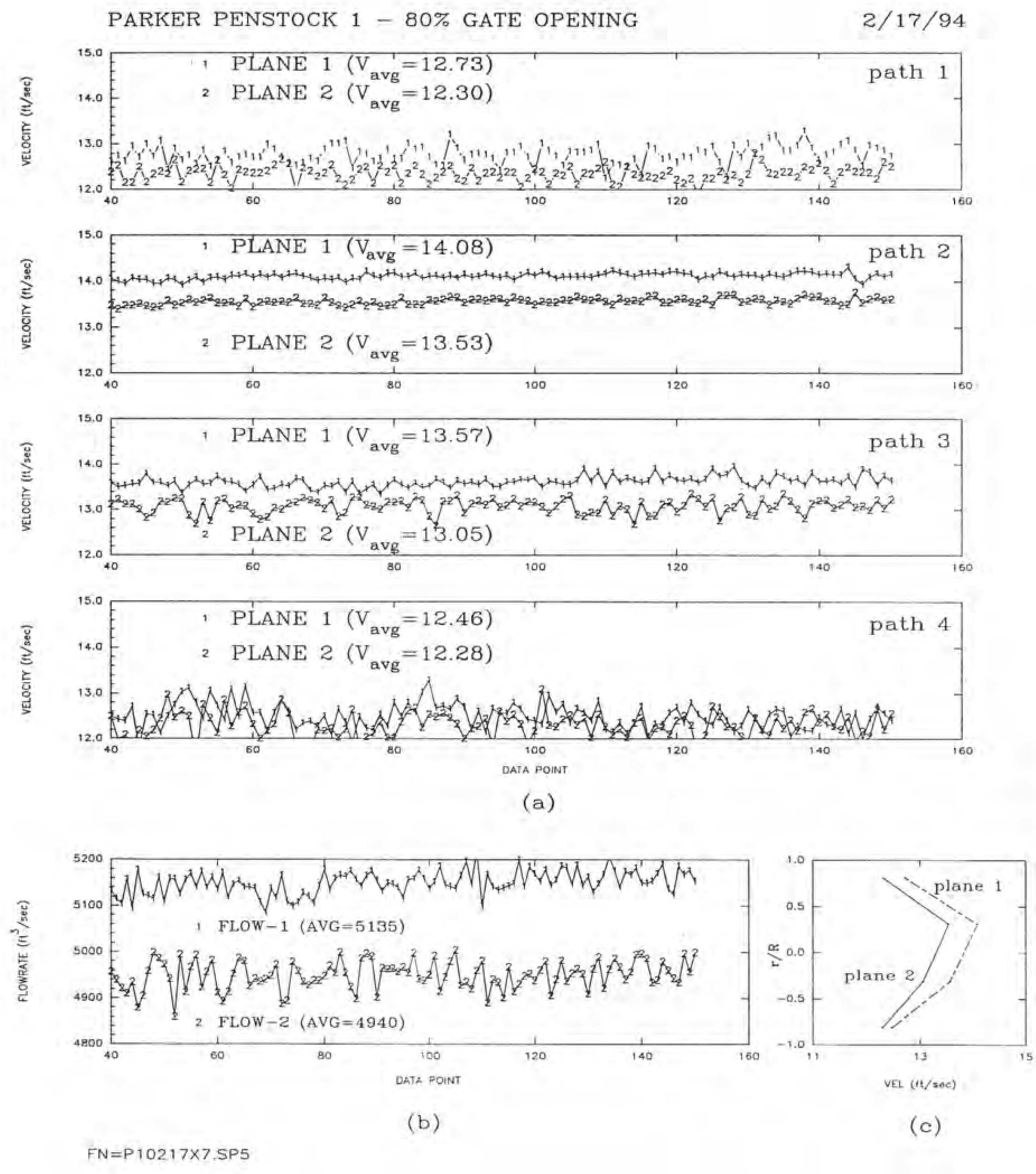

Figure 9. (a) Instantaneous path velocities for Parker penstock no. 1. Data were collected for crossing acoustic planes. (b) Instantaneous flowrates for plane 1 and 2. (c) Average velocity profiles for planes 1 and 2.

collected for a 65 percent wicket gate opening resulted in the following observations:

- The velocity profile is slightly skewed toward the pipe invert with path 1 velocities less than path 4. Paths 2 and 3 velocities were almost identical.

- Considering the cross flow errors in penstock No.1, to confirm accuracies on the order of ± 0.5 percent it is necessary to make cross plane measurements on this penstock. It is difficult to try and apply a correction to this discharge measurement, but because it has more pipe diameters of straight pipe upstream of the AVM measurement section, it is likely to be less than the ± 1.9 percent error on penstock No. 1.

Table 3. Comparison of cross plane discharge measurements for Parker Penstock No. 3 for a range of wicket gate openings. Flow-1 and Flow-2 are averaged to correct for cross flow errors in Parker penstock No. 3. The percent difference between Flow-1 and Flow-2 is an indication of cross flow error.

Wicket Gate Opening (%)	AVM Flow-1 (ft^3/s)	AVM Flow-2 (ft^3/s)	Percent Difference (%)
15	779.2	776.3	-0.36
25	1418.6	1420.7	+0.15
35	2004.5	1998.6	-0.30
50	3161.6	3151.2	-0.33
60	3939.6	3930.2	-0.24
72	4717.3	4700.5	-0.36
80	5063.8	5050.0	-0.27

Penstock No. 3 - This penstock has less than 5 pipe diameters of straight pipe upstream from the AVM measurement section. The combined bend is a vertical curve of 13° and a horizontal curve of 3.6°. Analysis of AVM data collected for many wicket gate openings (15, 25, 35, 50, 60, 72, and 80 percent) at reservoir elevation 446.6 ft resulted in the following observations:

- The path velocities are skewed with path 1 velocities much less than path 4 (see figure 10a). The degree of skewness escalates with increasing wicket gate opening. Skewness is caused by the combined bend located 4.5 pipe diameters upstream.

- The two crossed, acoustic planes produce average discharge measurements which are within ± 0.12 percent (see table 3), which indicates the cross flow component in the AVM measurement section is negligible for all wicket gate openings tested (see figure 10b).

- Average velocity profiles measured on both acoustic planes are in close agreement, as shown in figure 10c.

- Based on this data, it is not necessary to make continuous cross plane measurements for this penstock. However, it would be wise to occasionally check the primary plane versus the secondary plane, one plane is all that is necessary for a discharge measurement with the manufacturers accuracy with ± 0.5 percent. However, during performance tests it is recommended to always have both planes operating.

- It is apparent from comparison of cross flows at penstock No. 1 and No. 3 that the amount of straight pipe upstream of the AVM measurement section is directly related to the severity of cross flows.

Penstock No. 4 - This penstock has 6.4 pipe diameters of straight pipe upstream from the AVM measurement section. The combined bend is a vertical curve of 13° and a horizontal curve of 4.6°. No data files were collected for this penstock; however, the following comments are based on data collected on the penstocks No. 3:

- Additional pipe length should create a more uniform velocity distribution than penstock No. 3.

- There are no crossed acoustic planes for this penstock. However, because very small cross flow errors were measured on penstock No. 3, it is likely that none exist for this installation. As a result, AVM discharge measurement errors should be equal to or less than those measured in penstock No. 3.

RECOMMENDATIONS FROM FIELD EVALUATIONS

Field Surveys - Some interesting equipment problems were identified during the surveys. At Hoover and Davis Dams, when acoustic transducers were removed for cleaning or when the penstock was dewatered, there was a large number of transducers which failed. Transducer failures have been prevented by keeping transducers submerged in water during maintenance operations. Another common concern was the accuracy of field surveys of path angles and lengths, and cross-sectional areas of the penstocks. These parameters are very difficult to measure accurately, and must be determined to a high degree of accuracy. Therefore, operators should be comfortable with the survey accuracy prior to going on-line with an AVM system. This information should be recorded for future reference because it is important information in setting up the AVMs system parameters.

Review of the system parameter lists identified several errors in the system parameters. Errors in path angle and diameters resulted in relatively large systematic errors. Once identified these errors are easily corrected, provided as-built information is available. Another installation had two cables crossed which resulted in a negative path velocity. Of course, this error leads to a very large error in discharge measurement.

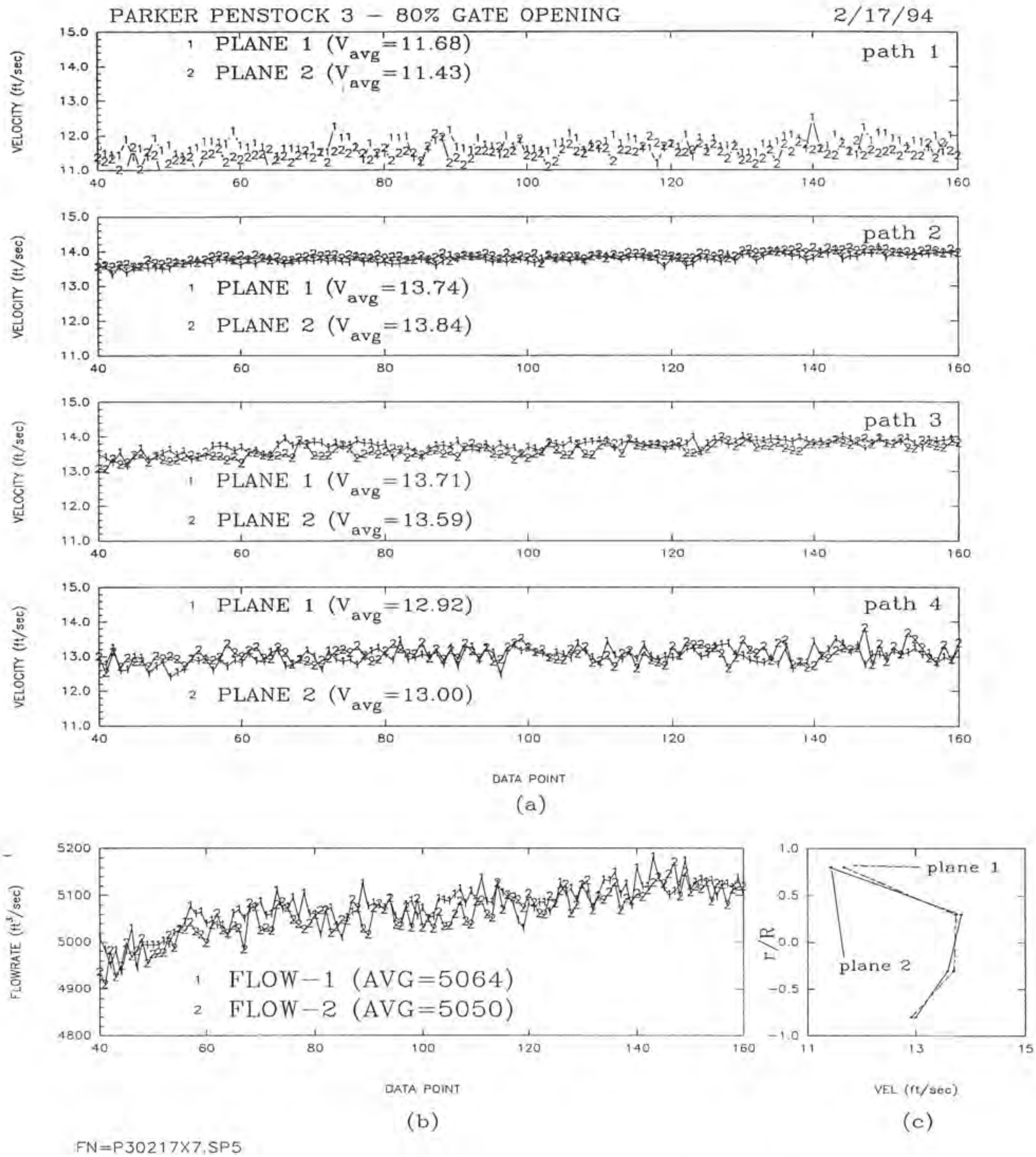

Figure 10. (a) Instantaneous path velocities for Parker penstock No. 3. Data were collected for crossing acoustic planes. (b) Instantaneous flowrates for plane 1 and 2. (c) Average velocity profiles for plane 1 and 2.

Recommended Installation and Set-up procedures

Installation of an AVM requires a layout survey, installation of transducer mounts, and an as-built survey of acoustic path lengths, average cross-sectional area, and acoustic path angles. Accurate installation and AVM setup is critical to assure accurate discharge measurements. ASME's Performance Test Code 18-1992 and ANSI Standard MFC-5M-1985 are good resources for AVM installation, operation, and maintenance guidelines. A list of field procedures which should be considered are:

- Acoustic signals received at each transducer should be examined, using an oscilloscope, to look for excessive noise and sufficient amplitude to assure proper signal detection. Signal strength should be examined periodically to check for transducer fouling.

- To check for timing bias errors, the upstream and downstream cables should be reversed and a repeat set of measurements taken. If the two time-averaged discharge values are different there is a bias error associated with a timing offset. This bias may be caused by unequal cable lengths or delays in the electronic circuitry. It is recommended by PTC 18-1992 to measure the ultrasonic pulse transit times independently and compare the transit times measured by the AVM.

- If cross planes are installed, comparisons of the two velocity profiles and discharge measurements should reveal the presence of cross flow (nonaxial) velocity components (see figures 9a and 9b). Cross flow can be caused by a nearby change in flow direction or by vortices which form near the penstock intake.

- The velocity profile established by the four acoustic path velocities should be studied to determine profile distortion. Likewise, strong fluctuations in instantaneous measurements can indicate nonstandard approach conditions to the AVM measurement section.

- Travel time along each acoustic path is calculated by the flowmeter. The AVM estimates the speed of sound for each measurement which should correspond to the speed of sound for the water temperature moving through the penstock. A difference between these two values could be caused by a temperature gradient in the water moving along the acoustic path. This type of problem can occur if the reservoir's thermocline develops at the same elevation as the penstock intake structure. A difference in speed of sound could also indicate a survey error.

- Tests should be performed to determine if any long period fluctuations exist, which may affect the average discharge measurement during short period performance evaluations. This type of fluctuation could be generated by a vortex which periodically develops near the intake.

References

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