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GILLHAM DAM OUTLET WORKS TOWER HYDRAULIC PROTOTYPE STUDY GILLHAM LAKE, ARKANSAS

by

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13. ABSTRACT (Maximum 200 words) In October 1984, severe vibrations of the outlet works gate tower of Gillham Dam, southwestern Arkansas, were observed by US Army Corps of Engineers project personnel. The reservoir elevation was about 50 ft above conservation pool when this occurred. Prototype tests were conducted to determine the severity and cause of vibrations of the intake tower at Gillham Dam. The test program measured the vibrations at the intake tower, wet well, and both service gates; sluice pressures upstream and downstream of each service gate; and the air demand through both air vents. The vibration data recorded on the intake tower and the wet well showed a predominant frequency of 4 cps. This correlates with the upstream pressure fluctuations measured. The tests in which motion was most severe occurred when gate 1 was at an opening of 4.8 ft or higher. A tapping noise heard off the (Continued)				
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upstream side of the intake tower was determined to be the bulkhead slot covers of gate 1 bouncing up and down at a 4-cps frequency. Cross-spectral density plots indicate a relationship between the upstream pressure fluctuations and the intake tower and wet well vibrations at a 4-cps frequency. The pressure fluctuations are approximately five times the pressure fluctuations considered normal for turbulent flow and therefore seem to be the driving force of the intake tower and wet well vibrations. Neither the air vent system, which provides sufficient air into the conduits, nor the downstream pressure fluctuations are a cause of the structure vibrations.

PREFACE

The prototype tests described in this report were conducted during June 1990 by the US Army Engineer Waterways Experiment Station (WES) under the sponsorship of the US Army Engineer District, Little Rock.

Tests were conducted under the general supervision of Messrs. F. A. Herrmann, Jr., Director of the Hydraulics Laboratory; R. A. Sager, Assistant Director of the Hydraulics Laboratory; and G. A. Pickering, Chief of the Hydraulic Structures Division, Hydraulics Laboratory. This report was prepared by Ms. D. C. McVan with assistance from Mr. R. G. McGee, both of the Hydraulic Analysis Branch, Hydraulic Structures Division, under the supervision of Dr. B. J. Brown, Chief of the Hydraulic Analysis Branch. Instrumentation support was obtained from Messrs. J. C. Ables and S. W. Guy, Instrumentation Services Division, WES.

Acknowledgment is made to Mr. V. P. Chiarito, Structures Laboratory, WES, for structural analysis support, and to individuals of the Little Rock District for their assistance in the investigation.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

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

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

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
acre-feet	1233.489	cubic metres
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	2.54	centimetres
miles (US statute)	1.609344	kilometers
pounds (mass) per square inch	6894.757	pascals

GILLHAM DAM OUTLET WORKS TOWER HYDRAULIC PROTOTYPE STUDY
GILLHAM LAKE, ARKANSAS

PART I: INTRODUCTION

Pertinent Features of the Project

1. Gillham Dam (Figure 1) is located on the Cossatot River in southwestern Arkansas, 49.0 river miles* upstream from the confluence with the Little River and approximately 17 miles north of DeQueen, Arkansas (Figure 2). The multiple purpose project provides water supply, flood control, water quality control, and fish and wildlife conservation to the area.
2. The main embankment is a rock fill structure with an impervious



Figure 1. Gillham Dam and Reservoir

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

earth core. At the top of the dam, el 586.0*, the embankment is 1,750 ft long. The structure impounds 33,030 acre-ft of water at conservation pool el 502.0.

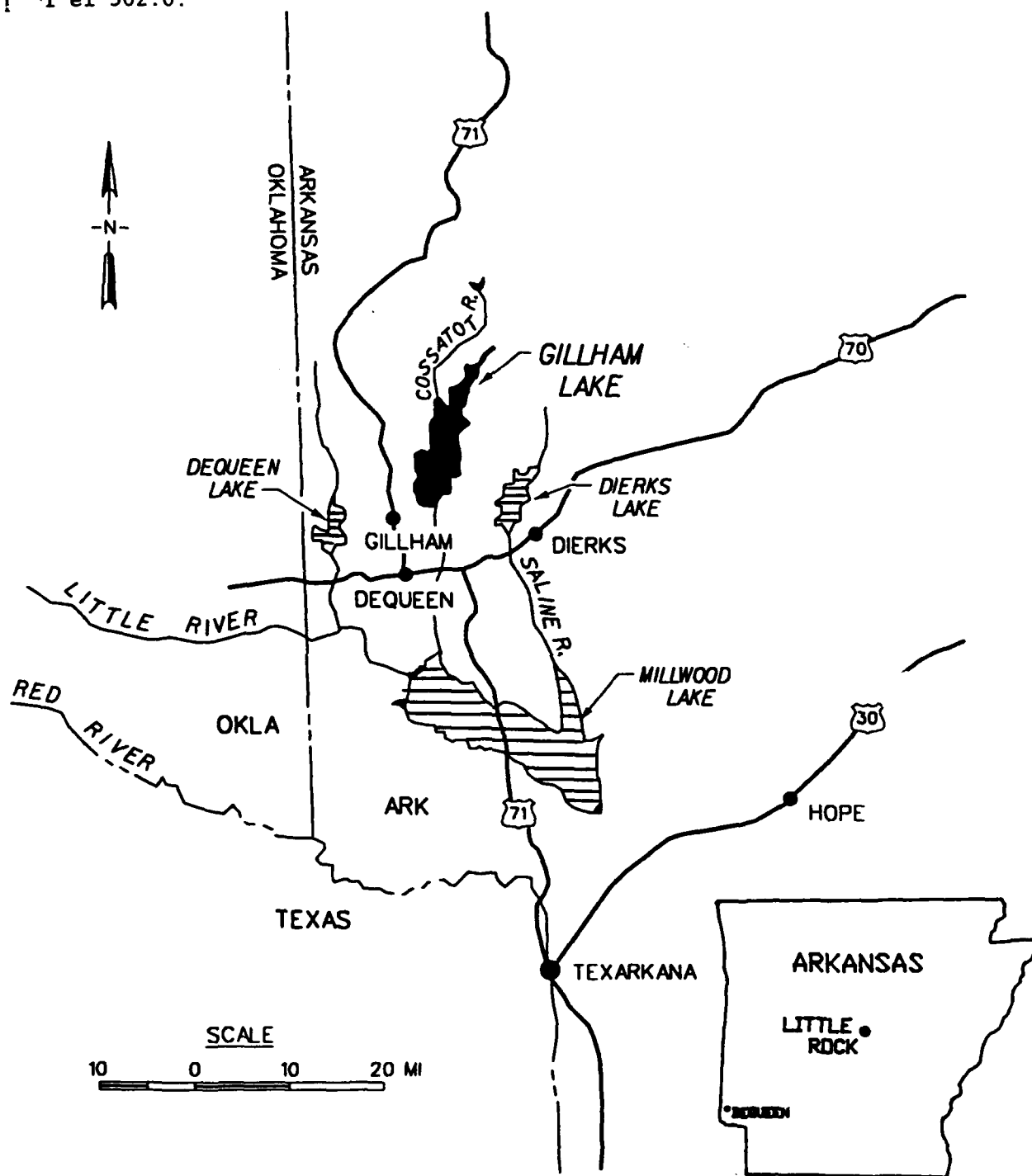


Figure 2. Location and vicinity map

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

Spillway and Outlet Works

3. The spillway is a gated concrete gravity ogee weir located about 1,500 ft west of the main embankment. The structure provides a clear opening of 200 ft controlled by four 50-ft-wide by 42-ft-high tainter gates. The crest is at el 527.0 with a sloping apron extending downstream about 200 ft, terminating at a flip bucket.

4. The outlet works consist of two 4.5-ft-wide by 10.0-ft-high conduits that transition into a 10-ft-diam conduit, 625 ft long with the invert at el 437.0. Flows are controlled by two 4.5-ft-wide by 10.0-ft-high hydraulically operated slide gates. Low-flow releases are normally made through a 30-in. low-flow pipe which conveys flow from the multilevel wet well. This flow is controlled by a butterfly valve and empties into the outlet conduit just downstream of service gate 2 through the 24-in.-diam air vent. The invert elevations of the wet well intakes are 472.0 and 487.0. There are 24-in.-diam air vents downstream from each service gate.

Purpose and Scope of Tests

Background

5. In October 1984, severe vibrations of the Gillham Dam outlet works gate tower were observed by Corps of Engineers project personnel. The reservoir elevation was about 50 ft above conservation pool when this occurred. Several investigation teams visited the site to study various operation features and structural behavior for possible vibration causes and structural problems. The procedures, findings, and recommendations of the investigations are given in a summary prepared by the US Army Engineer District, Little Rock (reference "Gillham Dam Inspection Summary," SWLED-HW 1985).

6. The investigating team found that vibrations increased when the low-flow valve was opened during service gate releases and recommended termination of combined releases of this type. Service gate openings were then determined which could be used to release flow without creating serious structural vibrations until the actual cause and subsequent solution to the vibration problems were determined. In addition, a prototype test program designed to determine the cause of the vibrations at Gillham was recommended. The Little Rock District requested that the US Army Engineer Waterways

Experiment Station (WES) propose a prototype test program (reference Mr. E. D. Hart's Memorandum for Record, WESHP-P, dated 12 March 1985).

7. In the recent past, project personnel have observed vibrations in the gate tower during conditions that normally have not produced any movement of the gate tower. The tower was vibrating at lower pool elevations (512.0 and 514.0 ft) and lower discharges. It was also vibrating at gate settings that in the past were considered "safe."

Purpose

8. The primary purpose of the test program was to assess the vibrations occurring at the intake tower, wet well, and sluice gates for a full range of gate openings under the maximum available head. In addition, it was desired to determine if a correlation existed between these vibrations and sluice pressure fluctuations and/or air vent velocity changes. The WES test program included measurement of (a) vibrations at the intake tower, wet well, and both service gates, (b) sluice pressures upstream and downstream of each service gate, and (c) air demand through both air vents. An additional pressure measurement was taken to measure changes in the water-surface elevations during testing.

Scope

9. Five series of tests (A, D, F, I, and B), each performed under different flow conditions, were conducted at Gillham Dam during 2-9 June 1990. Series A was conducted with service gate 2 open and service gate 1 and the low-flow valve closed; Series D was conducted with service gate 1 open and service gate 2 and the low-flow valve closed; Series F was conducted with both service gates open at balanced gate settings and the low-flow valve closed; Series I was conducted with both service gates open at unbalanced gate settings and the low-flow valve closed; and Series B was conducted with both service gates open at balanced gate settings and the low-flow valve open. Each series covered the full range gate openings from 3- to 4-ft and at 0.2-ft increments from 4.6 to 5.6 ft at an average pool elevation of 543.30. Both air vents remained open during the entire testing program. Table 1 is a list of the test schedule and comments.

PART II: TEST FACILITIES, EQUIPMENT, AND PROCEDURES

Test Facilities

10. Locations of the test instrumentation are shown in Plates 1 and 2, and the specifics of each transducer are listed in Table 2.

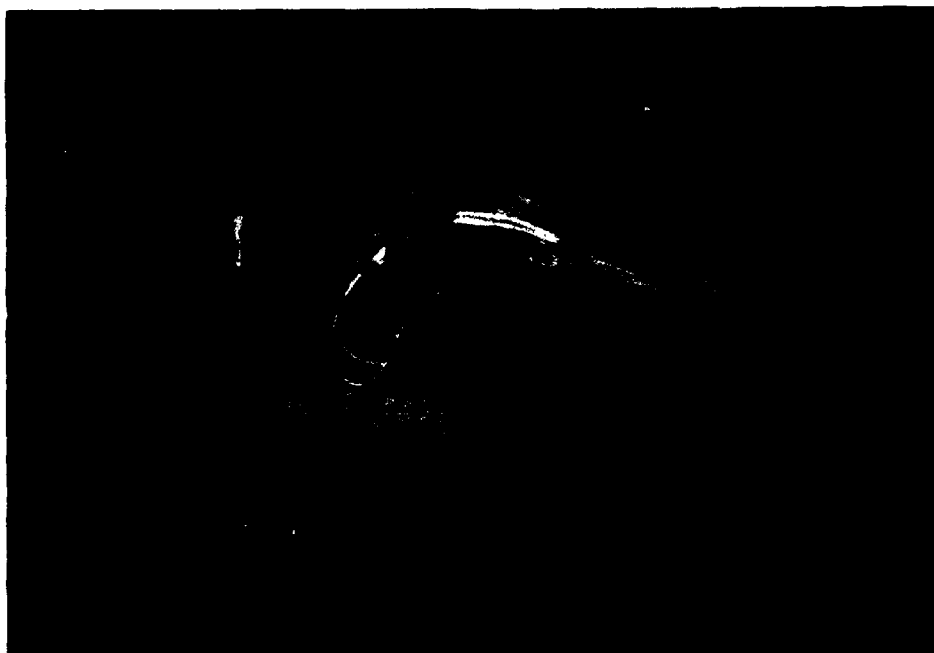
Structure and gate vibrations

11. Structure vibrations were measured with two clusters of three accelerometers measuring accelerations in the vertical, transverse, and parallel directions to flow. The first cluster (TAV, TAT, and TAP) was epoxied to the roof of the intake tower at el 586.0. The second cluster (WAV, WAT, and WAP), housed in a waterproof canister, was epoxied to the roof of the wet well at el 529.8 (Plate 2). The wet well accelerometers were previously installed 24-26 February 1985 to anticipate the higher pool elevations during testing. A special accelerometer plate was welded to the skinplate on the downstream side of each service gate and an identical cluster for each gate (GAV1, GAT1, GAP1 and GAV2, GAT2 and GAP2), housed in a waterproof canister, was attached to the plates (Plate 1). Additional vertical accelerometers (GV1 and GV2) were installed on the staff gage of each service gate (Plate 2) during testing. This was to provide backup measurement of the vertical movement of the service gates in case the gate accelerometers should fail. Figure 3 shows the accelerometer clusters on the intake tower and wet well roofs, and Figure 4 shows the clusters on the service gate and staff gage.

Sluice pressures

12. Static and dynamic pressures upstream and downstream of each service gate were measured with absolute pressure transducers, PUS1, PDS1, PUS2, and PDS2. The upstream transducers were installed in manhole covers located between the emergency and service gates at el 447.0, and the downstream transducers were installed in plates that were placed across each air vent outlet at el 447.0 (Plate 2). Figure 5 shows the placement of the upstream and downstream pressure transducers.

13. The transducer cables downstream of the service gates passed through their respective air vent and exited through a 1-3/8-in. cable pull hole cut in each air vent at el 486.0. The cables were then passed up through the equipment shaft to the top of the intake tower to the recording station.

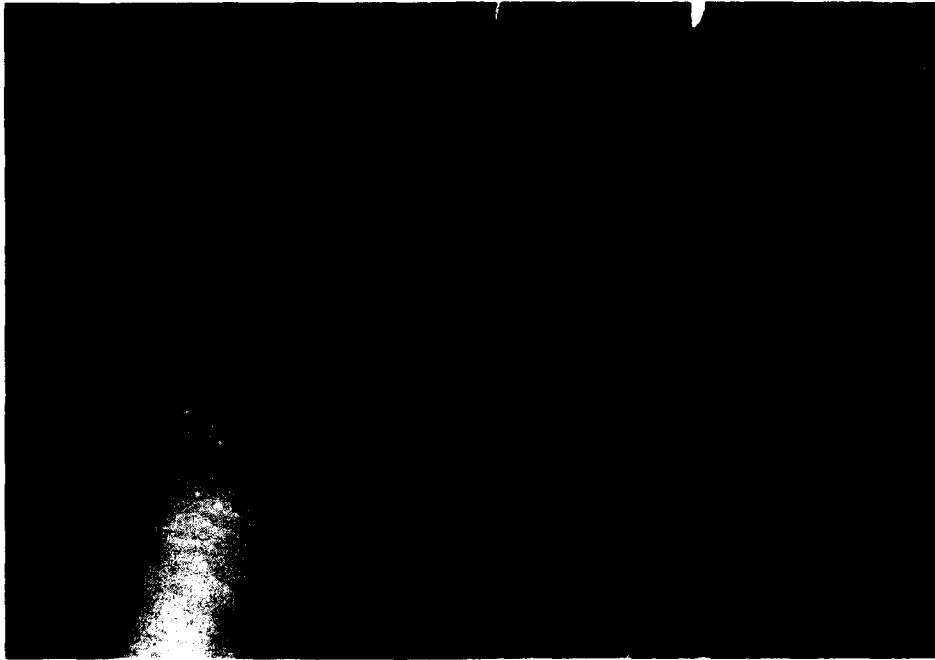


a. Accelerometers attached to roof
of intake tower at el 586.0

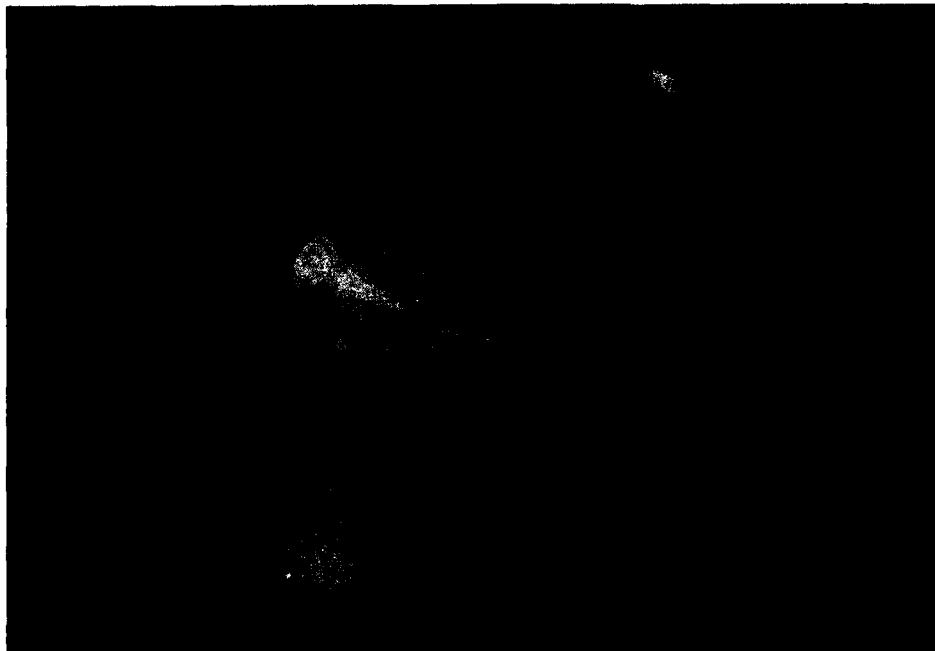


b. Accelerometer cluster attached
to roof of wet well at el 529.8

Figure 3. Accelerometer clusters on the
intake tower and wet well roofs



a. Vertical accelerometers attached to staff gage



b. Accelerometer canister attached to service gate

Figure 4. Accelerometer clusters on the service gate and staff gage



a. Upstream pressure transducer, PUS, installed
in manhole cover at el 447.0



b. Downstream pressure transducer, PDS, installed
in strut across the air vent at el 447.0

Figure 5. Pressure transducers upstream and
downstream of service gates

Air velocities

14. A 2-in. pipe modified to house 4 pitot tubes (AV1A, AV1B, AV1C, and AV1D) was installed in air vent 1 at el 484.0 (Plate 1). A single pitot tube (AV2) was installed in air vent 2 (Plate 2). The pitot tubes were placed facing upstream for measuring the air flow velocity in the conduits. The static and stagnation ports of each pitot tube were connected to electronic differential pressure transducers to measure the pressure differential. Figure 6 shows the four differential pressure transducers at air vent 1.



Figure 6. Differential pressure cells for air vent 1 at el 484.0

Other Measurements

15. Other recorded data consisted of reservoir water-surface elevation, air temperature, gate opening, and water discharge. These data were provided by the project and District personnel. Water discharge was determined from computed discharge rating curves provided by the Little Rock District.

Test Equipment

16. The test equipment listed and described herein includes the

transducers, cables, and recording equipment. Transducers used in the tests were as follows:

- a. Vibrations: 1 μ g to 25 g servo-accelerometers.
- b. Sluice pressures: 100 psia (PUS) and 50 psia (PDS) pressure transducers.
- c. Air velocity (pitot tube pressure differential): 0.125 psid to 0.50 psid pressure transducers.

17. Cable lengths required for the test program were determined from contract drawings and actual measurements at the project. These cable lengths (Table 2) were cut and used in the calibration of their corresponding transducers to account for line losses.

Data Acquisition

18. All data were digitally recorded using the Data Acquisition and Reduction System (DARS), a turn-key system built around a Masscomp MC5500 data acquisition system. This provided onsite data verification and analysis. The analog data were also recorded on magnetic tape as a backup with a portion of the data transferred to oscillograms for confirmation. The recording station was housed in an instrumentation truck located on the bridge of the intake tower at el 586.0. Figure 7 shows equipment setup at the recording station. Signal cables from all transducers were connected directly to the DARS.

Test Procedures

19. Testing began 5 June 1990 at pool el 544.9 and was completed 8 June 1990 at pool el 541.7. The digital data for all transducers were collected simultaneously at a sampling rate of 512 samples/sec. The data for each test were immediately displayed and verified and the time-history statistics generated. Spectrum analysis in the form of Fast Fourier Transforms (FFT) were conducted posttest to assist in preliminary onsite evaluations of the possible driving mechanisms of the vibrations. Each test took approximately two hours to complete. This allowed adequate time for the establishment of possible vibration conditions.

20. The procedure was generally the same for each test series and consisted of the following:



Figure 7. Recording station and equipment

- a. Record test number, gate opening, date, time, and conditions.
- b. Record step calibrations.
- c. Record zero levels.
- d. Raise test gates to desired opening; allow flow to stabilize.
- e. Record data on the DARS and magnetic tape.
- f. Record discharge, pool elevations, and air temperatures.
- g. Repeat steps a and d-f for each gate opening.
- h. Record post-test step calibrations.

21. Because of the time it took to close the gates (approximately 1-1/2 hr), the step calibrations and zero levels (requiring no flow conditions) were recorded at the beginning of test series A and D only and the post-test step calibrations were recorded at the end of test series B.

22. Voice comments on the tape and field notes were continuously made for later reference. Gain changes and calibrations were made as required during the test period.

PART III: TEST RESULTS AND ANALYSIS

23. All data channels were recorded and reduced simultaneously providing a direct time-dependent relationship among all channels. All data reduction was accomplished at WES. Representative tests from each test series were chosen and a 1-min sample of each data channel was digitized. A 12-Hz low-pass filter was chosen to preprocess the raw data to eliminate data not related to the forcing mechanism driving the structural vibration. The test conditions for the representative tests are presented in Table 3.

Structure and Gate Vibrations

24. Three-directional acceleration measurements were made on the roof of the intake tower (TAV, TAT, TAP), wet well (WAV, WAT, WAP), and on the service gates (GAV, GAT, GAP), as shown in Plates 1 and 2. A vertical acceleration measurement was made on the staff gages (GV), as shown in Figure 4. The measurements were made to obtain their magnitudes and frequency of motion at each gate opening and to determine if any correlation existed between the structure, gate vibrations, and conduit pressure fluctuations.

Intake tower and wet well vibrations

25. A summary of the intake tower and wet well accelerations are presented in Tables 4 and 5. The instantaneous maximum, minimum, and peak-to-peak accelerations and predominate frequencies were determined from the time histories and corresponding FFT's. The sinusoidal structural displacements were estimated by the equation

$$d = \frac{386.4 (a)}{(2\pi f)^2} \quad (1)$$

where

d = peak-to-peak sinusoidal displacement, in.

a = greatest peak-to-peak acceleration, g's

f = predominant frequency, cps

The same procedure was used in determining the service gate and staff gage acceleration data.

26. A predominate frequency recorded for both the intake tower and wet well during tests in which motion occurred was 4 cps. This frequency was

predominate in the transverse and parallel directions to flow (TAT, TAP, WAT, and WAP). The range of frequencies for the intake tower was 0.5 to 8.0 cps and for the wet well was 0.5 to 10.0 cps. The frequencies recorded for the wet well were somewhat higher than the intake tower. The accelerations were highest during tests in which gate 1 was at an opening of 4.8 ft or higher. Vibration of the tower was most severe during tests in which gate 1 was at an opening of 5.15 ft. Plate 3 presents graphs of the effects of vibrations as they relate to persons and structures. The accelerations and displacements lie within the region of troublesome to persons and severe to persons. A sample time-history with its corresponding FFT plot for each measured direction is shown in Plates 4 and 5.

27. A tapping/train noise was heard off the upstream side of the intake tower during all tests. This noise was believed to have been the bulkhead slot covers bouncing up and down. The frequency of the tapping was measured using a stopwatch and was measured at 4 cps. The force of the slot covers bouncing up and down could transmit enough energy to the tower to cause vibrations; however, since pressures were not directly measured in the slots, there were insufficient data to support this. The Little Rock District inspected the slot covers and determined that the tapping noise was coming from the slot cover for gate 1.

Service gates and staff gage vibrations

28. The acceleration data for the service gates and staff gage measurements are listed in Tables 6, 7, and 8. These data were not filtered because of the higher frequencies recorded by the accelerometers. Transducers GAV2, GAT2, GAP2, and GAV1 were damaged and did not produce a signal during tests 20-52. The vertical accelerometers (GV1 and GV2) located on the staff gages were installed after test 20. The measured gate accelerations were larger than those of the structures; however, the corresponding frequencies were higher than those frequencies that were considered to be causing the tower vibrations. The accelerations were largest at the higher gate openings. The accelerations measured on the staff gage for service gate 1 were higher than those measured for service gate 2. Typical gate acceleration time-history plots and FFT's are shown in Plate 6.

Sluice Pressures

29. During all tests, sluice pressures were measured upstream (PUS) and downstream (PDS) of both service gates at the locations shown in Plate 1. The maximum, minimum, and mean pressures were determined from the digitized data time-histories along with the maximum instantaneous peak-to-peak pressure fluctuation for each test, and the range of frequency was obtained from the FFT plots. The pressure transducer downstream of service gate 2 (PDS2) was damaged during operation of the low-flow valve (test series B) and did not produce a signal. These pressures are listed in Tables 9 and 10. The sluice pressures measured upstream of the service gates indicated a high concentration of energy at lower frequencies ranging between 0.5 to 8.0 cps. These lower frequencies correlate with the 4-cps frequency exhibited by the intake tower and the wet well. The predominate frequencies downstream of the service gates ranged from 0.5 to 1.0 cps. The time-history and FFT plots are shown in Plates 7 and 8. The peak-to-peak pressure fluctuations upstream of the service gates were considerably greater than the peak-to-peak pressure fluctuations downstream. The upstream pressure fluctuations ranged from 0.76 to 2.3 ft for service gate 1 and from 0.28 to 4.3 ft for service gate 2, and the pressure fluctuations downstream ranged from 0.15 to 0.94 ft for service gate 1 and 0.12 to 0.56 ft for service gate 2. The highest pressure fluctuations measured were during tests in which service gate 1 was at an opening of 4.8 ft or greater.

30. Pressure fluctuations are listed nondimensionally in Table 11 in terms of the velocity head of the flow in the conduit. The data show that the pressure fluctuations upstream of service gate 1 are approximately expressed by

$$\frac{P_{\max} - P_{\min}}{\gamma} = 0.322 \frac{V^2}{2g} \quad (2)$$

where

γ = specific weight of fluid, lbs/ft³

$\frac{V^2}{2g}$ = velocity head, ft

and for service gate 2

$$\frac{P_{\max}-P_{\min}}{\gamma} = .556 \frac{V^2}{2g} \quad (3)$$

Normal pressure fluctuations in turbulent flow are considered to be approximately 0.035 times the velocity head for Reynolds number greater than 5×10^5 . This information was based on experimental data and isotropic turbulent flow models (Neilson 1971). Accordingly, the pressure fluctuations experienced at Gillham Dam are about 5 times the pressure fluctuations considered normal for turbulent flow. Plate 9 shows the maximum upstream instantaneous peak-to-peak pressure fluctuations in relation to normal pressure fluctuations for turbulent flow. These higher pressure fluctuations and the low range of frequencies seem to be the driving mechanism of the intake tower and wet well vibrations and could be the cause of the slot covers bouncing up and down.

31. Long blunt objects, such as trashracks, placed crosswise to a fluid flow can sometimes cause the shedding of eddies or vortices to occur. These vortices shed regularly and alternately from opposite sides of the object (Vennard and Street 1975). When the shedding frequency of the vortices approaches the natural frequency of the structure, large amplitude vibrations to the structure can be produced. The Strouhal number, s , which is a function of the object's geometry and Reynolds number for low Mach number flows, is the proportionality constant between the predominate frequency of vortex shedding and the free stream velocity divided by the maximum width of the object (Blevins 1977).

$$fs = \frac{Sv}{D} \quad (4)$$

where

fs = predominate frequency of vortex shedding, cps

v = free stream velocity, fps

D = maximum width of object normal to the free stream, ft

For Reynolds numbers between 60 and 5,000, the Strouhal number is approximately 0.21 (Vennard and Street 1975). Using an average conduit velocity and the maximum width of the trashracks, the predominate frequency of the vortex shedding was determined to be approximately $fs = 4.2$ cps. This frequency correlates with the frequencies exhibited by the intake tower and wet well and

is within the low frequency range of the upstream pressure fluctuations. This is a gross calculation of the shedding frequency, and further testing is needed to accurately determine the frequency of vortex shedding from the trashracks.

32. An attempt was made to determine if there was a relationship between the frequency of pressure fluctuations upstream of the service gates and the intake tower and wet well vibration frequencies. Plates 10-13 present the power spectral density, coherence, and cross-spectral density plots for test 31. The cross-spectral density function for two sets of random data describes the general dependance of the value of one set of data on the other (Bendat and Piersol 1958). The degree of dependance is expressed in the frequency domain. If there is a high level of dependance between two signals at a particular frequency, it will plot as a relatively discrete spike on the amplitude-frequency graph. It is evident from the plots that a relationship between the upstream pressure fluctuations (PUS1 and PUS2) and the intake tower accelerations (TAT and TAP) does exist at a 4-cps frequency. A prominent peak of the cross-spectral density plot at 4 cps coincides with the 4-cps frequency of the intake tower accelerations on the power spectral density plots. This relationship is more prominent for service gate 1. This indicates that the upstream pressure fluctuations are the driving force of the intake tower and wet well vibrations.

Structural Dynamic Properties and Response of the Tower

33. The vibration data for the intake tower and wet well were examined more closely for response relating directly to the structural dynamic properties, specifically the natural frequencies, damping, and operating deflection shapes relating to natural mode shapes occurring at natural frequencies of the structure. The spectral density plots, as shown in Plates 10-13, show that the intake tower and wet well were excited or caused to vibrate at several of its natural frequencies. A simple calculation of the fundamental bending frequency of a cantilever beam, an ideal model of the tower, reveals that a natural frequency occurs near 2.9 cps. This frequency would be the first natural frequency in any direction assuming the structure is perfectly symmetric. However, because the structure is not perfectly symmetric, there exists a number of uncoupled and coupled modes that include bending and

torsional displacements of the intake tower and wet well. The data show the most significant natural frequencies corresponding to the bending and torsional vibrations occur between 0 and 20 cps.

34. The natural frequencies of a linear-elastic, idealized cantilever beam with uniform geometry throughout the height is given by Harris and Crede (1976) as:

$$\omega_n = A_n (EI/ul^4)^{1/2} \quad (5)$$

and

$$f_n = 2\pi\omega_n \quad (6)$$

where

ω_n - the nth natural frequency, rad/sec

f_n - the nth natural frequency, cps

A_n - 3.52 for the fundamental bending mode ($n = 1$) and 22.4 for the second order bending mode ($n = 2$)

E - modulus of elasticity, psi

I - area moment of inertia of the uniform cross section, in.⁴

u - mass per unit length, lbs-sec²/in.²

l - uniform length, in.

Using the above equations, the fundamental bending mode and the second order bending mode for the intake tower were determined to be $f_1 = 3.9$ cps and $f_2 = 24.8$ cps, respectively. This does not include the added water mass surrounding the tower. To account for the surrounding water mass, the fundamental bending mode and the second order bending mode were computed as $f_1 = 2.9$ cps and $f_2 = 18.4$ cps. To allow for flexibility of the foundation, the values of f_1 and f_2 would decrease further. The first natural frequencies for torsional and longitudinal modes of vibration of a cantilever are approximately 14 cps and 21 cps, respectively. This does not account for any added water mass.

35. These calculations are to show that the frequency responses observed in the data cover the ranges of the calculated natural frequencies. Furthermore, the spectral density characteristics of the pressure measurements show that energy has frequency content in the range of the observed and calculated bending and torsional responses of the intake tower. It is very likely that there exists coupled modes of vibration that correspond to peaks

in the autospectral and cross-spectral density plots. The existence of a 4-cps response is not unique; there do exist other responses of sufficient amplitude to warrant inspection of the correlation with the pressure and other acceleration measurements.

Air Discharge

36. Pitot tube differential pressures were measured at the locations shown in Plates 1 and 2 for determining the air discharge in the vents supplying air to the sluices (AV1A, AV1B, AV1C, AV1D, and AV2) and to determine if any correlation exists between air fluctuations and sluice pressure fluctuations. All differential pressures were used to compute airflow into the sluices (upstream direction).

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

$$V_p = K\sqrt{\Delta p} \quad (7)$$

where

K - constant of proportionality

Δp - differential pressure between points A and B shown in Figure 8.

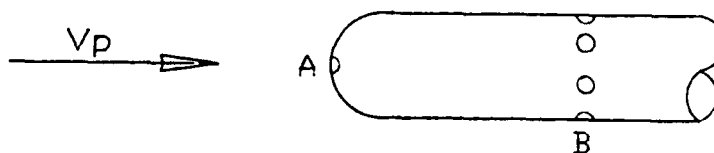


Figure 8. Pitot tube tip

38. The pitot tubes used in the Gillham Dam tests were calibrated by the National Space Technology Laboratories at Bay St. Louis, MS (Hart 1981). The calibrated value of K was determined to be 351.90. The Mach number for all point velocities measured was less than 0.30; therefore, the compressibility of air was not considered in the data analysis (Vennard and Street 1975).

39. The pitot tube support strut was located approximately 97.5 ft downstream from the vent exit. This corresponds to strut location of 48.75 equivalent diameters ($De = 2.0$ ft). The single pitot tube located in

air vent 2 was located approximately 94.5 ft downstream from the vent exit and corresponds to 47.25 equivalent diameters.

40. In air vent 1, the velocity distribution was assumed to be essentially uniform from wall to wall. This assumption is considered adequate due to the high Reynolds number computed for each test indicating turbulent flow and the fact that the measured data were essentially equal. Therefore, the velocity for air vent 1 was assumed to be the average of the four measurements (AV1A, AV1B, AV1C, and AV1D) while the velocities for air vent 2 was assumed to be the measured values of the single pitot tube, AV2. The standard deviation, on the average, was 2.7 percent of the mean implying that the assumption of uniform velocity distribution at the strut is reasonable. The velocities were multiplied by the cross-sectional area of the respective air vents to determine the discharge. Measured point velocities are given in Table 12 with the corresponding discharges presented in Table 13.

41. Kalinske and Robertson (1943) found the ratio of air demand to water discharge to be a function of the Froude number minus one. The Corps of Engineers combined this information with field measurements and derived a suggested design curve. The Gillham air vent discharges have been plotted on the Hydraulic Design Criteria (HDC) chart reproduced in Plate 14. The Froude number ($\mathcal{F}$) for the data was computed by

$$\mathcal{F} = \frac{V}{\sqrt{gy}} \quad (8)$$

where

V - water velocity at the vena contracta, fps

g - gravitational acceleration, ft/sec²

y - water depth at the vena contracta, ft

According to HDC, the plotted discharges indicate that the air vent system at Gillham Dam seems to be providing sufficient air into the conduits.

42. Typical time-history and the corresponding FFT plots are shown in Plate 15. A gusting frequency of 0.5 cps was measured in all tests. This correlates with the frequencies measured by the downstream pressure transducers and indicates that the pressures downstream are cushioned by the airflow from the air vents. During operation of the low-flow valve, the air supply to gate 2 was immediately shut off and the differential pressure transducer in air vent 2 did not produce a signal. This is the result of the

low-flow pipe emptying into the conduit through the air vent. Air vent 2 acts as a piezometer during operation of the low-flow valve and a water column in air vent 2 rose above the placement of the transducer at el 487.0.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

43. The following conclusions and determinations result from field observations and analysis of the reduced Gillham Dam prototype data.

44. Conclusions relative to vibrations are as follows:

- a. During tests in which motion occurred, a predominate frequency recorded for both the intake tower and the wet well was 4 cps and was predominate in the transverse and parallel direction to flow.
- b. The frequencies were generally higher for the wet well.
- c. Accelerations were highest during tests in which gate 1 was at an opening of 4.8 ft or higher. Vibration of the tower was most severe during tests in which gate 1 was at an opening of 5.15 ft (test 31).
- d. Displacements and accelerations measured for the intake tower and wet well are considered troublesome and severe to persons.
- e. The bouncing up and down of the bulkhead slot cover was determined to be the 4-cps tapping noise heard off the upstream side of the intake tower. This correlates with the structure's 4-cps predominate frequency. The force of the slot covers could transmit enough energy to cause the tower to vibrate; however, there are insufficient data to support this.
- f. The service gate accelerations were greater during tests with the higher gate openings, and the staff gage vertical accelerations for service gate 1 were greater than for service gate 2. Service gate frequencies do not seem to correlate with pressure fluctuations and tower vibrations.

45. Conclusions relative to sluice pressures are as follows:

- a. Significant correlation exists between the upstream pressure fluctuations and the intake tower and wet well vibrations.
- b. The pressure fluctuations are approximately 5 times the pressure fluctuations considered normal for turbulent flow and therefore seems to be the driving force of the intake tower and wet well vibrations.
- c. The downstream pressure fluctuations are not a cause of the structure's vibrations.
- d. The frequency produced by vortex shedding from the trashracks is approximately 4.2 cps which correlates with the intake tower and wet well frequency. Further testing is needed to accurately determine the shedding frequency.
- e. The cross-spectral density plots indicate a relationship between the upstream pressure fluctuations and the intake tower, and wet well exists at a 4-cps frequency and that the

pressure fluctuations are the driving force of the intake tower and wet well vibrations.

46. Conclusions relative to air discharge are as follows:

- a. The air vent system provides sufficient air into the conduits and is not a problem.
- b. During operation of the low-flow valve, the air supply to gate 2 is immediately shutoff as a result of the low flow emptying into the conduit through the air vent.

Recommendations

47. Since these tests were performed, the Little Rock District installed a vent system that vents the bulkhead slot covers to the atmosphere (Figure 9). This vent system consists of a single 10-in.-diam PVC pipe that

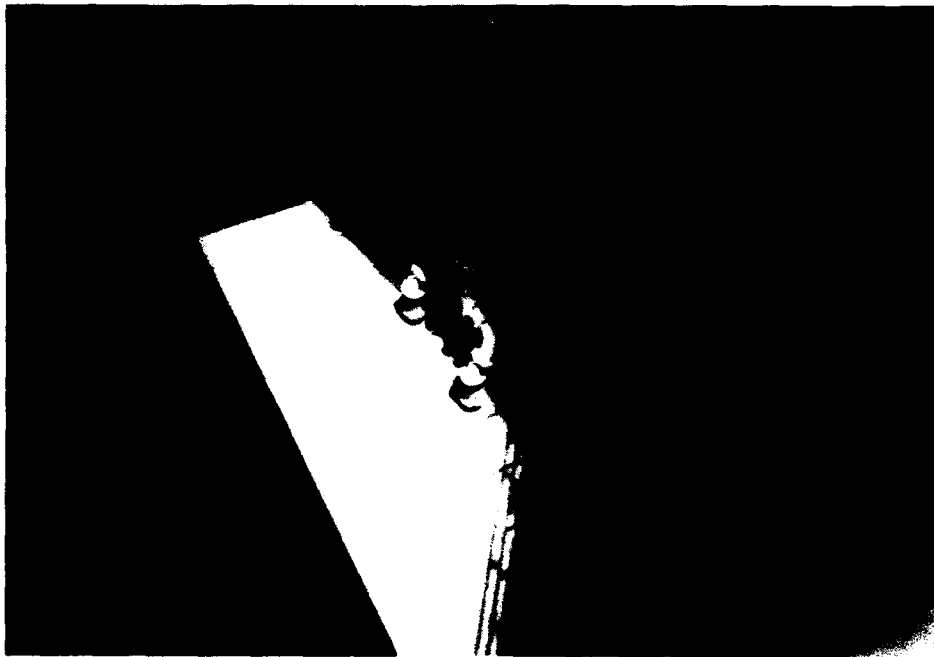


Figure 9. Bulkhead slot vent system

extends from near the top of the intake tower at el 583.0, down the side of the tower to approximately el 503.0, where it transitions into two 6-in.-diam galvanized steel pipes via a galvanized steel Tee. Each leg of the Tee extends to a slot cover where the pipe makes a 90-degree turn down into the slot cover. The Tee connection is constructed such that it can be

disconnected from the 10-in.-diam pipe and slot covers when access to the slots is necessary. The top of the pipe is turned down and covered with screen to prevent possible blockage of the pipe. This vent system is not sized for any particular flow. It is not intended to provide an air supply to the upstream side of the gates, but to provide relief to any pressure fluctuations that develop upstream of the bulkhead slots. These pressure fluctuations have damaged the slot covers in the past and are believed to be the forcing function that is causing the tower vibrations to occur. Since the vent system has been installed (fall, 1991), there have been three events which produced conditions (pool elevation and discharge) that have caused vibrations in the past. During each event, there was no evidence of vibration in the tower. The tower is closely monitored during these conditions so that if vibrations do occur, corrective measures can be taken.

48. If additional vibrations are experienced with the vent system in place, it is recommended that additional tests be conducted with instruments installed in and around the bulkhead slot covers and, if possible, the trash-racks. This will help to narrow the region in which the pressure fluctuations are most severe and to determine if the slot covers are the source of the vibrations. It is recommended that the slot covers be removed and a screen be installed. It is also recommended that a structural analysis be conducted on the tower to determine how much motion the tower can withstand.

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Table 1

Gillham Dam Prototype TestTest Schedule

<u>Series</u>	<u>Test</u>	<u>Gate #1</u> <u>(ft)</u>	<u>Gate #2</u> <u>(ft)</u>	<u>Air-vent</u>	<u>Low-flow</u>	<u>Comments</u>
A	1	Closed	3.0	Open	Closed	Normal vibrations. Tapping noise occurring off wet well. Vibrations slightly increased. Vibrations at high frequencies.
A	2	Closed	4.0	Open	Closed	
A	3	Closed	4.6	Open	Closed	
A	4	Closed	4.8	Open	Closed	Tapping noise stopped. Data collected while lowering gate #2, maintaining 1680 cfs discharge. Gate setting for overnight discharge. Next morning: Intake tower moving in both parallel and tangential directions. Rhythmic banging, sounds like train (150/min). +/- 12g pops on GAP2 - increasing in intensity. All vibrations at high frequencies.
A	5	Closed	5.0	Open	Closed	
A	6	Closed	5.2	Open	Closed	
A	7	Closed	6.0	Open	Closed	
A	8	1.0	5.0	Open	Closed	
A	9	3.0	3.2	Open	Closed	
D	10	3.0	Closed	Open	Closed	Tapping/train noise started. Tapping/train noise increased, 180/min.
D	11	4.0	Closed	Open	Closed	
D	12, 13	4.6	Closed	Open	Closed	Tapping/train noise increased, 200/min. Slight increase in tower movement.
D	14	4.8	Closed	Open	Closed	
D	15	5.0	Closed	Open	Closed	Tapping/train intensity increased, 220/min. Increase in tower movement.
D	16	5.2	Closed	Open	Closed	

(Continued)

Table 1 (Continued)

Series	Test	Gate #1 (ft)	Gate #2 (ft)	Air-vent	Low-flow	Comments
D	17	6.0	Closed	Open	Closed	While opening gate 1, the noise intensity increased until gate setting passed 5.4, then stopped. Tapping increased to 300/min. Tower motion did same.
D	18	5.7	Closed	Open	Closed	Moved gate opening from 6.0 to 5.4 to 5.7 ft. Structure moved significantly just prior to gate stopping. Motion decreased as very high frequencies and high 'g'-levels began on gate. Medium range whistle noise began inside tower. Whistle still noticed. Structure is vibrating - slight increase.
D	19	5.6	Closed	Open	Closed	
F	20	3.0	3.0	Open	Closed	Normal vibrations. **Refer to test 9A** Lost gages GAV2 and GAP2.
F	21, 22	4.0	4.0	Open	Closed	Tapping/train noise started, 180/min.
F	23	4.6	4.6	Open	Closed	Tapping/train noise increased, 210/min. Slight increase in tower vibrations.
F	24	4.8	4.8	Open	Closed	
F	25	5.0	5.0	Open	Closed	Tower motion increased immediately. Lost gage GAT2
F	26, 27, 28	5.2	5.2	Open	Closed	Tapping/train noise increased with time, from 235/min to 270/min. Tower movement increases with time. Low frequency vibrations (3-4 Hz) increasing.
F	29, 30	5.1	5.1	Open	Closed	
F	31	5.15	5.15	Open	Closed	Gage TAP was not working properly prior to this test. Prominent motion in tower.
F	32	5.4	5.4	Open	Closed	Normal vibrations in tower. Tapping intensity increased to >400/min.
F	33, 34	5.0	5.0	Open	Closed	

(Continued)

Table 1 (Continued)

<u>Series</u>	<u>Test</u>	<u>Gate #1</u> <u>(ft)</u>	<u>Gate #2</u> <u>(ft)</u>	<u>Air-vent</u>	<u>Low-flow</u>	<u>Comments</u>
F	35	4.8	4.8	Open	Closed	Tapping/train started, >300/min. While changing gate settings, felt vibration in tower around 5.1 ft. Normal vibrations at this setting.
I	36	5.6	3.0	Open	Closed	
I	37, 38	5.1	3.0	Open	Closed	Tapping/train intensity about 240/min. Tower started vibrating immediately and is increasing with time.
I	39	5.2	4.0	Open	Closed	Tower vibration decreased slightly.
I	40	5.2	4.6	Open	Closed	Tower vibration decreasing slightly.
I	41	5.2	4.8	Open	Closed	Tower vibration starting to increase.
I	42	5.2	5.0	Open	Closed	Tower vibration increasing/decreasing in a cyclic pattern.
I	43, 44	5.2	5.2	Open	Closed	
J	45	3.0	5.2	Open	Closed	Normal vibrations. Tapping/train intensity 190/min. Tapping/train increased to 240/min. Tower vibration increased immediately, tends to be cyclic.
J	46	4.0	5.2	Open	Closed	
J	47	5.0	5.2	Open	Closed	
B	48	5.0	5.0	Open	45	No change from test 3J. No air flow in vent #2. Lost gage PDS2. Water coming through air vent #2.
B	49	5.0	5.0	Open	90	Decrease in tapping/train noise - 160/min. Significant decrease in tower vibrations. Cavitation occurring in conduit #2. No air flow in #2.
B	50	4.0	4.0	Open	45	
B	51	4.0	4.0	Open	90	Vibration/noise continuing to decrease. Data recorded on mag tape.
B	52	3.0	3.0	Open	45	
B	53	3.0	3.0	Open	90	

(Continued)

Table 1 (Concluded)

<u>Series</u>	<u>Test</u>	<u>Gate #1</u> <u>(ft)</u>	<u>Gate #2</u> <u>(ft)</u>	<u>Air-vent</u>	<u>Low-flow</u>	<u>Comments</u>
B	54	2.0	2.0	Open	45	
B	55	2.0	2.0	Open	90	
B	56	0.9	0.9	Open	45	
B	57	0.9	0.9	Open	90	

Table 2

Summary of Instrumentation

<u>Code</u>	<u>Transducer Description</u>		<u>Transducer Location</u>	<u>Elev.</u>	<u>Cable Length (ft)</u>	<u>Meas.</u>	<u>Computed Quantity</u>
	<u>Type</u>	<u>Range</u>					
PUS1 PUS2	Absolute Pressure Cell	100 psia	Upstream of service gate 1 and 2	447.0	230	Press.	Press. fluctuations
PDS1 PDS2	Absolute Pressure Cell	50 psia	Downstream of service gate 1 and 2	447.0	230	Press.	Press. fluctuations
PWS	Absolute Pressure Cell	50 psia	10 ft below water surface	534.0	50	Press.	Water-surface elev.
AV1A AV1B AV1C AV1D	Differential Pressure Cell	0.5 psid	Left air vent	484.0	200	Diff Press.	Air-vent velocity
AV2	Differential Pressure Cell	0.5 psid	Right air vent	487.0	200	Diff Press.	Air-vent velocity
TAV TAT TAP	Accelerometer	1 g-25g	Roof of intake tower	586.0	100	Accel.	Vert. displ./freq. Trans. displ./freq. Parall. displ./freq.
WAV WAT WAP	Accelerometer	1 g-25g	Roof of wet well	529.8	250	Accel.	Vert. displ./freq. Trans. displ./freq. Parall. displ./freq.
GAV1 GAT1 GAP1	Accelerometer	2.5g	Service gate 1	438.5	200	Accel.	Vert. displ./freq. Trans. displ./freq. Parall. displ./freq.
GAV2 GAT2	Accelerometer	2.5g	Service gate 2	438.5	200	Accel.	Vert. displ./freq. Trans. displ./freq.

(Continued)

Table 2 (Concluded)

<u>Code</u>	<u>Transducer Description</u>		<u>Transducer Location</u>	<u>Elev.</u>	<u>Cable Length (ft)</u>	<u>Meas.</u>	<u>Computed Quantity</u>
	<u>Type</u>	<u>Range</u>					
GAP2							Parall. displ./freq.
GAV1	Accelerometer	2.5g	Staff gage of each service gate	465.0	200	Accel.	Vert. displ./freq.
GAV2							

Table 3
Evaluated Test Conditions

<u>Test No.</u>	<u>Gate 1 Opening ft</u>	<u>Gate 2 Opening ft</u>	<u>Low Flow Opening deg</u>	<u>Pool Elev ft</u>	<u>Water Discharge cfs</u>	<u>Conduit Velocity fps</u>
12	4.6	0	closed	544.58	1260	16.0
13	4.6	0	closed	544.58	1260	16.0
17	6.0	0	closed	544.53	1680	21.4
20	3.0	3.0	closed	544.50	1620	20.6
31	5.15	5.15	closed	543.39	2790	35.5
36	5.6	3.0	closed	542.25	2360	30.0
38	5.1	3.0	closed	542.22	2220	28.3
45	3.0	5.2	closed	541.94	2230	28.4
47	5.0	5.2	closed	541.90	2780	35.4
48	5.0	5.0	45	541.87	2775	35.5
49	5.0	5.0	90	541.85	2900	36.9
52	3.0	3.0	45	541.80	1675	21.3

Table 4
Intake Tower Vibrations

Test No.	Transducer Location	Max g	Min g	P-P g	Freq Hz	RMS g	Disp in.
12	Vertical	0.036	-0.042	0.064	4.0	0.0074	0.0391
	Transverse	0.022	-0.027	0.042	3.5	0.0056	0.0032
	Parallel	-0.013	-0.049	0.025	0.5	0.0037	0.9749
13	Vertical	0.038	-0.040	0.070	4.5	0.0068	0.0338
	Transverse	0.023	-0.026	0.043	3.5	0.0056	0.0348
	Parallel	-0.136	-0.169	0.024	0.5	0.0037	0.9514
17	Vertical	0.031	-0.037	0.062	5.0	0.0081	0.0243
	Transverse	0.024	-0.033	0.042	5.0	0.0056	0.0163
	Parallel	0.022	-0.012	0.029	4.0	0.0037	0.0175
20	Vertical	0.026	-0.030	0.046	4.0	0.0062	0.0281
	Transverse	0.015	-0.026	0.034	4.5	0.0050	0.0162
	Parallel	0.030	-0.004	0.025	8.0	0.0037	0.0390
31	Vertical	0.038	-0.047	0.072	5.5	0.0081	0.0233
	Transverse	0.025	-0.035	0.054	4.0	0.0062	0.0331
	Parallel	0.030	-0.037	0.053	4.0	0.0081	0.0324
36	Vertical	0.061	-0.030	0.074	6.5	0.0062	0.0171
	Transverse	0.065	-0.057	0.080	5.5	0.0050	0.0257
	Parallel	0.032	-0.032	0.047	5.5	0.0050	0.0151
38	Vertical	0.041	-0.042	0.067	8.0	0.0074	0.0102
	Transverse	0.025	-0.032	0.054	4.0	0.0056	0.0278
	Parallel	0.034	-0.034	0.054	4.0	0.0068	0.0331
45	Vertical	0.030	-0.020	0.043	4.0	0.0050	0.0266
	Transverse	0.019	-0.021	0.033	5.0	0.0044	0.0129
	Parallel	0.019	-0.021	0.030	5.0	0.0044	0.0119
47	Vertical	0.040	-0.032	0.066	2.0	0.0068	0.0162
	Transverse	0.025	-0.030	0.047	4.0	0.0056	0.0289
	Parallel	0.029	-0.030	0.047	4.0	0.0068	0.0289
48	Vertical	0.048	-0.034	0.067	2.5	0.0074	0.1049
	Transverse	0.030	-0.039	0.047	4.0	0.0056	0.0289
	Parallel	0.032	-0.035	0.053	4.0	0.0068	0.0327
49	Vertical	0.045	-0.038	0.072	2.0	0.0081	0.1762
	Transverse	0.027	-0.038	0.055	4.0	0.0068	0.0334
	Parallel	0.029	-0.034	0.050	4.0	0.0068	0.0308
52	Vertical	0.032	-0.022	0.048	1.5	0.0056	0.2081
	Transverse	0.019	-0.024	0.034	5.0	0.0050	0.0131
	Parallel	0.016	-0.025	0.029	2.5	0.0044	0.0457

Table 5
Wet Well Vibrations

Test No.	Transducer Location	Max g	Min g	P-P g	Freq Hz	RMS g	Disp in.
12	Vertical	0.025	-0.017	0.035	0.5	0.0043	1.3700
	Transverse	0.020	-0.023	0.037	5.5	0.0055	0.0120
	Parallel	0.024	-0.019	0.033	5.0	0.0044	0.0129
13	Vertical	0.028	-0.015	0.035	0.5	0.0043	1.3550
	Transverse	0.023	-0.023	0.039	2.5	0.0055	0.0608
	Parallel	0.023	-0.020	0.037	3.5	0.0044	0.0295
17	Vertical	0.029	-0.018	0.044	0.5	0.0056	1.7460
	Transverse	0.023	-0.027	0.049	5.0	0.0055	0.0193
	Parallel	0.018	-0.028	0.036	5.0	0.0056	0.0139
20	Vertical	0.020	-0.021	0.028	0.5	0.0043	1.0880
	Transverse	0.013	-0.023	0.033	4.5	0.0043	0.0158
	Parallel	0.016	-0.025	0.032	6.0	0.0044	0.0088
31	Vertical	0.033	-0.021	0.038	0.5	0.0056	1.4990
	Transverse	0.032	-0.047	0.070	4.0	0.0105	0.0426
	Parallel	0.018	-0.031	0.036	4.0	0.0050	0.0218
36	Vertical	0.057	-0.002	0.039	0.5	0.0049	1.5460
	Transverse	0.049	-0.052	0.068	3.0	0.0099	0.0737
	Parallel	0.038	-0.024	0.047	10.5	0.0044	0.0042
38	Vertical	0.045	-0.004	0.035	0.5	0.0056	1.3780
	Transverse	0.035	-0.051	0.067	4.0	0.0105	0.0407
	Parallel	0.021	-0.029	0.032	4.0	0.0050	0.0195
45	Vertical	0.028	-0.011	0.030	0.5	0.0037	1.1590
	Transverse	0.031	-0.045	0.065	4.5	0.0092	0.0316
	Parallel	0.018	-0.023	0.029	5.0	0.0038	0.0115
47	Vertical	0.041	-0.007	0.033	0.5	0.0056	1.3080
	Transverse	0.035	-0.045	0.073	2.5	0.0105	0.1149
	Parallel	0.016	-0.027	0.031	4.0	0.0044	0.0187
48	Vertical	0.028	-0.029	0.046	3.0	0.0062	0.0503
	Transverse	0.040	-0.056	0.073	9.0	0.0123	0.0878
	Parallel	0.023	-0.030	0.038	9.0	0.0056	0.0046
49	Vertical	0.088	-0.067	0.115	8.5	0.0117	0.0156
	Transverse	0.106	-0.163	0.261	10.0	0.0197	0.0255
	Parallel	0.039	-0.058	0.087	10.0	0.0088	0.0085
52	Vertical	0.023	-0.028	0.043	5.0	0.0062	0.0167
	Transverse	0.037	-0.055	0.071	9.0	0.0117	0.0086
	Parallel	0.018	-0.031	0.036	9.0	0.0050	0.0043

Table 6
Service Gate Vibrations
Gate 1

Test No.	Transducer Location	Max g	Min g	P-P g	Low Freq Hz	High Freq Hz	RMS g	Low Disp in. E-03	High Disp in. E-03
12	Vertical	0.194	-0.219	0.357	38.5	228.0	0.0376	2.358	0.0672
	Transverse	0.105	-0.100	0.210	38.5	212.5	0.0185	1.385	0.0455
	Parallel	0.599	-0.698	1.185	48.5	218.0	0.1111	4.931	0.2240
13	Vertical	0.194	-0.213	0.301	38.5	231.5	0.0376	1.985	0.0549
	Transverse	0.191	-0.154	0.204	38.5	205.0	0.0185	1.345	0.0474
	Parallel	0.821	-0.901	1.284	48.5	215.5	0.1049	5.343	0.2706
17	Vertical	0.282	-0.219	0.470	38.5	228.0	0.0501	3.103	0.0885
	Transverse	0.160	-0.173	0.247	38.5	216.5	0.0247	1.630	0.0515
	Parallel	0.784	-0.778	1.500	50.0	227.5	0.1235	5.872	0.2837
20	Vertical	0.251	-0.282	0.019	38.5	**	0.0439	**	**
	Transverse	0.191	-0.160	0.049	38.5	**	0.0247	**	**
	Parallel	0.975	-0.975	0.055	38.5	**	0.1667	**	**
31	Vertical	—	—	—	—	—	—	—	—
	Transverse	0.136	-0.179	0.265	53.0	198.0	0.0247	0.0923	0.0661
	Parallel	0.667	-0.642	1.185	95.0	193.5	0.1111	1.2850	0.3098
36	Vertical	—	—	—	—	—	—	1.3630	—
	Transverse	0.506	-0.611	1.006	85.0	242.5	0.0679	18.7600	0.1674
	Parallel	0.741	-0.728	1.296	26.0	236.0	0.1543	—	0.2277
38	Vertical	—	—	—	—	—	—	—	—
	Transverse	0.136	-0.284	0.321	38.5	200.0	0.0247	2.120	0.0785
	Parallel	0.611	-0.772	1.278	104.5	232.5	0.1173	1.145	0.2314
45	Vertical	—	—	—	—	—	—	—	—
	Transverse	0.228	-0.228	0.265	18.5	251.0	0.0309	7.578	0.0412
	Parallel	0.709	-1.000	1.679	83.5	222.5	0.1543	2.357	0.3319
47	Vertical	—	—	—	—	—	—	—	—
	Transverse	0.259	-0.426	0.413	38.5	207.5	0.0247	2.727	0.0939
	Parallel	0.728	-0.772	1.352	99.5	234.0	0.1235	1.337	0.2417
48	Vertical	—	—	—	—	—	—	—	—
	Transverse	0.346	-0.278	0.370	38.5	210.0	0.0247	2.443	0.0821
	Parallel	0.698	-0.796	1.426	98.0	237.0	0.1235	1.453	0.2485

(Continued)

** Data was lost for frequencies greater than 100 Hz.
— Lost gage GAV1 during Test 20.

Table 6 (Concluded)

Test No.	Transducer Location	Max g	Min g	P-P g	Low Freq Hz	High Freq Hz	RMS g	Low Disp in. E-03	High Disp in. E-03
49	Vertical	—	—	—	—	—	—	—	—
	Transverse	0.167	-0.210	0.302	38.5	212.0	0.0247	1.994	0.0658
	Parallel	0.679	-0.889	1.407	100.5	233.5	0.1235	1.363	0.2526
52	Vertical	—	—	—	—	—	—	—	—
	Transverse	0.136	-0.204	0.216	26.5	251.0	0.0247	3.010	0.0335
	Parallel	0.796	-1.012	1.679	102.0	202.0	0.1420	1.579	0.4027

Table 7
Service Gate Vibrations
Gate 2

Test No.	Transducer Location	Max g	Min g	P-P g	Low Freq Hz	High Freq Hz	RMS g	Low Disp in. E-03	High Disp in. E-03
12	Vertical	0.025	-0.038	0.050	38.5	251.0	0.0063	0.3315	0.0672
	Transverse	0.037	-0.037	0.055	38.5	251.0	0.0062	0.3665	0.0455
	Parallel	0.025	-0.031	0.044	38.5	251.0	0.0063	0.2905	0.2240
13	Vertical	0.025	-0.038	0.044	38.5	251.0	0.0063	0.2905	0.0549
	Transverse	0.037	-0.037	0.062	38.5	251.0	0.0062	0.4074	0.0474
	Parallel	0.031	-0.031	0.044	38.5	251.0	0.0063	0.2905	0.2706
17	Vertical	0.025	-0.038	0.050	38.5	251.0	0.0063	0.3302	0.0885
	Transverse	0.037	-0.049	0.074	38.5	251.0	0.0062	0.4886	0.0515
	Parallel	0.025	-0.031	0.044	38.5	251.0	0.0063	0.2905	0.2837

* Lost accelerometers on Gate 2 during Test 20.

Table 8
Service Gates Staff Gage Vibrations
Vertical Accelerometers Only

Test No.	Transducer Location	Max g	Min g	P-P g	Low Freq Hz	High Freq Hz	RMS g	Low Disp in. E-03	High Disp in. E-03
31	Gate 1	3.518	-3.103	5.226	57.5	217.0	0.3392	15.470	1.0860
	Gate 2	1.006	-1.006	1.938	54.5	229.0	0.2160	6.386	0.3617
36	Gate 1	2.098	-1.997	3.197	26.0	242.5	0.5151	46.290	0.5321
	Gate 2	1.858	-2.099	2.802	88.5	208.5	0.2346	3.501	0.6309
38	Gate 1	0.879	-0.861	1.489	57.5	224.0	0.1884	4.408	0.2904
	Gate 2	2.117	-2.025	3.000	88.0	208.0	0.5407	3.792	0.6787
45	Gate 1	3.354	-4.497	4.680	68.0	221.0	0.2952	9.906	0.9379
	Gate 2	1.012	-1.080	1.728	26.5	226.5	0.2346	24.080	0.3297
47	Gate 1	3.838	-3.769	7.041	70.5	222.0	0.5779	13.860	1.3980
	Gate 2	1.284	-1.154	2.111	26.5	196.5	0.2284	29.420	0.5351
48	Gate 1	5.063	-5.013	8.587	69.5	223.5	0.6156	17.400	1.6820
	Gate 2	1.185	-1.235	1.747	27.5	222.5	0.2346	22.610	0.3454
49	Gate 1	3.580	-4.139	7.720	68.0	223.5	0.6093	16.340	1.5130
	Gate 2	2.198	-1.889	3.200	27.5	219.0	0.3210	41.410	0.6530
52	Gate 1	4.152	-3.298	4.024	74.5	219.0	0.2701	7.096	0.8212
	Gate 2	1.191	-1.321	24.070	28.5	215.0	0.2654	29.000	0.5096

* Vertical accelerometers were mounted on staff gage prior to Test 31.

Table 9
Sluice Gate Pressures
Gage 1

Test No.	PUS1					
	Max ft	Mean ft	Min ft	RMS ft	P-P ft	Freq Hz
12	-3.313	-4.243	-5.716	0.3294	1.395	3.5
13	-3.468	-4.418	-6.258	0.3294	1.240	6.5
17	-6.452	-7.460	-10.056	0.4069	2.192	5.0
20	-1.511	-2.131	-2.771	0.1550	0.930	6.0
31	-5.580	-6.646	-8.758	0.3681	2.174	6.0
36	-6.220	-7.556	-10.095	0.5231	2.286	8.0
38	-5.231	-6.142	-7.692	0.3681	1.647	6.0
45	-2.616	-3.236	-4.049	0.1938	1.260	4.0
47	-5.115	-6.375	-8.893	0.4263	2.170	4.0
48	-5.328	-6.355	-8.331	0.4069	1.683	4.0
49	-5.173	-6.297	-7.983	0.3681	1.760	6.0
52	-2.654	-3.178	-3.720	0.1550	0.756	4.0
Test No.	PDS1					
	Max ft	Mean ft	Min ft	RMS ft	P-P ft	Freq Hz
12	-1.916	-2.042	-7.127	0.0361	0.2350	3.0
13	-1.157	-1.265	-1.392	0.0181	0.1460	3.5
17	-1.211	-1.305	-1.446	0.0181	0.1450	6.5
20	-1.482	-1.645	-1.880	0.0542	0.2350	5.0
31	-1.283	-1.428	-1.609	0.0361	0.1800	3.0
36	-2.078	-2.585	-3.018	0.1446	0.8670	2.5
38	-2.078	-2.566	-3.109	0.1627	0.5240	3.0
45	-2.133	-2.675	-3.127	0.1446	0.4700	2.0
47	-1.952	-2.097	-2.313	0.0542	0.2350	2.5
48	-2.494	-2.874	-3.416	0.1446	0.5420	2.5
49	-2.404	-2.639	-3.000	0.0904	0.5420	2.0
52	-2.422	-2.928	-13.100	0.1627	0.9400	6.0
	-1.916	-2.042	-7.127	0.0361	0.2350	3.0

Table 10
Sluice Gate Pressures
Gage 2

Test No.	PUS2					
	Max ft	Mean ft	Min ft	RMS ft	P-P ft	Freq Hz
12	-0.284	-0.435	-0.636	0.0502	0.2844	3.5
13	-0.301	-0.485	-0.686	0.0502	0.2844	6.5
17	-0.301	-0.519	-0.703	0.0669	0.3346	5.0
20	-1.506	-2.075	-2.727	0.1673	0.9540	6.0
31	-5.538	-7.295	-9.035	0.4685	2.5600	6.0
36	-5.237	-5.990	-6.759	0.2175	1.3050	8.0
38	-5.270	-6.023	-6.809	0.2175	1.3050	6.0
45	-8.650	-10.925	-13.418	0.0856	4.0370	4.0
47	-9.219	-11.243	-13.939	0.5187	4.3030	4.0
48	-8.549	-10.373	-12.732	0.5019	2.7750	4.0
49	-8.031	-10.256	-13.100	0.5856	4.0350	6.0
52	-5.454	-6.274	-7.127	0.2342	1.3550	6.0

PDS2						
12	-0.816	-0.895	-1.074	0.0199	0.1193	3.5
13	-0.735	-0.835	-1.014	0.0199	0.1193	6.5
17	-1.114	-1.233	-1.472	0.0398	0.2390	5.0
20	-0.995	-1.114	-1.273	0.0398	0.1990	3.0
31	-1.671	-2.188	-2.566	0.1392	0.5770	2.5
36	0.597	0.139	-0.358	0.1591	0.4770	3.0
38	0.577	0.000	-0.358	0.1392	0.3980	2.0
45	1.094	0.935	0.756	0.0398	0.1790	2.5
47	0.497	0.159	-0.378	0.1392	0.5560	2.5
48	**	**	**	**	**	**
49	**	**	**	**	**	**
52	**	**	**	**	**	**

** Lost gage PDS2 during operation of low-flow valve.

Table 11
Nondimensional Pressure Fluctuations

Test No.	$V^2/2g$ ft Gate 1	$V^2/2g$ ft Gate 2	$\frac{P_{\max} - P_{\min}}{V^2/2g} / \gamma$			
			PUS1	PDS1	PUS2	PDS2
			ft	ft	ft	ft
12	12.17	0	0.264	0.028	*	*
13	12.17	0	0.235	0.027	*	*
17	21.64	0	0.234	0.025	*	*
20	5.03	5.03	0.427	0.083	0.438	0.091
31	14.92	14.92	0.336	0.134	0.396	0.089
36	18.18	5.16	0.290	0.066	0.584	0.213
38	14.81	5.28	0.257	0.073	0.570	0.174
45	5.16	15.24	0.564	0.105	0.611	0.027
47	14.39	15.24	0.348	0.087	0.652	0.084
48	14.08	14.08	0.276	0.089	0.455	**
49	14.08	14.08	0.288	0.154	0.661	**
52	5.03	5.03	0.347	0.108	0.622	**
		Avg	0.322	0.082	0.556	0.113

* Gate 2 was closed during these tests.

** Lost gage PDS2 during operation of low flow valve.

Table 12
Air Vent Point Velocities

Test No.	Item	AV1A fps	AV1B fps	AV1C fps	AV1D fps	Ave fps	R _e x 10 ⁶	AV2 fps	R _e x 10 ⁶
12	Max	125.41	117.77	117.77	11.13	93.02	6.790	11.13	1.085
	Mean	90.40	93.10	84.01	11.13	69.66	6.796	11.13	1.085
	Min	33.38	61.95	*	11.13	32.83	3.203	11.13	1.085
13	Max	124.40	116.72	118.81	115.11	118.76	11.590	111.28	10.850
	Mean	89.72	91.76	84.75	81.01	86.81	8.469	91.76	8.952
	Min	*	52.19	0	0	15.83	1.544	65.83	6.4222
17	Max	163.17	159.33	158.16	153.79	158.61	15.470	165.80	16.170
	Mean	128.33	134.46	120.37	116.71	124.97	12.190	136.74	13.340
	Min	93.77	97.01	66.77	65.83	80.84	7.887	106.74	10.410
20	Max	131.67	145.94	126.88	121.90	131.60	12.840	127.37	12.430
	Mean	102.59	129.77	97.01	90.40	104.94	10.240	107.89	10.530
	Min	76.29	108.46	60.95	53.37	74.77	7.294	84.75	8.268
31	Max	212.89	226.15	212.02	202.15	213.30	20.810	207.59	20.250
	Mean	202.46	212.31	190.16	181.49	196.60	19.180	205.49	20.050
	Min	143.81	156.98	106.15	109.03	128.99	12.580	165.06	16.100
36	Max	212.89	226.15	212.02	202.15	213.30	20.810	207.59	20.250
	Mean	190.16	192.42	177.35	162.03	180.49	17.610	197.82	19.300
	Min	137.19	136.74	100.15	94.42	117.12	11.430	141.64	13.820
38	Max	212.89	226.15	212.02	202.15	213.30	20.810	207.59	20.250
	Mean	198.75	203.68	180.81	170.59	188.46	18.390	203.37	19.840
	Min	144.24	152.98	114.03	99.53	127.69	12.460	147.21	14.360
45	Max	157.37	150.54	149.71	143.81	150.36	14.670	154.19	15.040
	Mean	119.33	122.41	110.72	107.31	114.94	11.210	124.41	12.140
	Min	87.62	91.76	60.95	59.93	75.06	7.323	93.77	9.148
47	Max	212.89	226.15	212.02	202.15	190.55	18.590	207.59	20.250
	Mean	188.52	192.42	171.31	162.03	178.57	17.420	188.19	18.360
	Min	136.74	149.30	93.77	98.91	119.68	11.680	143.81	14.030
48	Max	208.78	208.48	209.39	196.24	205.72	20.070	**	**
	Mean	170.59	182.17	152.98	147.21	163.24	15.930	**	**
	Min	125.90	154.19	95.73	—	93.96	9.166	**	**
49	Max	212.89	226.15	212.02	202.15	213.30	20.810	**	**
	Mean	183.53	196.24	170.23	164.68	178.67	17.430	**	**
	Min	128.82	154.19	98.91	—	95.48	9.315	**	**

(Continued)

* Minimum velocities were in error.

** Air vent 2 acts as a piezometer during operation of low-flow valve.

Table 12 (Concluded)

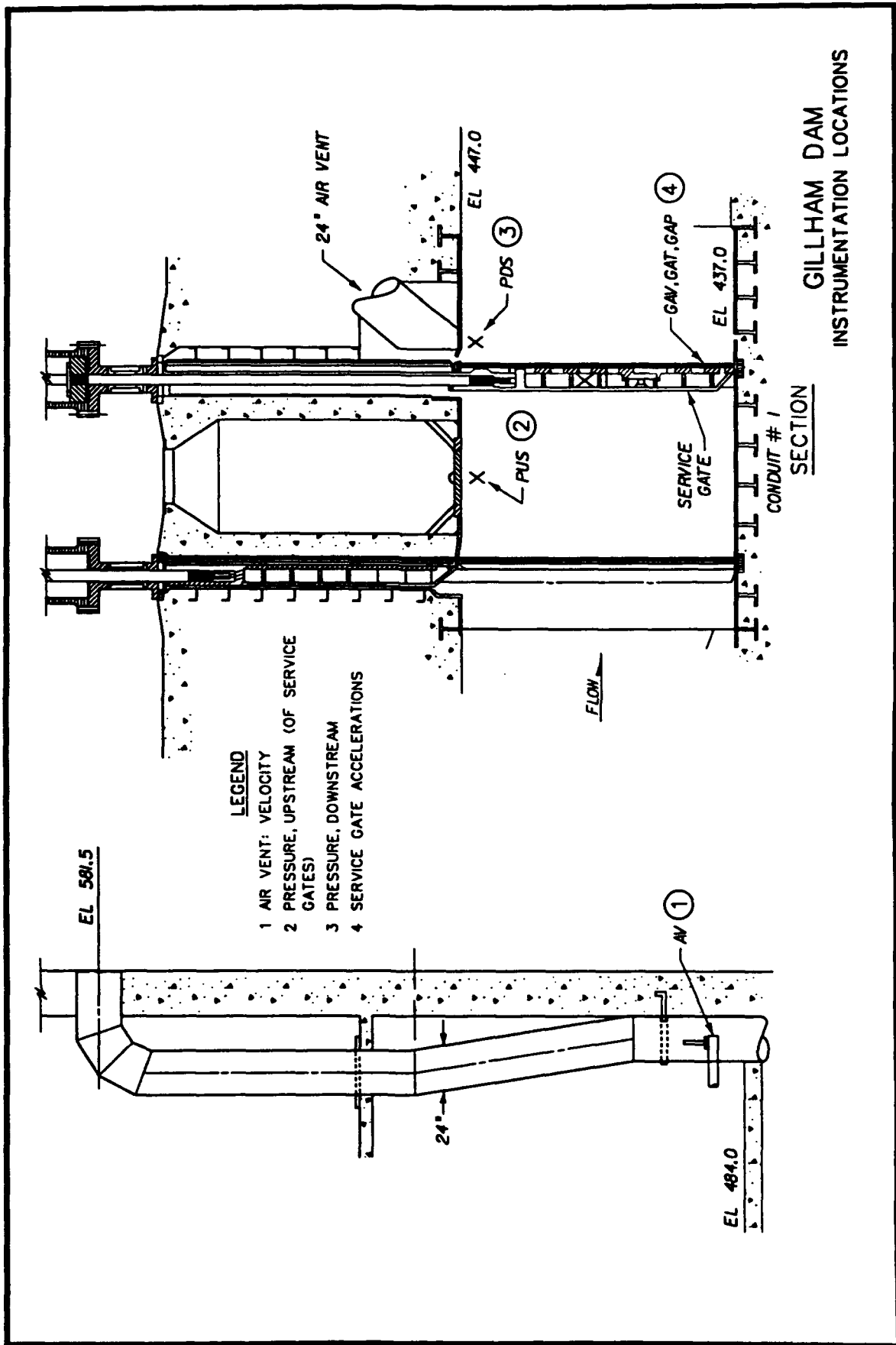
Test No.	Item	AV1A fps	AV1B fps	AV1C fps	AV1D fps	Ave fps	R_e $\times 10^6$	AV2 fps	R_e $\times 10^6$
52	Max	124.40	140.32	122.91	118.29	126.48	12.340	**	**
	Mean	101.38	122.41	93.77	89.02	101.64	9.916	**	**
	Min	70.38	104.39	52.19	50.99	69.24	6.755	**	**

** Air vent 2 acts as a piezometer during operation of low-flow valve.

Table 13
Air Discharge

Test No.	AV1				AV2			
	Max cfs	Mean cfs	Min cfs	Freq cps	Max cfs	Mean cfs	Min cfs	Freq cfs
12	292.23	218.84	103.14	0.5	34.97	34.97	34.97	0.5
13	373.09	272.72	49.73	0.5	349.60	288.27	206.81	0.5
17	498.29	392.60	253.97	0.5	520.88	429.58	335.33	0.5
20	413.43	329.68	234.90	0.5	400.14	338.95	266.25	0.5
31	670.10	617.64	405.23	0.5	652.16	645.57	518.55	0.5
36	670.10	567.03	367.94	0.5	652.16	621.47	444.97	0.5
38	670.10	592.06	401.15	0.5	652.16	638.91	462.47	0.5
45	472.37	361.09	235.81	0.5	484.40	390.85	294.59	0.5
47	598.63	560.99	375.99	0.5	652.16	591.22	451.79	**
48	646.29	512.83	295.18	0.5	**	**	**	**
49	670.10	561.31	299.96	0.5	**	**	**	**
52	397.35	319.31	217.52	0.5	**	**	**	**

** Air vent 2 acts as a piezometer during operation of low-flow valve.



GILLHAM DAM
INSTRUMENTATION LOCATIONS

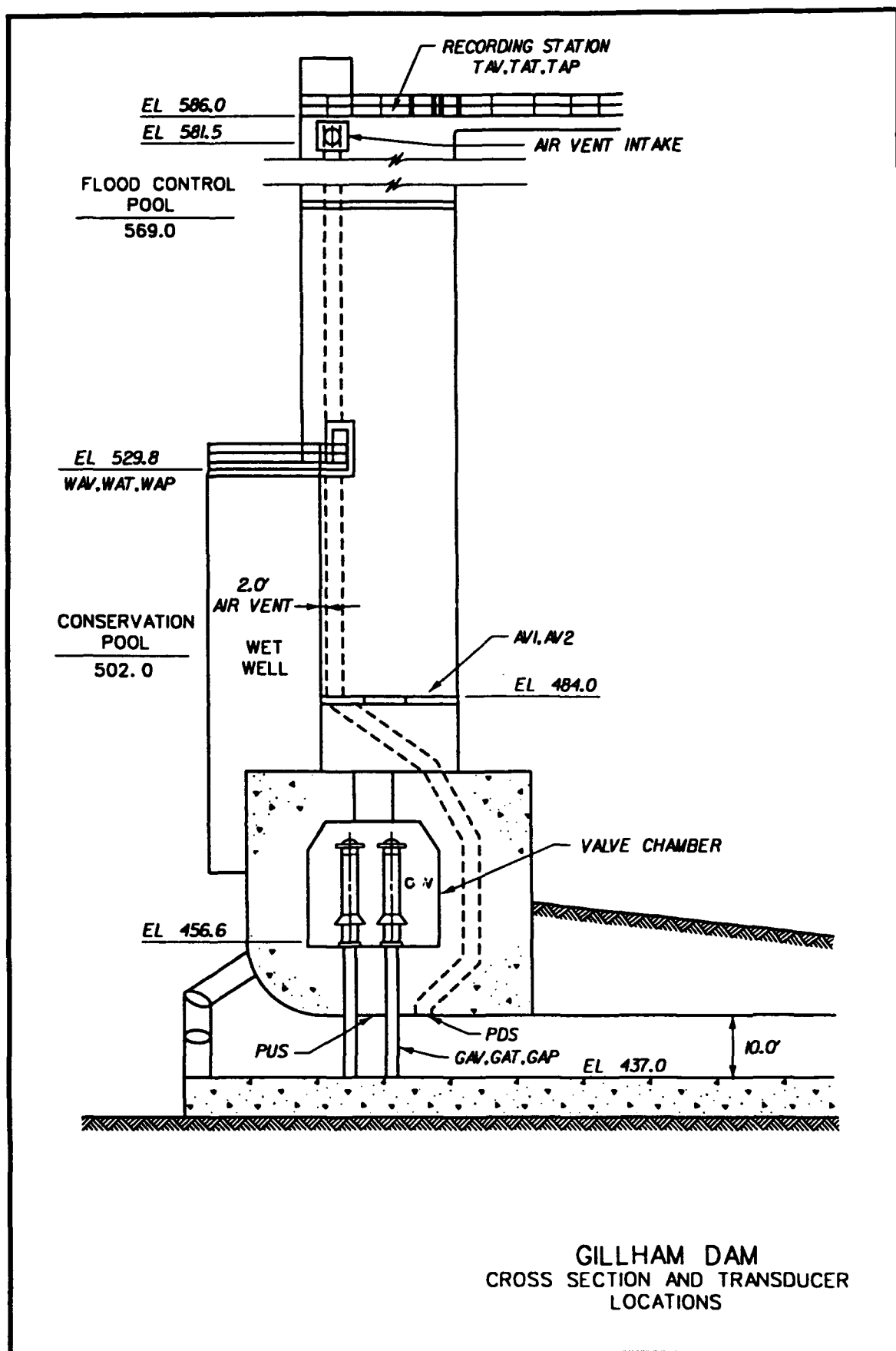
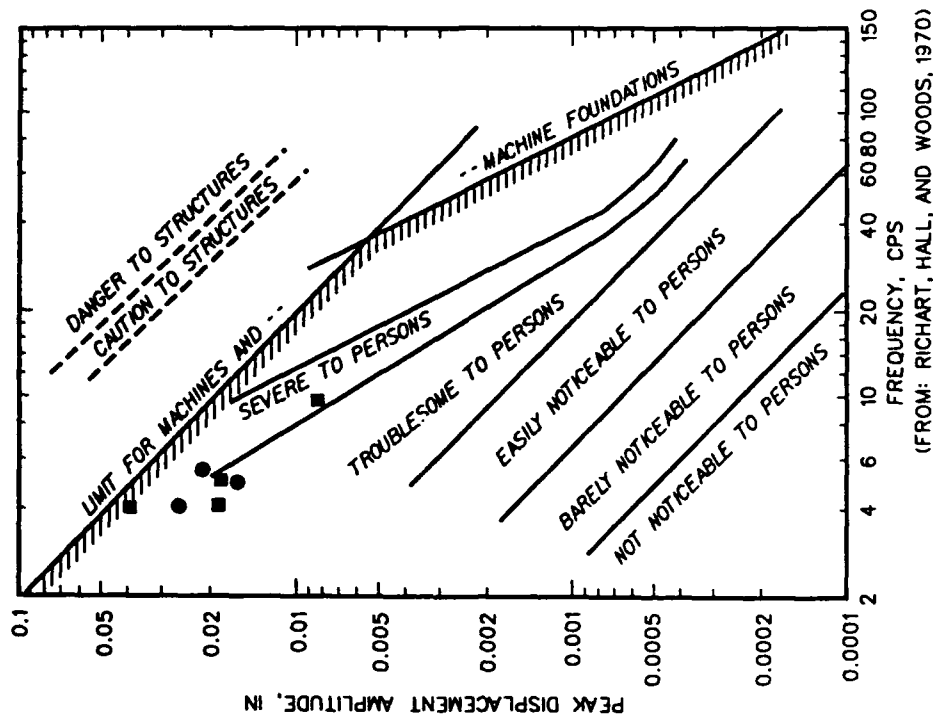
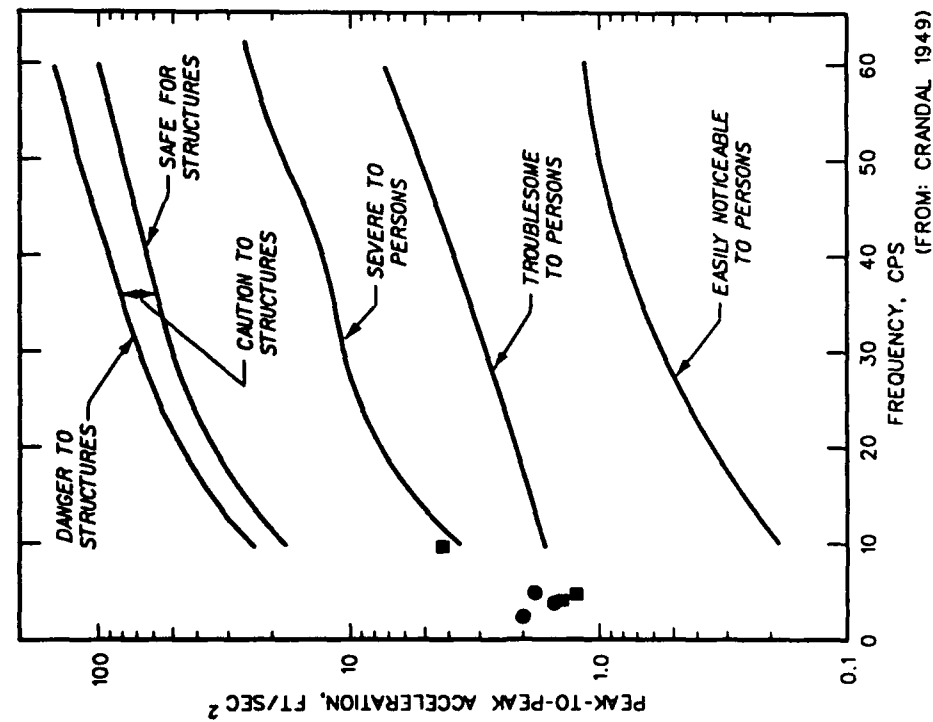
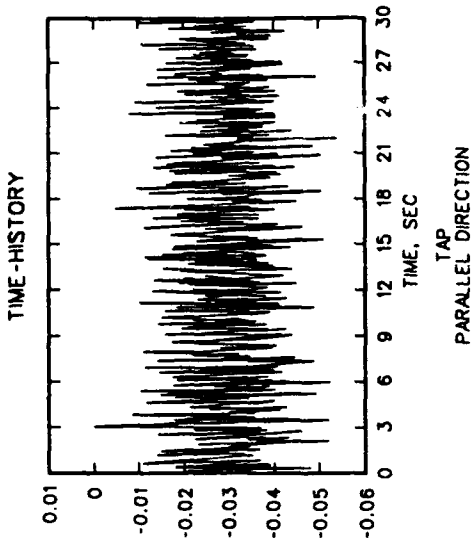
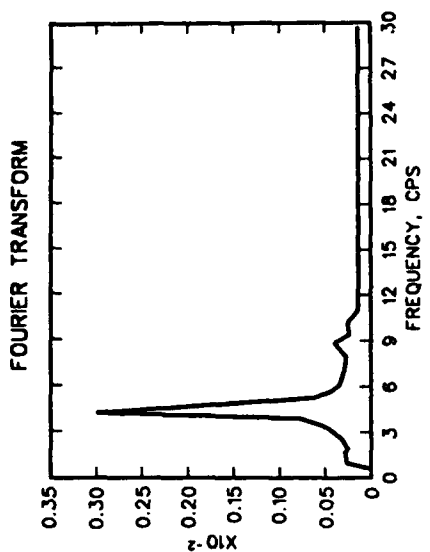
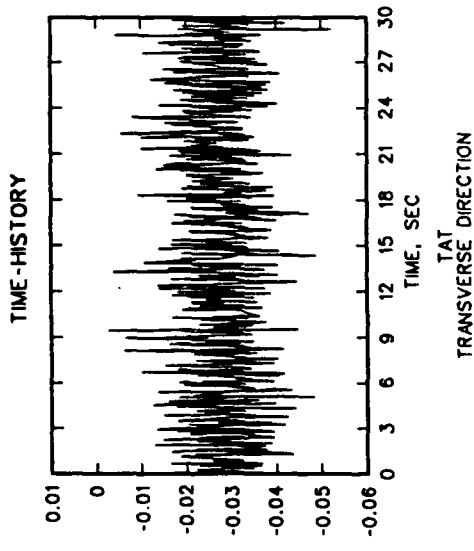
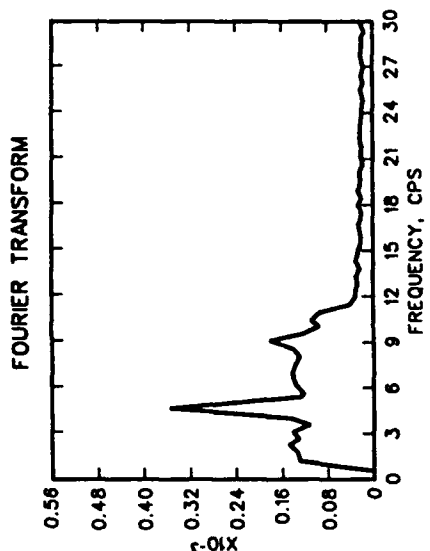
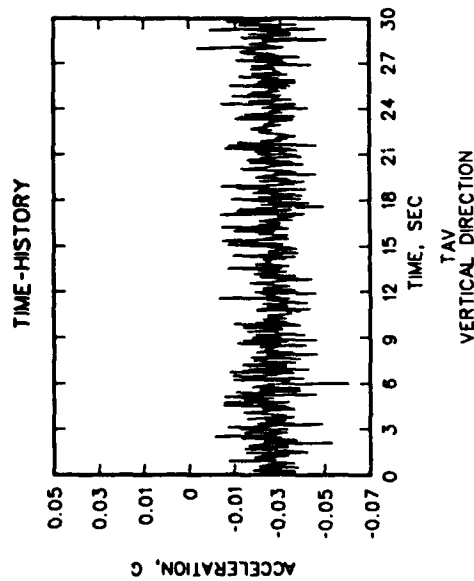
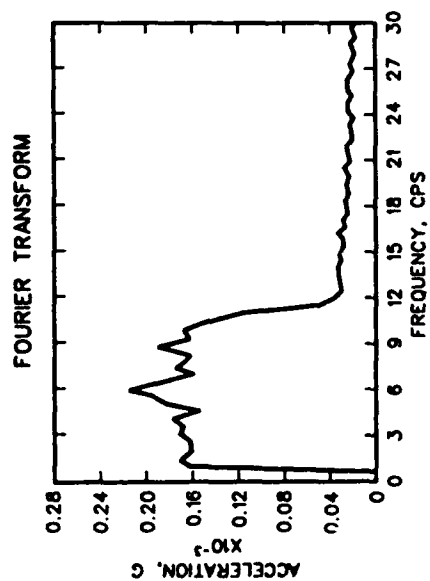


PLATE 2



GILLHAM DAM
INTAKE TOWER AND WET WELL
ACCELERATION AND
DISPLACEMENT

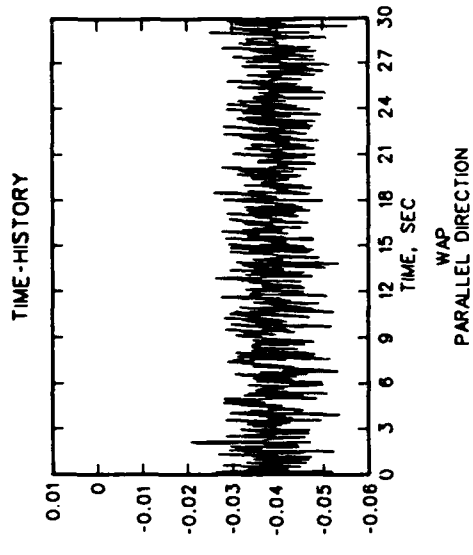
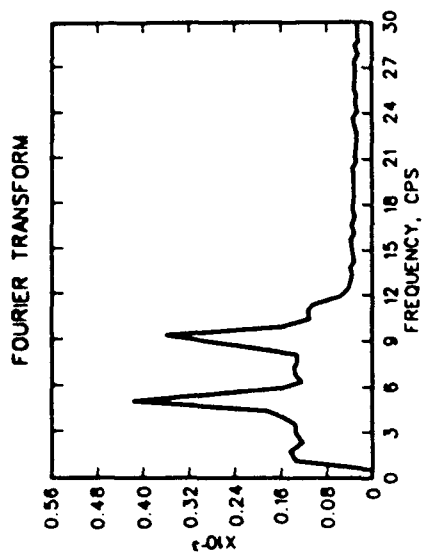
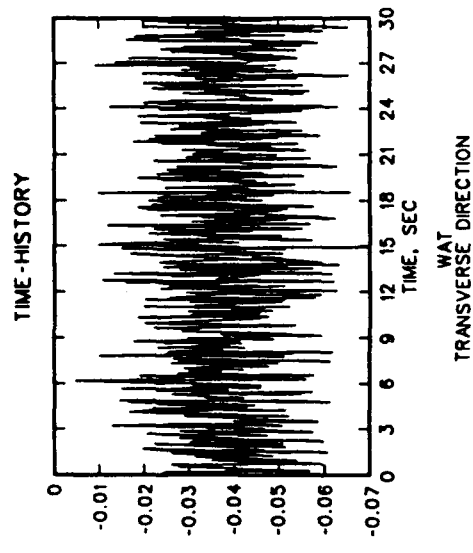
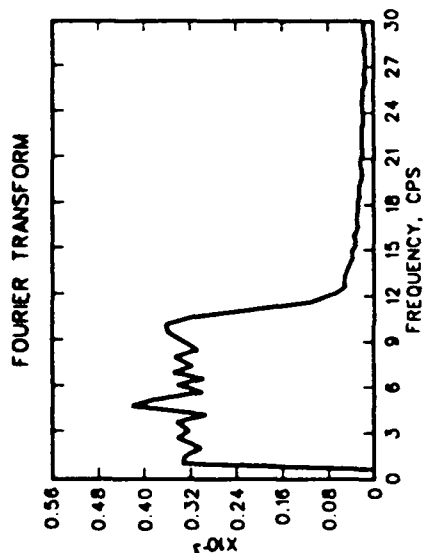
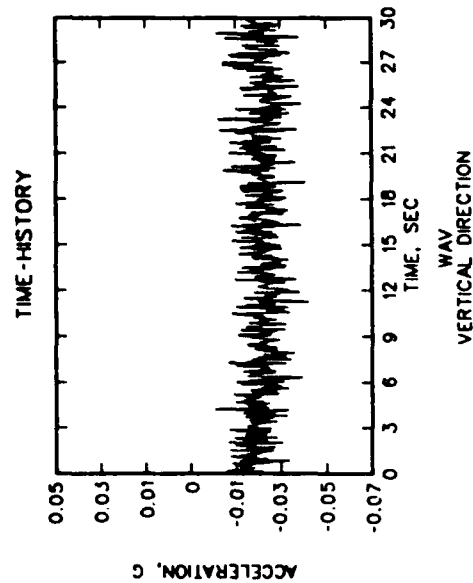
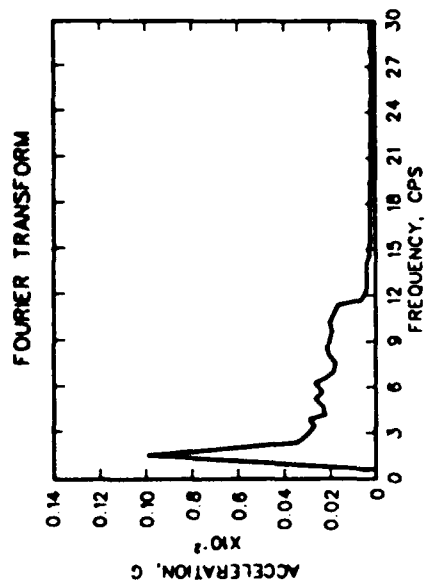


TAV
VERTICAL DIRECTION

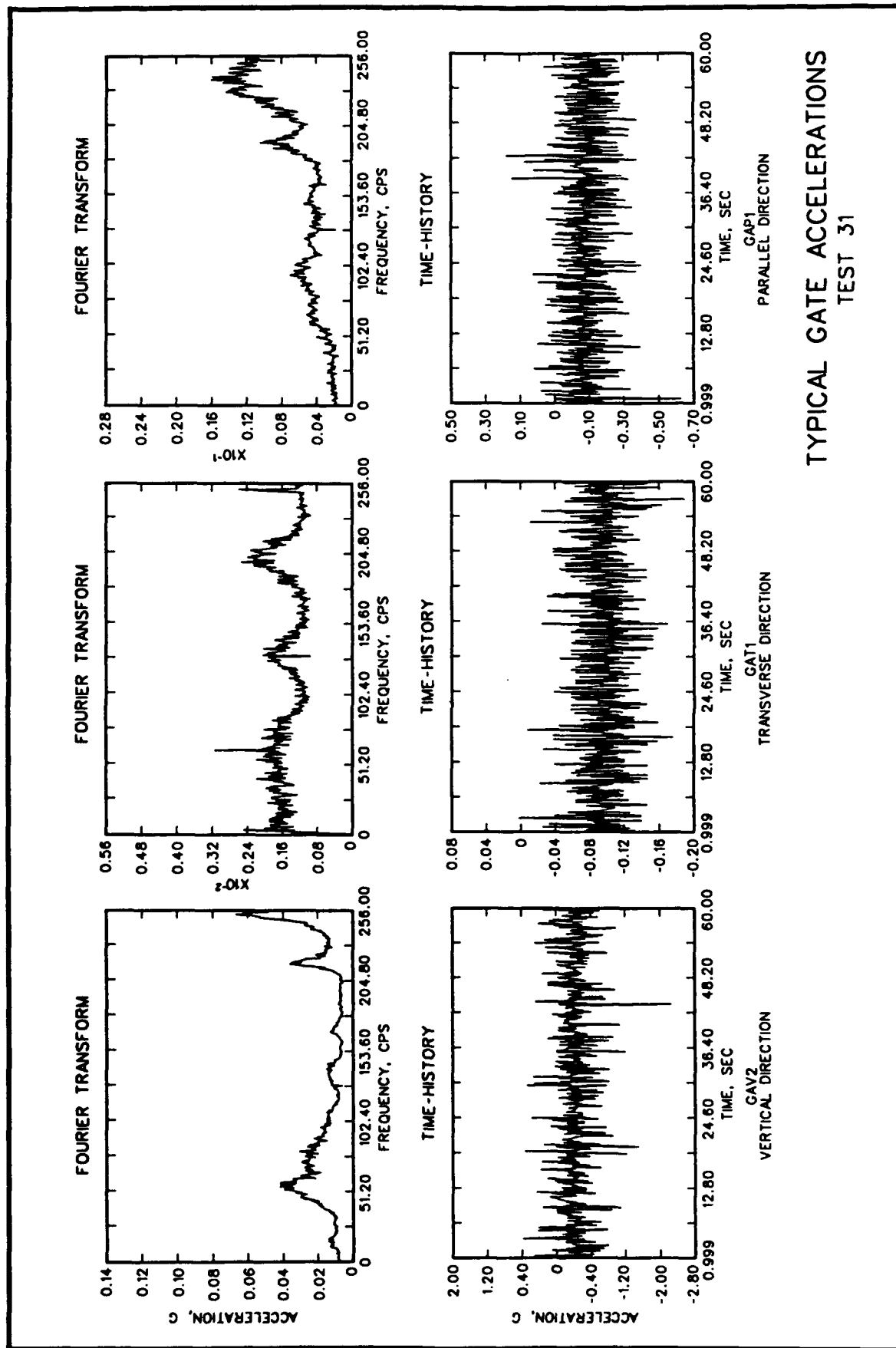
TAT
TRANSVERSE DIRECTION

TAP
PARALLEL DIRECTION

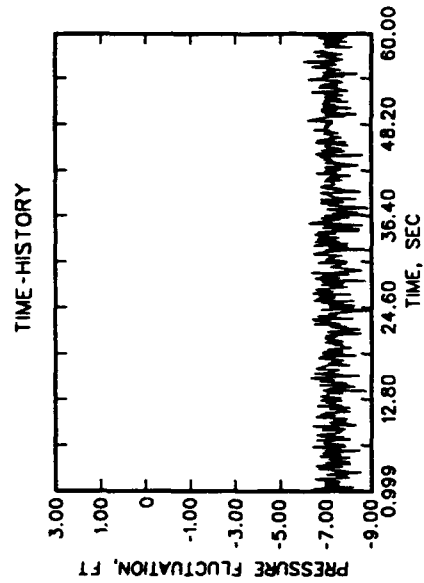
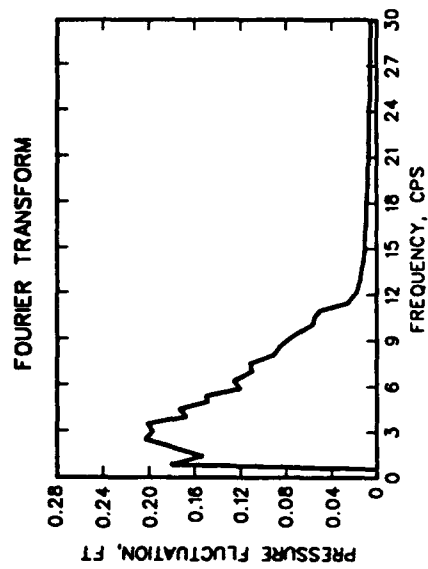
INTAKE TOWER ACCELERATIONS TEST 31



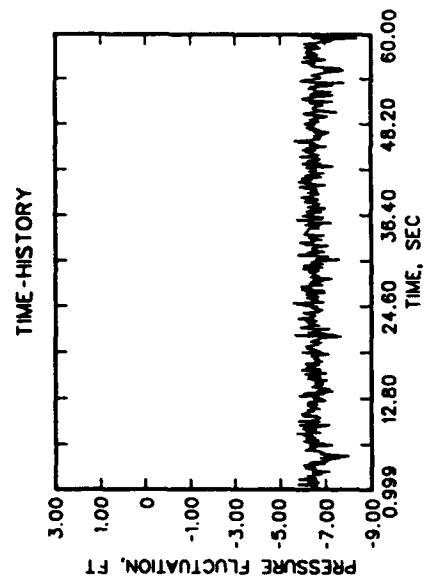
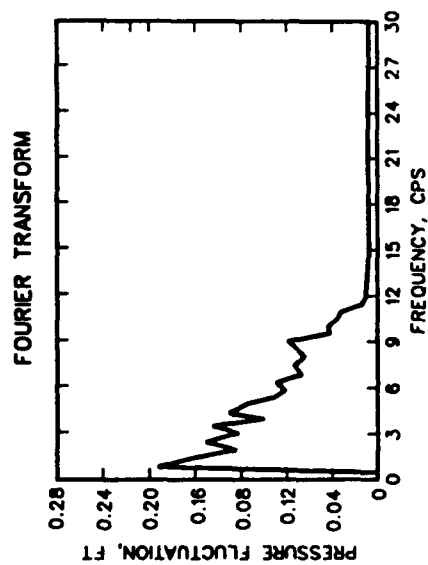
WET WELL ACCELERATIONS TEST 31



TYPICAL GATE ACCELERATIONS
TEST 31

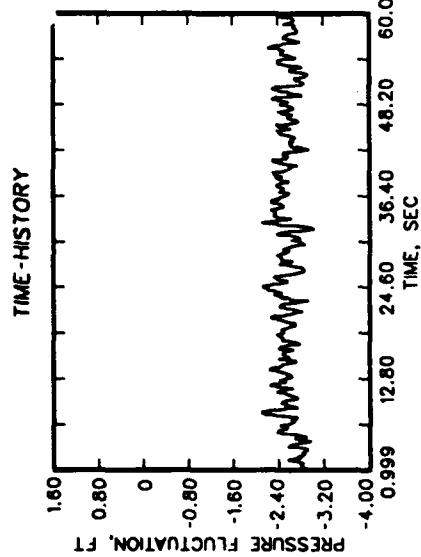
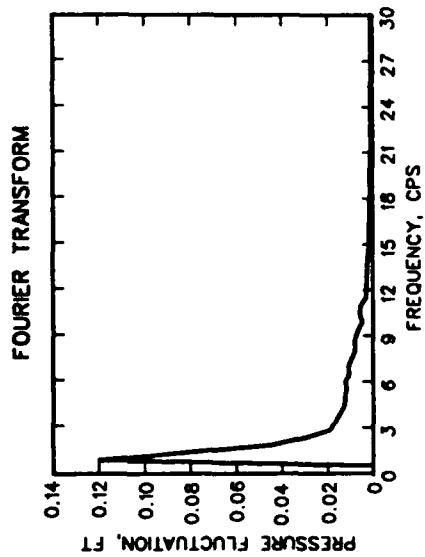


PUS 2
GATE 2

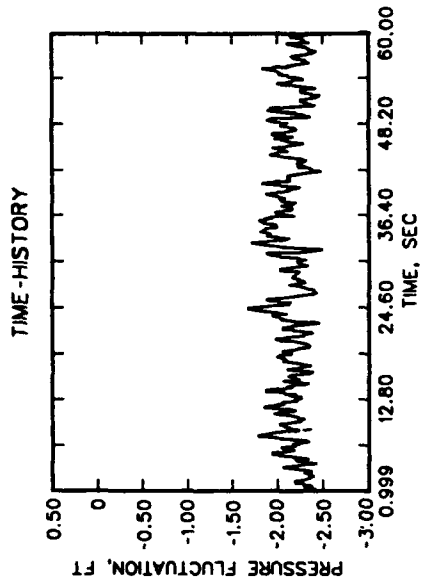
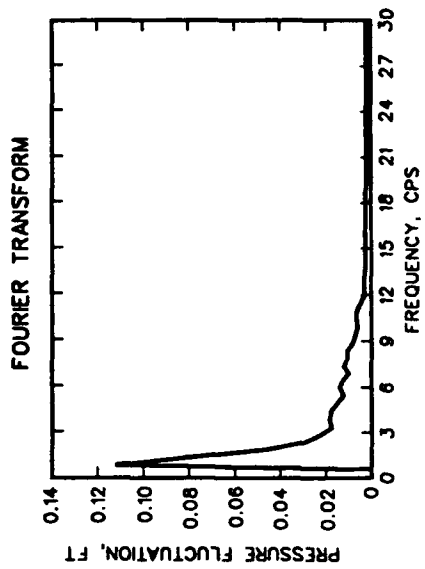


PUS 1
GATE 1

UPSTREAM PRESSURE FLUCTUATIONS TEST 31

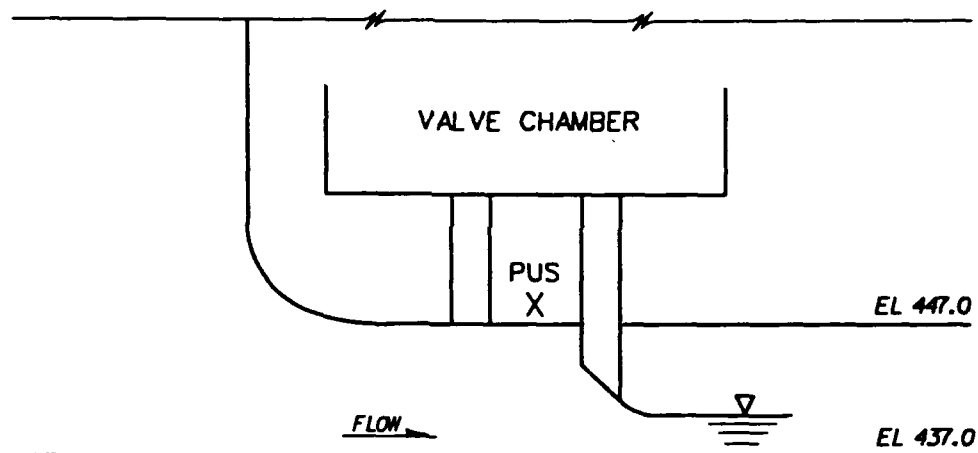
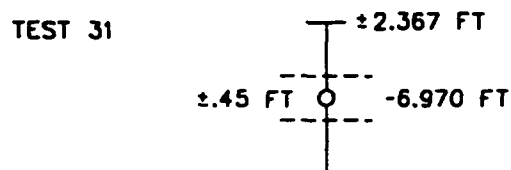
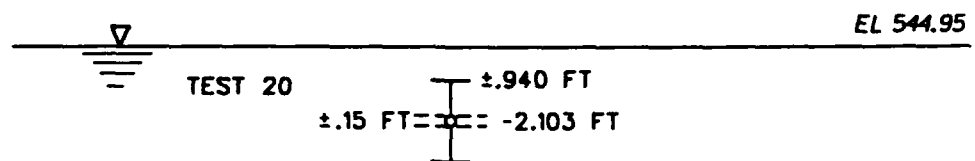


PDS 1
GATE 1

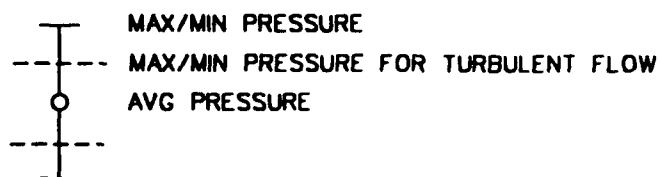


PDS 2
GATE 2

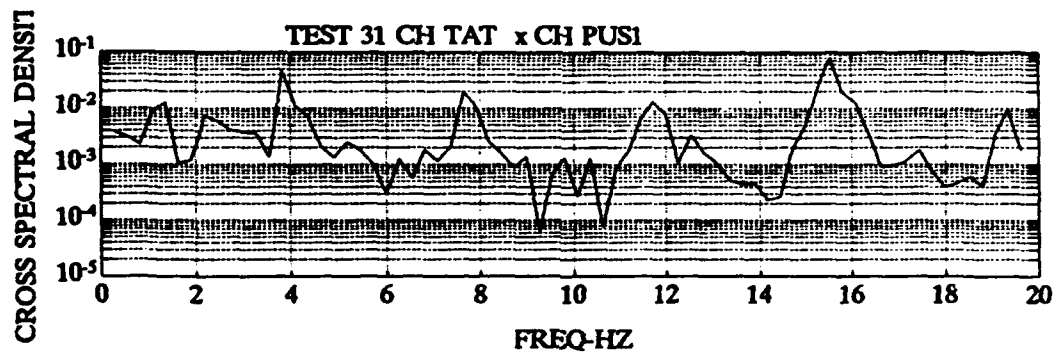
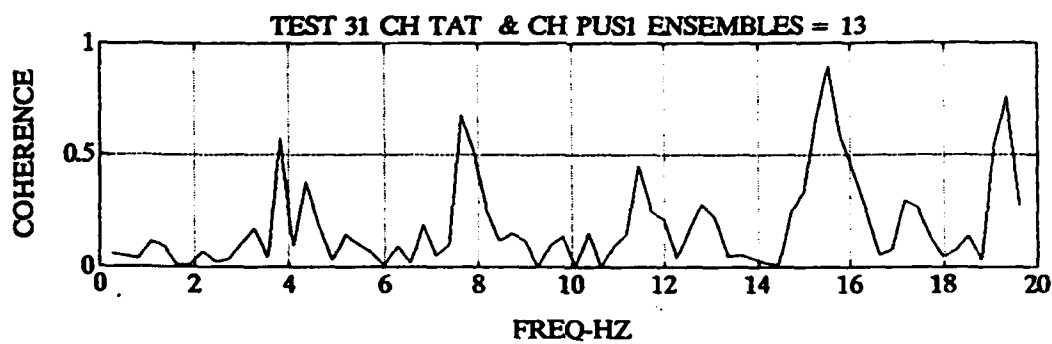
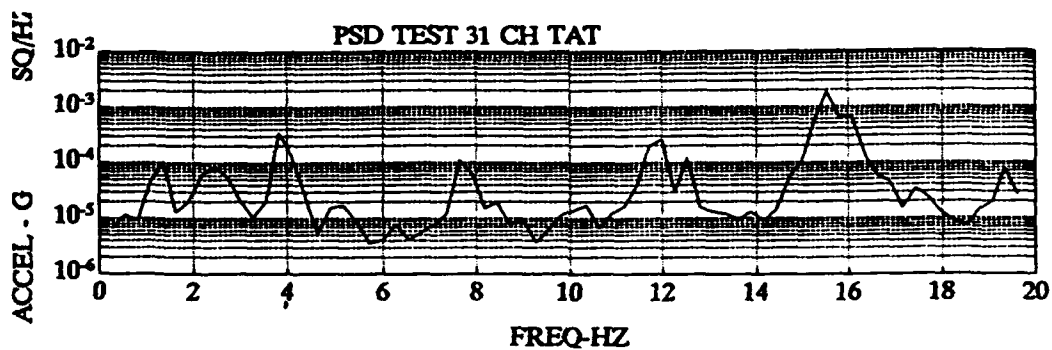
DOWNSTREAM
PRESSURE FLUCTUATIONS
TEST 31



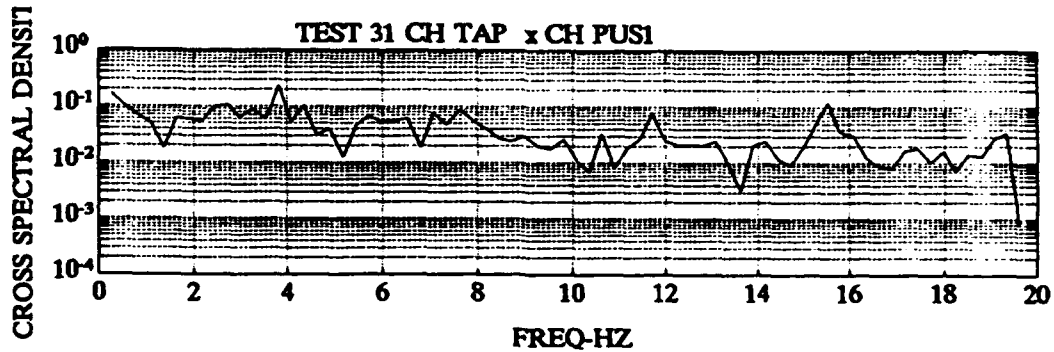
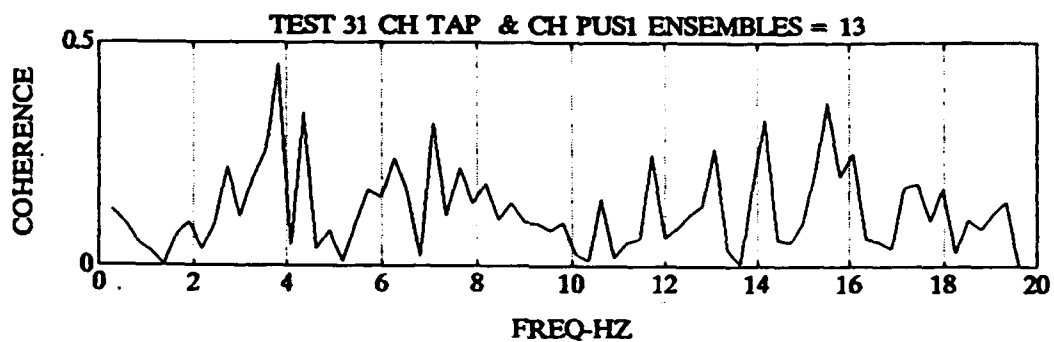
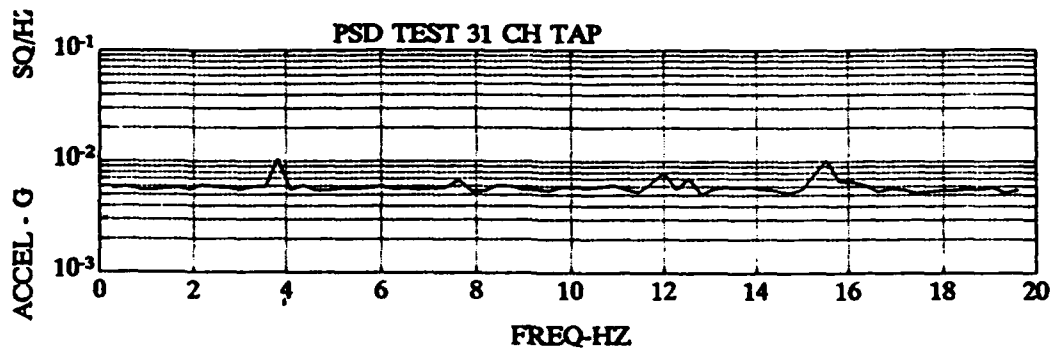
LEGEND



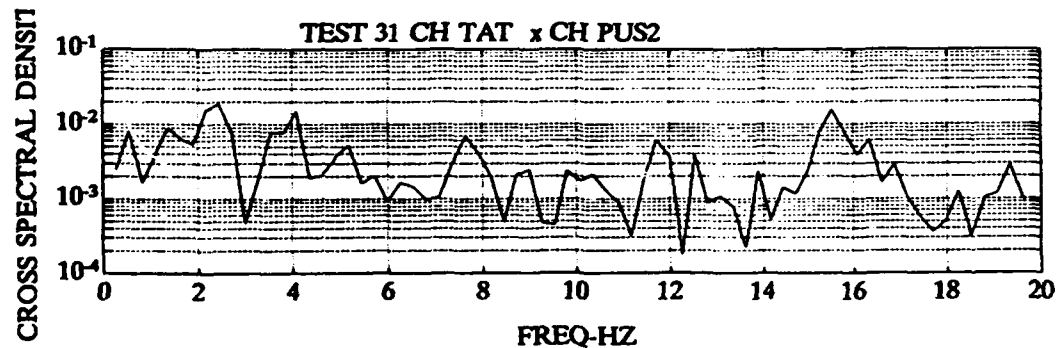
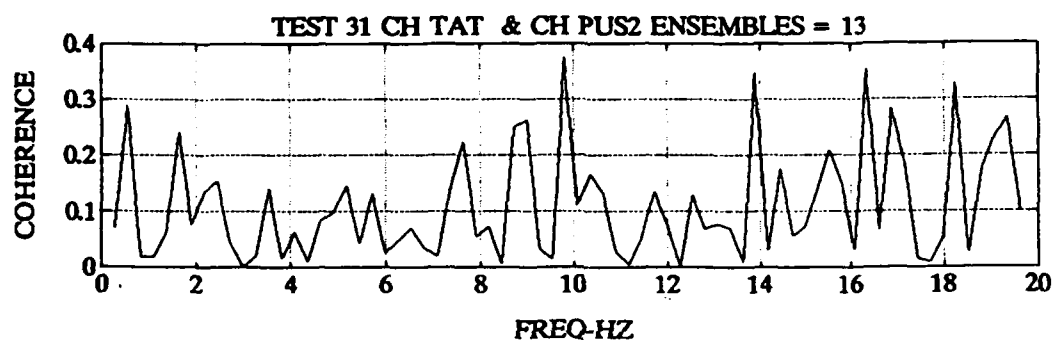
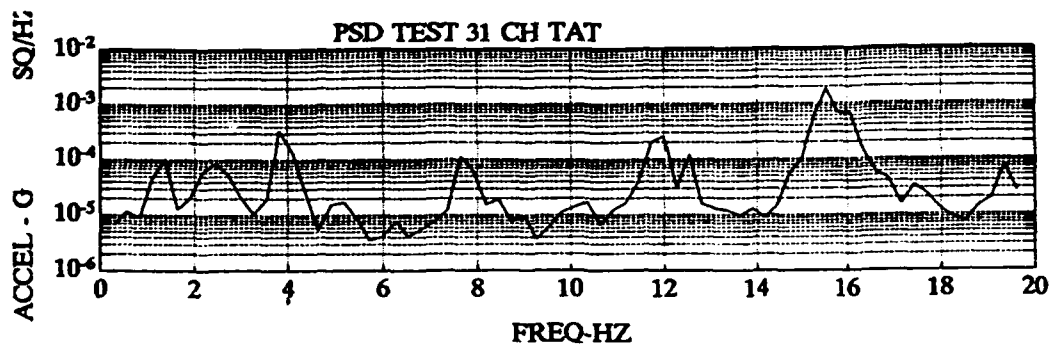
MAXIMUM
PEAK-TO-PEAK PRESSURE
FLUCTUATIONS IN RELATION TO
NORMAL PRESSURE FLUCTUATIONS
FOR TURBULENT FLOW



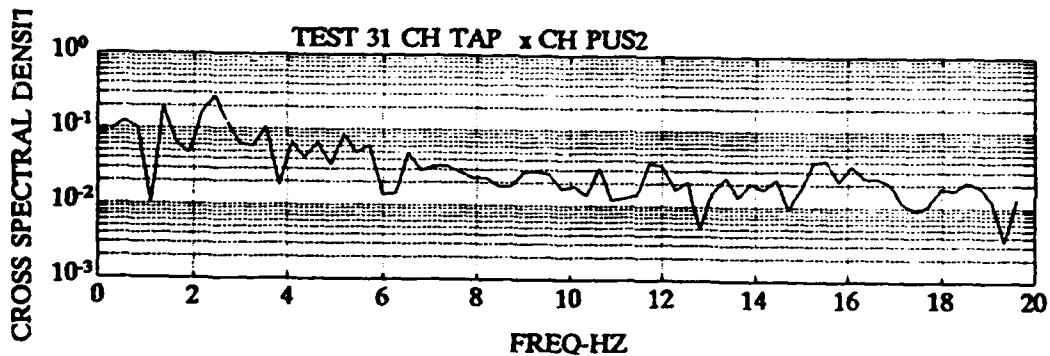
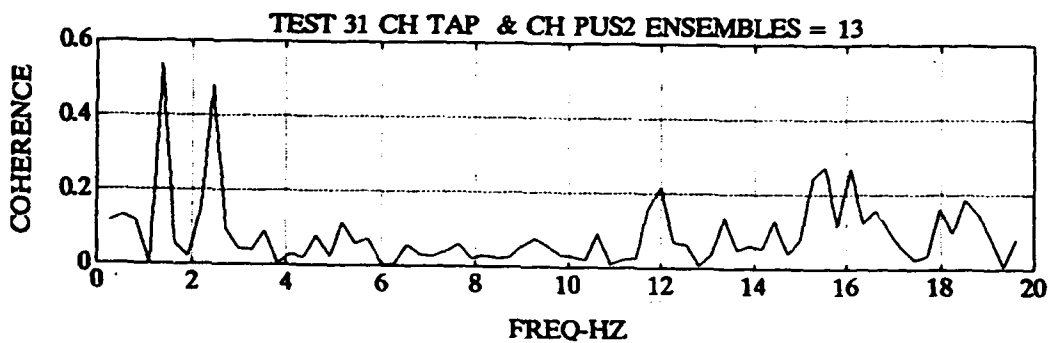
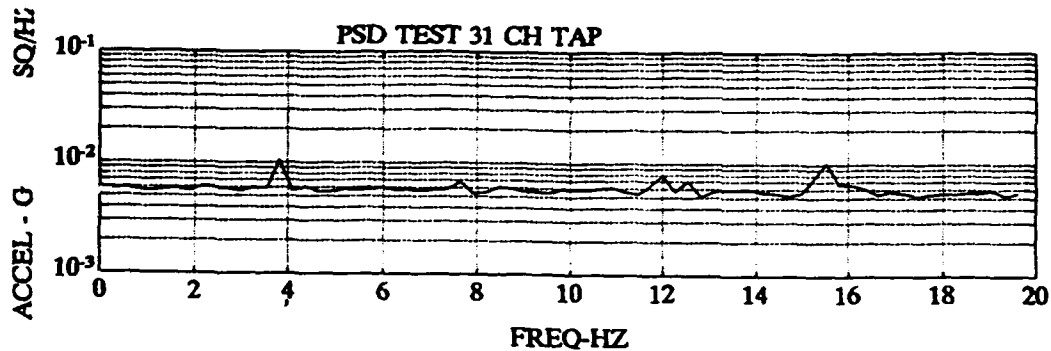
SPECTRAL DENSITY PLOTS
CHANNELS TAT AND PUS1
TEST 31



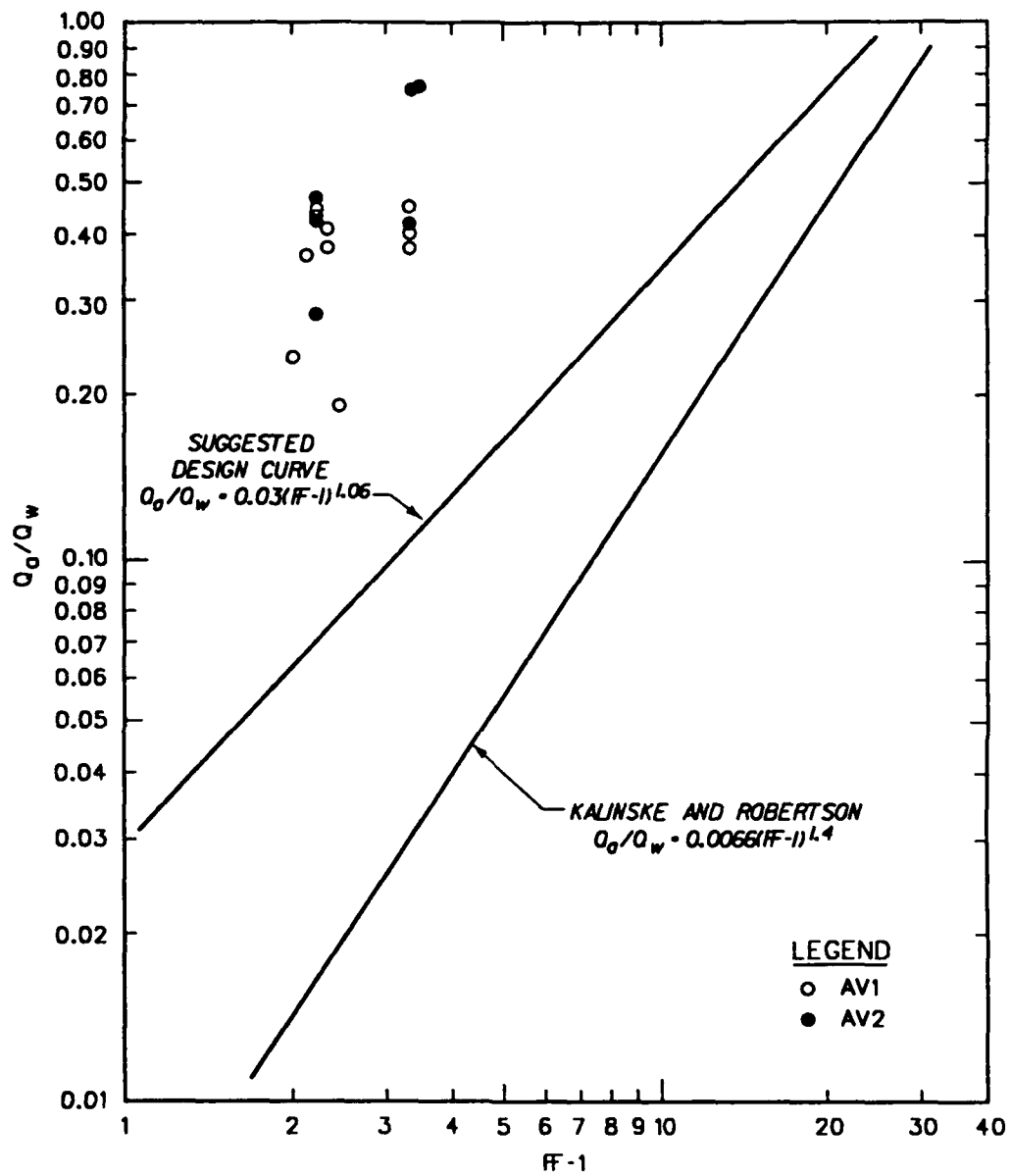
SPECTRAL DENSITY PLOTS
CHANNELS TAP AND PUS1
TEST 31



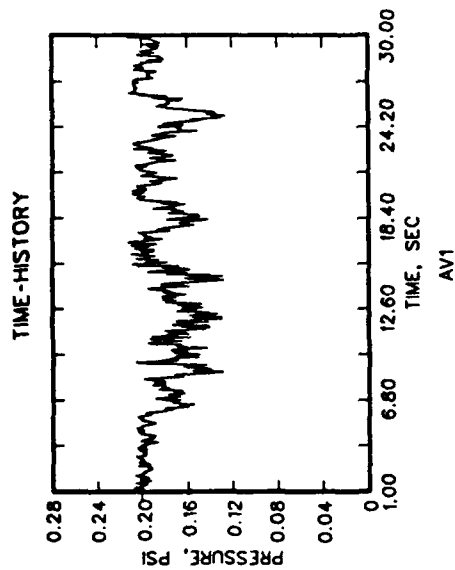
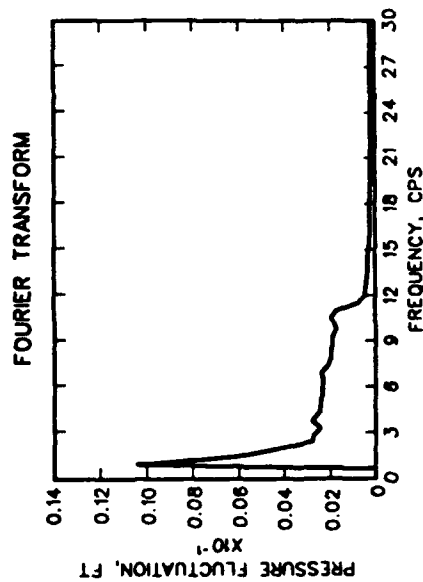
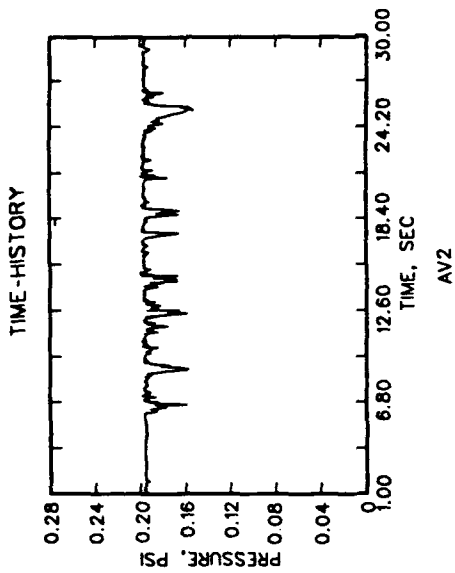
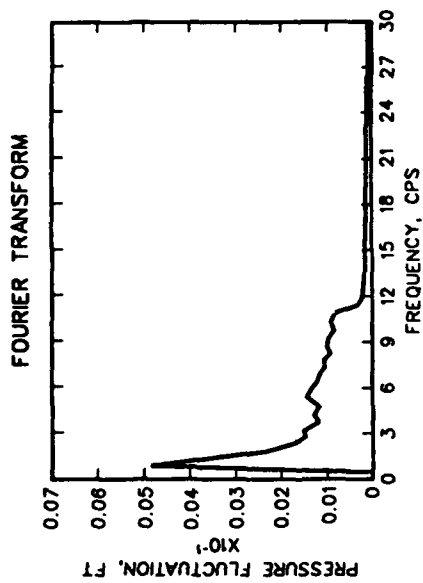
SPECTRAL DENSITY PLOTS
CHANNELS TAT AND PUS2
TEST 31



SPECTRAL DENSITY PLOTS
CHANNELS TAP AND PUS2
TEST 31



AIR DEMAND
FROM HDC 050-1



DIFFERENTIAL AIR-VENT PRESSURES TEST 31

Waterways Experiment Station Cataloging-in-Publication Data

McVan, Darla C.

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