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SUGAR PINE SLEEVE VALVE TESTS

BY

BRENT W. MEFFORD

PAP-486

Form DPC-11
(12-51)
Bureau of Reclamation

INFORMATIONAL ROUTING

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PAP-486

Memorandum
Chief, Division of Water and Land Technical Services

Denver, Colorado
October 4, 1985

ACTING Chief, Division of Electrical, Mechanical, and Plant Design
ACTING Chief, Division of Research and Laboratory Services

Test Report for Sleeve Valve on Outlet Works at Sugar Pine Dam - Central Valley Project
(Memorandum Dated April 11, 1984, from Regional Director, Sacramento, California, and our Memorandum Dated October 12, 1984, to Regional Director, Sacramento, California)

The operational tests performed on the sleeve valve were in response to two concerns:

1. Whether the vibrations of the sleeve valve encountered over part of the operating range were detrimental to the structural integrity of the valve.

2. Possible excess velocities in the pipe elbow and the maximum operating discharge being in excess of the design discharge through the stilling well.

GPO 852320

A test report was produced based on the data obtained from the sleeve valve tests performed on November 27 and 28, 1984. Attached is a copy of both the test report and the travel report. The two areas of concern were resolved as follows:

1. The sleeve valve absorbs insufficient energy for fatigue damage to occur to the external structure of the valve.

2. Discharges calculated from the field test headloss data are up to 10 percent higher than discharge values given in the designers' operating criteria. The higher discharge values do not produce significant increases in cavitation potential of the sleeve valve elbow, and do not effect the efficiency of the stilling well.

Recommendations

1. To determine the status of the structural integrity of the internal structure of the sleeve valve the following areas should be inspected at the next inspection:

a. Check the fillet welds for cracks using the dye penetrant method on part 6, sleeve valve stem, and part 15, connector.

b. Check for cracks using the dye penetrant method on the surfaces adjacent to the 13/16-inch-diameter holes in part 15, connector.

2. To prevent vibration induced damage to the hydraulic piping system, insert flexible hose connections at the hydraulic cylinder.

G. A. Hiett

W. R. Lundin

Attachments

Copy to: D-215
D-220
D-223 (with copy of attachments)
D-230
D-250
D-252 (with copy of attachments)
D-400
D-430 (with copy of attachments)
D-1500
D-1530
D-1531 (PAP file)
D-1532 (with copy of attachments)
D-3210
D-3300

SUGAR PINE SLEEVE VALVE TESTS

Test Procedure

The field tests were performed to obtain pressure drop across the valve and collect acceleration and strain data over the valve's operating range. All three inlets were opened for the tests.

A single piezometer tap was installed at Station 3+40.3 m and a ring of four taps was installed at Station 3+56.6 m. The single upstream tap was installed for comparison with the piezometer ring due to the ring's proximity to the elbow section. Bourdon tube pressure gages were used to measure the pressure. Tailwater elevations were measured using a staff gage placed in the stilling well exit channel.

Eight accelerometers were used to obtain the vibrational response of the sleeve valve. Accelerometers No. 1, 3, 5, and 7 were mounted on the sleeve valve to record accelerations in the direction of flow, and accelerometers No. 2, 4, 6, and 8 were mounted perpendicular to the flow, see figure 1. To obtain a strain history, four axial strain gages were located on the stand adjacent to the cutout as shown.

Acceleration and strain data were recorded using two, dual channel FFT spectrum analyzers. Two analyzers were used to reduce the time required for testing. Data were recorded over a frequency spectra of 0 to 100 Hz. Amplitude, phase and transfer functions were recorded for each transducer. Accelerometers No. 1 and 2 were defined as references for phase and transfer function relationships in their respective directions. Accelerometers labeled 3, 5, and 7 were referenced to No. 1 and accelerometers No. 4, 6, and 8 were referenced to No. 2. The strain gages were all referenced to strain gage No. 1. Each analyzer was set to obtain an ensemble average of 256 spectra. All spectra were recorded on disk drives for future analysis.

The test was conducted by raising the gate in 10 percent increments of gate stroke. A gate over-travel of 74 mm was assumed at full closure. Total gate stroke was measured prior to watering up the outlet works conduit. Pressure and tailwater readings were taken at each gate opening from 10 to 100 percent. Acceleration and strain readings were recorded at gate strokes of 40, 60, 70, 80, and 100 percent.

Results of Pressure Head Measurements

The pressure drop across the valve is shown in figure 2. The results were used to estimate the discharge through the valve, assuming a coefficient of discharge through the ports of 0.6, figure 3.

Model Response of the Sleeve Valve

Passing flow at gate openings below 40 percent resulted in low vibrational response on all transducers. At 60 percent gate opening, the sleeve valve responded with a wide range of frequencies being

excited, a typical response to a broad band energy input. No resonance was encountered. The two fundamental modes, frequency 7.2 Hz in the direction of flow and frequency 10.4 Hz perpendicular to the flow, were consistent in their amplitude and phase responses to changes in discharge. The second mode, frequency 50 Hz perpendicular to the flow, and the third mode, frequency 46 Hz in the direction of flow were prominent at some discharges. The responses of these two modes were not consistent with discharge, see figures 4 through 9.

The stainless steel hydraulic piping was not instrumented, but visual observation showed pronounced vibrations.

A finite element model representing the external structure of the sleeve valve was constructed. Theoretical calculations of modal shapes and frequencies correlated with the field test results for first, third, and fourth modal shapes in the direction of the flow, XY plane, and the first and second modal shapes perpendicular to the flow, YZ plane, see figure 10.

A plot of the response of accelerometer No. 2 at a frequency of 10.4 Hz against the discharge squared, shows a change of slope in this relationship at 60 to 70 percent, see figure 11. A similar relationship also existed for accelerometer No. 1, at a frequency of 7.2 Hz, see figure 12. As discharge squared is directly proportional to kinetic energy, there is more energy in the stilling well in the 60 to 70 percent range being transmitted to the sleeve valve structure. This higher level of energy is also evident in figures 13 and 14, where the frequency range is from 46 to 50 Hz. The broader energy spectrum at 60 to 70 percent was also apparent from the overall visual and audible response of the structure.

The strain gages were located on the stem support of the operator just above a flange, see figure 1. This location is the most highly stressed area of the structure when subjected to a broad band excitation. The highest average peak stress, 3630 KN/m^2 occurred at strain gage No. 4, for the fundamental mode perpendicular to the flow, 10.4 Hz, at 100 percent gate opening. The highest acceleration encountered (0.74 gs) was for accelerometer No. 2, at a frequency of 50 Hz and 60 percent gate opening. This corresponds to a peak stress of 828 KN/m^2 at strain gage No. 4. Neither of these cases will result in any fatigue damage to the adjacent welds or bolts.

Energy Sources Causing Structural Vibration of Sleeve Valve

The vertical bend section and its internal cylinders are sources of nonuniform turbulent flow. Above 3 m/s the Strouhal numbers for the 7.6-cm- and 19-cm-diameter cylinders will be in the critical Reynolds number range and nonperiodic vortices will be generated. There will also be nonuniform flow in the region of the nozzles.

The nonuniform turbulent flows will give rise to a random source of energy which will be transferred to the sleeve valve. This energy

source is proportional to the kinetic energy of the water flowing through the valve, i.e., porportional to the discharge squared. However, in the cases of the third mode 46 Hz, in the XY plane and second mode 50 Hz in the YZ plane, this relationship was not followed, instead peak accelerations were encountered at 70 and 60 percent openings, respectively. The internal moving structure of the valve comprising: sleeve, sleeve stem; piston rod; and piston was modeled separately. The frequencies of this internal structure are dependent upon the fixities or reaction points. The sleeve and piston move relative to the guide plate which results in the frequencies also being dependent upon valves opening position. For a setting of 60 percent open, the second mode shape, the theoretical frequency (49 Hz) of the internal structure, correlates with the second mode of the external structure (50 Hz). Because both the internal and external structures are vibrating synchronously, there will be amplification of their amplitudes.

As the valve moves beyond the 70 percent open position, the frequency of the internal structure changes and the system is detuned, resulting in reduced amplification, reference figure 14. The internal structure was not instrumented, so we do not have any test data to confirm this hypothesis. However, we recommend at the next inspection of the internal structure of the sleeve valve that the fillet welds on parts 6 and 15 be checked for any sign of distress. Also, the surface adjacent to the 13/16-in-diameter holes in part 15 should be visually inspected for cracks.

Conclusions

Discharges calculated from the field test headloss data are up to 10 percent higher than discharge values given in the designer's operating criteria. The higher discharge values do not produce significant increases in the cavitation potential of the sleeve valve elbow. Releasing maximum discharge through the outlet works will produce an average velocity of 10.1 m/s and a cavitation index of 0.92 in the elbow section. During maximum releases, cavitation occurring within the wake of the flow downstream of the internal structure in the elbow should be limited to low levels of noise and vibration.

The general structural response of the sleeve valve was that typical of a lightly damped structure being excited by a broad band energy spectrum. The exception being that for the third mode in the XY plane and the second mode in the YZ plane, where maximum responses occurred at 70 and 60 percent openings, respectively.

There was insufficient energy in the system to result in fatigue damage to the sleeve valve. Therefore, no operational restrictions need to be imposed because of the structural integrity of the valve.

As the hydraulic piping is an all welded system, there is a higher probability of fatigue damage. The hydraulic lines should be isolated from the vibration of the hydraulic cylinder.

Recommendations

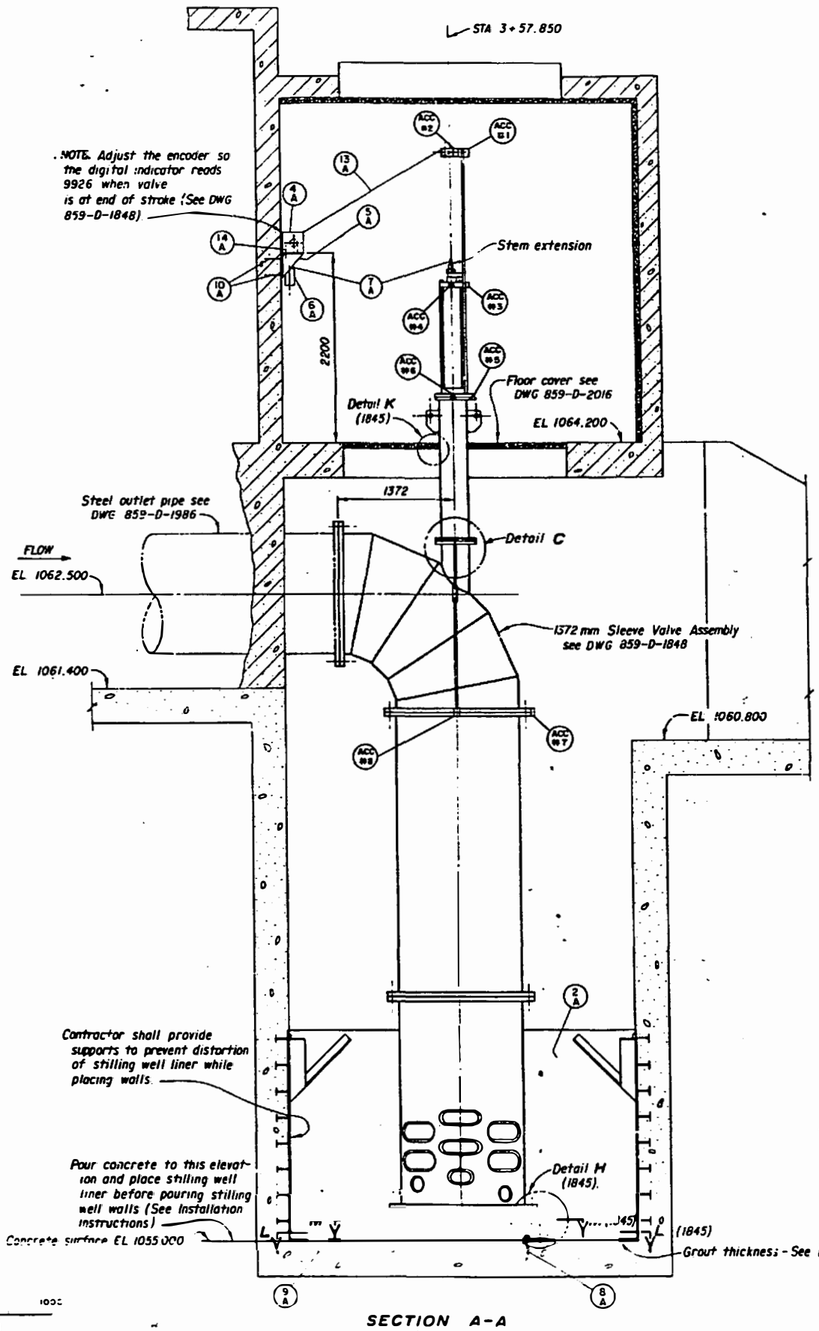
1. At the next inspection of the internal structure of the sleeve, check the fillet welds for cracks using the dye penetrant method on parts 6 and 15. Also, check for cracks on the surfaces adjacent to the 13/16-in-diameter holes in part 15.

2. Isolate the hydraulic piping system from the sleeve valve with flexible hose connections located at the hydraulic cylinder.

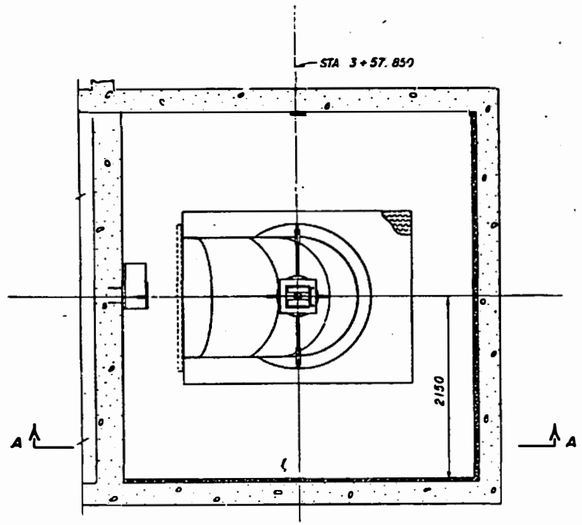
Nomenclature:

(ACC ##X) = Location of accelerometer. Accelerometers are in pairs, orientated perpendicular to each other.

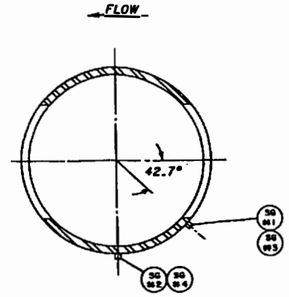
(SG ##X) = Location of SR4 temperature compensated strain gage. Axis located parallel to vertical axis of stand pipe.



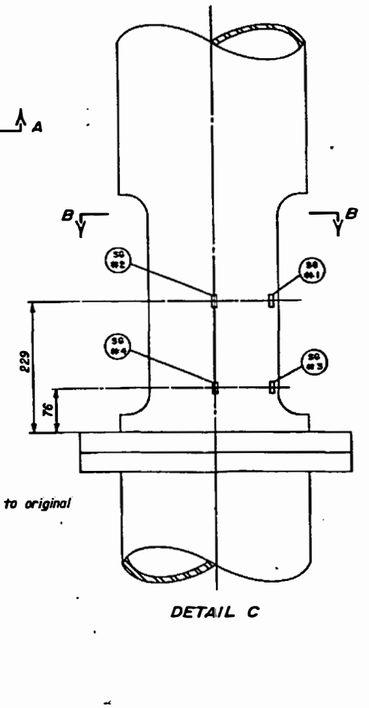
SECTION A-A



SECTIONAL PLAN
EL 1068.000



SECTION B-B



DETAIL C

NOTE: Instrumentation added to original drawing 859-D-1844.

NOTES

Dimensions, unless otherwise shown, are in millimeters.
Stationing and Elevations are in meters.

LIST OF DRAWINGS

INSTALLATION-LIST OF DRAWINGS	859-D-1844
INSTALLATION-LIST OF PARTS	859-D-1845
STILLING WELL LINER	859-D-1846
ENCODER SUBASSEMBLY-BRACKET	859-D-1847

REFERENCE DRAWINGS

1372 MILLIMETER SLEEVE VALVE-ASSEMBLY-LIST OF PARTS	859-D-1848
CONTROL STRUCTURE - SECOND STAGE	859-D-1963
STEEL OUTLET, STEEL LATERAL, AND DIVERSION PIPING	859-D-1986
METALWORK-COVERS AND FRAMES	859-D-2016
HIGH PRESSURE GATE AND SLEEVE VALVE CONTROLS-HYDRAULIC POWER UNIT INSTALLATION	859-D-1873

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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT
AUBURN-FOLSOM SOUTH UNIT-CALIFORNIA

SUGAR PINE DAM
OUTLET WORKS
1372 MILLIMETER SLEEVE VALVE INSTALLATION-LIST OF DRAWINGS

DESIGNED G.L. Hurst — TECHNICAL
DRAWN — SUBMITTED
CHECKED M.L. Cuzzo — APPD. — CHIEF, DESIGN BRANCH

DENVER, COLORADO, JUNE SHEET 1 OF 30, 1970

D-252-321

FIG. 1

NON-ORIGINAL

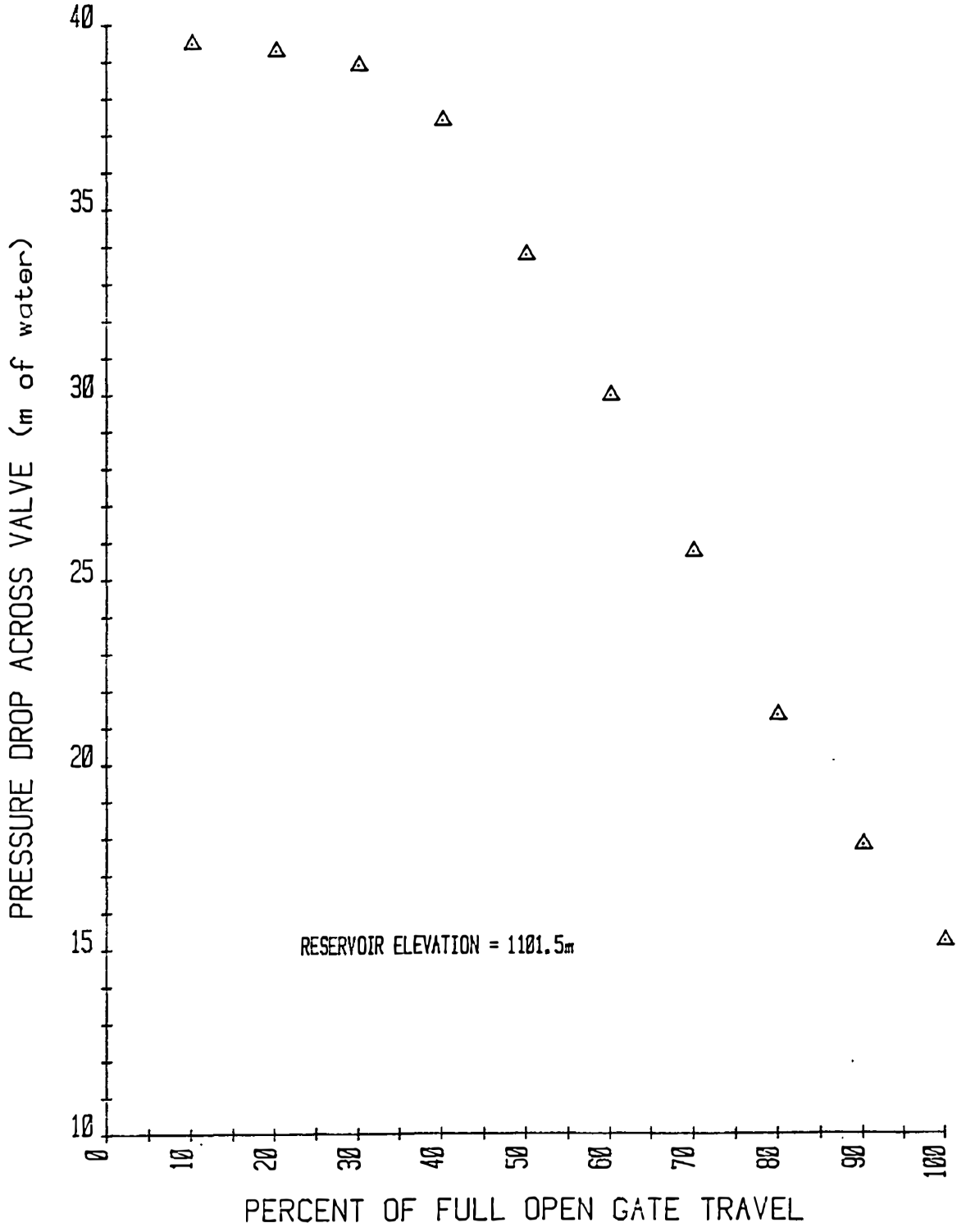

40
35
30
25
20
15
10
PRESSURE DROP ACROSS VALVE (m of water)
RESERVOIR ELEVATION = 1101.5m
0
10
20
30
40
50
60
70
80
90
100
PERCENT OF FULL OPEN GATE TRAVEL

Figure 2

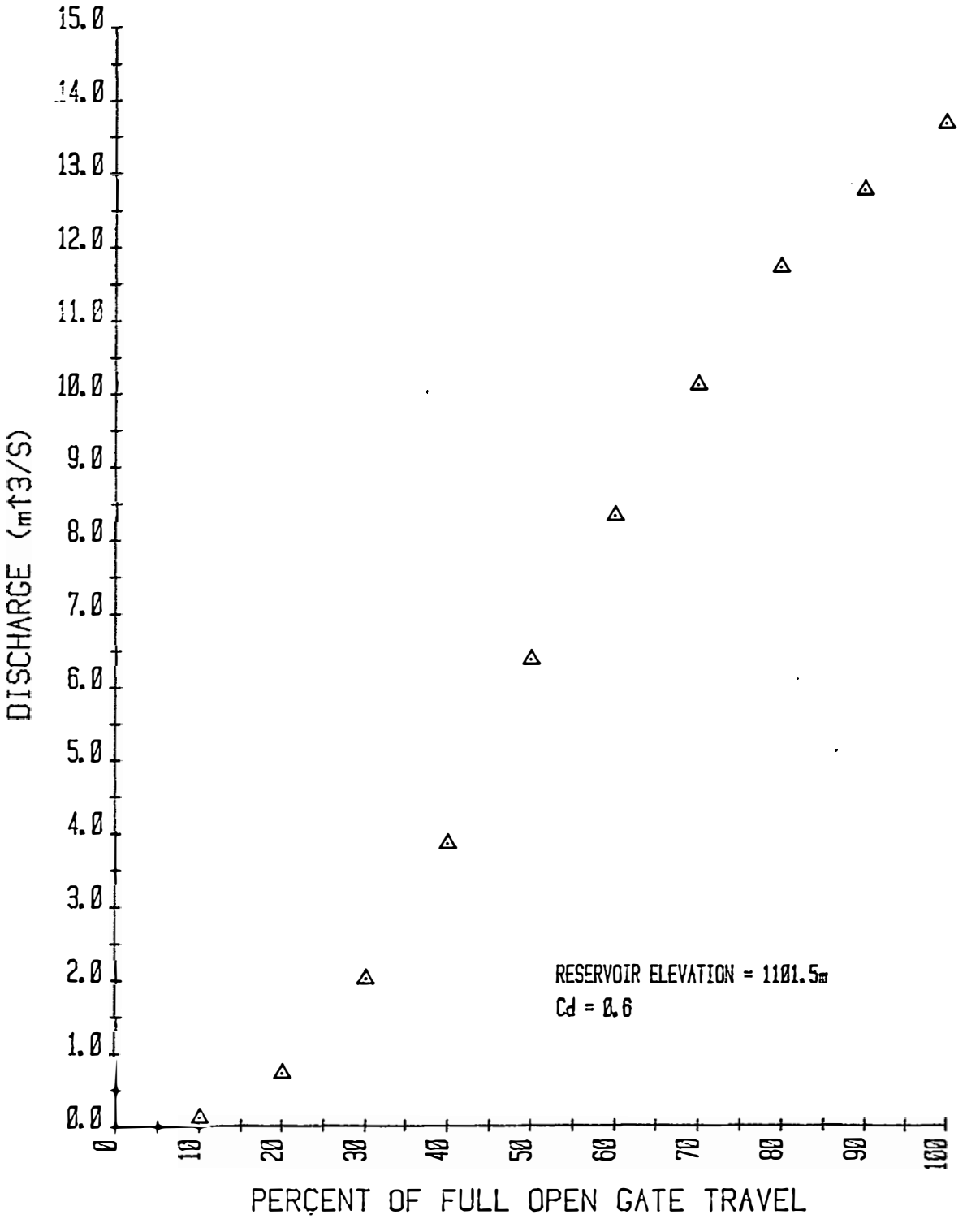

15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
DISCHARGE (m↑3/S)
0
10
20
30
40
50
60
70
80
90
100
PERCENT OF FULL OPEN GATE TRAVEL
RESERVOIR ELEVATION = 1101.5m
Cd = 0.6

Figure 3

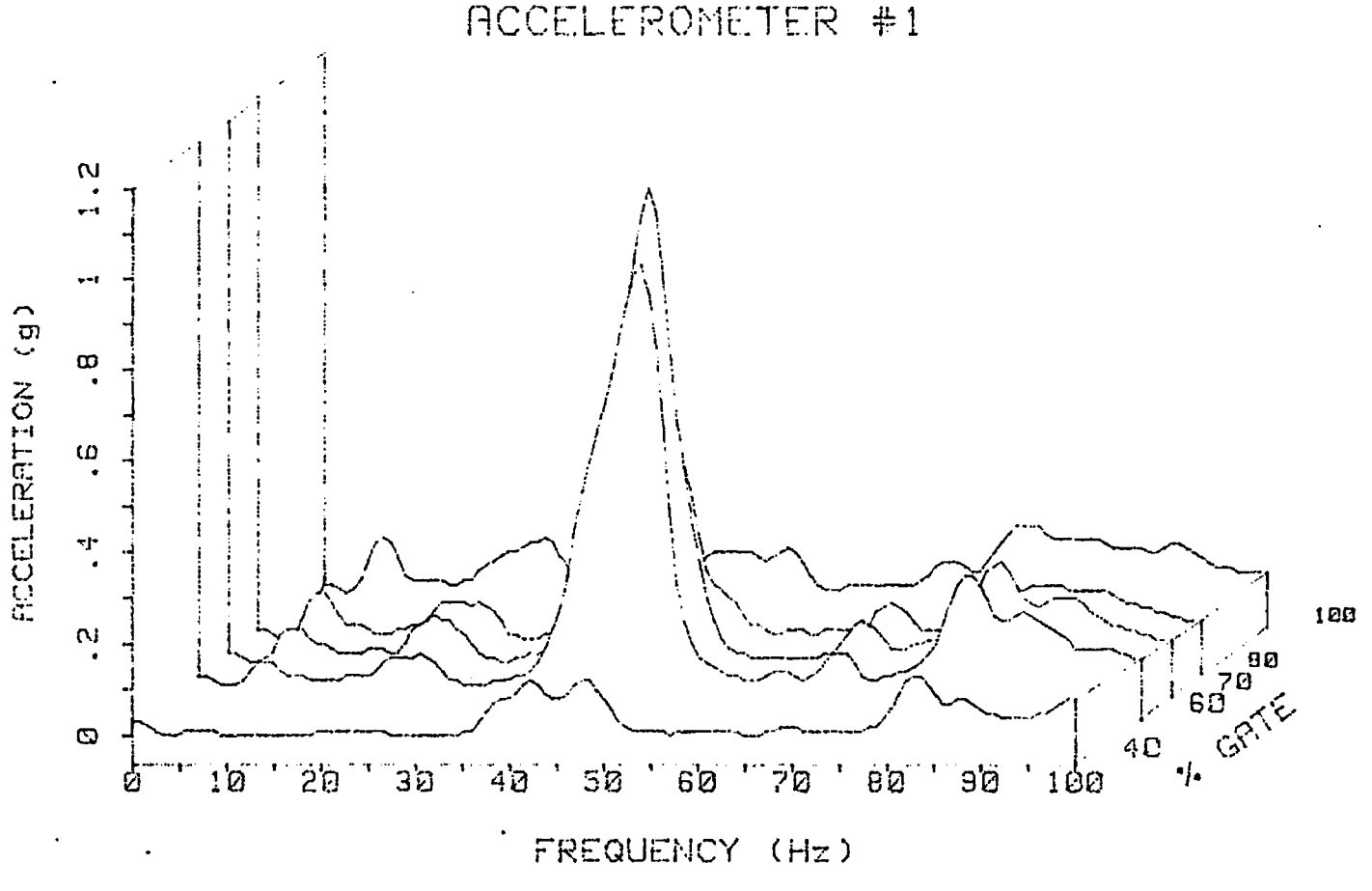

ACCELEROMETER #1
ACCELERATION (g)
0
.2
.4
.6
.8
1
1.2
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
100
90
70
60
40
GATE
%

Figure 4

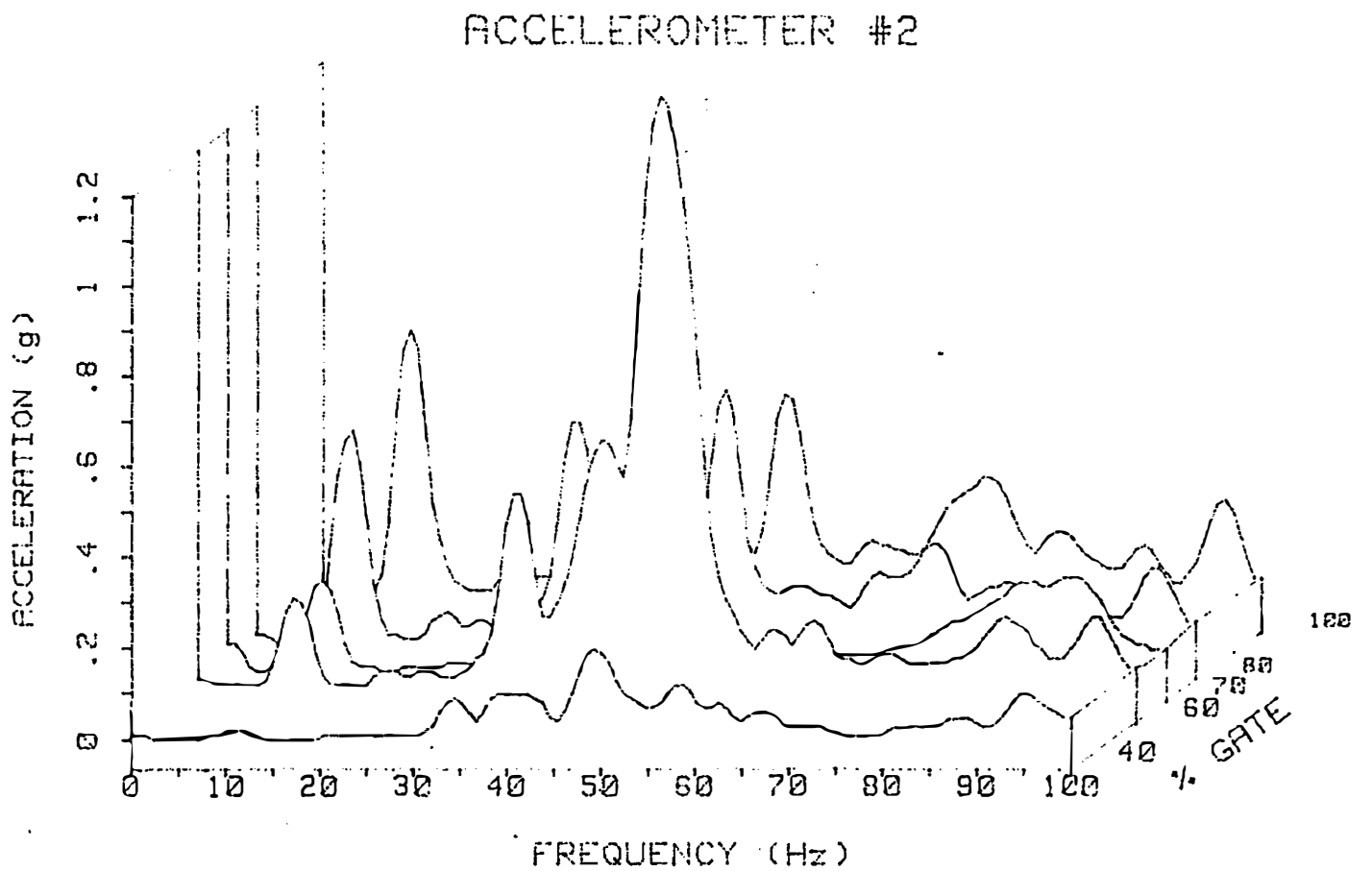

ACCELEROMETER #2
ACCELERATION (g)
0
.2
.4
.6
.8
1
1.2
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
40
60
70
80
100
% GATE

Figure 5

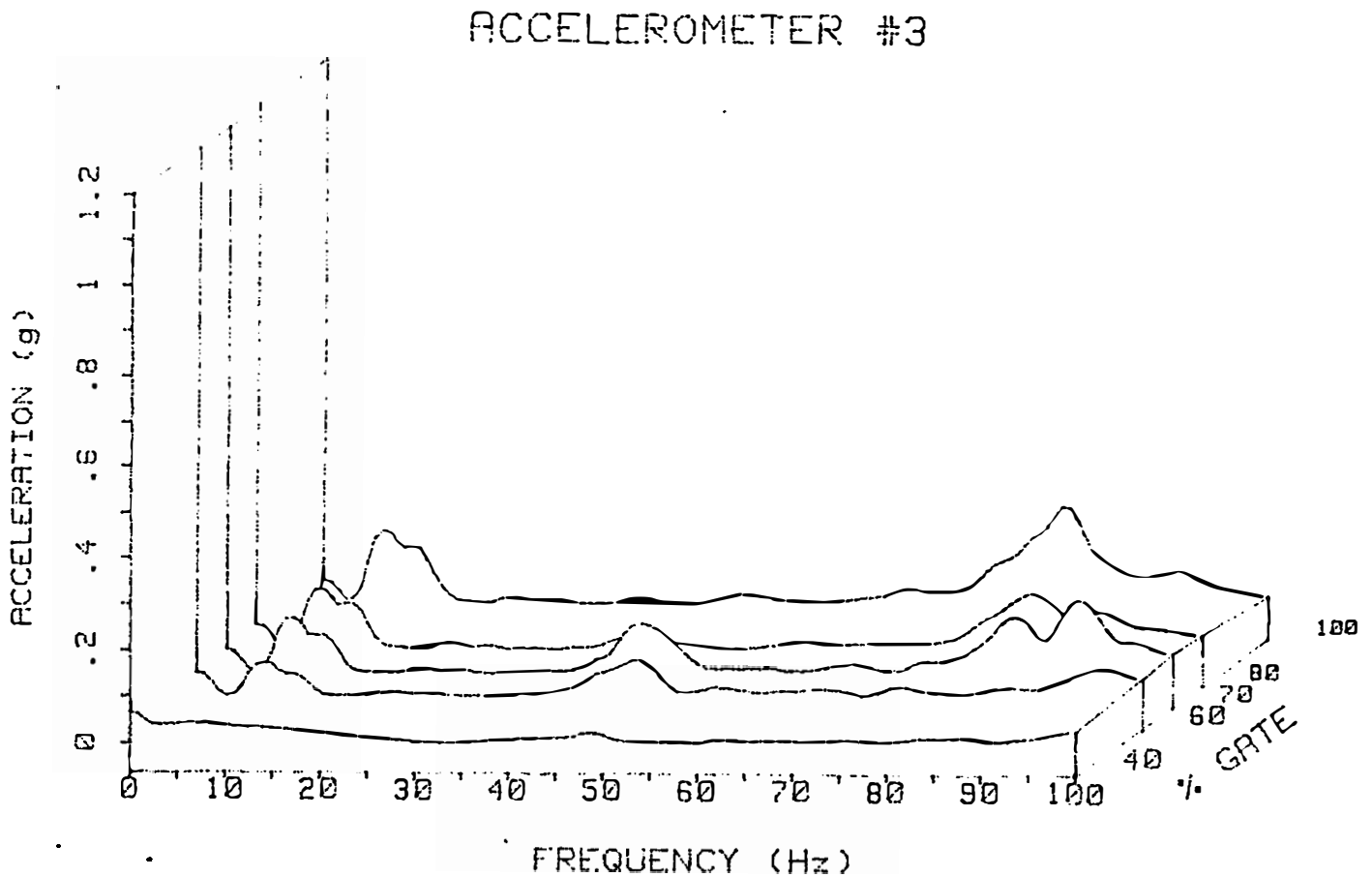

ACCELEROMETER #3
ACCELERATION (g)
0
.2
.4
.6
.8
1
1.2
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
40
60
70
80
100
% GATE

Figure 6

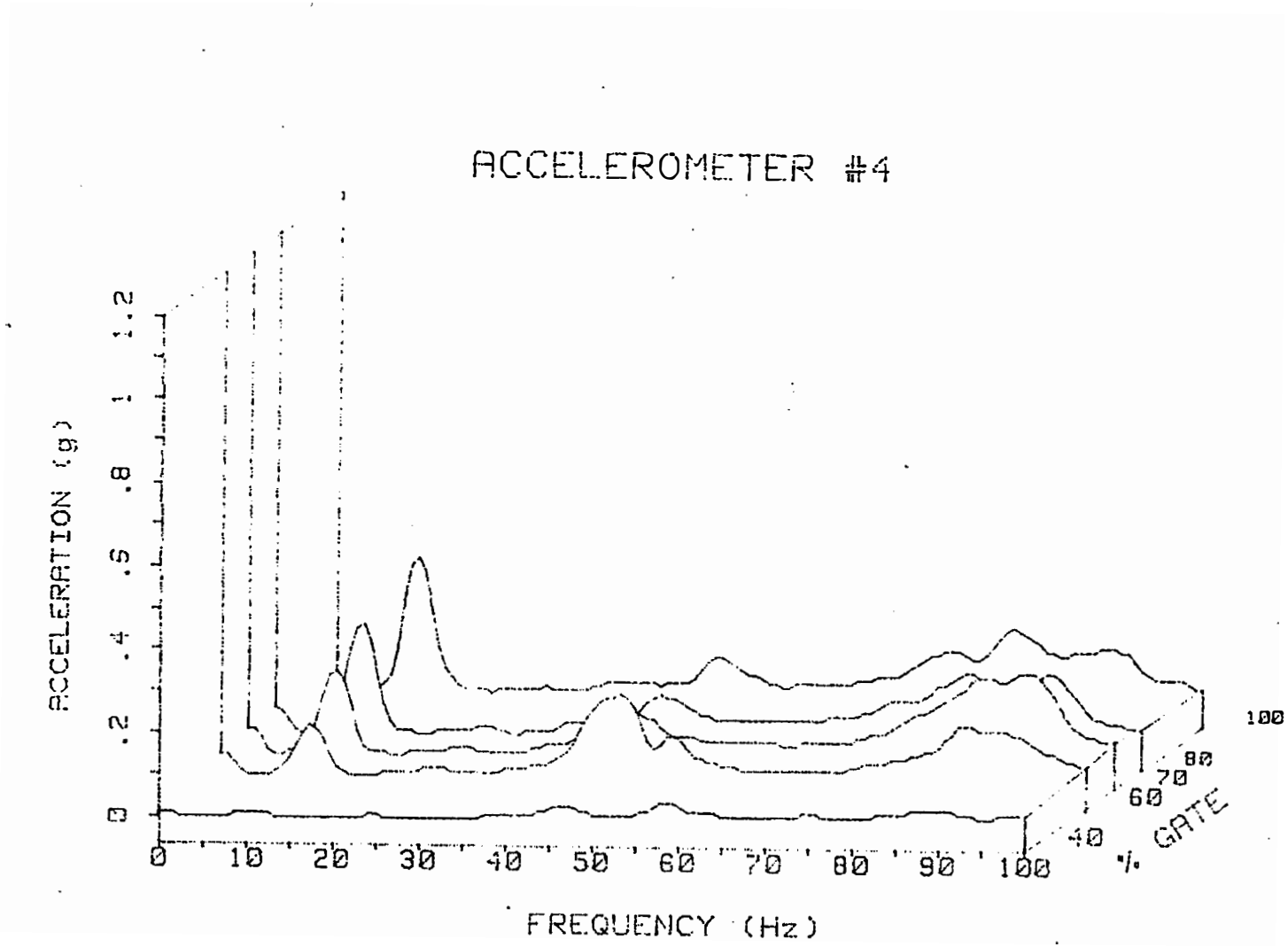

ACCELEROMETER #4
ACCELERATION (g)
0
.2
.4
.5
.8
1
1.2
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
40
60
70
80
100
GATE
%

Figure 7

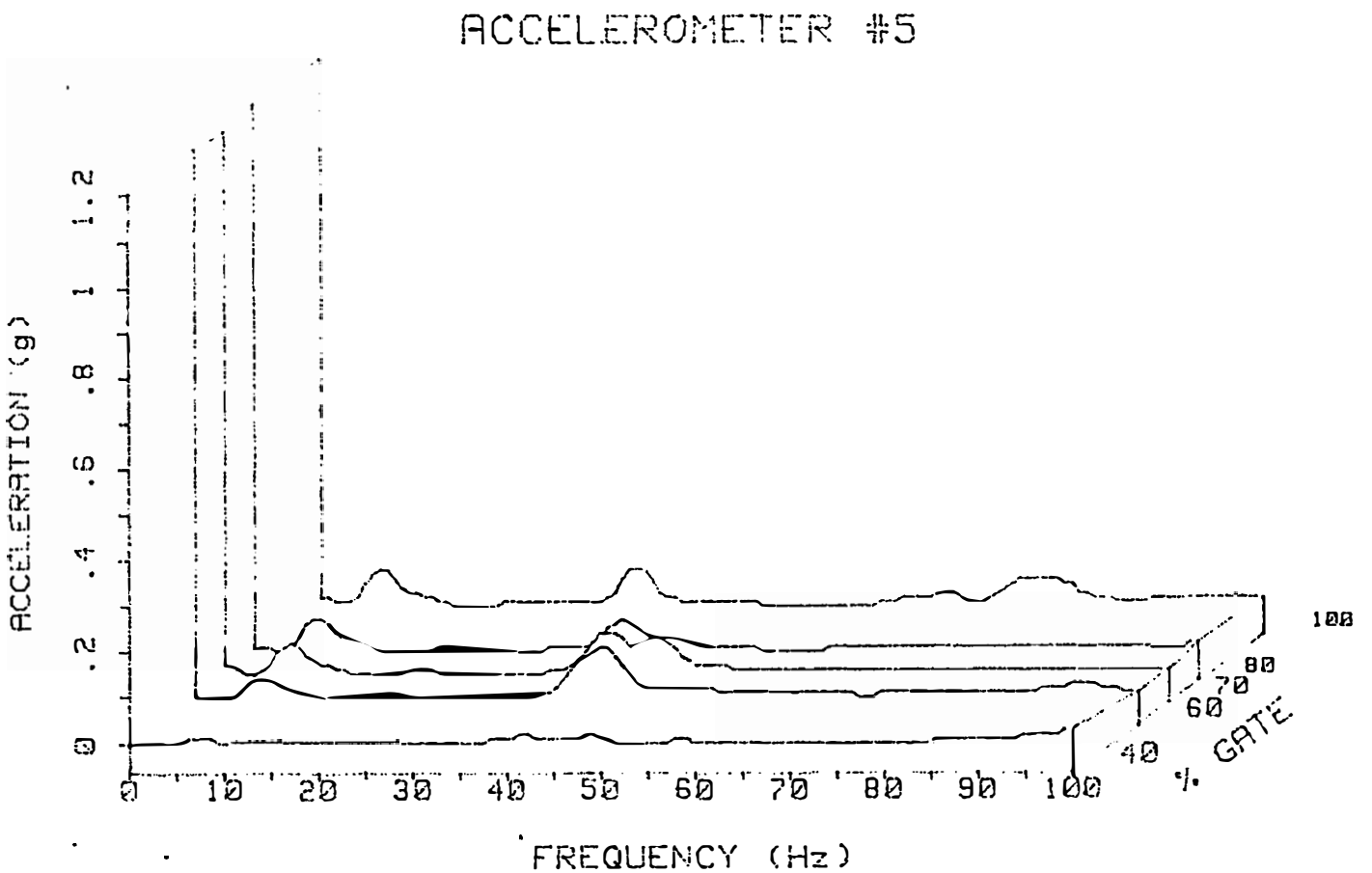

ACCELEROMETER #5
ACCELERATION (g)
0
.2
.4
.6
.8
1
1.2
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
100
80
70
60
40
% GATE

Figure 8

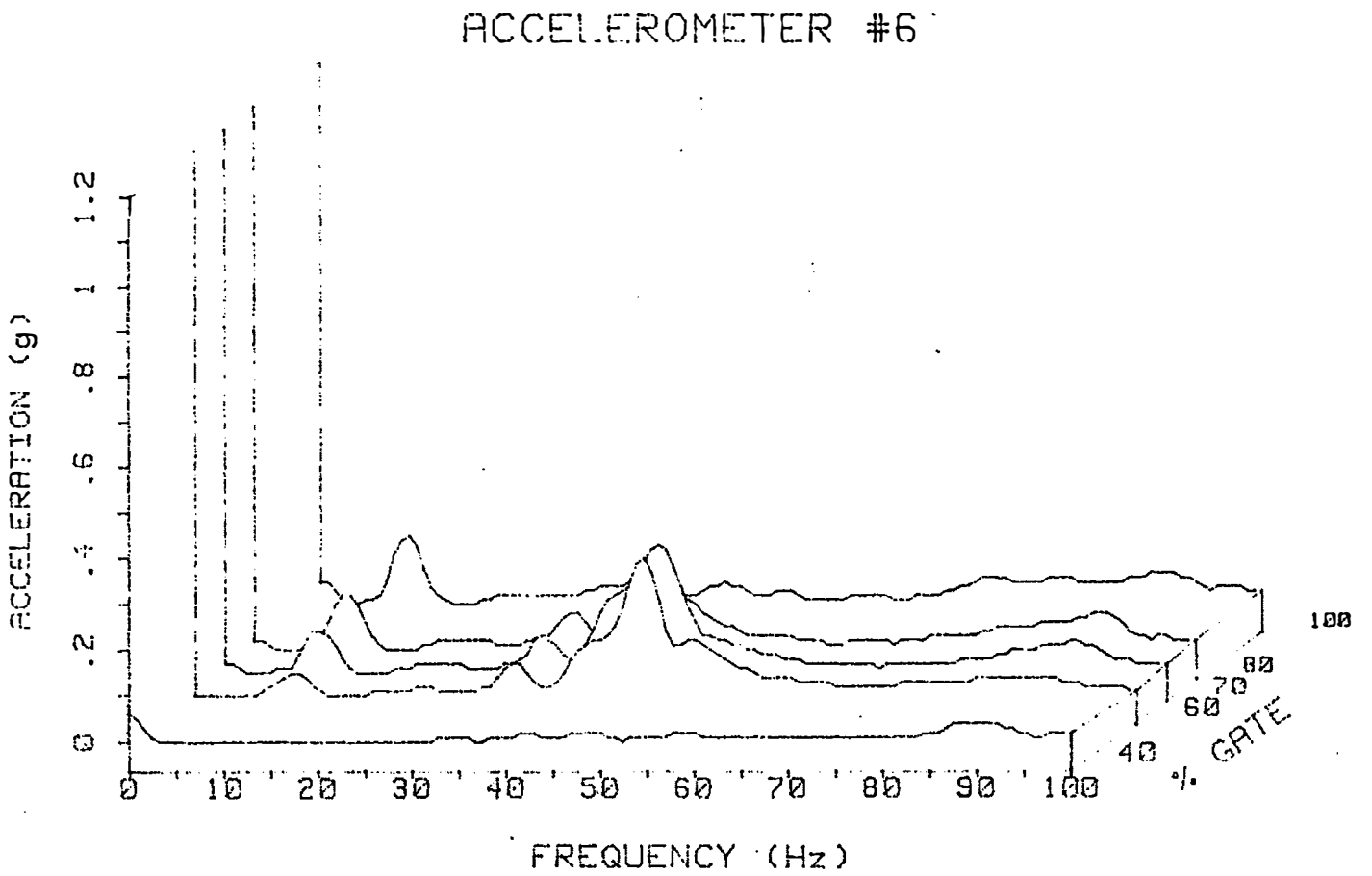
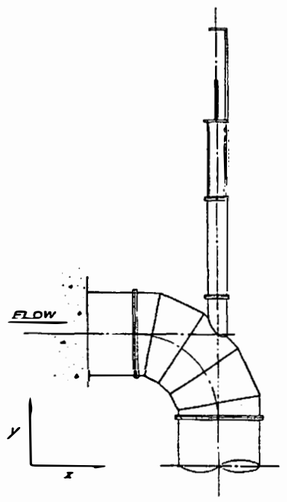
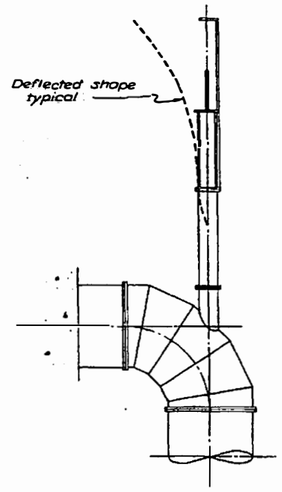

ACCELEROMETER #6
ACCELERATION (g)
0
.2
.4
.6
.8
1
1.2
0
10
20
30
40
50
60
70
80
90
100
%
FREQUENCY (Hz)
40
60
70
80
100
GATE

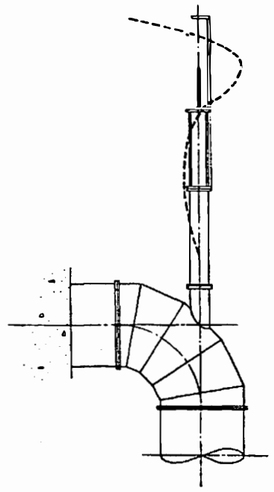
Figure 9



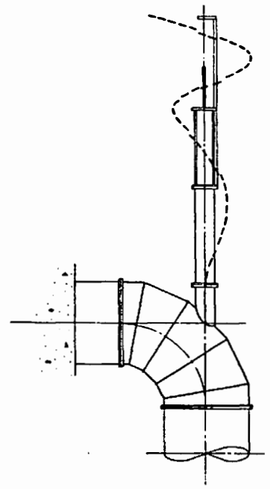
ELEVATION
XY PLANE



FIRST MODE, XY PLANE
fn THEORY = 7.9 Hz
fn TEST = 7.2 Hz



THIRD MODE, XY PLANE
fn THEORY = 50.6 Hz
fn TEST = 46.0 Hz



FOURTH MODE, XY PLANE
fn THEORY = 78.7 Hz
fn TEST = 76.0 Hz

NOMENCLATURE

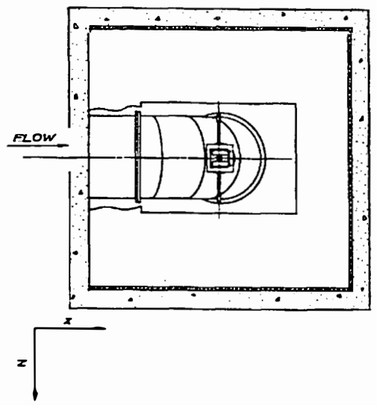
fn THEOR = Theoretical natural frequency. Obtained from STR5 program.
fn TEST = Natural frequency obtained from test.
Hz = Cycles per second, Hertz.

NOTES

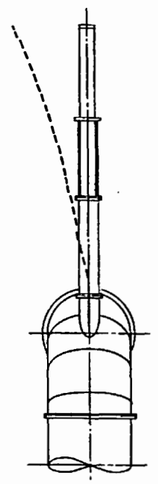
To obtain the theoretical natural frequencies and modal shapes of the sleeve valve, a finite element model of the sleeve valve was made. A Bureau of Reclamation finite element program, STR5, was used for the analysis. STR5 is a structural analysis program for static and dynamic analysis of linearly elastic systems.
Correlation between the theoretical and test modal shapes was obtained by consideration of the phase angles between accelerometers, see drawing D-252-321.

REFERENCE DRAWING

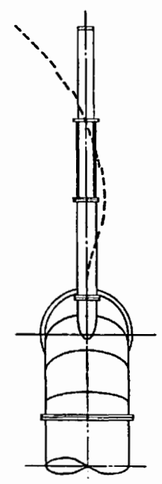
OUTLET WORKS -
1372 MILLIMETERS SLEEVE VALVE -
INSTALLATION - LIST OF DRAWINGS D-252-321



PLAN
X Z PLANE



FIRST MODE, YZ PLANE
fn THEORY = 10.95 Hz
fn TEST = 10.4 Hz



SECOND MODE, YZ PLANE
fn THEORY = 47.85 Hz
fn TEST = 30.0 Hz

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AUBURN-FOLSOM SOUTH UNIT-CALIFORNIA

SUGAR PINE DAM
OUTLET WORKS
1372 MILLIMETER SLEEVE VALVE
MODAL SHAPES AND NATURAL FREQUENCIES

DESIGNED K.V. ... TECHNICAL APPROVAL
DRAWN ... SUBMITTED
CHECKED ... APPROVED
CHIEF, MECHANICAL BRANCH
DENVER, COLORADO FEB. 22, 1985
SHEET 1 OF 1
D - 252 - 322

FIG. 10

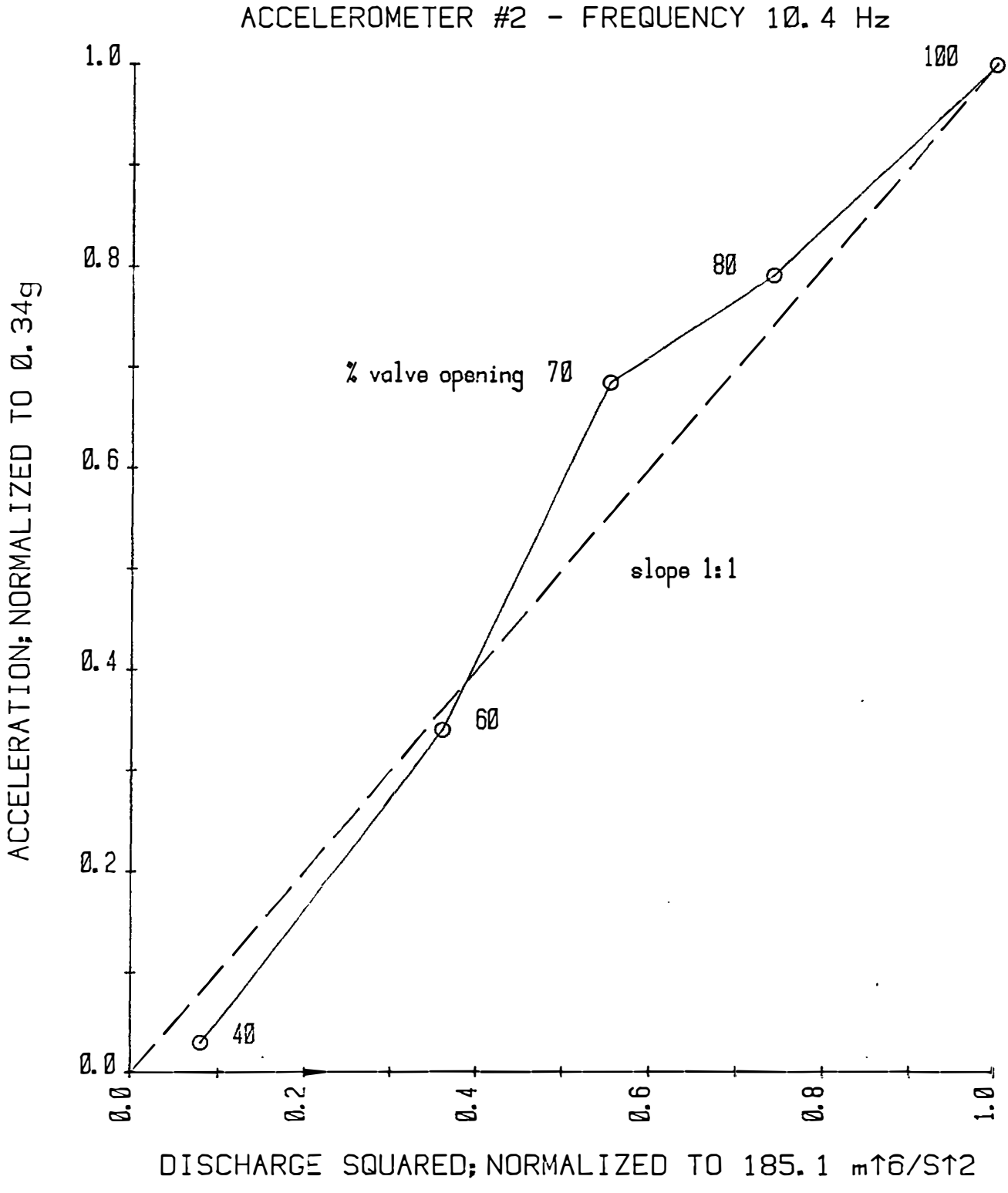

ACCELEROMETER #2 - FREQUENCY 10.4 Hz
ACCELERATION; NORMALIZED TO 0.34g
DISCHARGE SQUARED; NORMALIZED TO 185.1 m↑6/S↑2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
100
80
% valve opening 70
60
40
slope 1:1

Figure 11

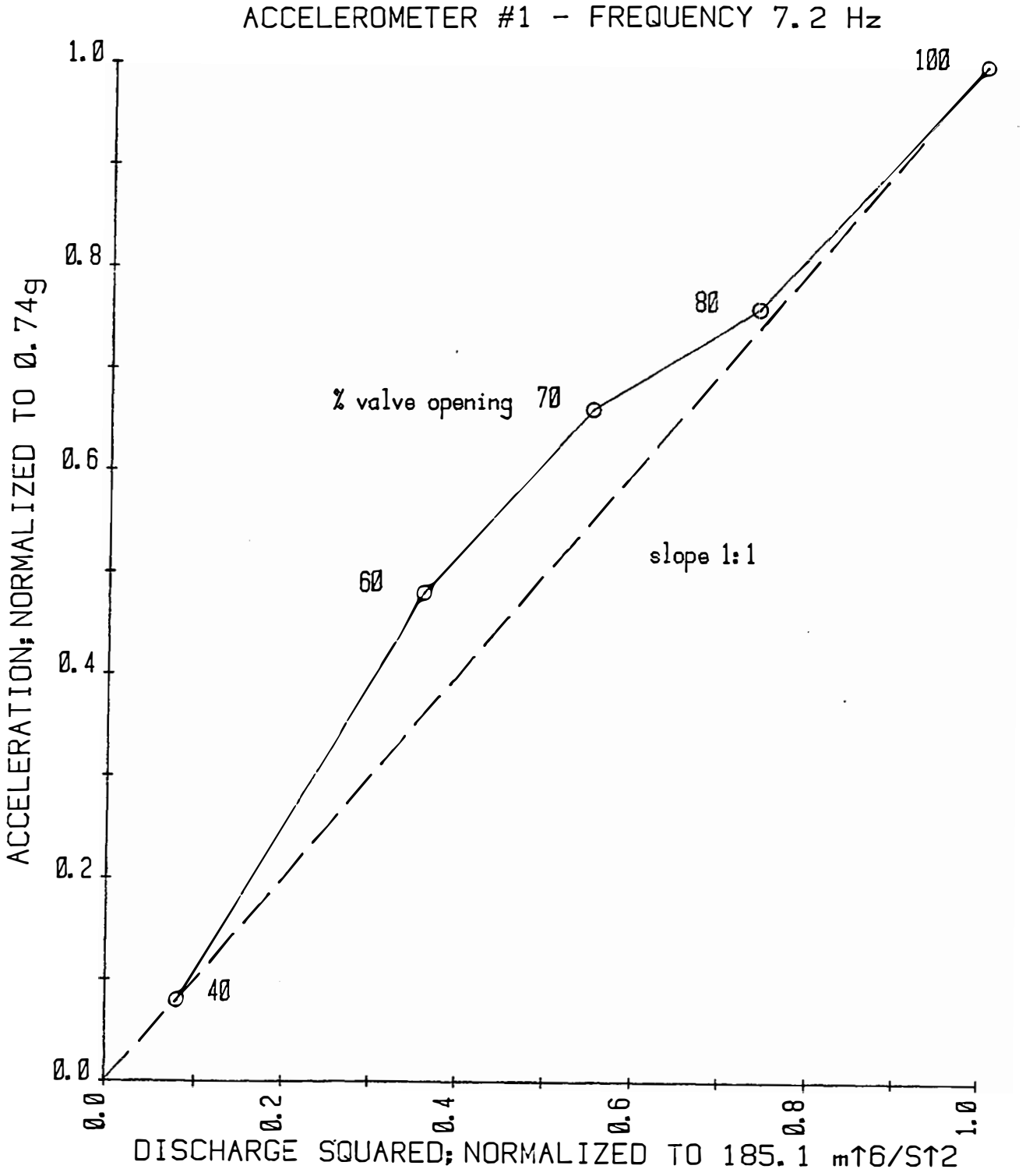

ACCELEROMETER #1 - FREQUENCY 7.2 Hz
ACCELERATION; NORMALIZED TO 0.74g
1.0
0.8
0.6
0.4
0.2
0.0
100
80
% valve opening 70
60
40
slope 1:1
0.0
0.2
0.4
0.6
0.8
1.0
DISCHARGE SQUARED; NORMALIZED TO 185.1 m↑6/S↑2

Figure 12

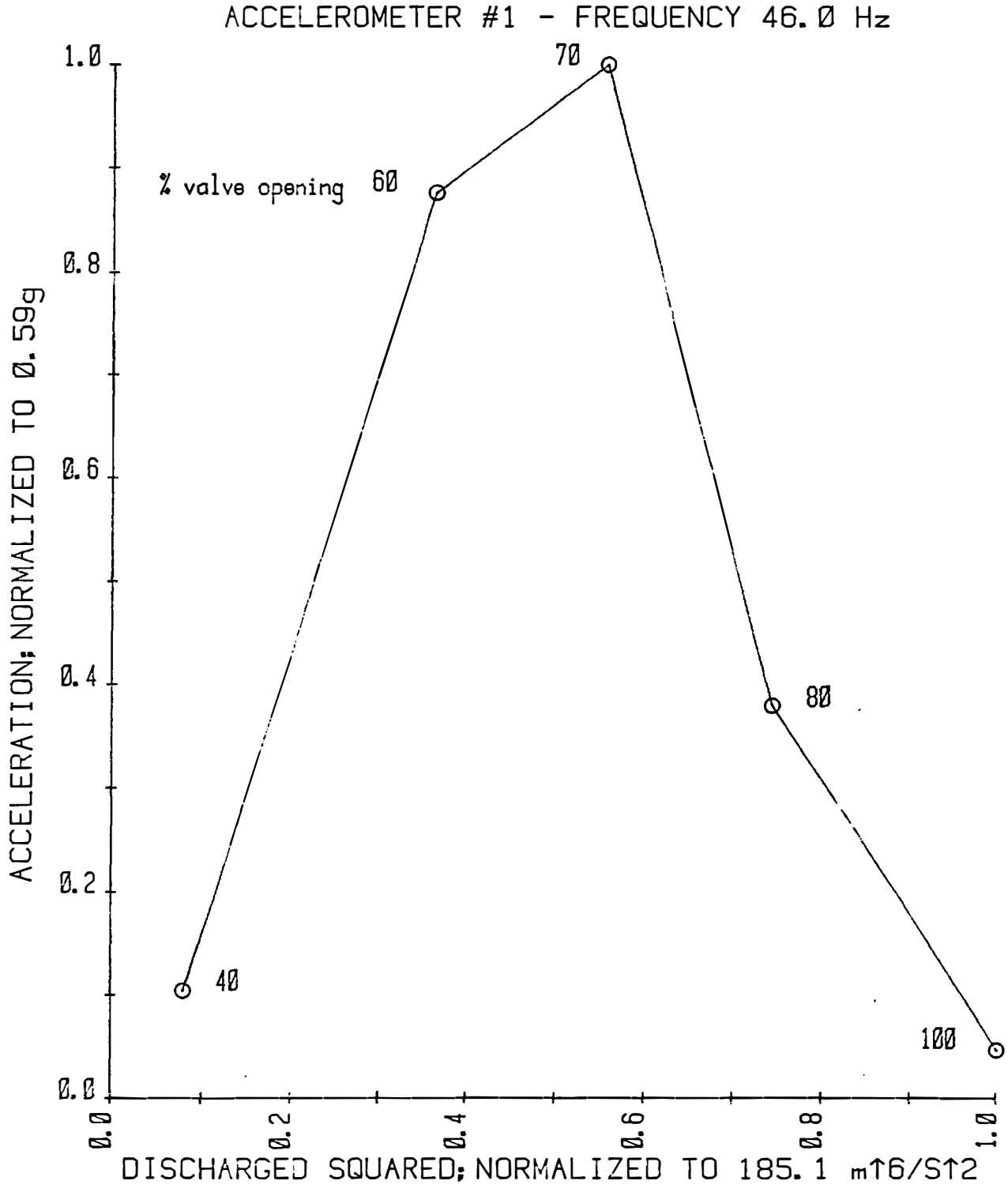

ACCELEROMETER #1 - FREQUENCY 46.0 Hz
% valve opening
40
60
70
80
100
1.0
0.8
0.6
0.4
0.2
0.0
ACCELERATION; NORMALIZED TO 0.59g
0.0
0.2
0.4
0.6
0.8
1.0
DISCHARGED SQUARED; NORMALIZED TO 185.1 m↑6/S↑2

Figure 13

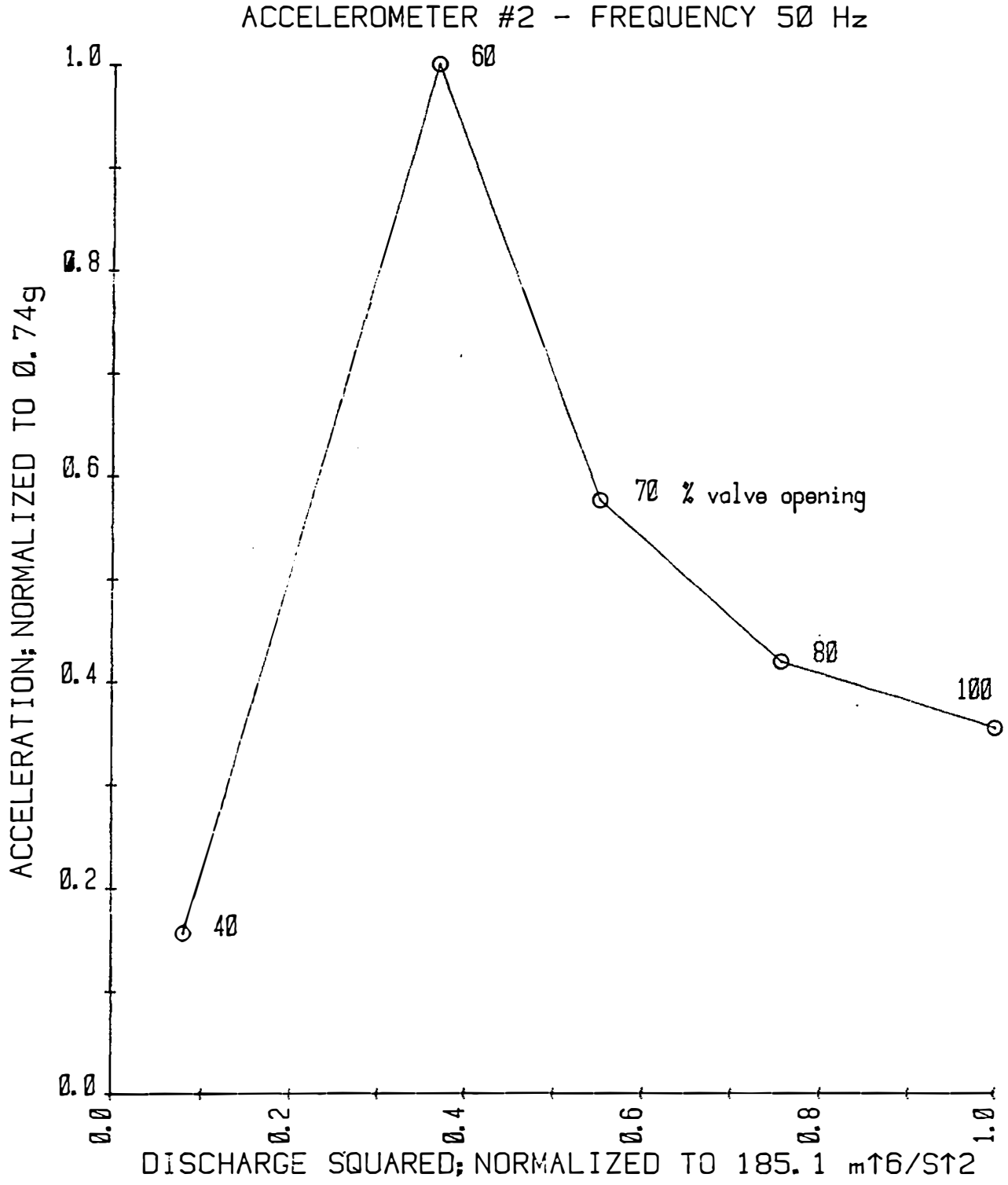
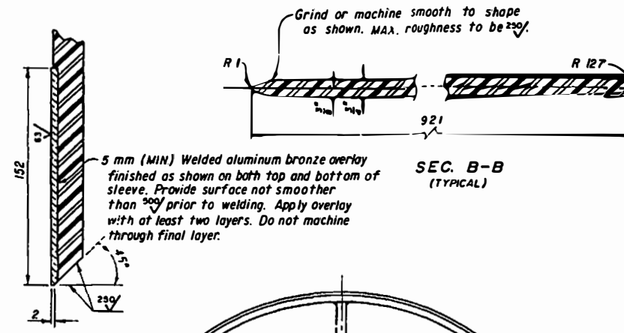
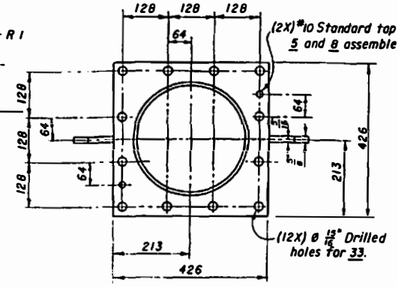
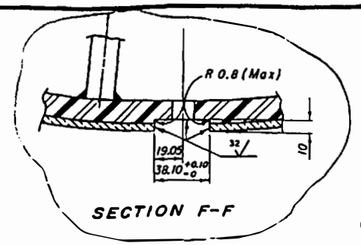
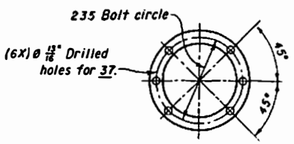

ACCELEROMETER #2 - FREQUENCY 50 Hz
ACCELERATION; NORMALIZED TO 0.74g
1.0
0.8
0.6
0.4
0.2
0.0
60
70 % valve opening
80
100
40
0.0
0.2
0.4
0.6
0.8
1.0
DISCHARGE SQUARED; NORMALIZED TO 185.1 m↑6/S↑2

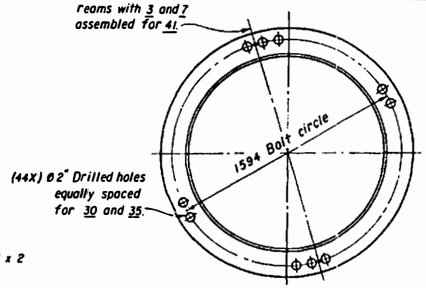
Figure 14

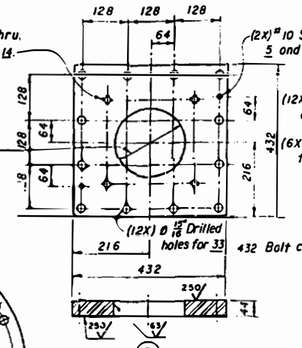


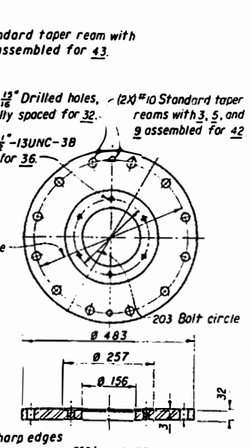


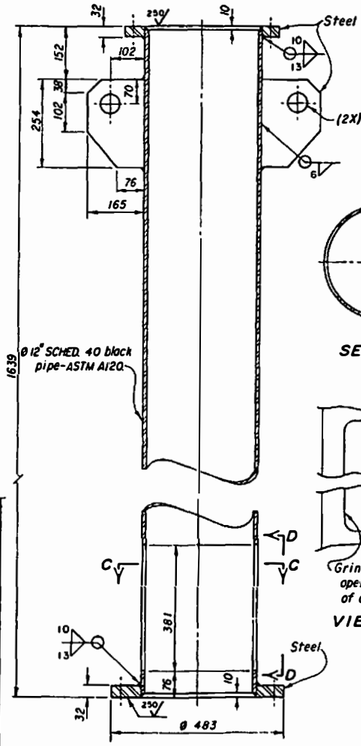


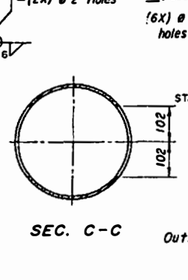


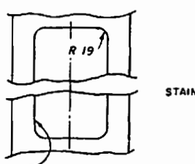


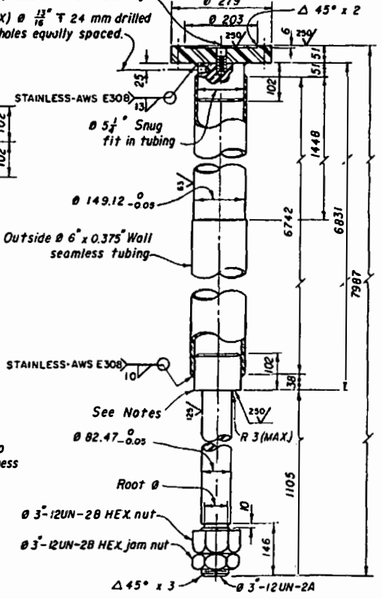


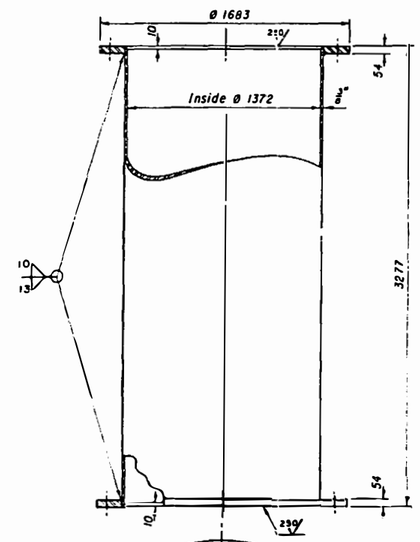


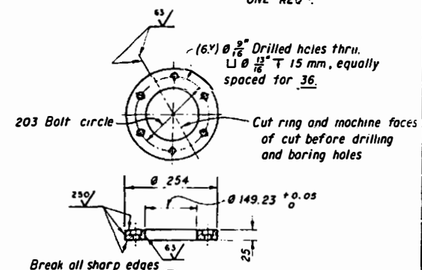


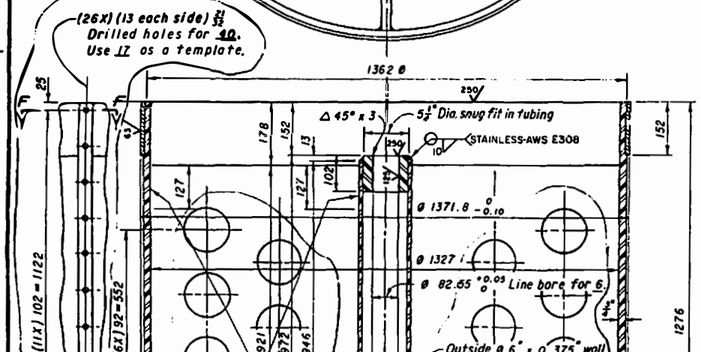


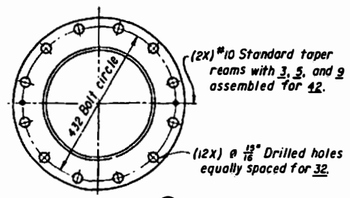


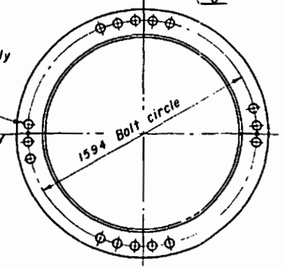












NOTES

Unless otherwise noted break all sharp edges and corners.
Dimensions, unless otherwise shown, are in millimeters.
All surface textures are in microinches.
All cylindrical parts may be rolled from flat plates and joined with full strength welds.

DRAWING NOT TO SCALE

6-10-83 D-R.Y.D.	KEYSEATS AND HOLES IN SPLITTERS ADDED TO SLEEVE, PART 4.

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT
AUBURN-FOLSOM SOUTH UNIT CALIFORNIA

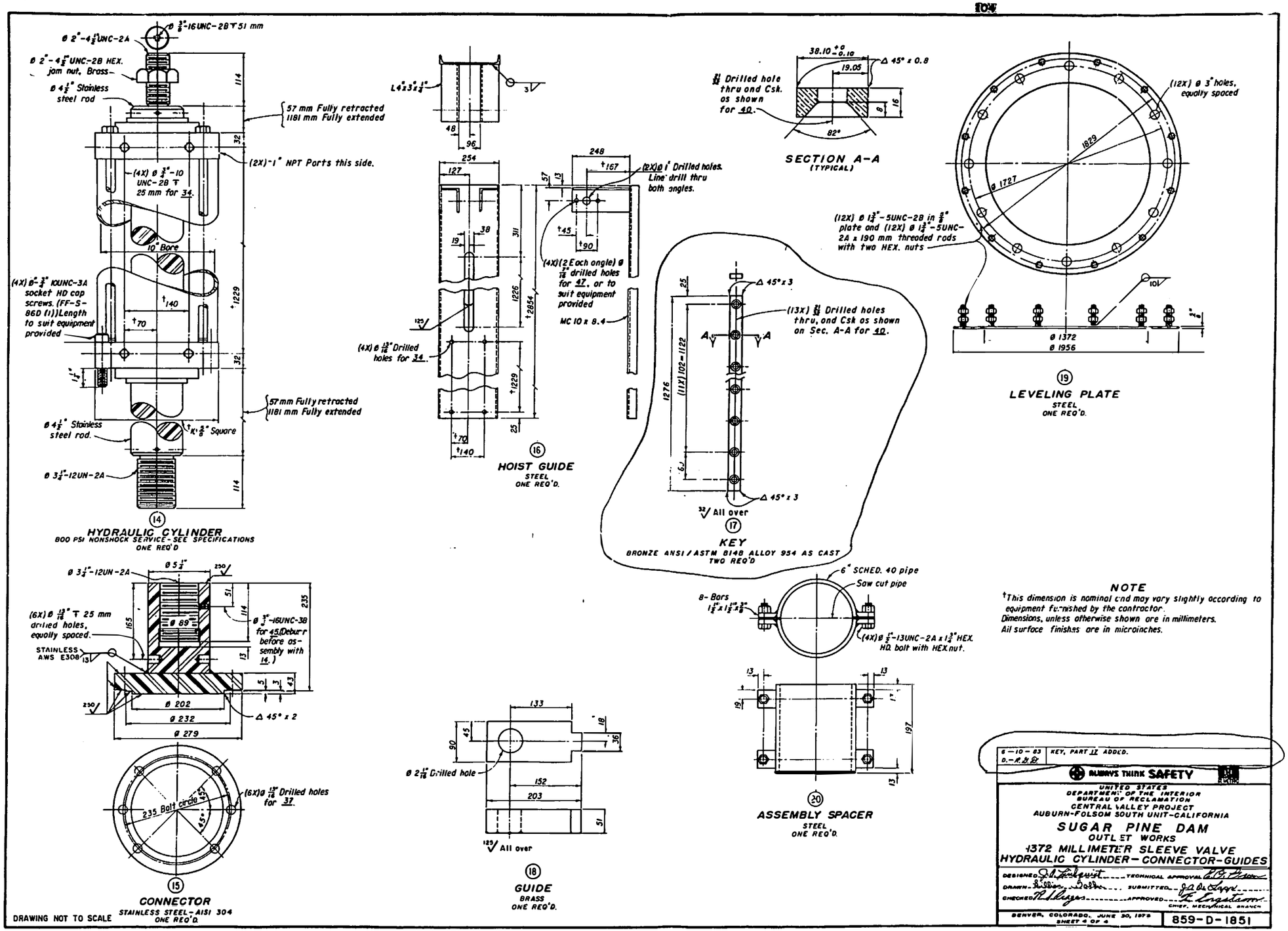
SUGAR PINE DAM
OUTLET WORKS
1372 MILLIMETER SLEEVE VALVE SLEEVE-STAND-STEM-SPOOL

DESIGNED		TECHNICAL APPROVED	
DRAWN	T.C. Mc Clure	SUBMITTED	
CHECKED		APPROVED	CHIEF, DESIGN BRANCH

DENVER, COLORADO, JUNE 30, 1978
SHEET 3 OF 4

859-D-1850

FIG. 15



DRAWING NOT TO SCALE

NOTE

†This dimension is nominal and may vary slightly according to equipment furnished by the contractor.
Dimensions, unless otherwise shown are in millimeters.
All surface finishes are in microinches.

6-10-83 D.-R.H.D.	KEY, PART 17 ADDED.

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT
AUBURN-FOLSOM SOUTH UNIT-CALIFORNIA

SUGAR PINE DAM
OUTLET WORKS
1372 MILLIMETER SLEEVE VALVE
HYDRAULIC CYLINDER-CONNECTOR-GUIDES

DESIGNED J.A. Lindquist — TECHNICAL APPROVAL E.B. Green
DRAWN Gillian Gallo — SUBMITTED J.A. DeLapp
CHECKED R.H. Rogers — APPROVED E. Engstrom, CHIEF, MECHANICAL BRANCH

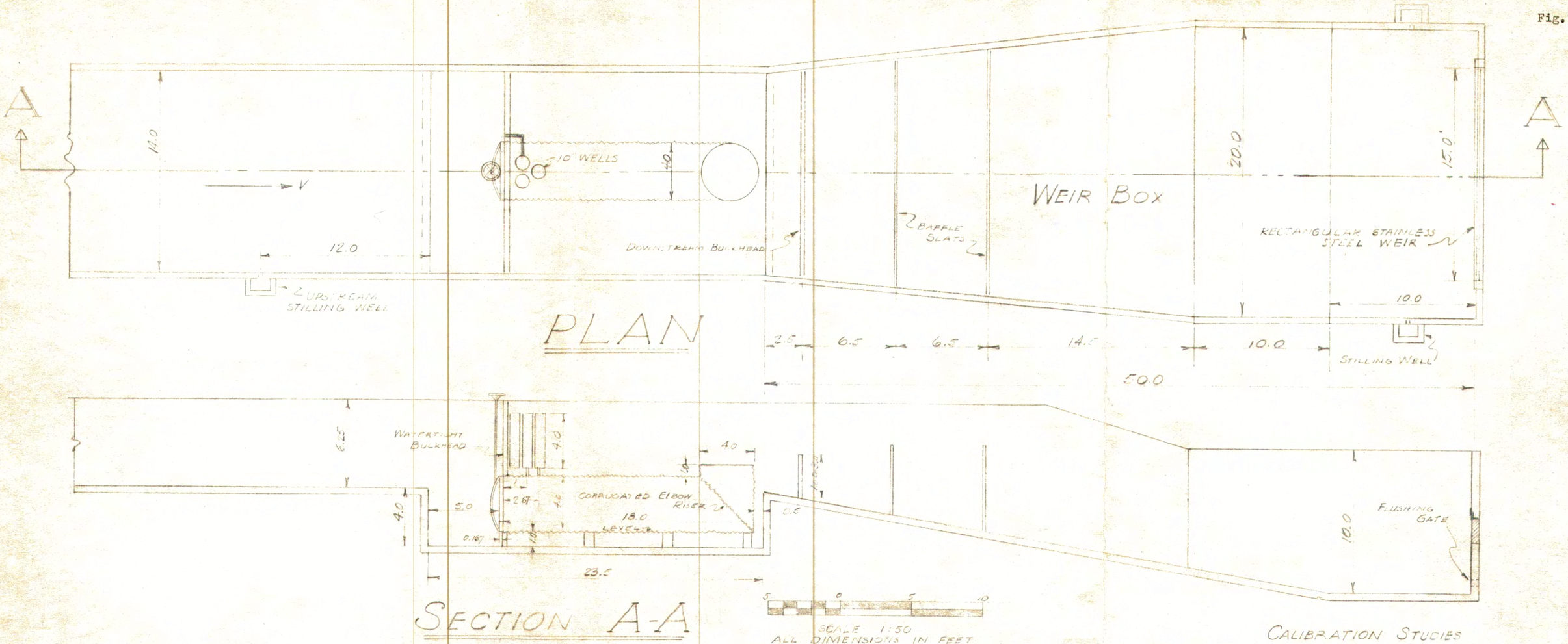
DENVER, COLORADO, JUNE 30, 1975
SHEET 4 OF 4

859-D-1851

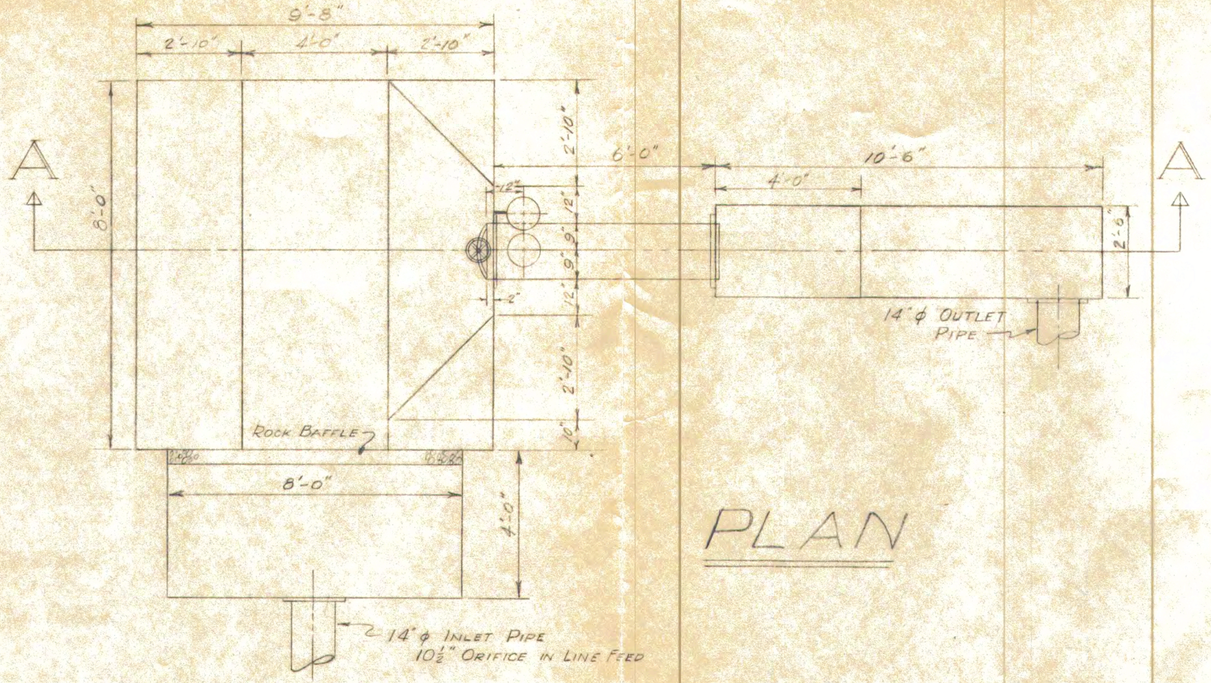
FIG. 16

M DEC 28 78

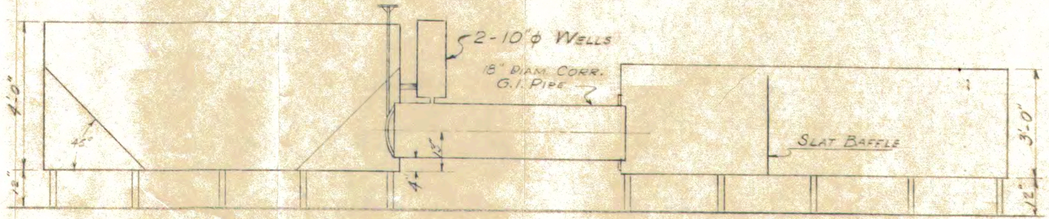
Fig. 4



CALIBRATION STUDIES
OF
48-in. ARMCO METERGATE MODEL No. 101
COLORADO A&M COLLEGE
HYDRAULICS LABORATORY
FORT COLLINS, COLO. DECEMBER, 1950.

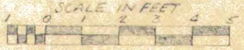


PLAN



SECTION A-A

CALIBRATION STUDIES
OF
18-in ARMCO METERGATE; MODEL No. 101
COLORADO A&M COLLEGE
HYDRAULICS LABORATORY
FORT COLLINS, COLO. DECEMBER, 1950



SCALE: 1"=30"

Variation of Coefficient of Discharge with Relative Opening of Metergate

$$C = \frac{Q}{A\sqrt{2g\Delta h}}$$

Note:

a = gate opening
D = diameter of pipe
A = area of gate
Δh = head difference with well at X = 12"

Gate Size: 8 in, 10 in, 12 in, 15 in, 18 in, 24 in, 30 in, 36 in, 45 in

2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03

0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

$\frac{a}{D}$

Calibration Studies
of
Armco Metergates Model No. 101
Colorado A&M College
Hydraulics Laboratory
Fort Collins, Colo. December, 1950