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AD-A207 056

MISCELLANEOUS PAPER HL-89-1

LOWER GRANITE FISH GUIDANCE EFFICIENCY STUDY SNAKE RIVER, WASHINGTON

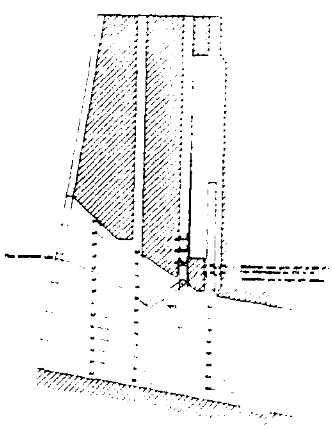
Hydraulic Model Investigation

by

Robert A. Davidson

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39181-0631



U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION

April 1989

Final Report

Approved For Public Release: Distribution Unlimited

HYDRAULICS LABORATORY

Prepared for US Army Engineer District, Walla Walla
Walla Walla, Washington 99362-9265

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Miscellaneous Paper HL-89-1	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION USAEWES Hydraulics Laboratory — 6b. OFFICE SYMBOL (If applicable) CEWES-HS-L	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) PO Box 631 Vicksburg, MS 39181-0631	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION USAED, Walla Walla — 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Building 602, City-County Airport Walla Walla, WA 99362-9265	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Lower Granite Fish Guidance Efficiency Study, Snake River, Washington; Hydraulic Model Investigation

12. PERSONAL AUTHOR(S)
Davidson, Robert A.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final report	FROM ______ TO ______	April 1989	84

16. SUPPLEMENTARY NOTATION
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Flow intercept; Juvenile salmon bypass systems; Powerhouses; Submerged traveling screens

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

Each year the adult salmon migrate up the Columbia and Snake rivers to spawn. Their offspring (juvenile salmon) must migrate to the ocean along the same path as their parents did. With the damming of the rivers for navigation and hydropower, the salmon encountered new obstacles. The juvenile salmon had to pass through the powerhouses on their trip to the ocean. Systems that diverted the juvenile salmon away from the turbines were designed. The system developed for the Lower Granite Powerhouse is not performing near its anticipated level. Tests were conducted on a 1:25-scale one-bay intake unit model to improve the fish guidance efficiency of the juvenile bypass system. Modifications to the submerged traveling screen, different positions of the emergency closure gate, blocked trashracks, and various other modifications in the vicinity of the submerged traveling screen were tested to achieve this purpose. The modification that showed the most

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20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

19. ABSTRACT (Continued).

potential for improving the fish guidance efficiency consisted of the extended submerged traveling screen lowered 4 ft from the current position with the false gap device in place and the emergency closure gate raised 20 ft.

[illegible]

[illegible] Little Goose Dam, Lower Granite Dam [illegible]

PREFACE

The model investigation reported herein was authorized by the Headquarters, US Army Corps of Engineers, on 1 October 1984 at the request of the US Army Engineer District, Walla Walla (NPW).

The model tests were accomplished during the period January 1985 to March 1987 in the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, under the general supervision of Messrs. F. A. Herrmann, Jr., Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., and G. A. Pickering, past and present Chiefs, respectively, of the Hydraulic Structures Division, and under the direct supervision of Mr. John F. George, Chief of the Locks and Conduits Branch. The tests were conducted by Messrs. R. A. Davidson and R. G. Frazier, Locks and Conduits Branch. This report was prepared by Mr. Davidson and edited by Mrs. M. C. Gay, Information Technology Laboratory, WES.

Personnel from NPW; US Army Engineer Division, North Pacific; the Oregon Fish and Wildlife Agency; and the National Marine Fisheries Services visited WES to observe model operation and discuss test results.

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

CONTENTS

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

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

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	25.4	millimetres
miles (US statute)	1.609344	kilometres
square feet	0.09290304	square metres

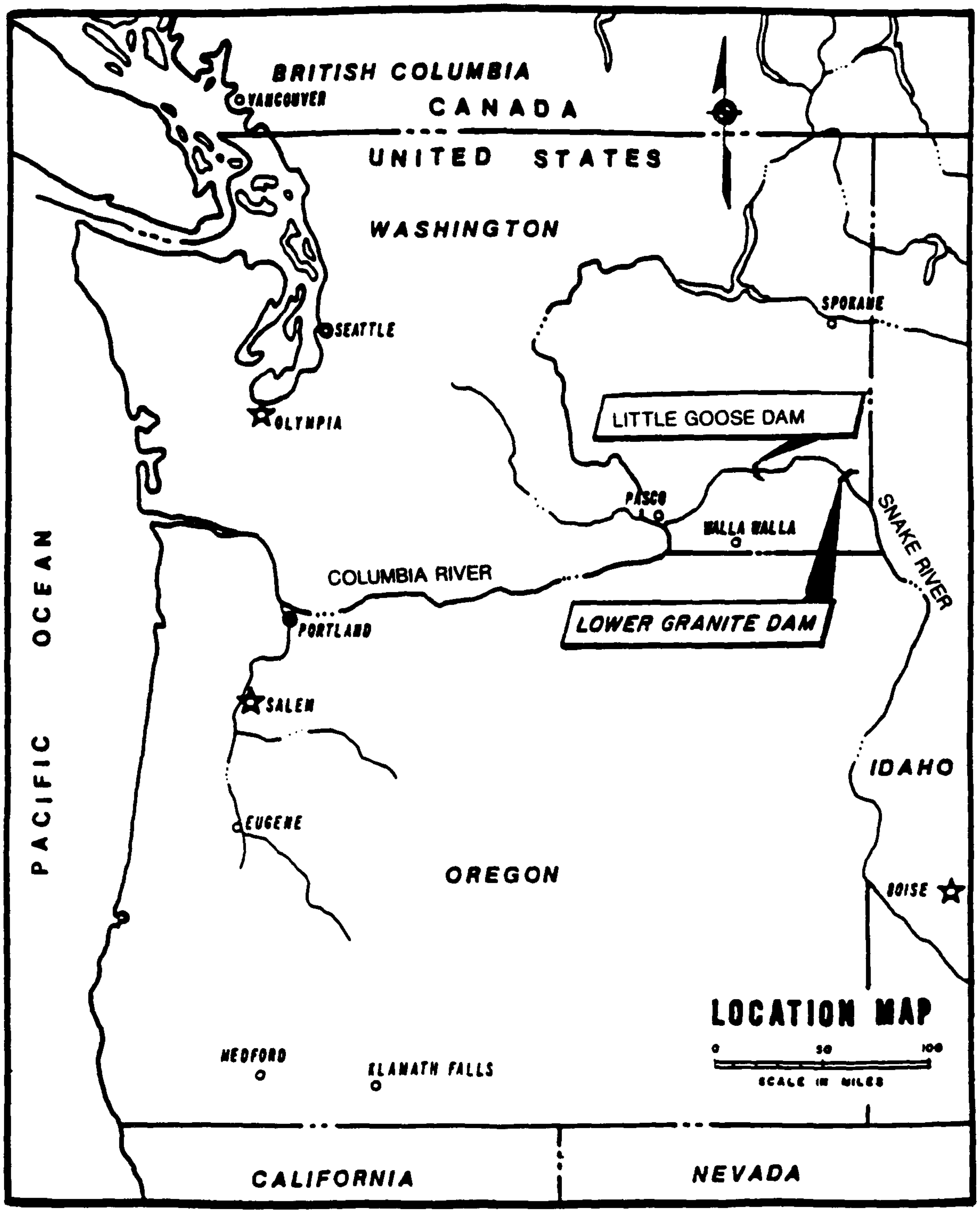

Figure 1. Location map

LOWER GRANITE FISH GUIDANCE EFFICIENCY STUDY

SNAKE RIVER, WASHINGTON

Hydraulic Model Investigation

PART I: INTRODUCTION

Background

1. The Lower Granite Project is located on the Snake River 37.2 miles* upstream from Little Goose Dam and 107.5 miles upstream from the confluence of the Snake and Columbia rivers (Figure 1). The project consists of an eight-bay tainter-gate-controlled spillway, a six-unit powerhouse having an overload capacity of 931,500 kw, an 86-ft-wide by 675-ft-long navigation lock, and a 20-ft-wide fish ladder (Figure 2).

2. The US Army Corps of Engineers eight hydroelectric projects on the Lower Columbia and Snake rivers have been identified as a major factor contributing to mortality of downstream-migrating juvenile salmon and steelhead. The Corps has recognized the need to reduce juvenile fish mortality and has undertaken bypass measures. These measures include transporting fish by barge and truck around the projects, flushing fish through ice/trash sluiceways, and operating mechanical bypass systems at five projects. At projects without mechanical bypass and those projects where these facilities do not work as prescribed, the Corps has passed large quantities of water over the spillways. However, spilling required to bypass juvenile fish results in significant loss of power revenues. To reduce the amount of spilling required and improve migrant bypassing, the Districts of the US Army Engineer Division, North Pacific, have initiated a major research program. This model study is one element of that effort.

Purpose of the Model Study

3. The Juvenile Bypass System (JBS), designed to intercept the juvenile salmon that pass through the Lower Granite Powerhouse, is not performing at

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

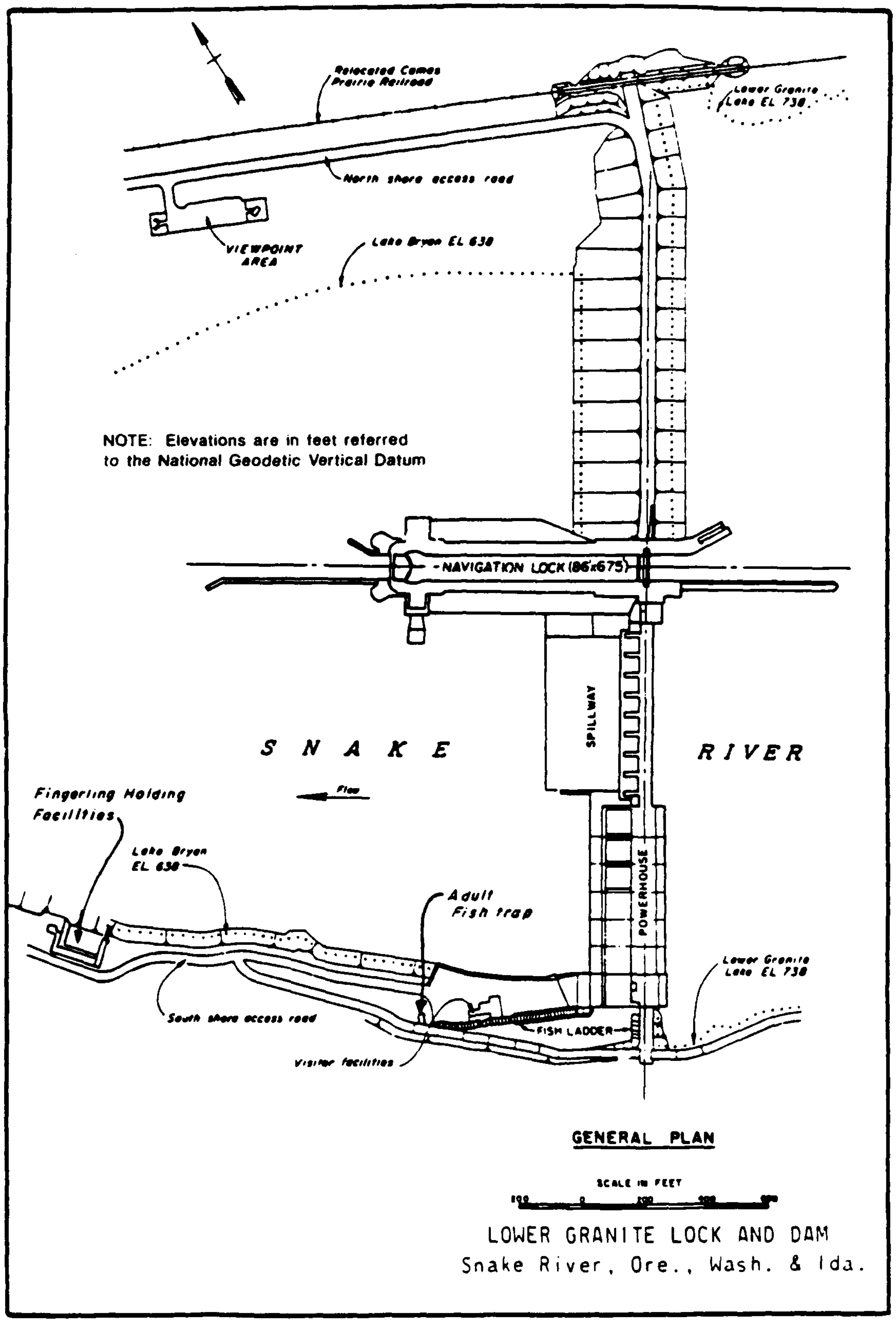


Figure 2. Project layout

its anticipated level, which has resulted in a greater number of juvenile salmon passing through the turbines instead of being diverted around them. The US Army Engineer District, Walla Walla, requested the US Army Engineer Waterways Experiment Station (WES) to conduct a model investigation on a section of the Lower Granite Powerhouse for the purpose of improving the fish guidance efficiency (FGE) of the JBS.

PART II: THE MODEL

Description

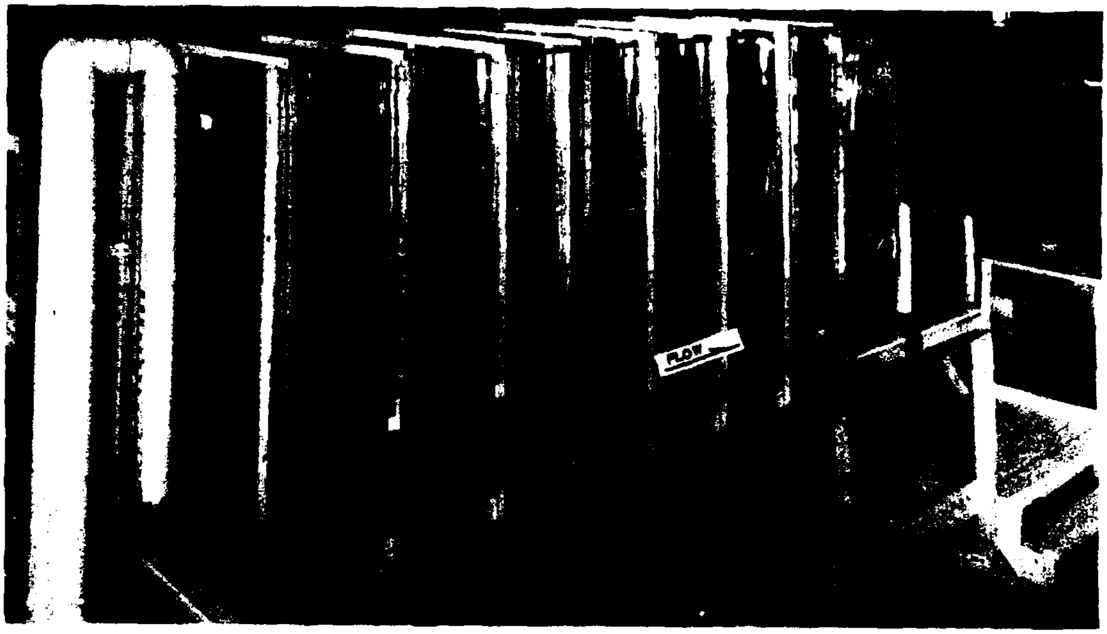
4. Previous model studies of the Lower Granite structure were conducted by Engineering Hydraulics, Inc., in Longmont, CO. The 1:25-scale one-bay intake unit with the submerged traveling screen (STS) and the vertical barrier screen (VBS) that was used in the previous model studies was supplied to WES for use in this model study. The upstream approach area, the trashracks, and the emergency closure gate were constructed by personnel of WES. General views of the model are shown in Figure 3. The model itself was constructed of transparent plastic for visual observations with the upstream topography constructed of plywood. The trashracks (Figure 4) and the emergency closure gate (Figure 5, Plate 1) were constructed of brass.

5. The JBS (Figure 6) consists of an STS, a bulkhead slot, a VBS, a pair of orifices, and a collection channel. The STS intercepts the flow in the upper portion of the intake where a large percentage of juveniles are located. The fish are then guided into a bulkhead slot and up to the two orifices, which pass the fish into a collection channel. The fish are then transported to the holding facility at the tailrace level. The VBS (Figure 7 shows the probable configuration of the VBS) prevents the fish from passing into the emergency gate slot and back into the intake.

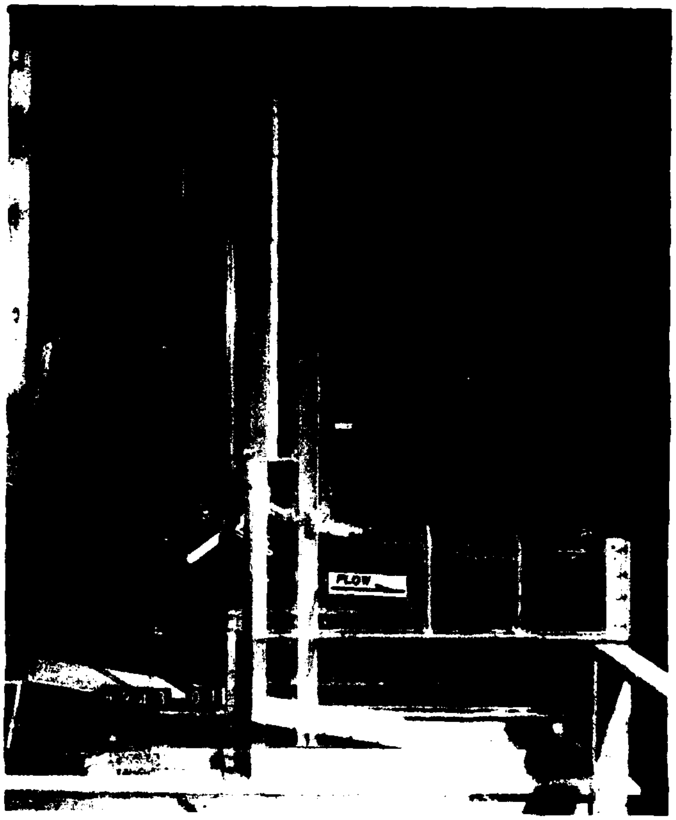
Appurtenances

6. Water was supplied to the model through a circulating system. Model discharge was measured by two industrial flowmeters. The upper pool was controlled by a valve downstream of the model.

7. Velocities were measured initially in five locations: downstream of the trashracks, immediately upstream of the STS, downstream from the STS, above the STS, and in the emergency closure gate slot. At each location, three velocity measurements, each at four positions, were obtained along the width of the intake structure. Each velocity point shown in the plates presenting velocity vectors is the average of 12 velocity measurements recorded at the 5 locations. The velocities obtained from the model were measured with a Nixon velocity meter. The velocity probes used were directional,



a. Overall view looking downstream



b. Intake structure

Figure 3. General views of model

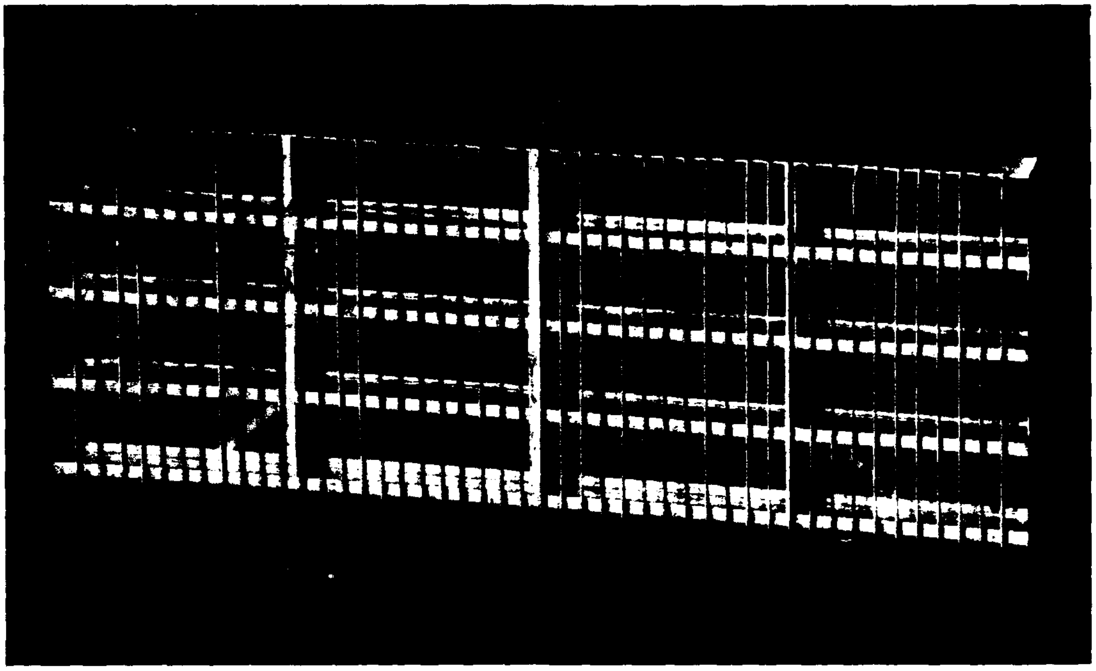


Figure 4. Typical trashrack section

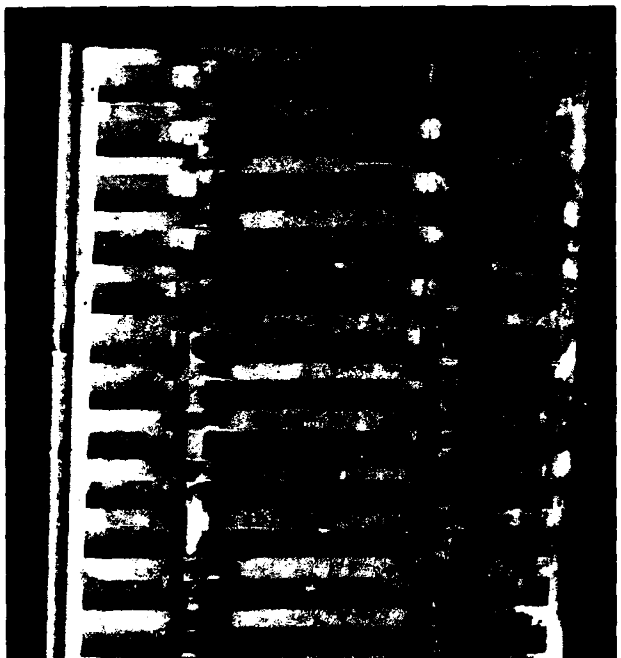
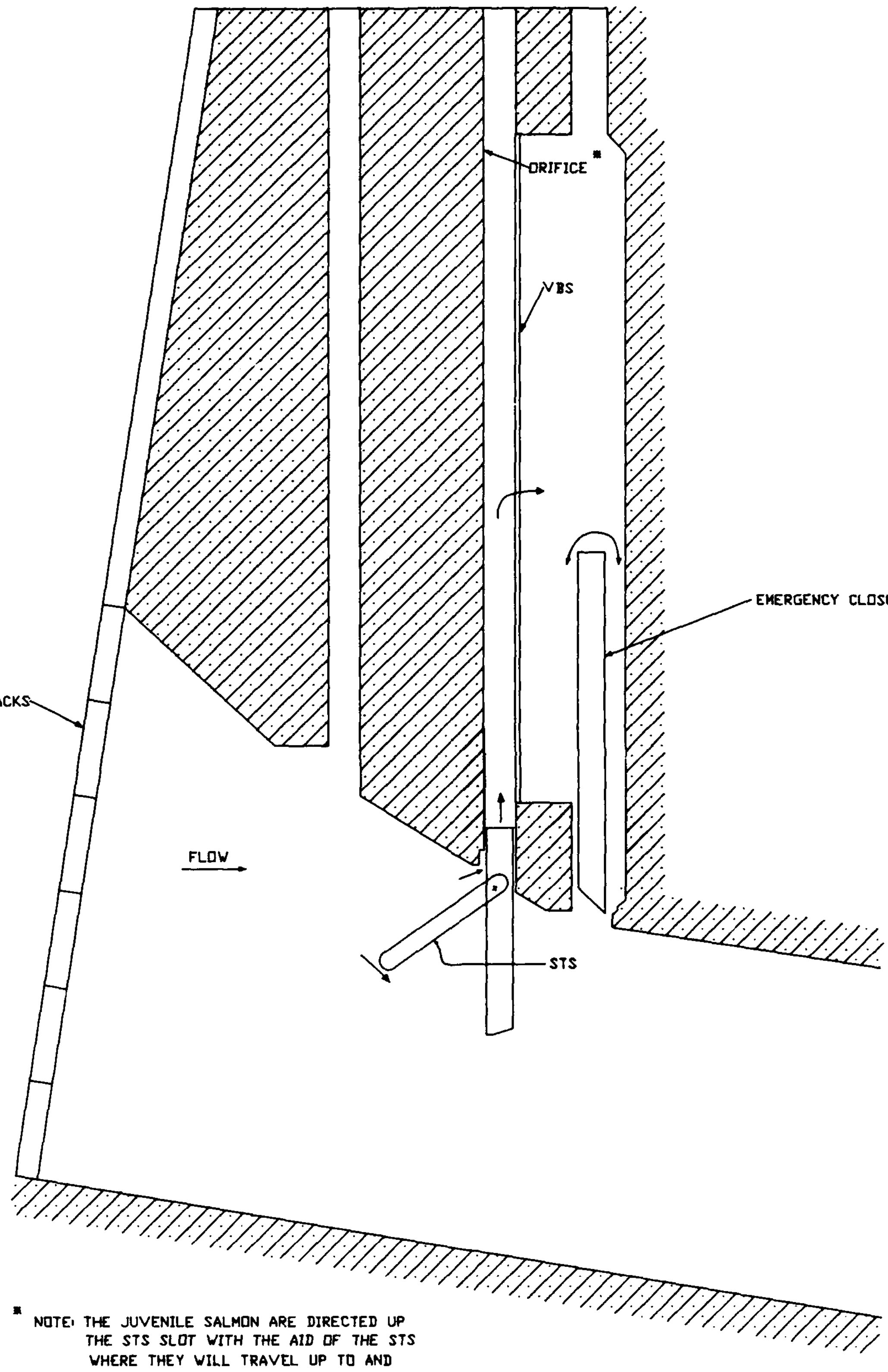


Figure 5. Emergency closure gate, upstream view



* NOTE: THE JUVENILE SALMON ARE DIRECTED UP THE STS SLOT WITH THE AID OF THE STS WHERE THEY WILL TRAVEL UP TO AND THROUGH THE ORIFICES TO BE COLLECTED

Figure 6. Juvenile bypass system

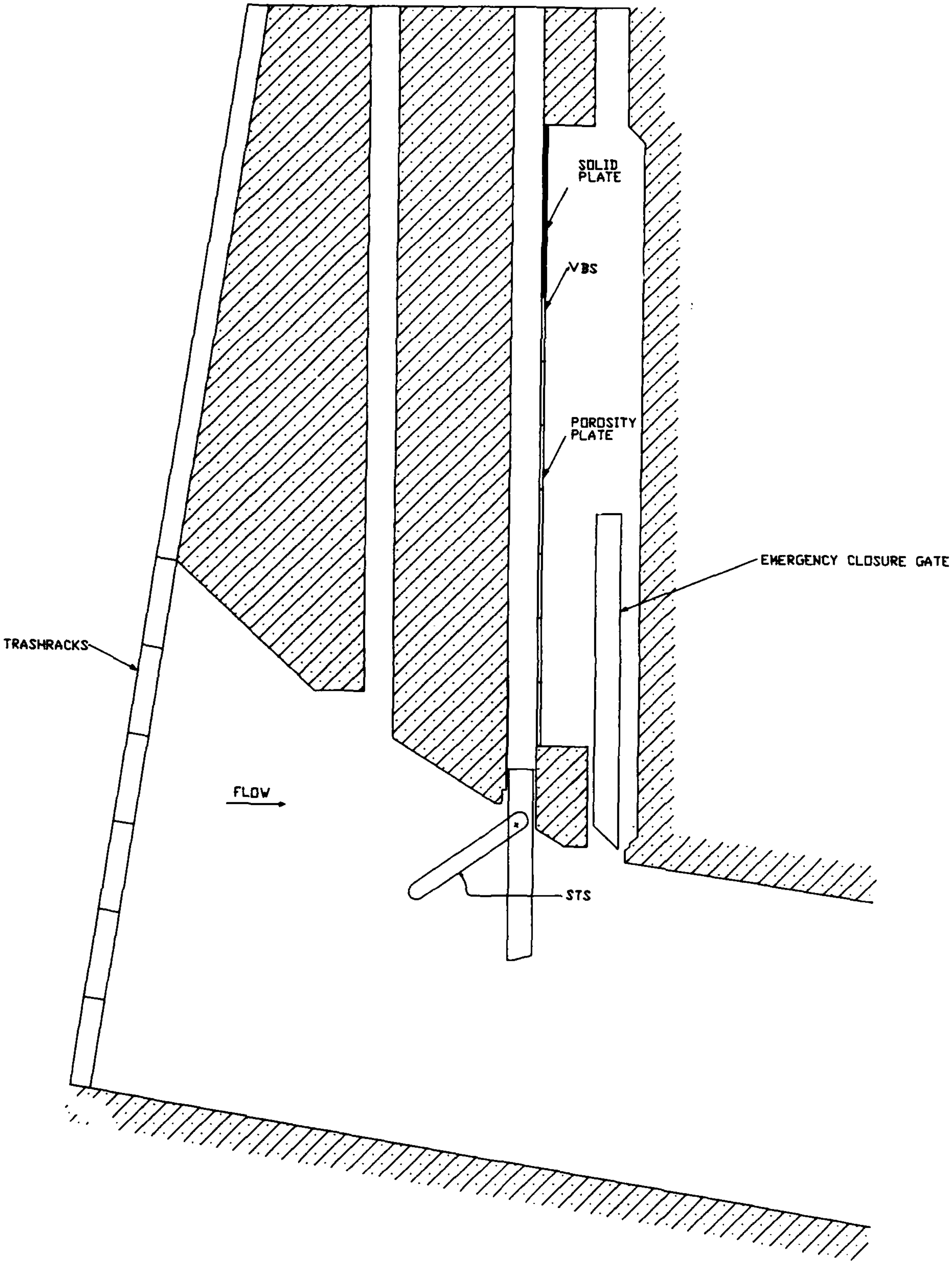


Figure 7. Probable configuration of VBS

measuring the velocity vector parallel to the axis of the propeller. Thus, the measured velocities had to be converted to actual velocity vectors by correcting for the angle between the flow path and the axis of the velocity probe. Dye was used in the model to obtain the correct angle for determining the true velocity vector. The accuracy of the measured velocities is estimated to be within ±5 percent.

Interpretation of Test Results

8. The accepted equations of hydraulic similitude, based on the Froudian relations, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General relations for the transfer of model data to prototype equivalents, or vice versa, are presented in the following tabulation:

Dimension*	Ratio	Scale Relation Model:Prototype
Length	$L_r = L$	1:25
Pressure	$P_r = L_r$	1:25
Area	$A_r = L_r^2$	1:625
Velocity	$V_r = L_r^{1/2}$	1:5
Discharge	$Q_r = L_r^{5/2}$	1:3,125

* Dimensions are in terms of length.

PART III: TESTS AND RESULTS

Test Result Criteria

9. Several parameters were used to judge the relative merits of the various modifications to the JBS. One of the parameters involved the percent flow intercepted by the STS. Dye was injected upstream of the trashracks with a dye tube. The dye tube was moved up and down the trashracks until a point was found at which the dye streak passed through the tip of the STS. All the flow above this line was intercepted flow. The percent of flow intercepted by the STS was determined by dividing the intercepted flow by the total flow through the structure. The larger the percentage of flow intercepted, the greater the potential to intercept more juvenile salmon.

10. Another parameter used dealt with the amount of discharge that was directed up the slot where the STS was located and down the emergency closure gate slot. It was thought that as more flow was directed up the STS slot, more fish would be attracted into the slot where they could be collected. The percent flow intercepted and discharge through the emergency closure gate slot along with a description of all tests for various designs are provided in Table 1.

11. The final parameter used involved the additional head loss that was created by the various modifications added to the JBS. Any additional head loss would result in a decrease in the amount of power that could be produced by the powerhouse. Preliminary head loss data were developed from piezometric pressures measured at several locations in the model. The measured pressures for selected tests and the locations of the pressure taps are shown in Table 2 and Plate 2, respectively. These pressures give a rough indication of head loss. However, because of the complexity of the flow patterns resulting from the various modifications and the importance of the head loss data, a separate slot was added to the model that allowed measurement of velocities for the depth and width of the section and measurement of pressures along one side of the section (the locations of the additional slot and piezometer taps are shown in Plate 3, and the locations of velocity measurements obtained in this section are shown in Plate 4). Measured velocities and piezometric pressures in this section are provided in Table 3. In the head loss analysis, the velocity head and the pressure were adjusted because of an unequal flow

distribution in the section. A pressure measurement should have been obtained for each velocity measurement to adjust the average pressure correctly for an unequal flow distribution. However, since the velocity magnitude did not vary much across each piezometer elevation, the corrected average pressure obtained by using the pressure measured at the edge of the section should be fairly accurate. Final head loss values for selected tests can be seen in Table 1.

Modifications to the JBS

Test 1 (base test)

12. All tests were conducted with the STS installed at a 55-deg operating angle with a constant discharge of 7,000 cfs and an upper pool elevation of 738.0.* Initially these conditions were tested without any modifications in place (Test 1, Table 1 and Photo 1). This test, which was used as the base condition for comparison of other designs, indicated that approximately 26 percent of the flow through the intake was intercepted by the STS. Flow through the emergency closure gate slot was found to be 185 cfs. Velocities obtained from this test are shown in Plate 5.

Test 2 (raised emergency closure gate)

13. The emergency closure gate was tested at various elevations to determine the effect of raising the gate on flow down the emergency closure gate slot. Test results indicated that flow down the gate slot increased when the gate was raised. The flow increased from 185 cfs with the gate in the normal storage position to 455 cfs with the gate raised 16 ft. No additional increase in flow down the gate slot was obtained for gate raises greater than 16 ft. A plot of flow down the gate well versus the intake gate elevation is shown in Plate 6. No additional flow was intercepted by the STS as a result of raising the emergency closure gate, as can be seen by comparing Test 1 with Test 2 in Table 1. Velocities obtained from Test 2 are shown in Plate 7.

Tests 3-6 (false gap device)

14. Tests were conducted with the STS lowered 2 ft and 4 ft (Photo 2). A false gap device installed in the model partially blocked flow at the top of the STS (Tests 3 and 4). Results from these tests are shown in Plates 8

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

and 9, respectively. These tests indicated that a greater percentage of flow can be intercepted by lowering the STS. A larger flow is directed up the STS slot with the false gap device in place and the STS lowered (compare Test 1 with Tests 3 and 4 in Table 1).

15. Tests were conducted with the STS lowered 4 ft, with the false gap device in place, and with a 5- and 20-ft gate raise (Tests 5 and 6). Velocities obtained from these two tests are shown in Plates 10 and 11, respectively. An increase in flow down the emergency closure gate slot was obtained from these modifications (compare Test 4 with Tests 5 and 6 in Table 1), but little improvement in the percentage of flow intercepted by the STS was seen over previously tested designs (Table 1).

Tests 7-9 (miscellaneous modifications)

16. The following modifications were added to the JBS: a modified STS upper support beam (Plate 12), a skin plate and orifices added to the upstream side of the emergency closure gate (Photos 3 and 4 and Plates 13 and 14), and a rounded gate well beam. These modifications were tested with the STS in the normal operating position and with it lowered 2 ft and 4 ft (Tests 7-9). Velocities obtained from these tests are shown in Plates 15-17, respectively. Note that the false gap device was added in Tests 8 and 9. Little change in overall flow conditions was observed (compare Test 9 with Test 5 in Table 1).

Tests 10 and 11 (floor sill designs)

17. Two different floor sill designs (Tests 10 and 11) were tested. These floor sills (Plates 18 and 19) would be needed to accommodate a 5-ft gate raise without extensive modifications of the gate operating equipment. The floor sills were tested in combination with the STS lowered 4 ft, the false gap device in place, and the emergency closure gate raised 5 ft. Velocities obtained from these tests (provided in Plates 18 and 19) indicated the floor sills had little effect on overall flow conditions (compare Test 10 with Test 5 in Table 1). The sill would be acceptable as a cost-saving measure if the 5-ft gate raise provided satisfactory FGE.

Tests 12 and 13 (blocked trashracks)

18. Tests were conducted with the two bottom trashracks blocked (Photo 5). Data obtained with these tests (Tests 12 and 13) are shown in Plates 20 and 21, respectively. Test results indicated that the blockage of the two bottom trashracks resulted in both an increase in flow intercepted by the STS, and an increase in flow down the emergency closure gate slot (compare

Tests 1 and 5 with Tests 12 and 13 in Table 1); but it also increased the average velocity between the trashracks and the STS, which might increase stress on the juvenile fish. The piezometer readings indicated that there was an additional 1.2 ft of loss in piezometric head by blocking the bottom trashracks (compare Test 1 with Test 13 in Table 2), which indicates that there would probably be a substantial increase in head loss.

Tests 14-16 (extended STS)

19. An extended STS with a length of 35 ft was installed in the model (Plate 22 and Photo 6). The extended STS simulated either a longer STS or the placement of a deflector immediately upstream of the existing STS through the fish screen slot. It was tested with the emergency closure gate in its normal storage position and with it raised 5 ft and 20 ft (Tests 14-16, respectively). Data obtained from these tests are shown in Plates 23-25, respectively. A substantial increase in the percentage of flow intercepted by the FGE and a slight increase in flow down the emergency closure gate slot was observed (compare Test 1 with Test 14 in Table 1).

Tests 17-19
(additional extended STS tests)

20. The extended STS was lowered 4 ft with the false gap device in place (Photo 7), and was tested with the emergency closure gate in the standard position and raised 5 ft and 20 ft (Tests 17-19, respectively). Velocities obtained from these tests are shown in Plates 26-28, respectively. Compared to previous tests involving the extended STS, an increase in intercepted flow and flow down the emergency closure gate slot was observed (compare Tests 17-19 with Tests 14-16 in Table 1).

Tests 20-23 (trashrack deflectors)

21. A series of four tests employing deflectors attached to the trashrack were conducted as a potential prototype configuration for Little Goose Dam, whose intake section is similar to that at Lower Granite. The STS was tested with a deflector attached to the trashracks at el 636.4 at an angle of 13 deg to the horizontal (Test 20, Table 1). Velocities obtained from this test are shown in Plate 29. Thirty-three percent of the flow was intercepted by the FGE. This was an improvement over the original design (compare Test 1 with Test 20 in Table 1). The impact angle at which flow struck the deflector was found to be 33 deg. This angle borders on being too severe for the

juvenile fish to escape injury. An impact angle of 30 deg or less was thought desirable by the Walla Walla District.

22. The STS was tested with a deflector attached to the trashracks at el 638.3 at an angle of 4 deg to the horizontal (Test 21). Thirty percent of the flow was intercepted by the STS, which indicates that this modification has the potential for guiding more juvenile fish at the prototype structure than does the existing design. The flow impact angle was 20 deg which probably would not increase the stress that the fish would encounter in the JBS. Velocities obtained from this test can be seen in Plate 30.

23. A test was conducted with the deflector attached to the trashracks at el 626.8. The deflector was rotated upward as required to guide fish to the STS. This resulted in the deflector angled at 67 deg to the horizontal (Test 22, Photo 8). Data that were obtained with this modification in place are shown in Plate 31. Forty-seven percent of the flow was intercepted by the STS. This was a large improvement over the original design; however, the flow impact angle was 75 deg which in all probability would greatly increase the amount of stress on the juvenile fish. Therefore, this would not be a feasible design to test at the prototype structure.

24. A 30 percent porosity plate was added to the deflector and attached to the trashracks at el 627 (Test 23). When the deflector was raised to intercept the maximum amount of flow possible, flow passed over the top of the deflector and under the STS. This would allow juvenile fish to pass through the middle of the JBS without being guided to the STS, since the intercept line that passed through the top of the deflector did not pass through the STS. The juvenile salmon would not be successfully guided up the STS slot; therefore, this would not be a feasible design to test at the prototype structure. Data obtained for this test are shown in Plate 32.

Optimum Position of STS

25. The STS was tested at different elevations without a false gap device to determine the operating elevation that would maximize flow down the emergency closure gate slot without the use of a false gap device. A plot of STS elevation versus flow down the gate slot is provided in Plate 33. The optimum elevation was with the STS lowered 2 ft.

26. It was discovered by personnel of the Walla Walla District that the

STS was being operated at an elevation 1 ft lower (pivot point el 635.4) than was previously thought. Several key tests were repeated to determine the effect of lowering the STS one additional foot on the JBS.

27. The emergency closure gate was tested at various elevations with the STS lowered 1 ft to determine the effect of raising the gate on flow down the emergency closure gate slot. Test results indicated that flow increased when the gate was raised. A plot of flow down the gate slot versus the intake gate elevation can be seen in Plate 6.

28. Tests were conducted with the STS lowered 1 ft with the emergency closure gate in the normal storage position and with it raised 20 ft. Velocities obtained from these tests are shown in Plates 34 and 35, respectively. There was no appreciable increase in interception over the test condition with the STS in its normal position, but there was an increase in flow down the emergency closure gate slot (compare Test 1 with Tests 24 and 25 in Table 1).

29. The STS was lowered 5 ft with the false gap device in place and with a 5- and 20-ft gate raise (Tests 26 and 27). Velocities obtained from these two tests are shown in Plates 36 and 37, respectively. An increase in flow down the emergency closure gate slot was obtained by lowering the STS one additional foot, but no improvement in the amount of flow intercepted by the STS was obtained (compare Tests 5 and 6 with Tests 26 and 27 in Table 1).

30. A test was conducted with the STS lowered 5 ft, the false gap device in place, the emergency closure gate raised 5 ft, and the abrupt sill in place (Test 28). The amount of flow intercepted by the STS remained about the same, but the amount of flow down the emergency closure gate slot slightly increased (compare Test 11 with Test 28 in Table 1). There was also an increase in the amount of head loss through the structure (Test 28, Table 1). Data obtained from this test are shown in Plate 38.

31. Tests 15, 18, and 19 were repeated with the extended STS lowered an additional foot (Tests 29-31). Velocities obtained from these tests can be seen in Plates 39-41, respectively. Data obtained from these tests indicated a slight increase in flow down the emergency closure gate slot but no noticeable improvement in interception (compare Tests 15, 18, and 19 with Tests 29-31 in Table 1).

32. There was no noticeable increase in the amount of flow intercepted by the STS due to raising the emergency closure gate (compare Test 24 with Test 25, Test 26 with Test 27, and Test 30 with Test 31 in Table 1). In each

Table 1

Test Comparisons

Test No.	Structure	Pivot Point Elevation	Type of STS	STS Position	Emergency Closure Gate Position	Deflector Position	Trashracks Blocked	Modified Intake Gate	False Gap Device	Additional Test Items	Percent Flow Intercepted By STS	Flow Down Emergency Gate Slot cfs	Head Loss ft
1 (Plate 5)	Lower Granite	636.4	Original	Normal	Normal	None	None	No	No	None	26	185	N/A
2 (Plate 7)	Lower Granite	636.4	Original	Normal	Raised 20 ft	None	None	No	No	None	26	455	N/A
3 (Plate 8)	Lower Granite	634.4	Original	Lowered 2 ft	Normal	None	None	No	Yes	None	29	225	N/A
4 (Plate 9)	Lower Granite	632.2	Original	Lowered 4 ft	Normal	None	None	No	Yes	None	31	215	N/A
5 (Plate 10)	Lower Granite	632.2	Original	Lowered 4 ft	Raised 5 ft	None	None	No	Yes	None	30	410	N/A
6 (Plate 11)	Lower Granite	632.4	Original	Lowered 4 ft	Raised 20 ft	None	None	No	Yes	None	30	660	N/A
7 (Plate 15)	Lower Granite	636.4	Original	Normal	Raised 5 ft	None	None	Yes	No	Rounded gate well beam, modified STS beam	28	330	N/A
8 (Plate 16)	Lower Granite	634.4	Original	Lowered 2 ft	Raised 5 ft	None	None	Yes	Yes	Rounded gate well beam, modified STS beam	29	380	N/A
9 (Plate 17)	Lower Granite	632.4	Original	Lowered 4 ft	Raised 5 ft	None	None	Yes	Yes	Rounded gate well beam, modified STS beam	28	380	N/A
10 (Plate 18)	Lower Granite	632.4	Original	Lowered 4 ft	Raised 5 ft	None	None	No	Yes	Gradually sloping floor sill	32	405	N/A
11 (Plate 19)	Lower Granite	632.4	Original	Lowered 4 ft	Raised 5 ft	None	None	No	Yes	Abruptly sloping floor sill	28	390	N/A
12 (Plate 20)	Lower Granite	636.4	Original	Normal	Normal	None	Two bottom	No	No	None	33	190	N/A
13 (Plate 21)	Lower Granite	632.4	Original	Lowered 4 ft	Raised 5 ft	None	Two bottom	No	Yes	None	36	480	N/A
14 (Plate 23)	Lower Granite	636.4	Extended	Normal	Normal	None	None	No	No	None	50	190	N/A
15 (Plate 24)	Lower Granite	636.4	Extended	Normal	Raised 5 ft	None	None	No	No	None	51	350	N/A
16 (Plate 25)	Lower Granite	636.4	Extended	Normal	Raised 20 ft	None	None	No	No	None	50	480	N/A
17 (Plate 26)	Lower Granite	632.4	Extended	Lowered 4 ft	Normal	None	None	No	Yes	None	56	220	N/A
18 (Plate 27)	Lower Granite	632.4	Extended	Lowered 4 ft	Raised 5 ft	None	None	No	Yes	None	56	430	N/A

(Continued)

Table 1 (Concluded)

Test No.	Structure	Pivot Point Elevation	Type of STS	STS Position	Emergency Closure Gate Position	Deflector Position	Trashracks Blocked	Modified Intake Gate	False Gap Device	Additional Test Items	Percent Flow Intercepted By STS	Flow Down Emergency Gate Slot cfs	Head Loss ft
19 (Plate 28)	Lower Granite	632.4	Extended	Lowered 4 ft	Raised 20 ft	None	None	No	Yes	None	56	720	N/A
20 (Plate 29)	Little Goose	636.4	Original	Normal	Normal	Attached to trashrack at el 636.4	None	No	No	None	33*	N/A	N/A
21 (Plate 30)	Little Goose	636.4	Original	Normal	Normal	Attached to trashrack at el 638.3	None	No	No	None	30*	N/A	N/A
22 (Plate 31)	Little Goose	636.4	Original	Normal	Normal	Attached to trashrack at el 626.8	None	No	No	None	47*	N/A	N/A
23 (Plate 32)	Little Goose	636.4	Original	Normal	Normal	Attached to trashrack at el 626.8	None	No	No	None	N/A*	N/A	N/A
24 (Plate 34)	Lower Granite	635.4	Original	Lowered 1 ft	Normal	None	None	No	No	None	26.5	195	0.6
25 (Plate 35)	Lower Granite	635.4	Original	Lowered 1 ft	Raised 20 ft	None	None	No	No	None	26.5	505	0.6
26 (Plate 36)	Lower Granite	631.4	Original	Lowered 5 ft	Raised 5 ft	None	None	No	Yes	None	30	410	0.7
27 (Plate 37)	Lower Granite	631.4	Original	Lowered 5 ft	Raised 20 ft	None	None	No	Yes	None	30	670	0.7
28 (Plate 38)	Lower Granite	631.4	Original	Lowered 5 ft	Raised 5 ft	None	None	No	Yes	Abruptly sloping floor sill	29	405	1.3
29 (Plate 39)	Lower Granite	635.4	Extended STS	Lowered 1 ft	Raised 5 ft	None	None	No	No	None	51.5	365	0.8
30 (Plate 40)	Lower Granite	631.4	Extended STS	Lowered 5 ft	Raised 5 ft	None	None	No	Yes	None	57	450	1.1
31 (Plate 41)	Lower Granite	631.4	Extended STS	Lowered 5 ft	Raised 20 ft	None	None	No	Yes	None	57	720	1.1
32 (Plate 42)	Little Goose	636.4	Normal	Normal	Raised 5 ft	None	None	No	No	None	25	295	N/A
33 (Plate 43)	Little Goose	632.4	Normal	Lowered 4 ft	Raised 5 ft	None	None	No	Yes	None	28	400	N/A
34 (Plate 44)	Little Goose	636.4	Extended STS	Normal	Raised 5 ft	None	None	No	No	None	51	360	N/A
35 (Plate 45)	Little Goose	632.4	Extended STS	Lowered 4 ft	Raised 5 ft	None	None	No	Yes	None	56	435	N/A

* Percentage includes additional flow intercepted by deflector.

Table 2

Piezometer Readings

Discharge 7,000 cfs, Headwater el 738.0

Test No.	Piezometer No. 1	2	3	4	5
1	737.7	737.6	737.0	735.7	736.0
8	737.5	737.4	737.0	735.4	735.8
9	737.5	737.4	736.9	735.3	735.8
11	737.6	737.5	737.2	735.3	735.8
12	736.4	737.2	735.8	734.3	734.8
13	736.9	736.9	735.8	733.7	734.4
17	737.3	737.1	736.7	735.1	735.3
21	737.5	737.5	737.0	735.8	736.5
22	737.5	737.5	737.0	735.5	736.0
23	737.5	737.7	737.3	735.7	735.2

Table 3

Velocities and Piezometric Pressures

Additional Slot

Piezometer No.	Pressure ft of Water	Velocity, fps, for Velocity Measurement Location 1	2	3	4
		Test 24			
6	735.75	3.27	3.01	2.85	3.05
7	735.80	4.00	4.18	3.97	3.75
8	735.90	8.78	7.80	7.70	6.52
9	736.00	11.25	10.73	10.85	10.56
10	736.10	10.86	10.80	10.82	10.88
11	736.20	10.30	10.33	10.38	10.35
12	736.30	9.78	9.84	9.55	9.15
		Test 25			
6	735.75	2.90	2.41	1.91	2.33
7	735.80	4.85	4.62	4.69	4.71
8	735.85	8.56	7.60	7.57	6.60
9	736.00	11.23	10.75	10.64	10.32
10	736.10	10.93	10.88	10.85	10.83
11	736.20	10.39	10.40	10.37	10.30
12	736.30	9.14	9.86	9.45	9.13
		Test 26			
6	735.45	1.66	1.14	1.50	1.67
7	735.55	5.09	4.63	3.40	5.10
8	735.65	6.26	6.33	6.36	6.50
9	735.75	8.84	9.36	9.66	10.37
10	735.85	11.69	11.71	11.72	11.75
11	735.95	11.11	11.20	11.20	11.19
12	736.05	11.10	11.20	11.39	11.10

(Continued)

Table 3 (Continued)

Piezometer No.	Pressure ft of Water	Velocity, fps, for Velocity Measurement Location 1	2	3	4
		Test 27			
6	735.50	1.49	1.29	1.73	2.33
7	735.60	4.85	4.38	5.01	5.51
8	735.70	6.06	6.27	6.37	6.39
9	735.80	8.95	9.57	9.90	10.18
10	735.90	11.51	11.52	11.59	11.50
11	736.00	10.94	11.01	11.04	11.06
12	736.10	10.90	11.04	11.10	11.03
		Test 28			
6	734.80	2.95	1.18	2.25	2.20
7	734.90	6.63	4.40	6.40	5.90
8	735.00	8.53	8.16	8.26	7.68
9	735.10	12.53	11.30	10.99	10.50
10	735.35	12.30	12.14	12.23	12.02
11	735.60	11.17	11.10	10.53	9.16
12	735.80	6.03	6.50	8.07	5.78
		Test 29			
6	735.80	5.53	5.23	4.99	4.94
7	735.90	6.81	6.55	6.77	6.56
8	736.00	6.64	6.57	6.50	6.24
9	736.10	6.98	6.87	6.82	6.73
10	736.20	9.82	9.31	9.51	8.61
11	736.30	10.70	10.80	10.84	10.56
12	736.40	8.17	8.50	8.54	8.53

(Continued)

Table 3 (Concluded)

Piezometer No.	Piezometer Pressure ft of Water	Velocity, fps, for Velocity Measurement Location 1	2	3	4
		Test 30			
6	735.35	2.75	2.65	2.44	2.85
7	735.45	7.05	6.90	6.14	7.31
8	735.55	7.70	7.49	7.61	7.98
9	735.65	7.04	7.40	7.45	7.71
10	735.75	7.40	8.43	8.64	9.25
11	735.85	10.51	11.81	11.20	10.75
12	735.95	11.32	11.10	10.91	10.84
		Test 31			
6	735.35	2.70	2.75	2.39	2.85
7	735.45	7.05	6.29	6.71	7.36
8	735.55	7.70	7.42	7.80	7.88
9	735.65	7.04	7.45	7.50	7.61
10	735.75	7.60	8.20	8.64	9.25
11	735.85	10.81	11.01	11.81	11.63
12	735.95	11.15	11.19	10.97	10.84

(Sheet 3 of 3)

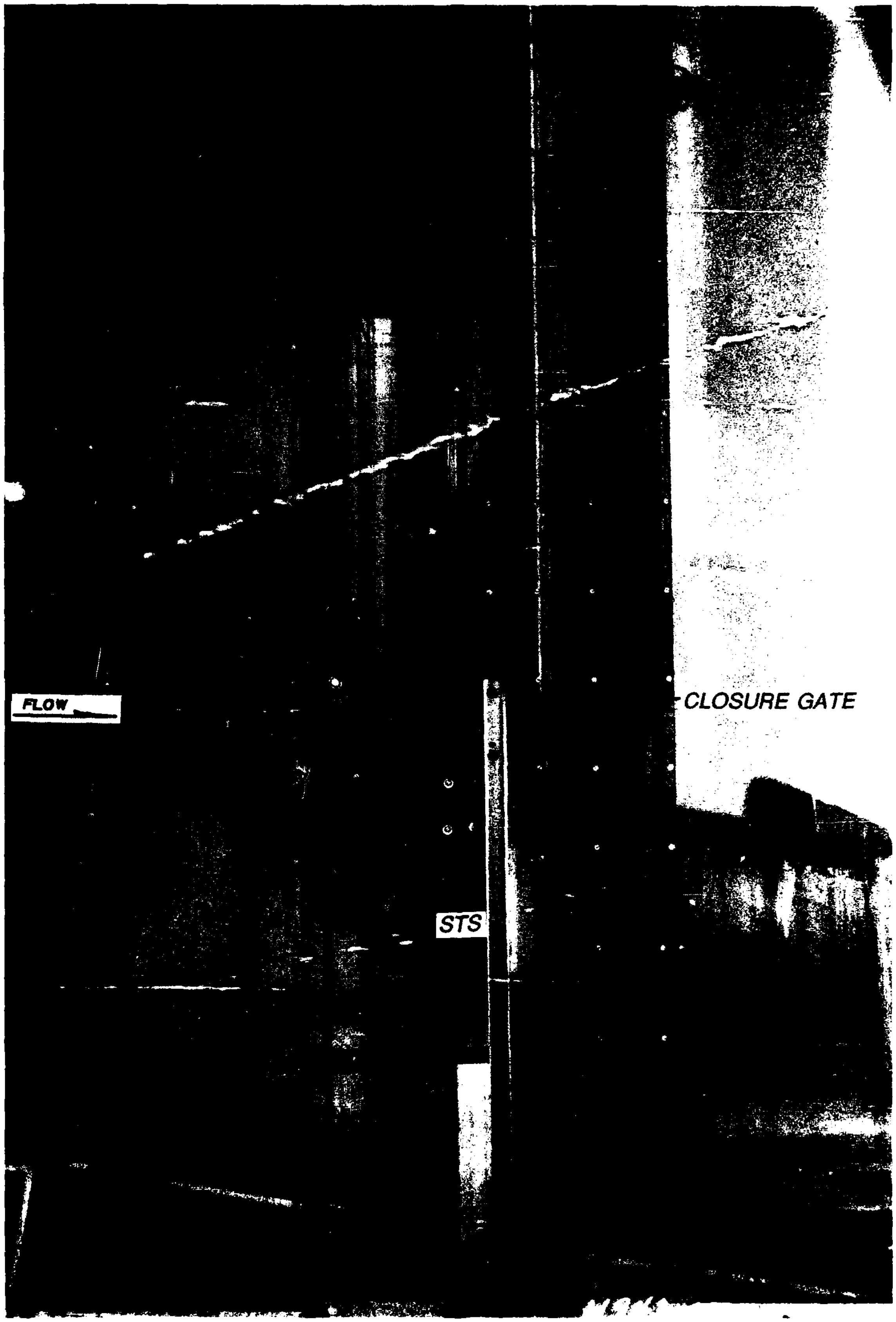


Photo 1. Base test, 55-deg STS, closure gate in normal position

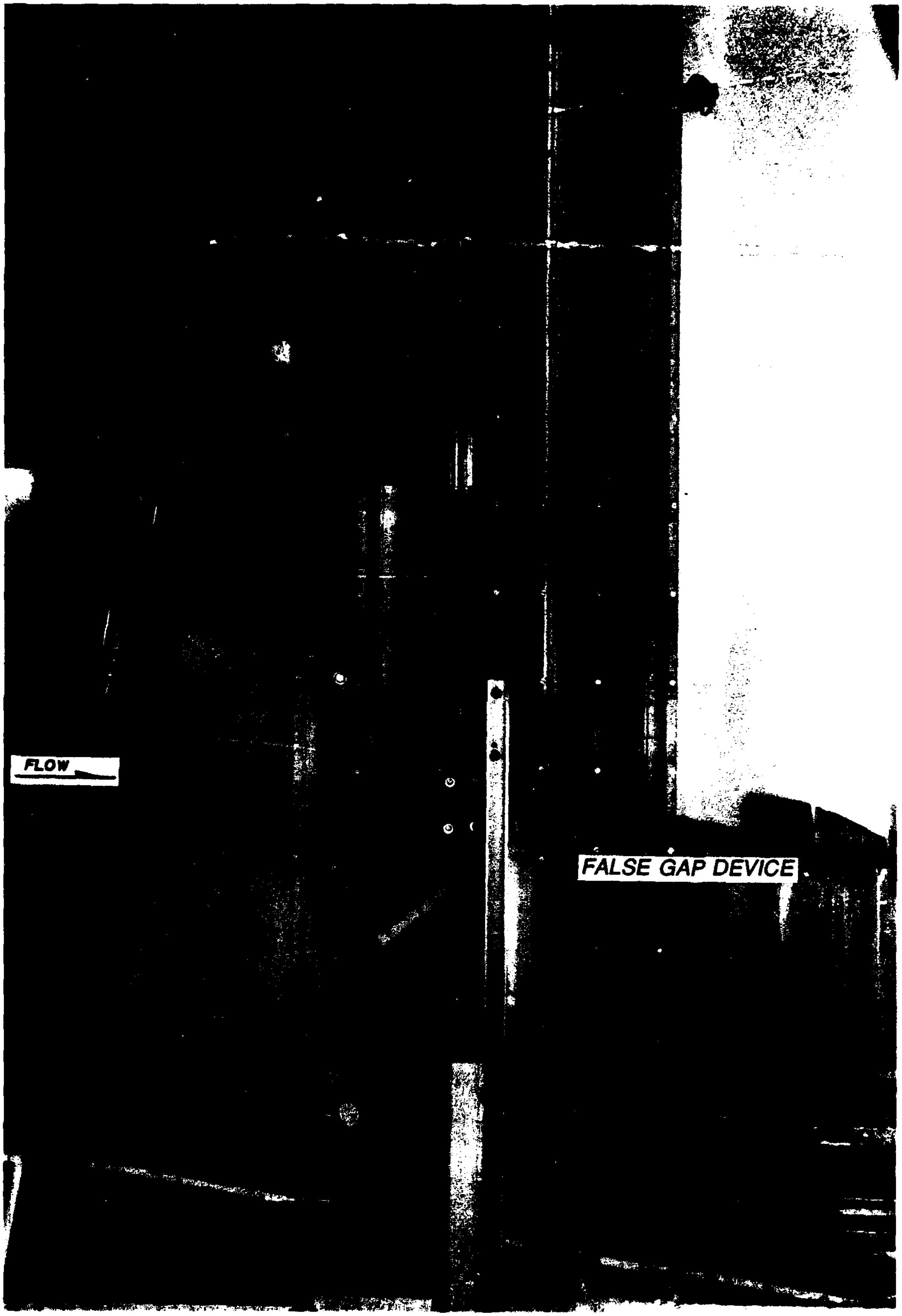


Photo 2. 55-deg STS lowered 4 ft, false gap device in place, and closure gate in normal position

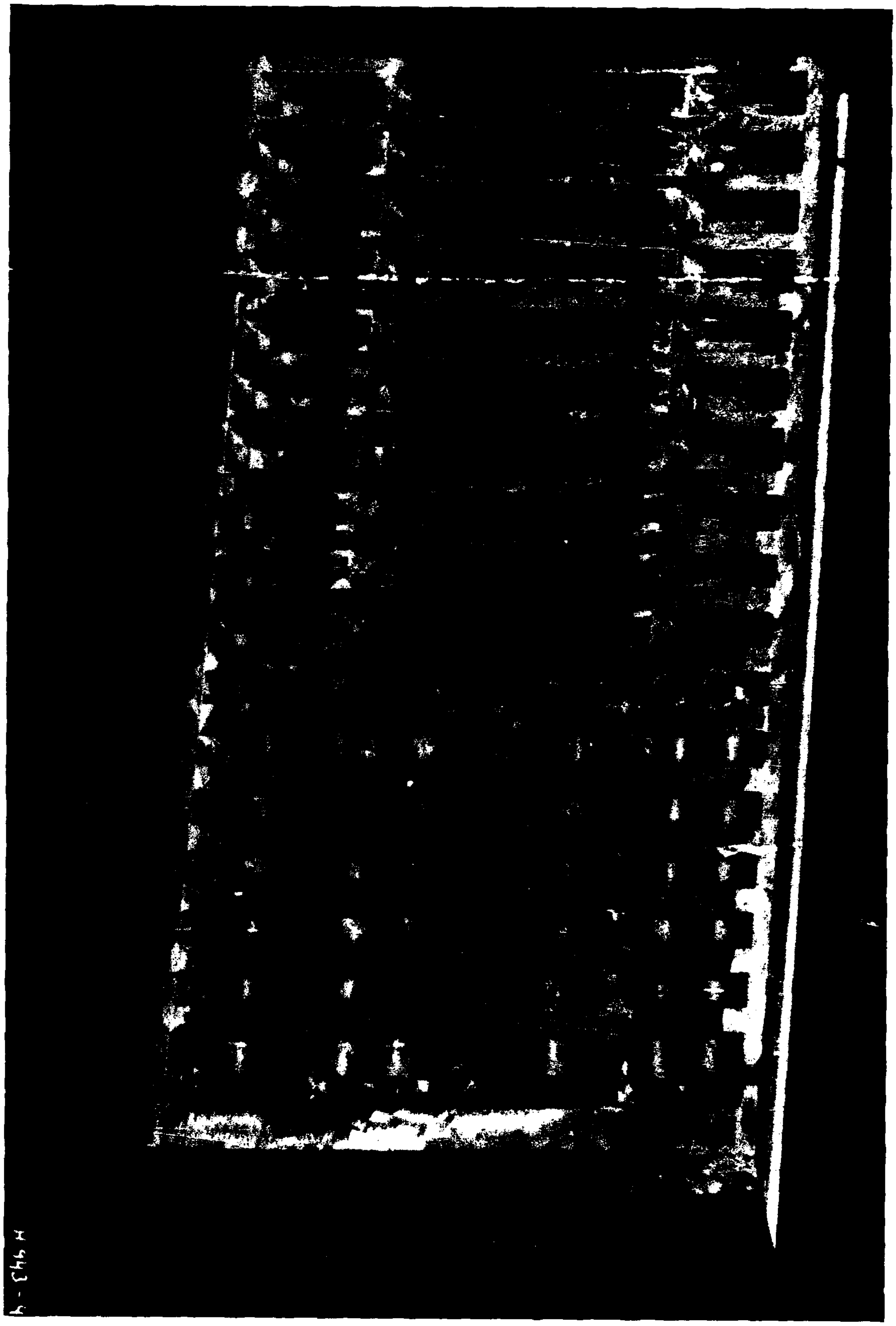


Photo 3. Emergency closure gate with orifices and tubes added to upstream side

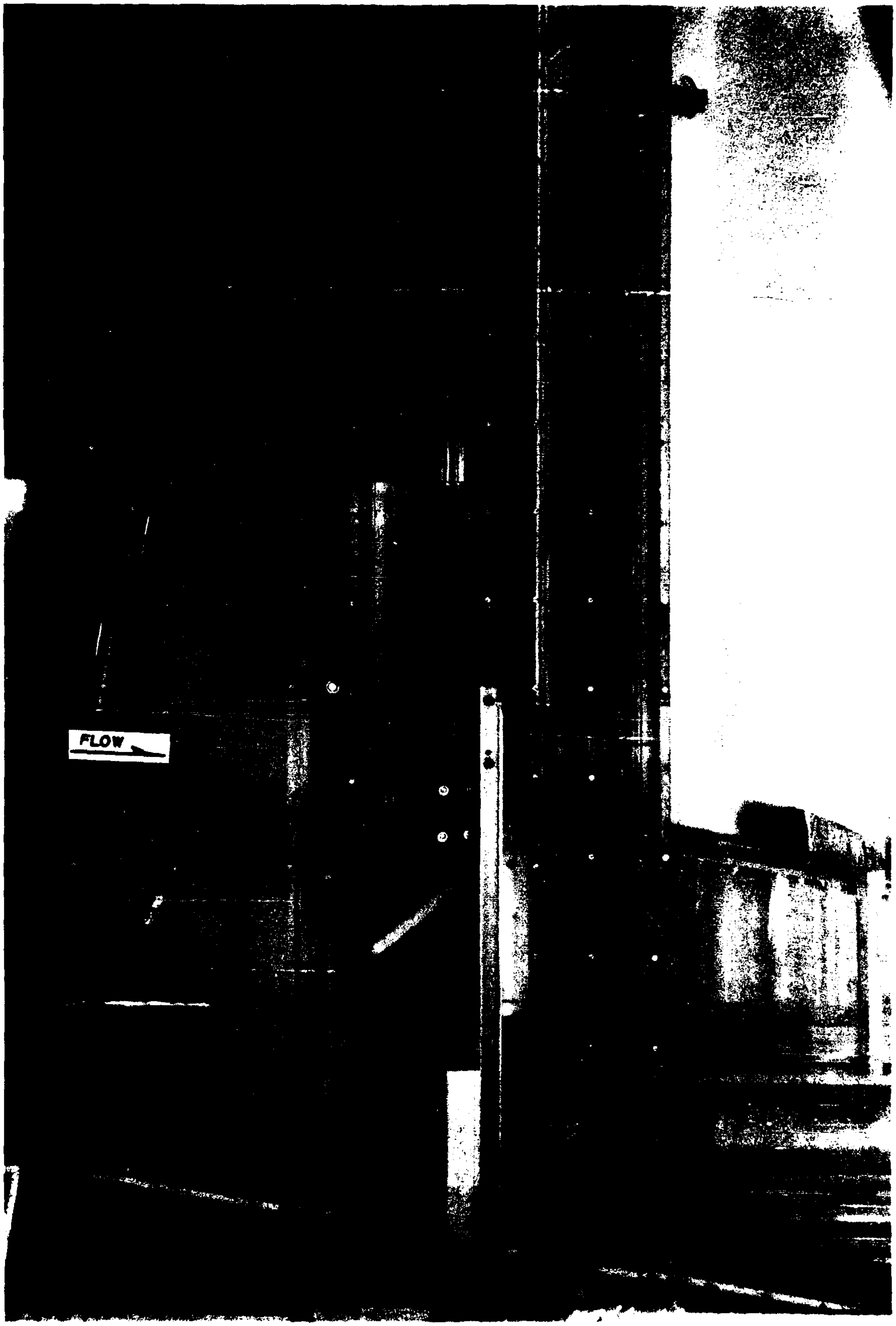


Photo 4. 55-deg STS lowered 4 ft with the false gap device in place and with the modified closure gate raised 5 ft

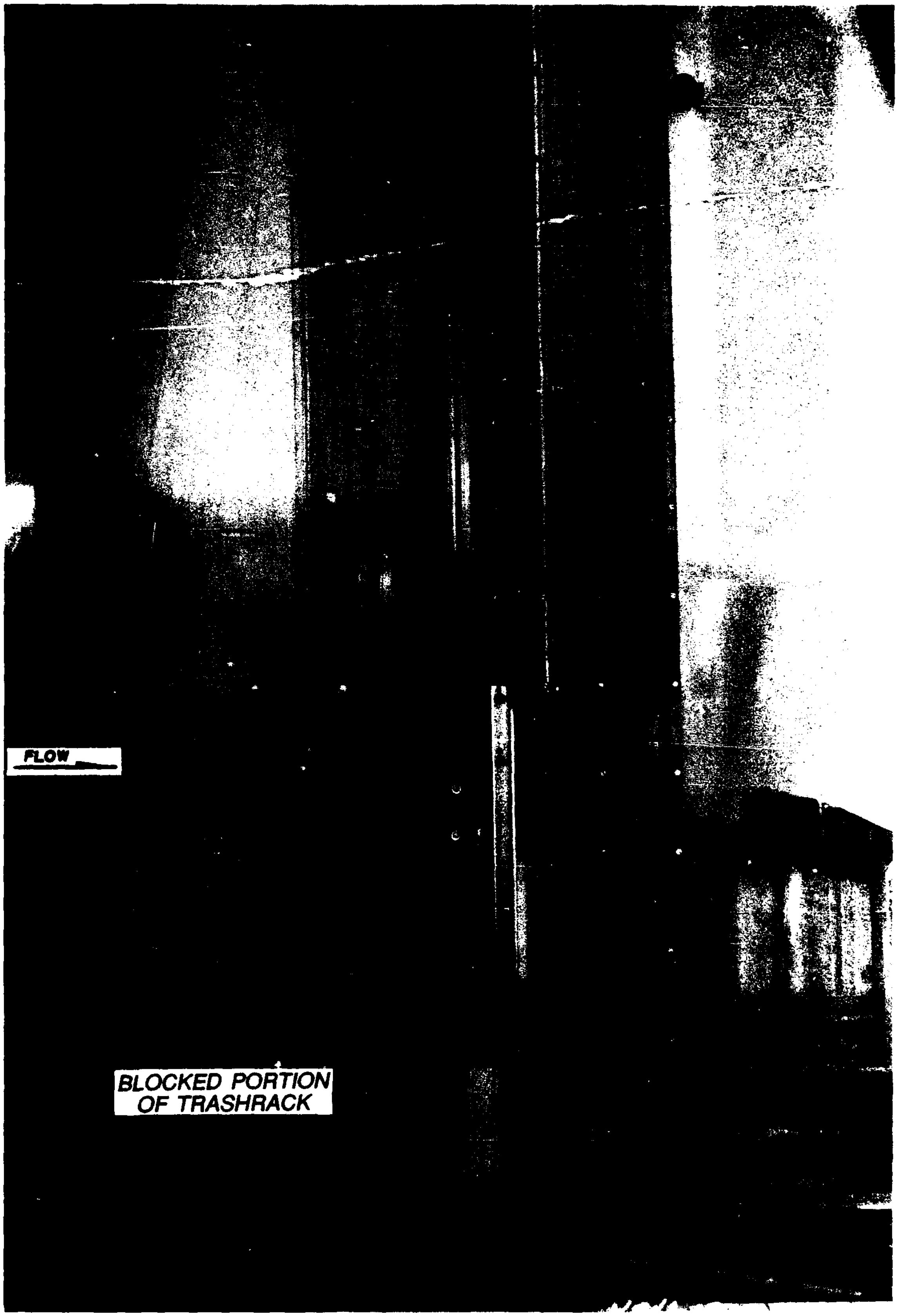


Photo 5. 55-deg STS with the bottom two trashracks blocked and the closure gate raised 5 ft

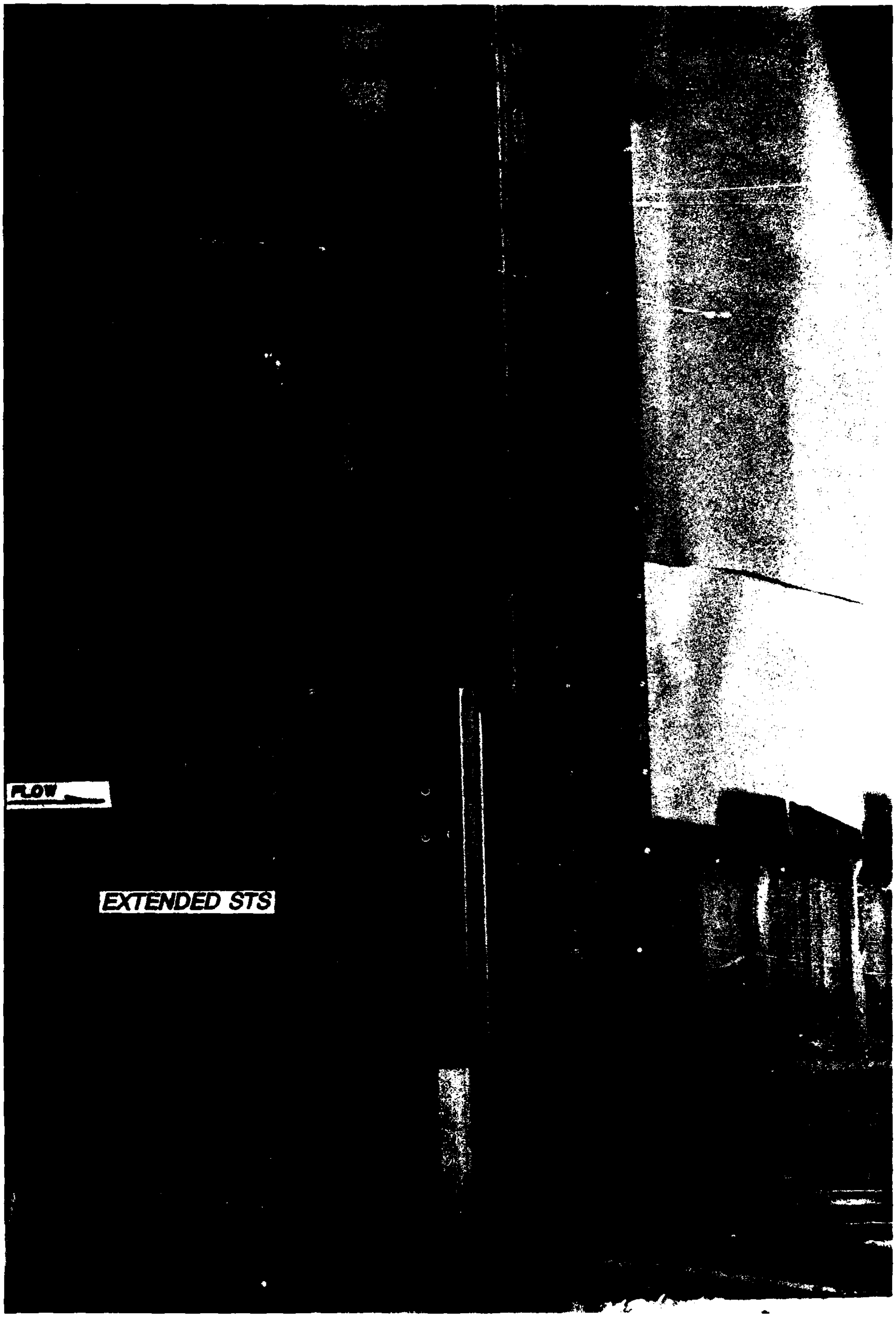


Photo 6. 55-deg extended STS with closure gate in its normal position

Photo 7. 55-deg extended STS lowered 4 ft with the false gap device in place and the closure gate in its normal position

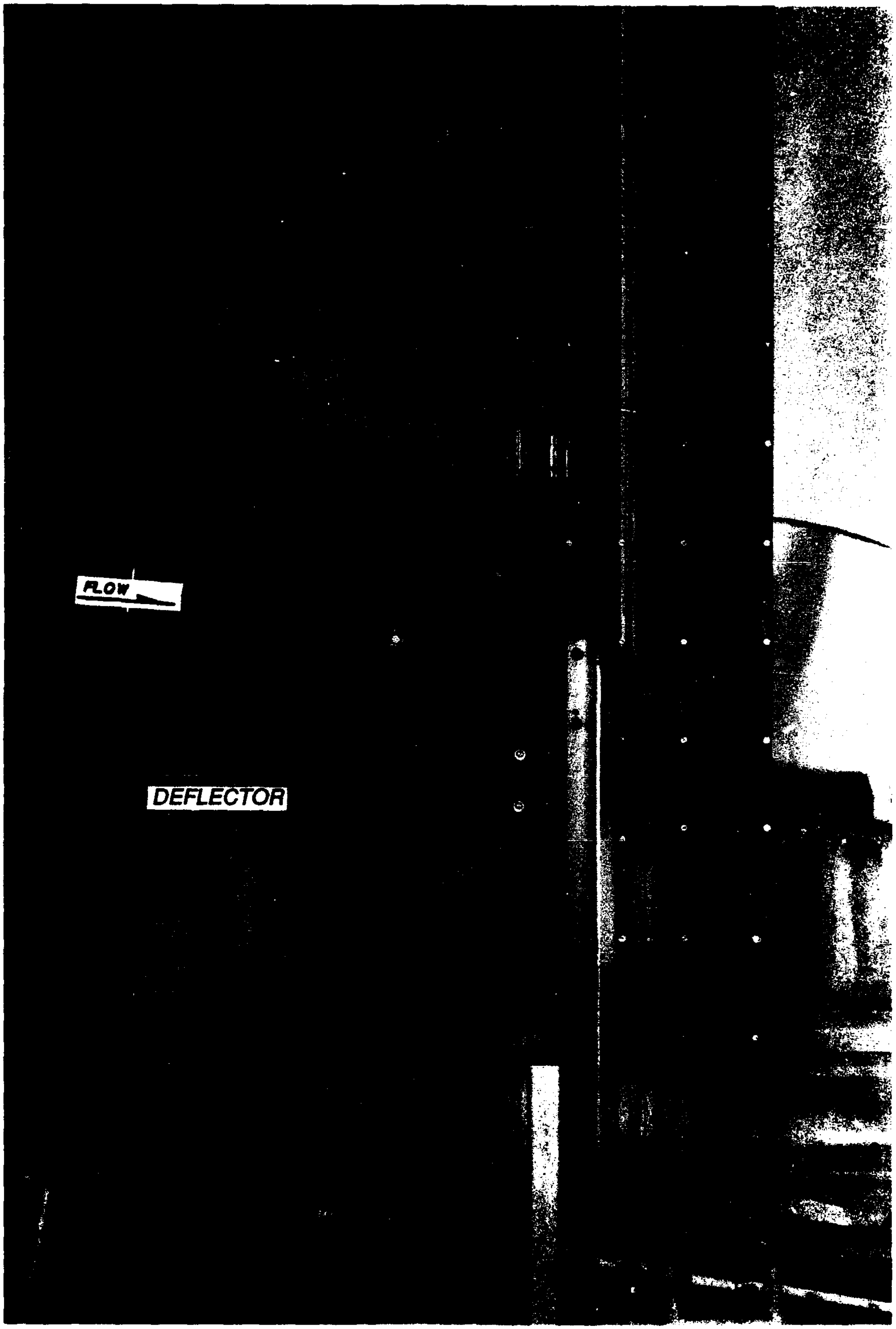
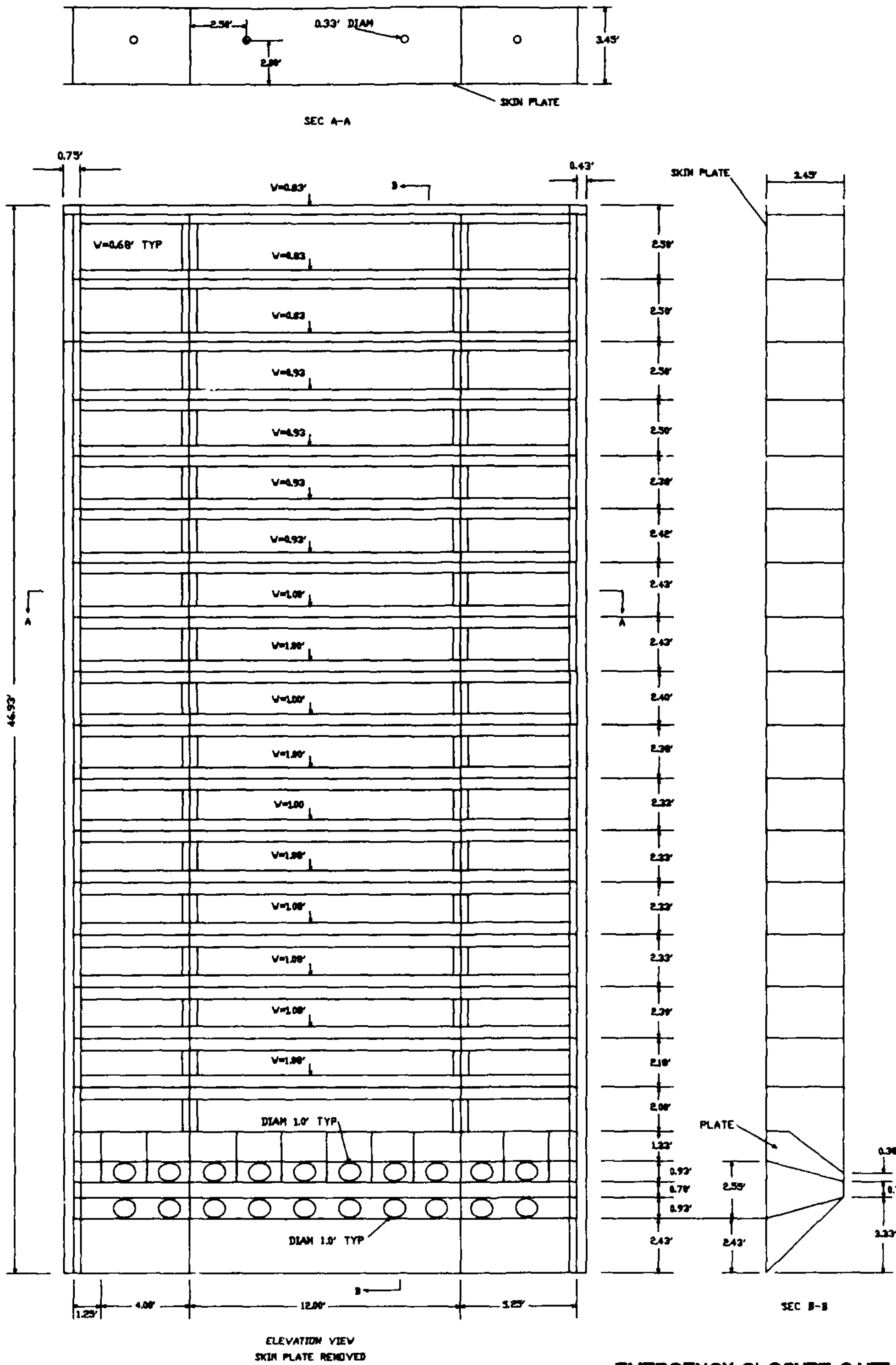
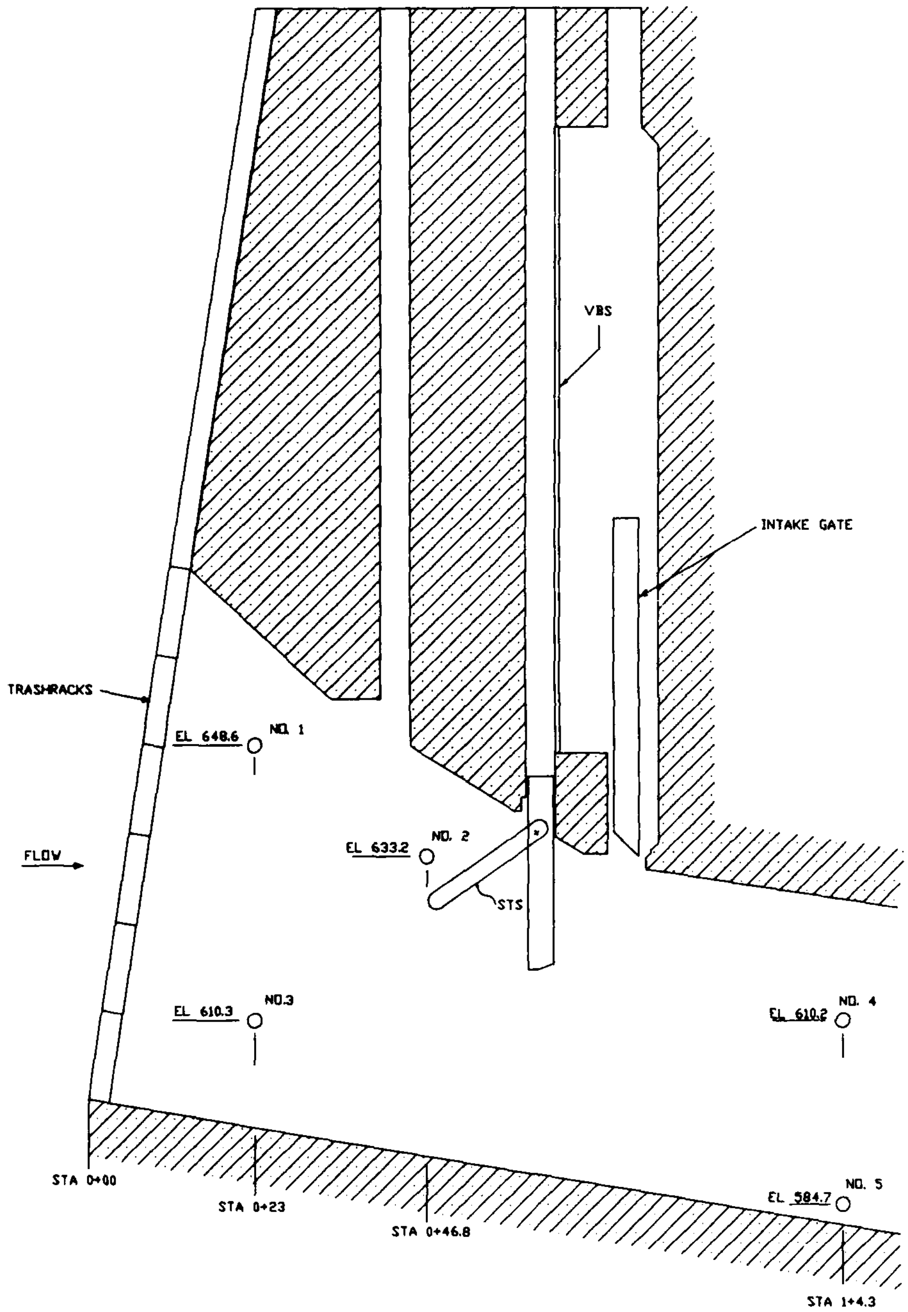


Photo 8. 55-deg STS with the deflector attached to the trashracks at el 626.8 and with the closure gate in its normal position

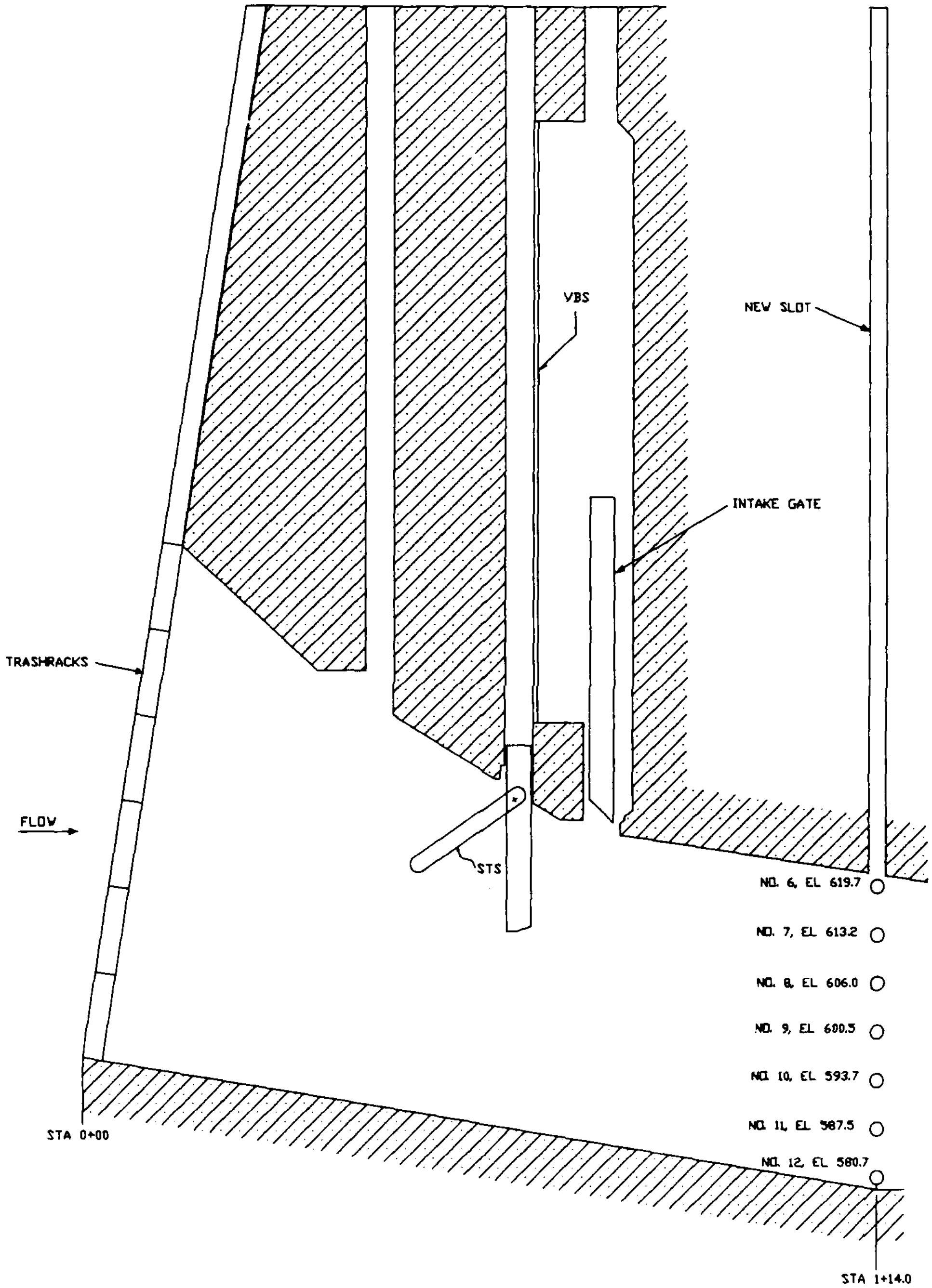


EMERGENCY CLOSURE GATE

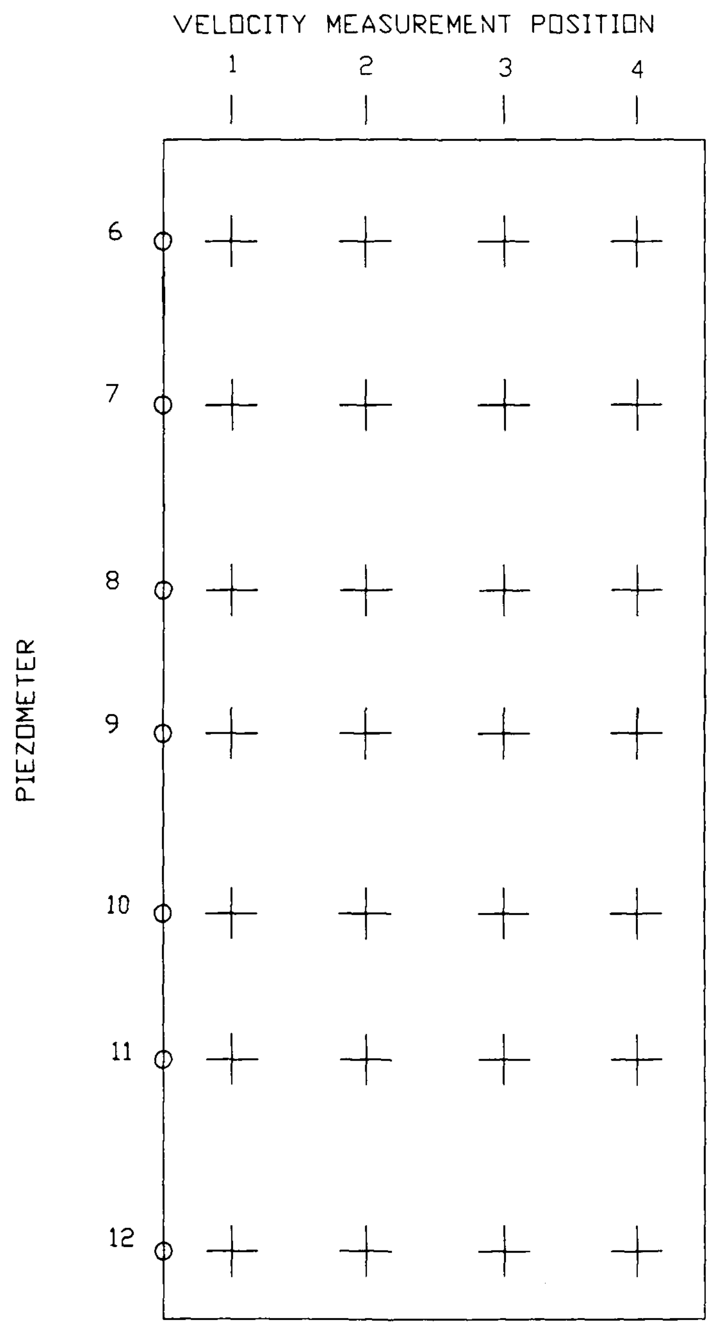


LOWER GRANITE FGE STUDY
PIEZOMETER LOCATIONS

PLATE 2

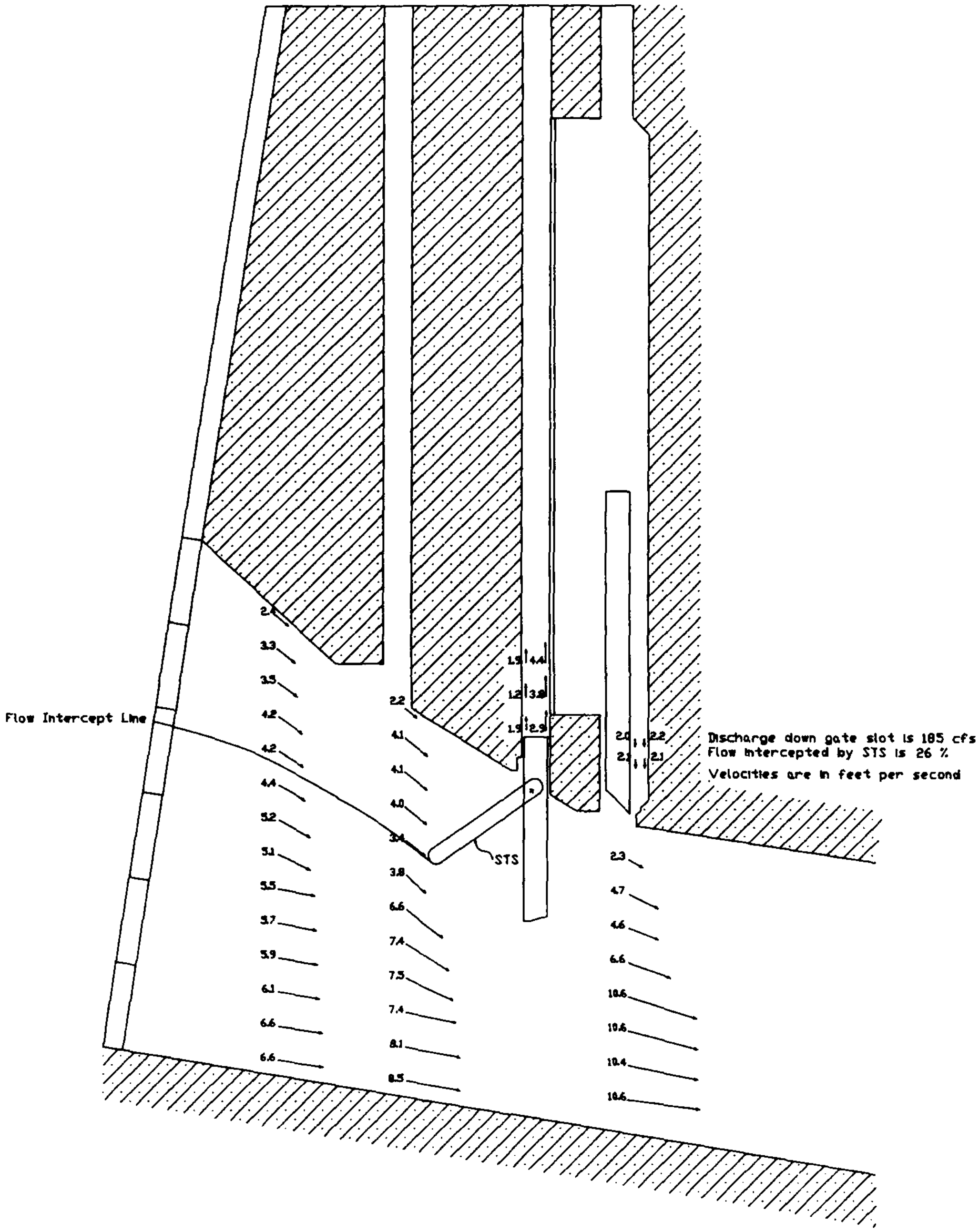


LOWER GRANITE FGE STUDY
ADDITIONAL PIEZOMETER LOCATIONS

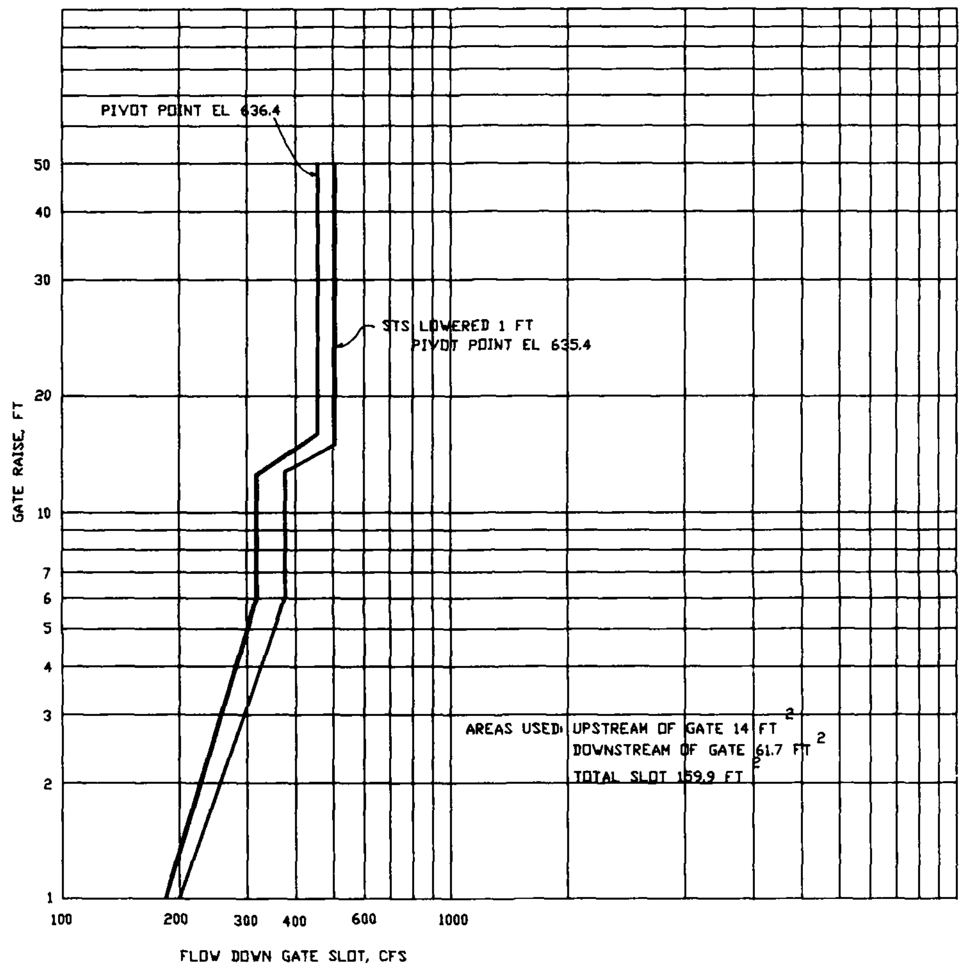


VELOCITY MEASUREMENT LOCATIONS AT STATION 1+14.0

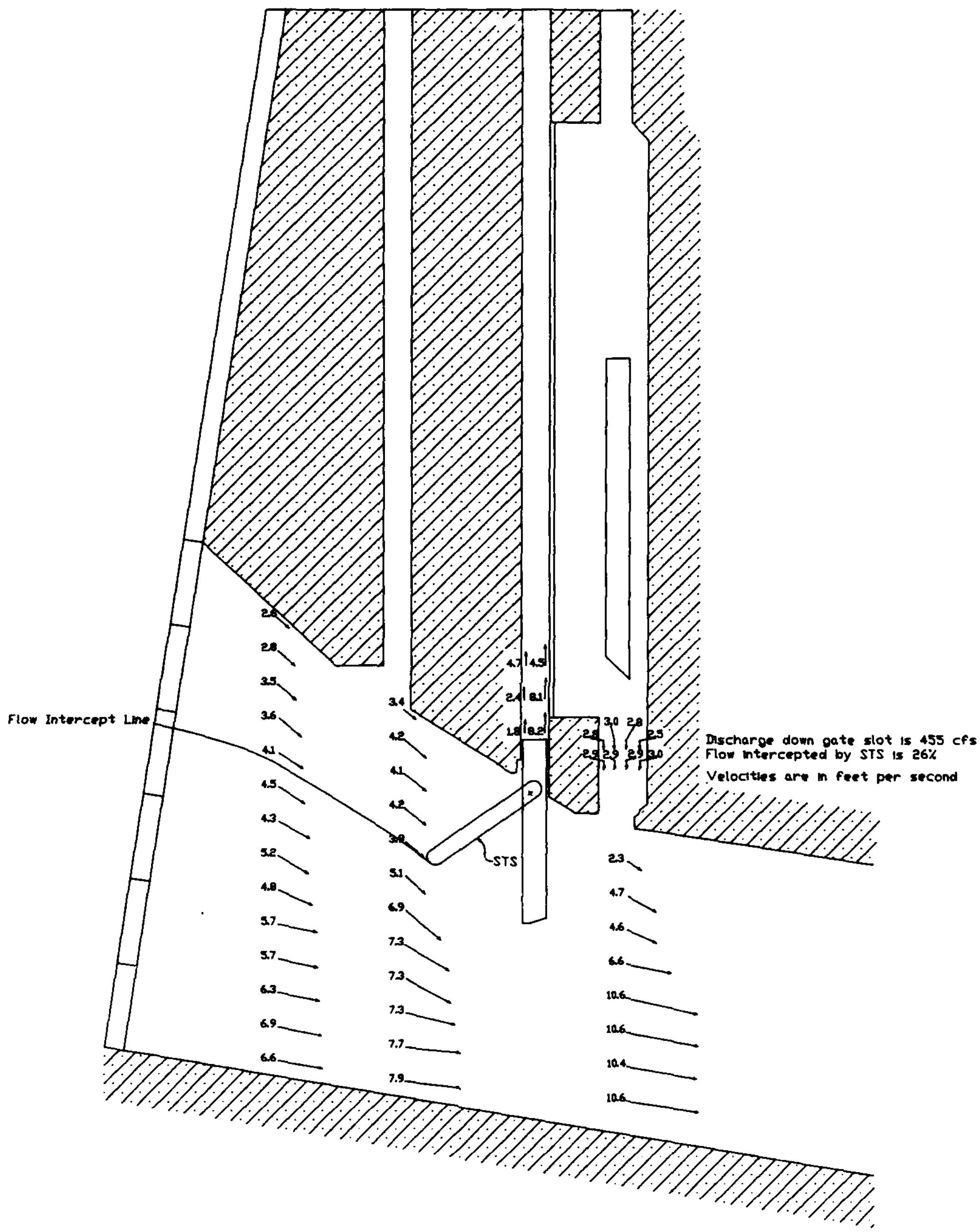
PLATE 4



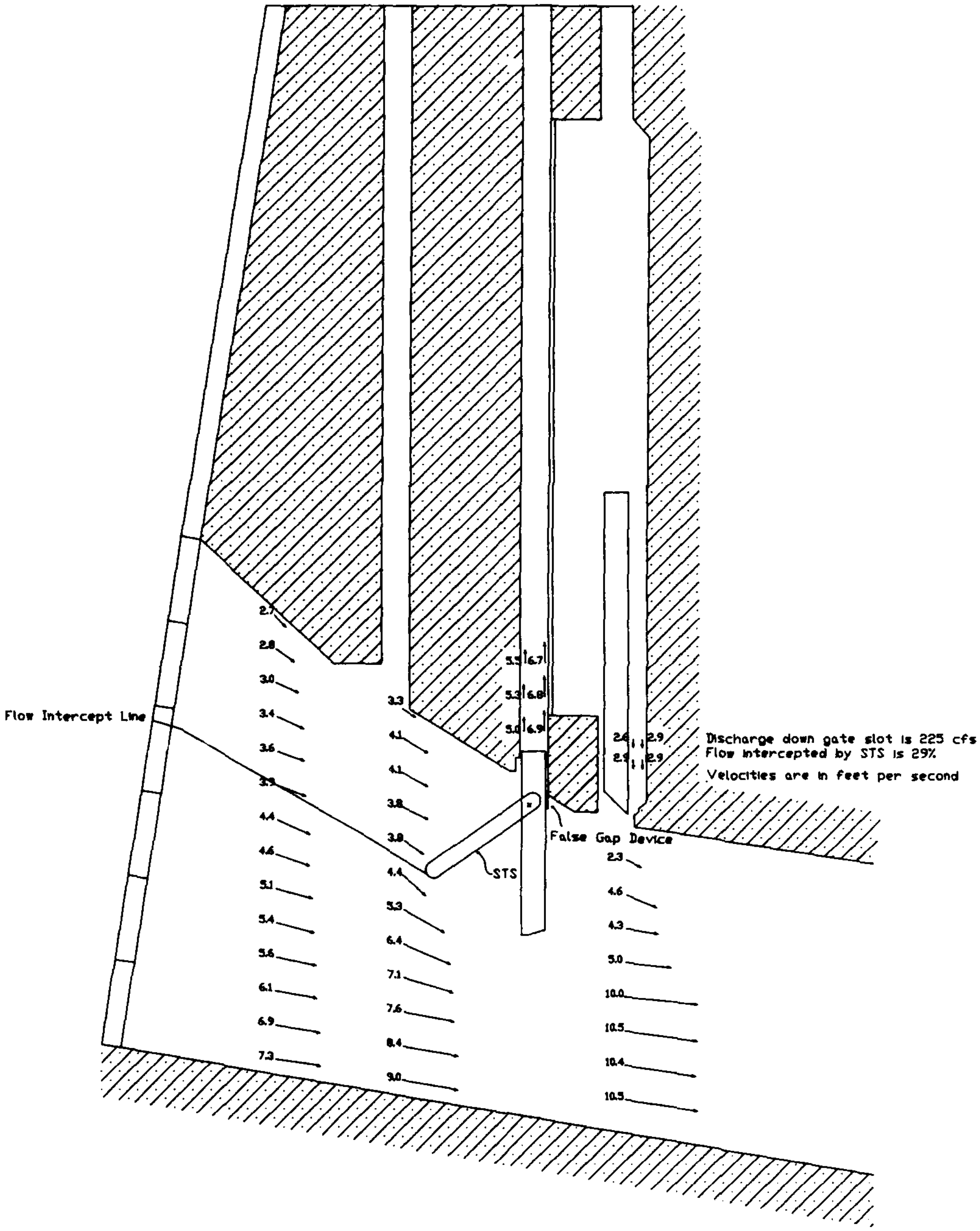
LOWER GRANITE FGE STUDY
Test 1 Velocities
55-deg STS
Pivot El 636.4



LOWER GRANITE FGE STUDY
GATE RAISE Vs FLOW DOWN SLOT

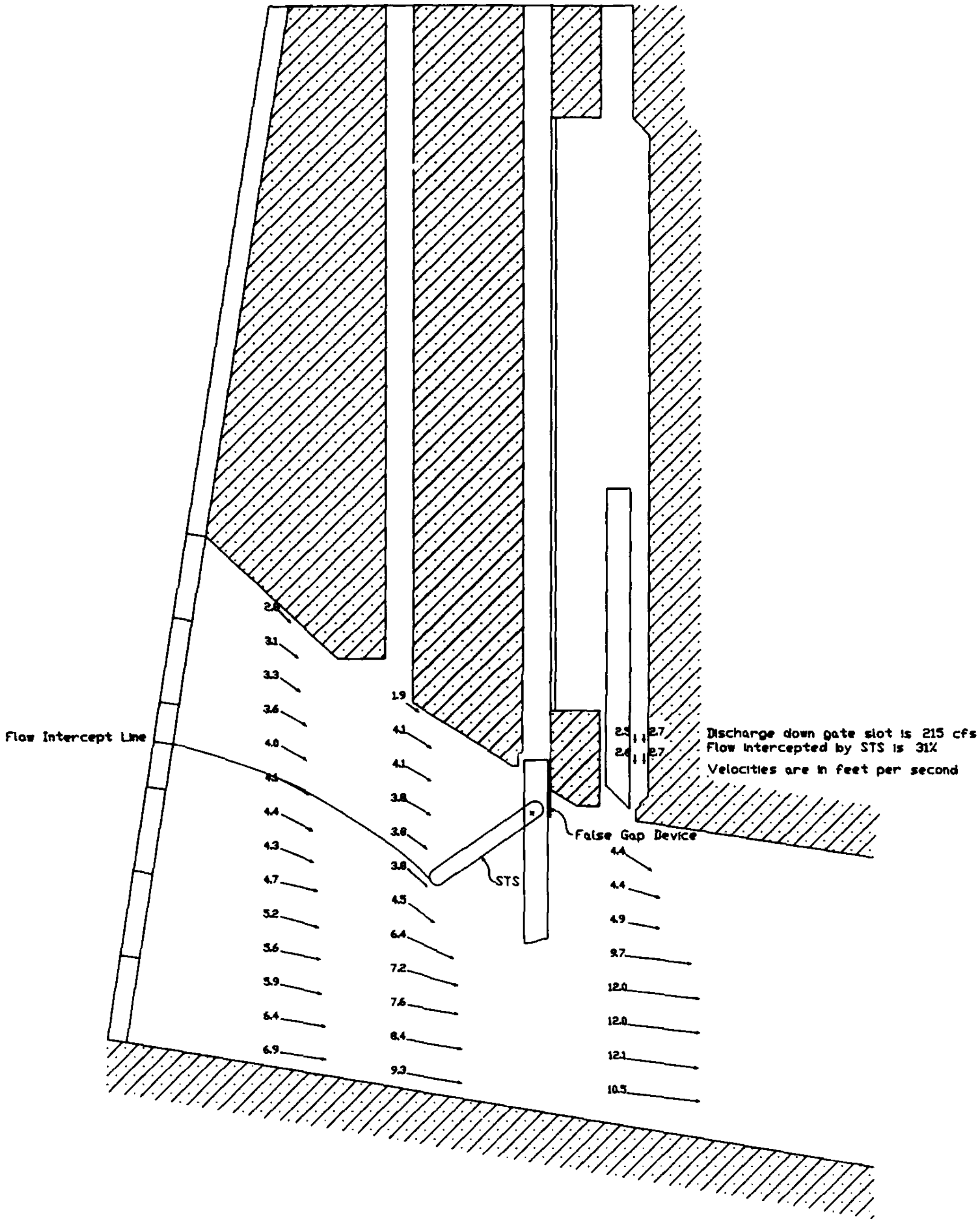


LOWER GRANITE FGE STUDY
Test 2 Velocities
55-deg STS
Gate Raised 20 FT
Pivot El 636.4

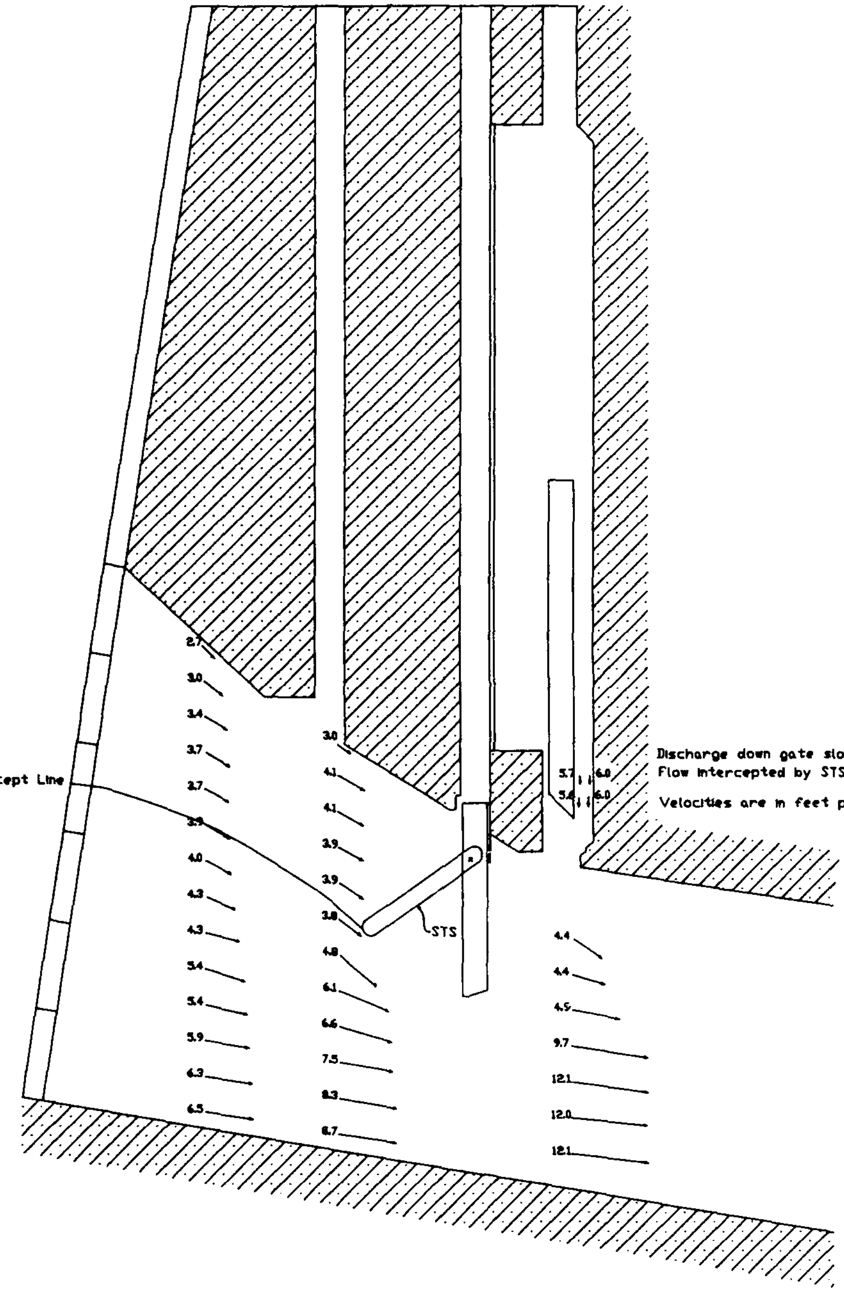


LOWER GRANITE FGE STUDY
Test 3 Velocities
55-deg STS Lowered 2 FT
False Gap Device
Pivot El 634.4

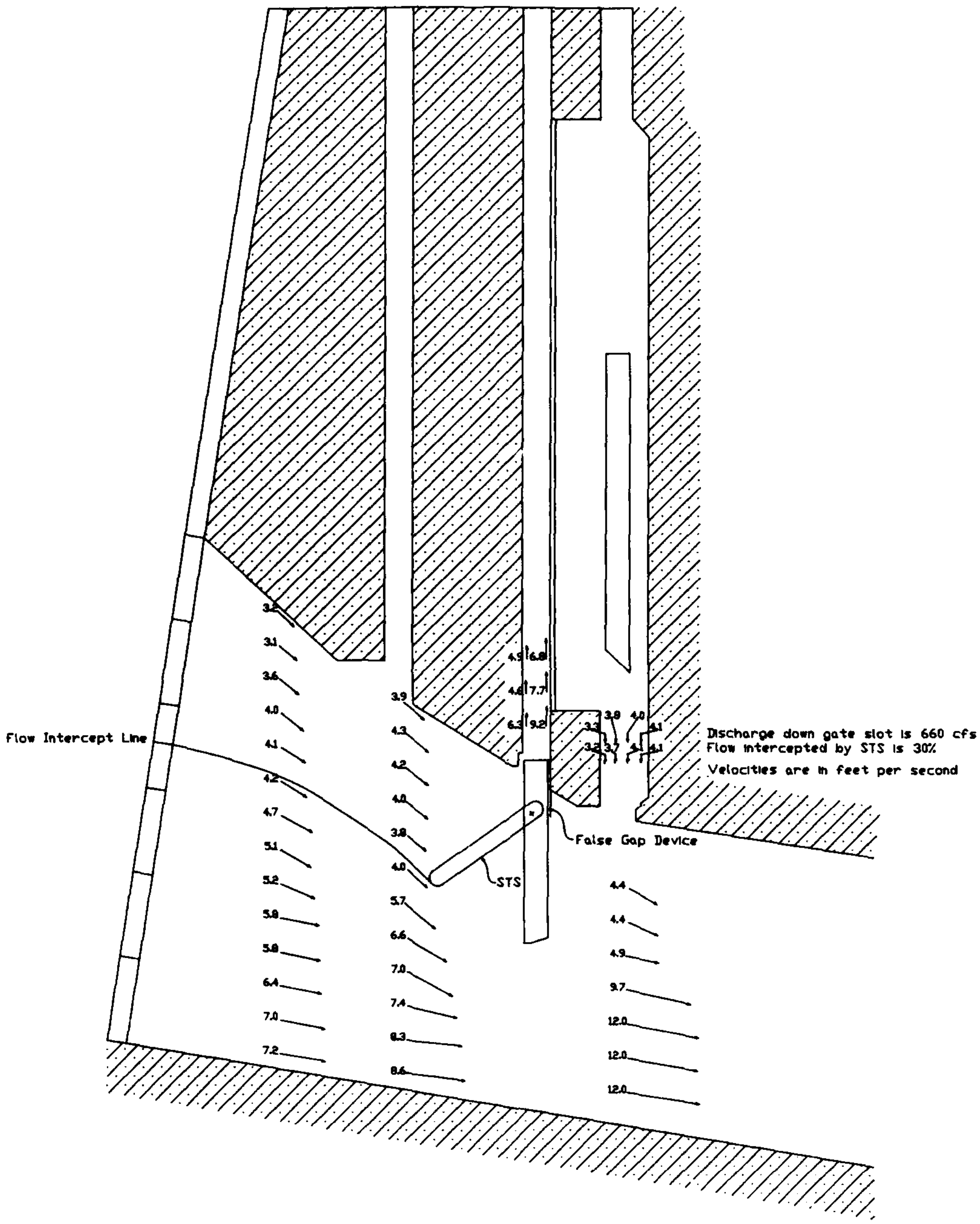
PLATE 8



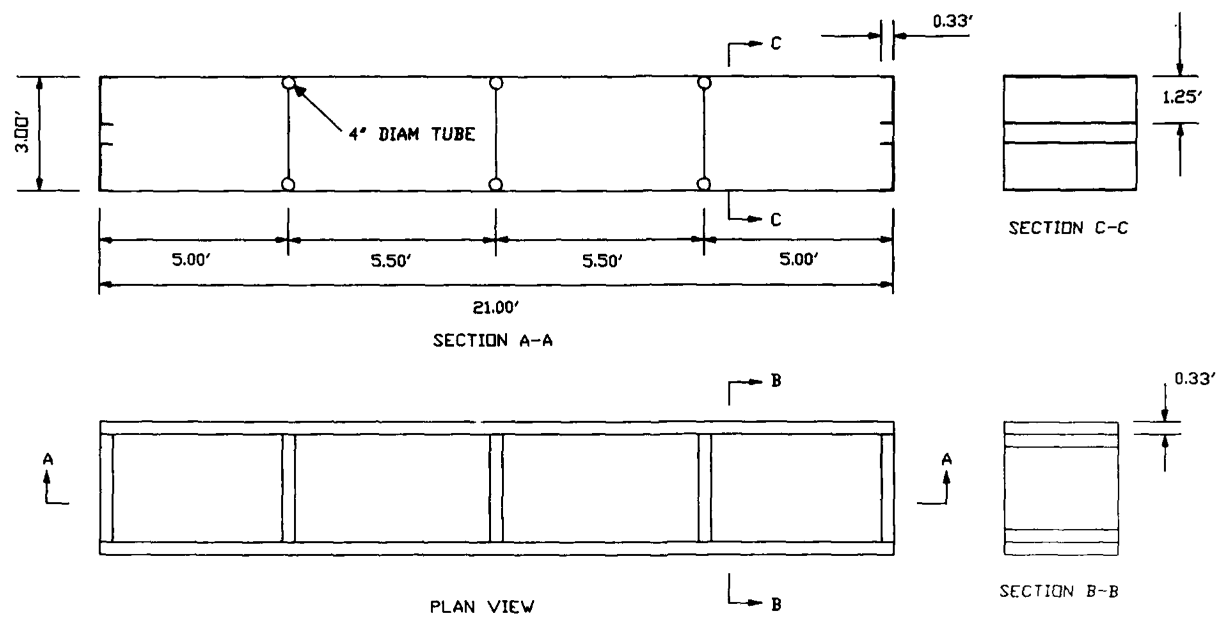
LOWER GRANITE FGE STUDY
Test 4 Velocities
55-deg STS Lowered 4 FT
False Gap Device
Pivot El 632.4



LOWER GRANITE FGE STUDY
Test 5 Velocities
55-deg STS Lowered 4 FT
False Gap Device
Gate Raised 5 FT
Pivot El 632.2

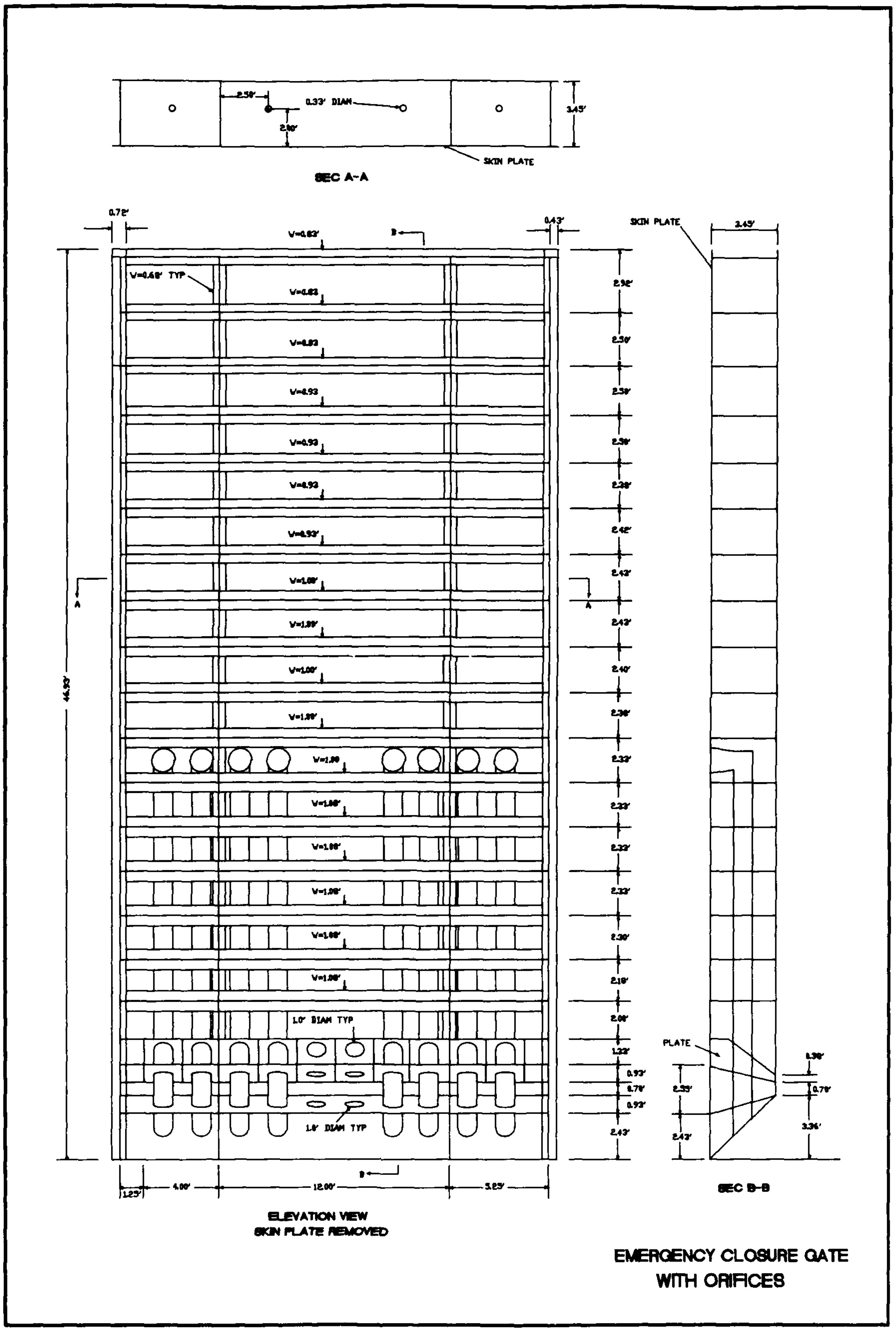


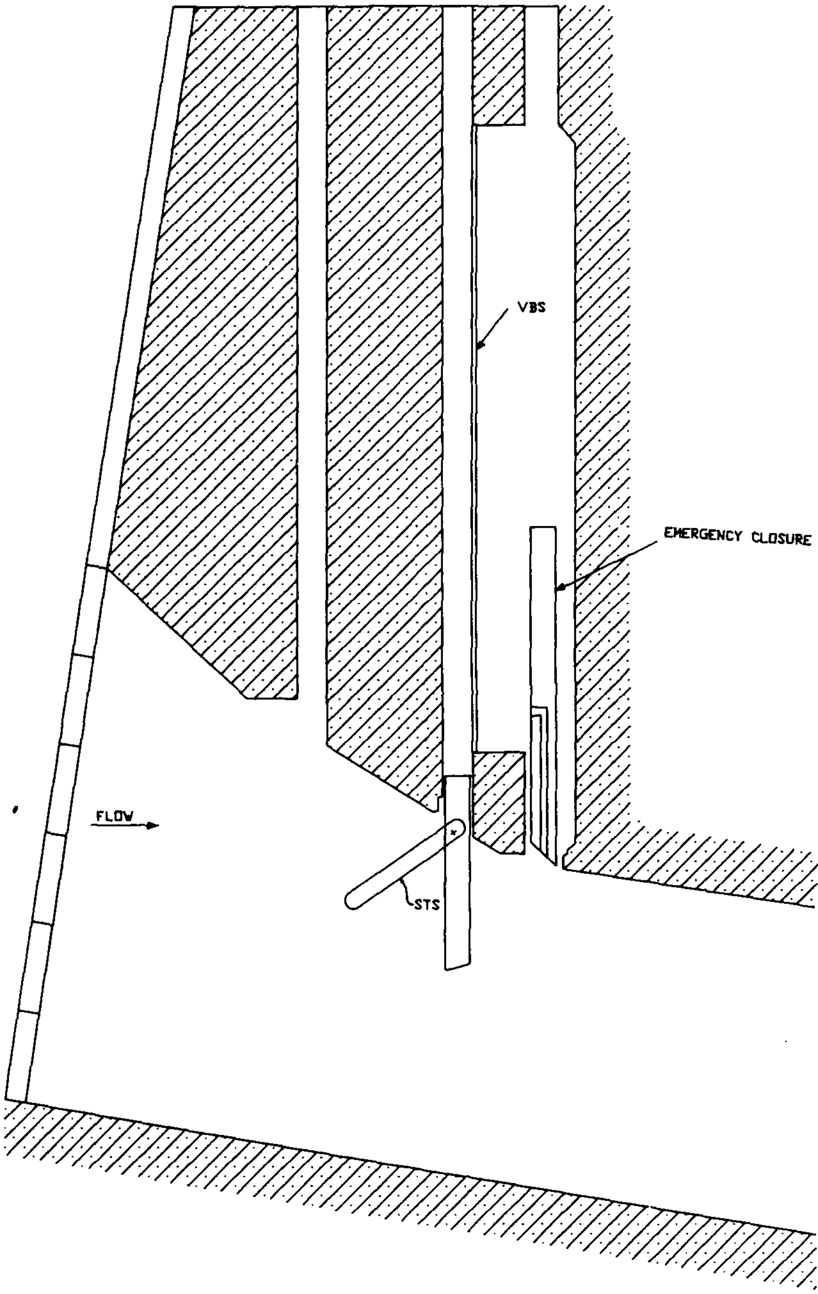
LOWER GRANITE FGE STUDY
Test 6 Velocities
55-deg STS Lowered 4 FT
False Gap Device
Gate Raised 20 FT
Pivot El 632.4



MODIFIED STS UPPER SUPPORT BEAM

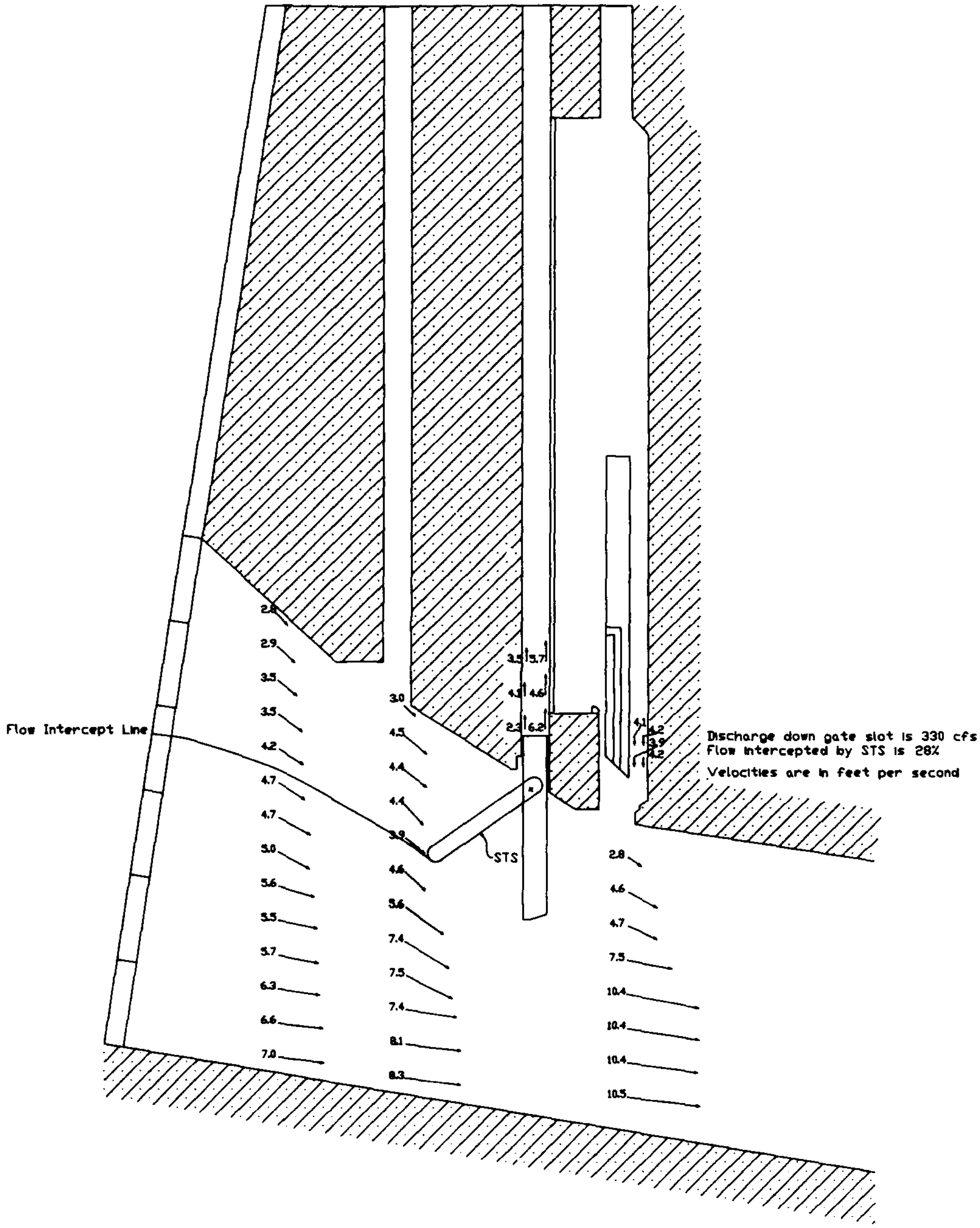
PLATE 12


SEC A-A
SKIN PLATE
0.33' DIAM
ELEVATION VIEW
SKIN PLATE REMOVED
SEC B-B
1.0' DIAM TYP
EMERGENCY CLOSURE GATE
WITH ORIFICES

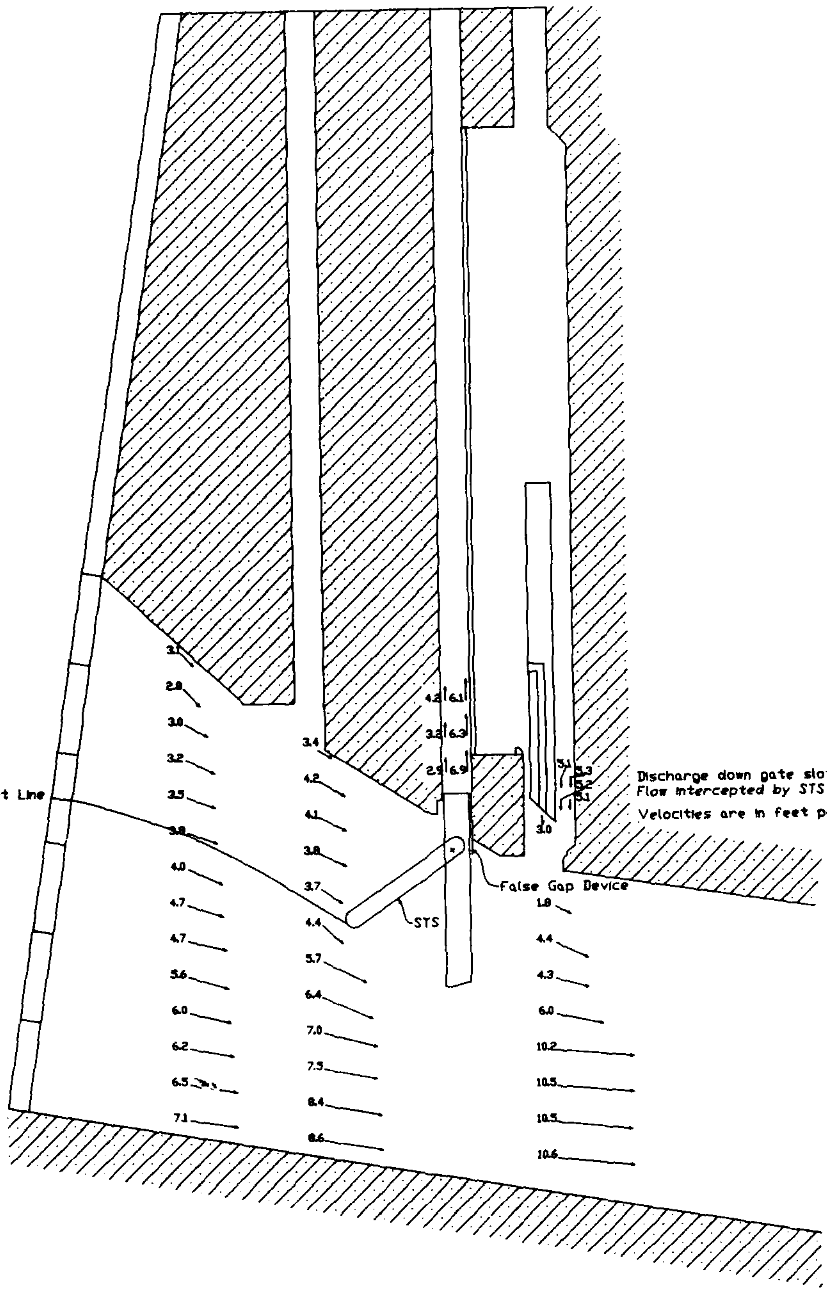


EMERGENCY CLOSURE GATE
WITH ORIFICES
TRANSVERSE SECTION

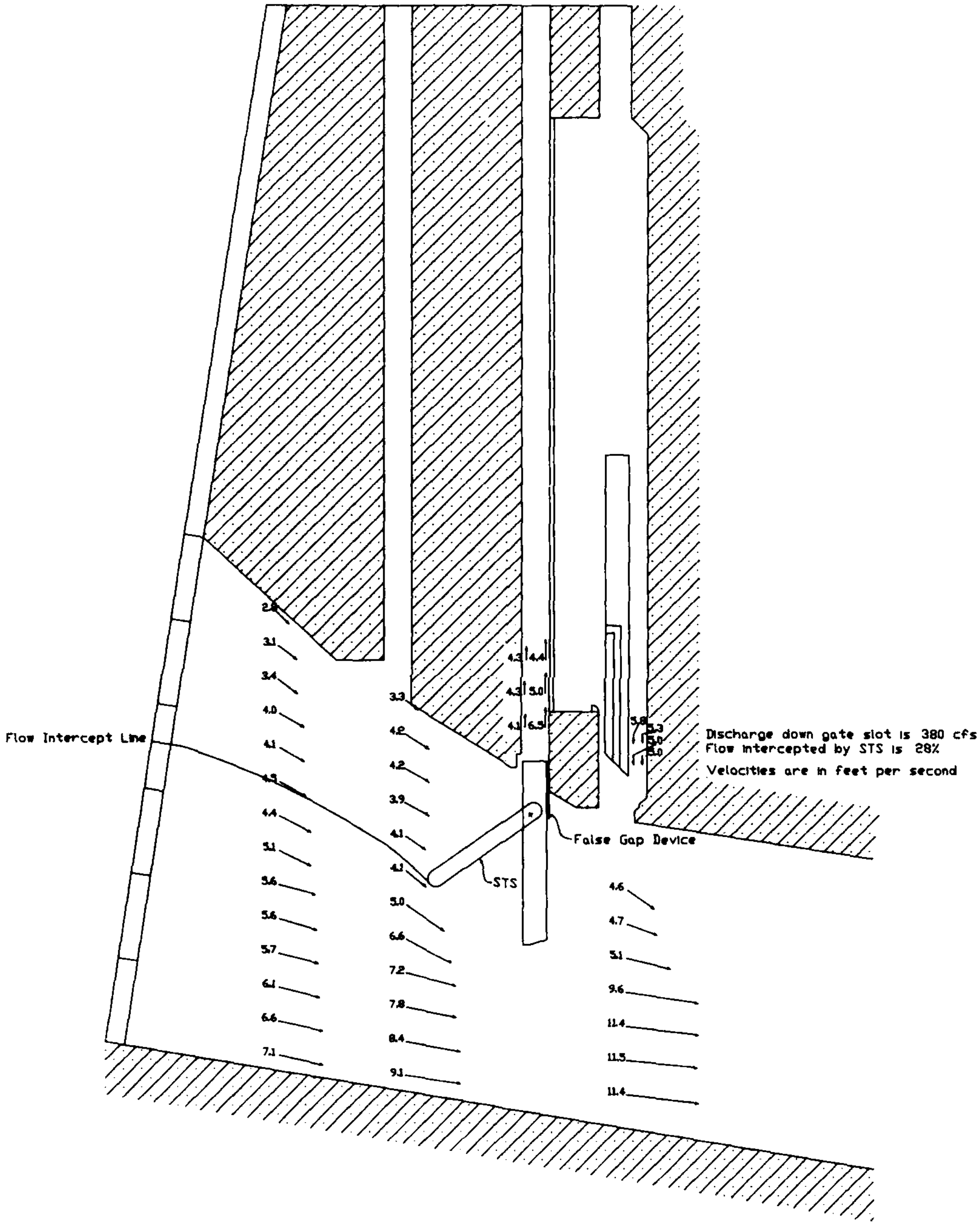
PLATE 14



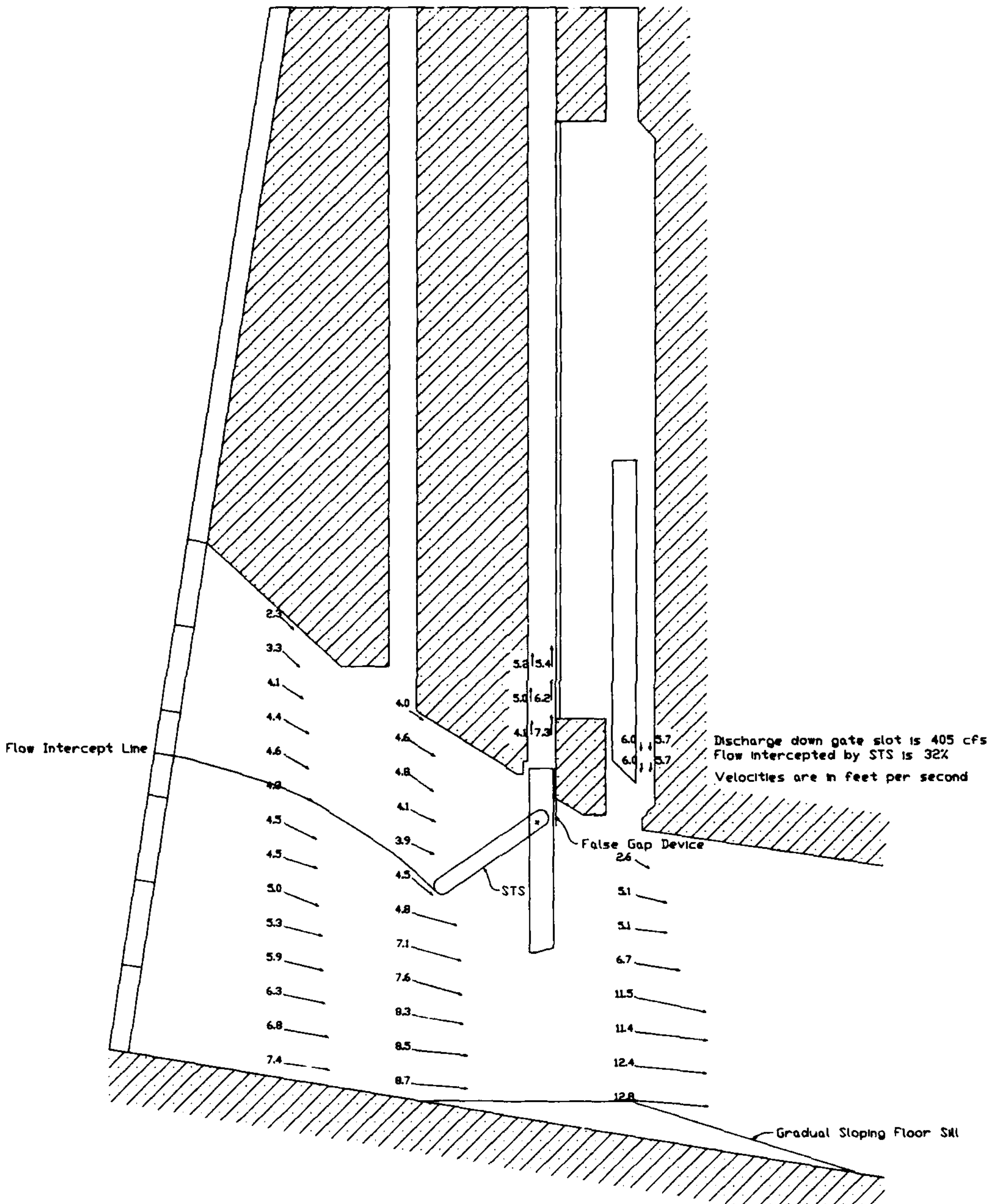
LOWER GRANITE FGE STUDY
Test 7 Velocities
55-deg STS
Miscellaneous Modifications
Gate Raised 5 FT
Pivot El 636.4



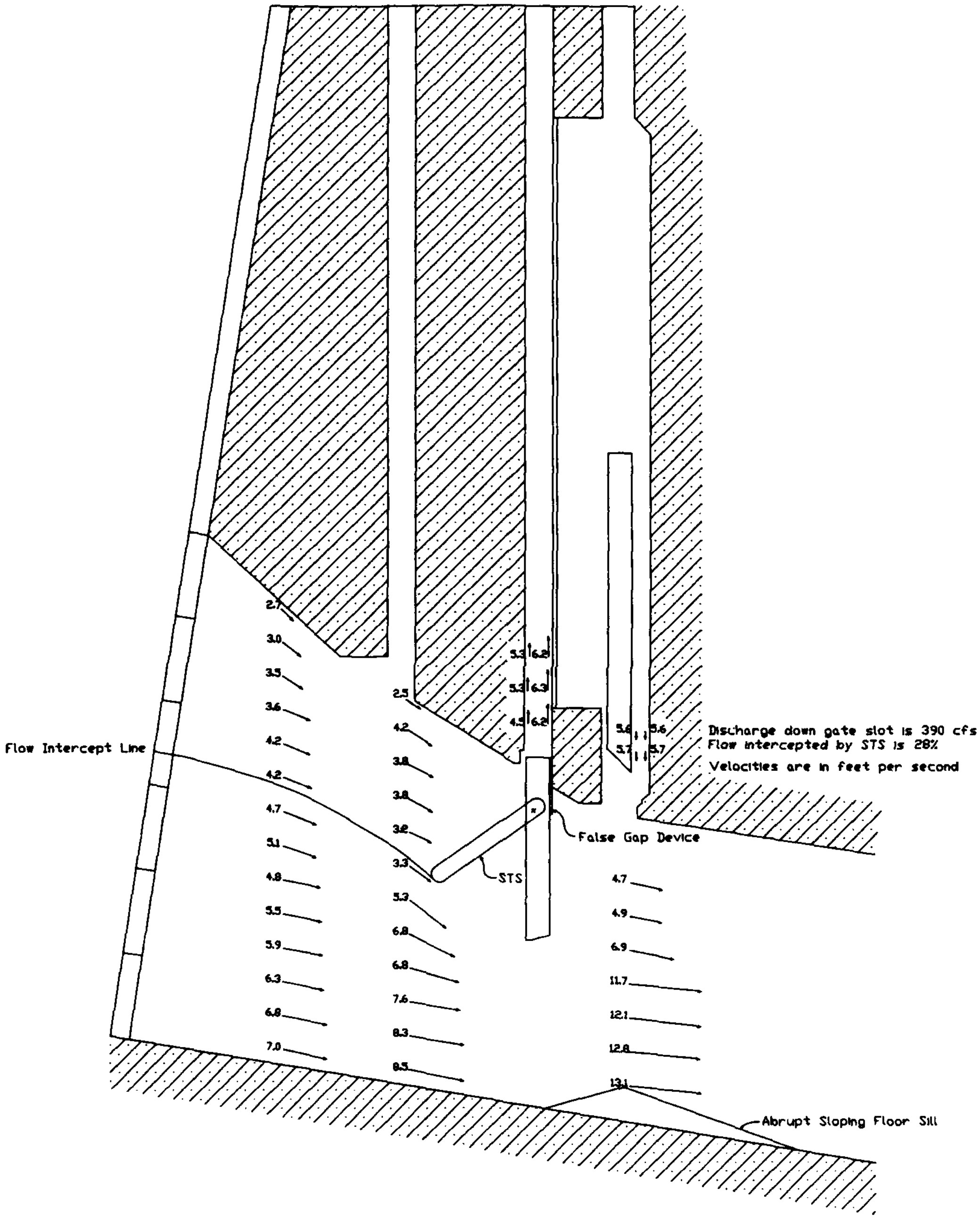
LOWER GRANITE FGE STUDY
Test 8 Velocities
55-deg STS Lowered 2 FT
Miscellaneous Modifications
False Gap Device
Gate Raised 5 FT
Pivot El 634.4



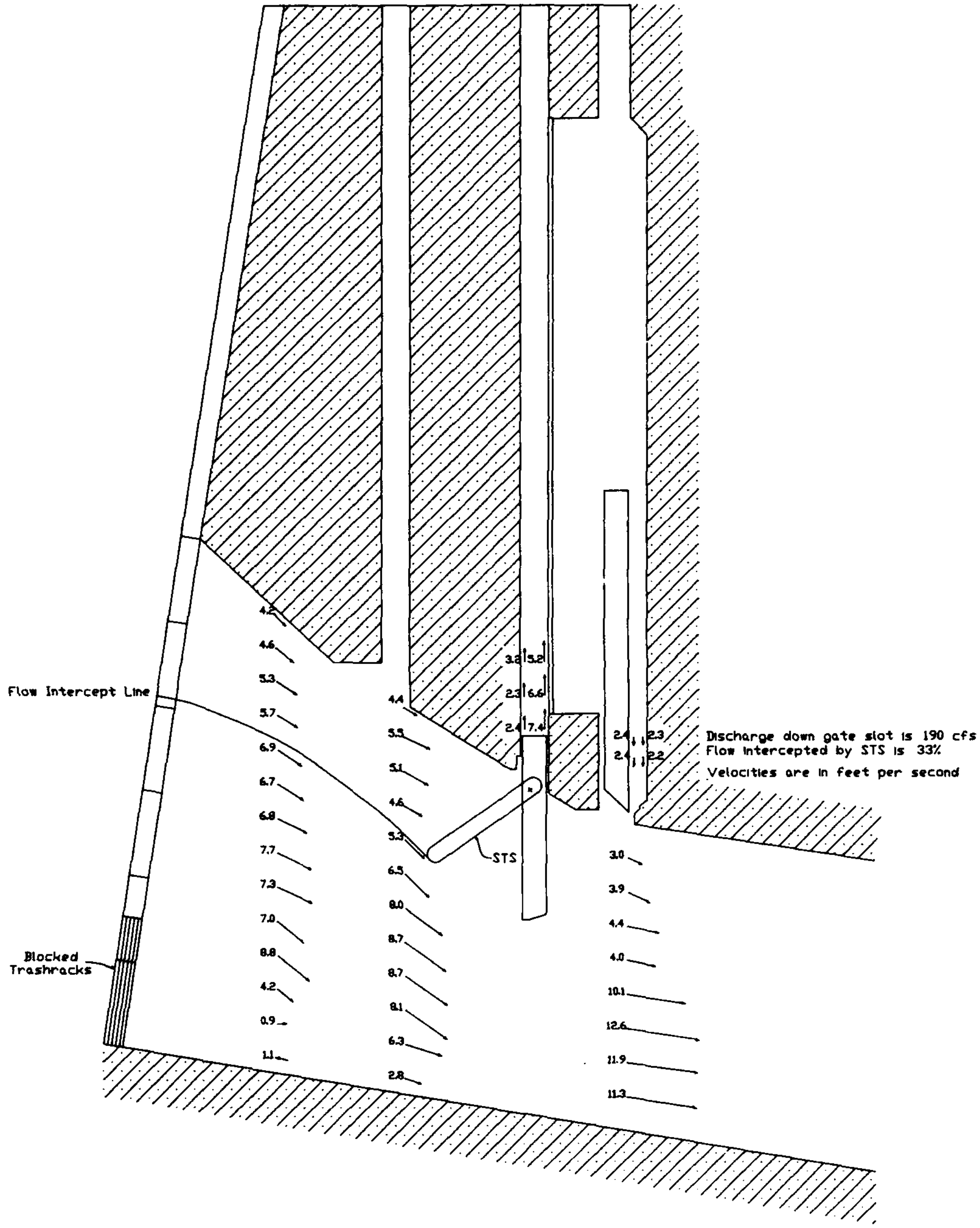
LOWER GRANITE FGE STUDY
Test 9 Velocities
55-deg STS Lowered 4 FT
Miscellaneous Modifications
False Gap Device
Gate Raised 5 FT
Pivot El 632.4



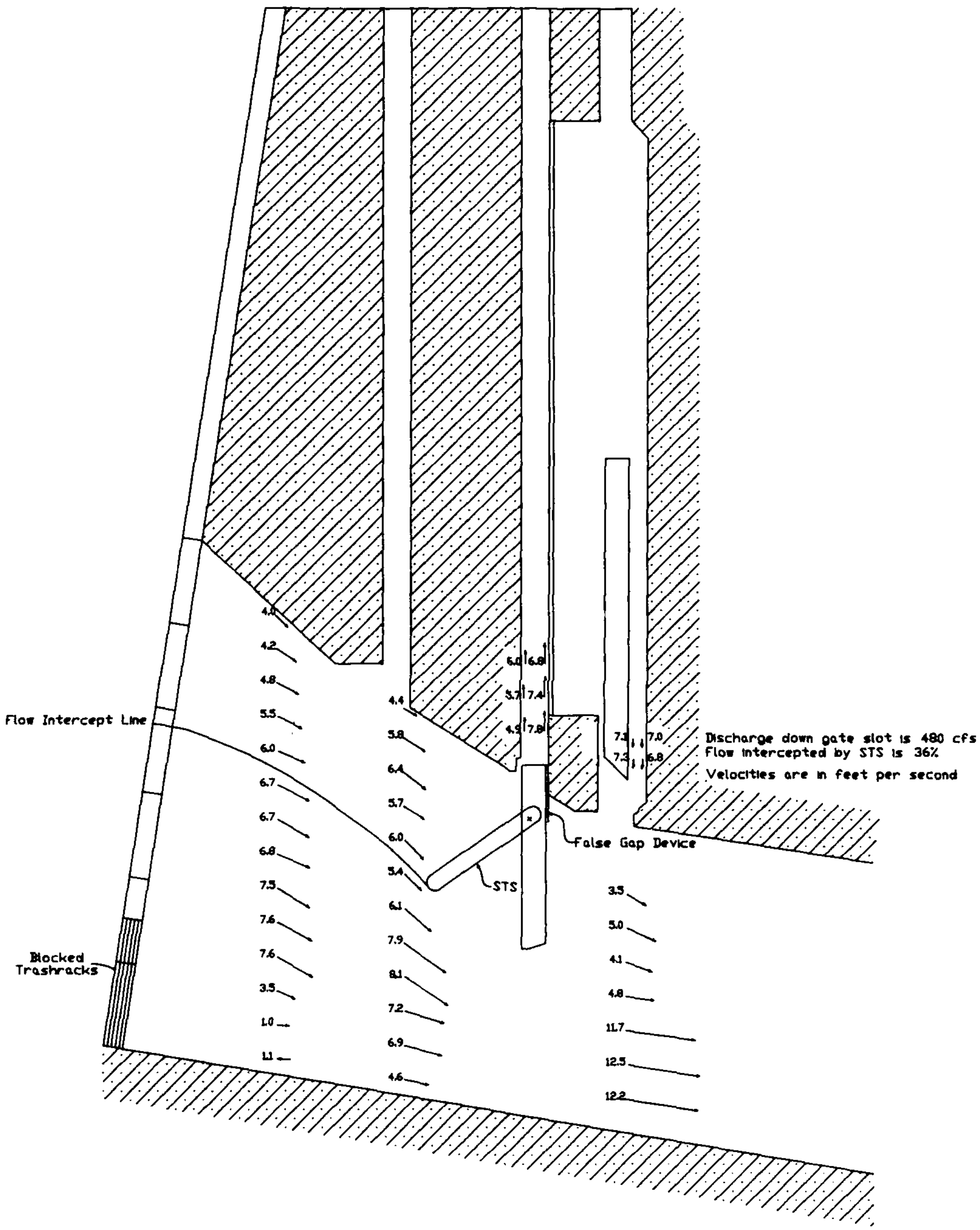
LOWER GRANITE FGE STUDY
Test 10 Velocities
55-deg STS Lowered 4 FT
Gradual Sloping Floor Sill
False Gap Device
Gate Raised 5 FT
Pivot El 632.4



LOWER GRANITE FGE STUDY
Test 11 Velocities
55-deg STS Lowered 4 FT
Abrupt Sloping Floor Sill
False Gap Device
Gate Raised 5 FT
Pivot El 632.4



LOWER GRANITE FGE STUDY
Test 12 Velocities
55-deg STS
Trashracks Blocked to El 618
Pivot El 636.4



LOWER GRANITE FGE STUDY
Test 13 Velocities
55-deg STS Lowered 4 FT
Trashracks Blocked to El 618
False Gap Device
Gate Raised 5 FT
Pivot El 632.4

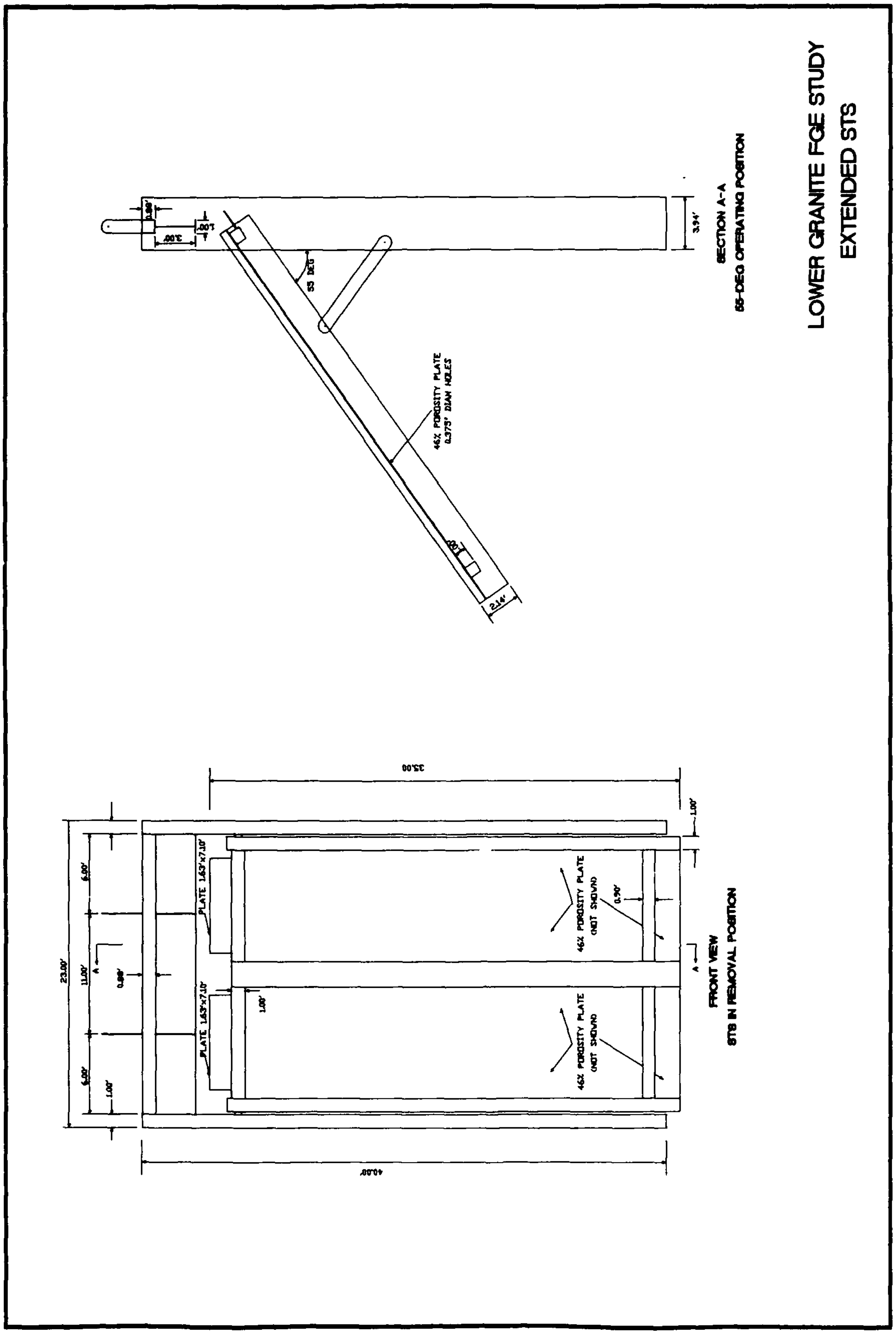
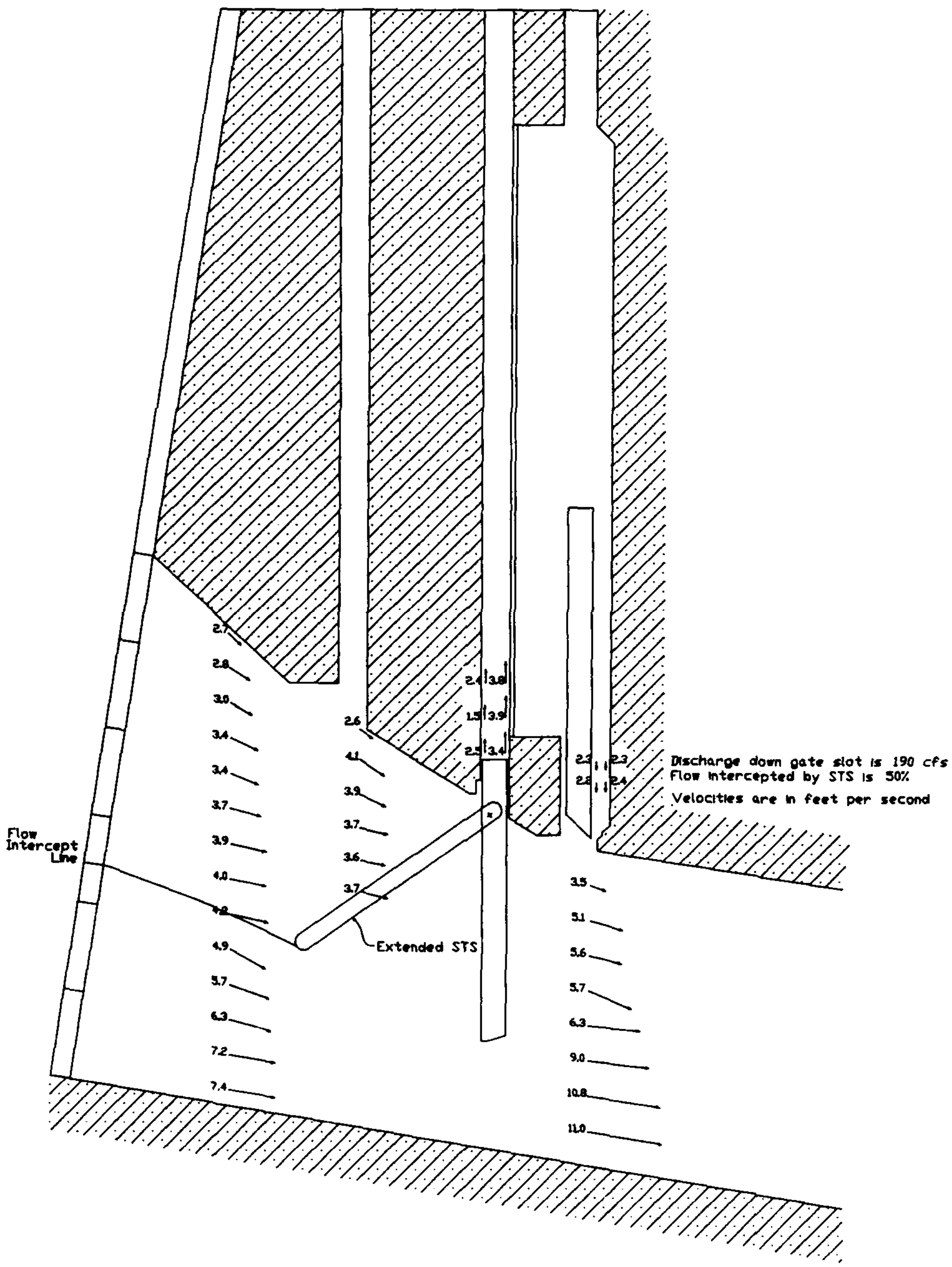
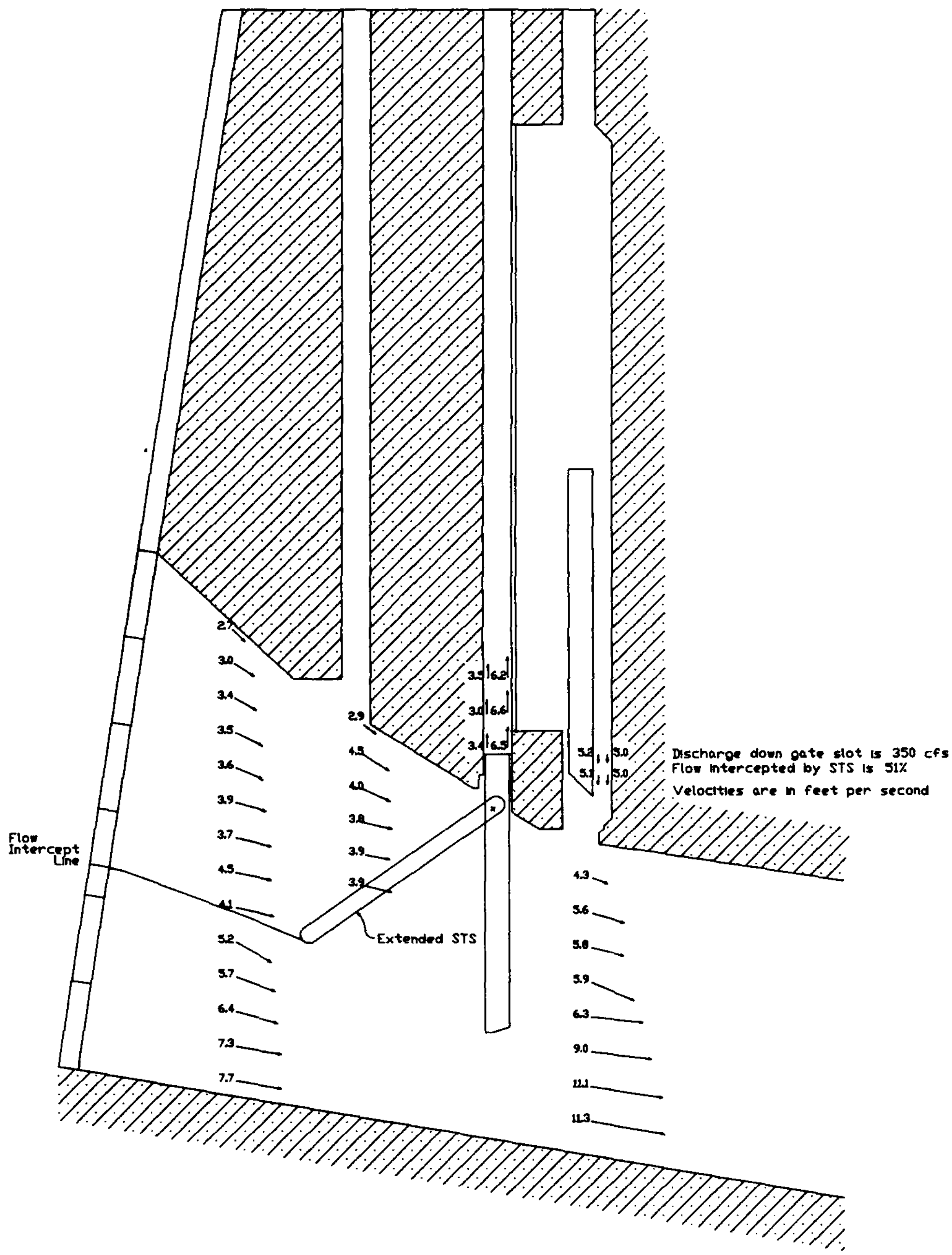

LOWER GRANITE FGE STUDY
EXTENDED STS
SECTION A-A
55-DEG OPERATING POSITION
46% POROSITY PLATE
0.375" DIAM HOLES
55 DEG
3.94'
3.00'
1.00'
2.14'
FRONT VIEW
STS IN REMOVAL POSITION
46% POROSITY PLATE
(NOT SHOWN)
PLATE 1.63'x7.10'
23.00'
11.00'
6.00'
1.00'
0.88'
0.90'
32.08'
40.00'

PLATE 22

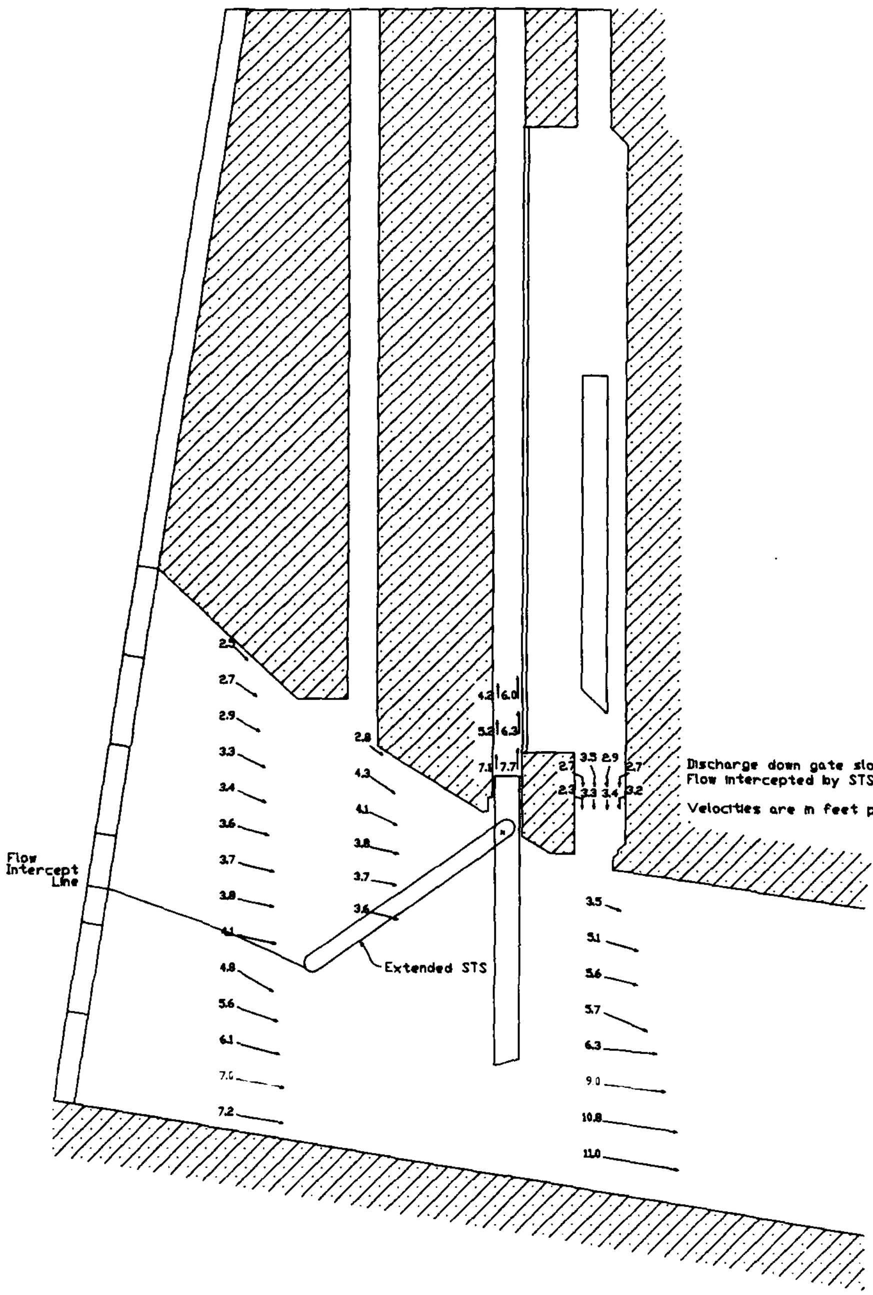


LOWER GRANITE FGE STUDY
Test 14 Velocities
55-deg Extended STS
Pivot El 636.4

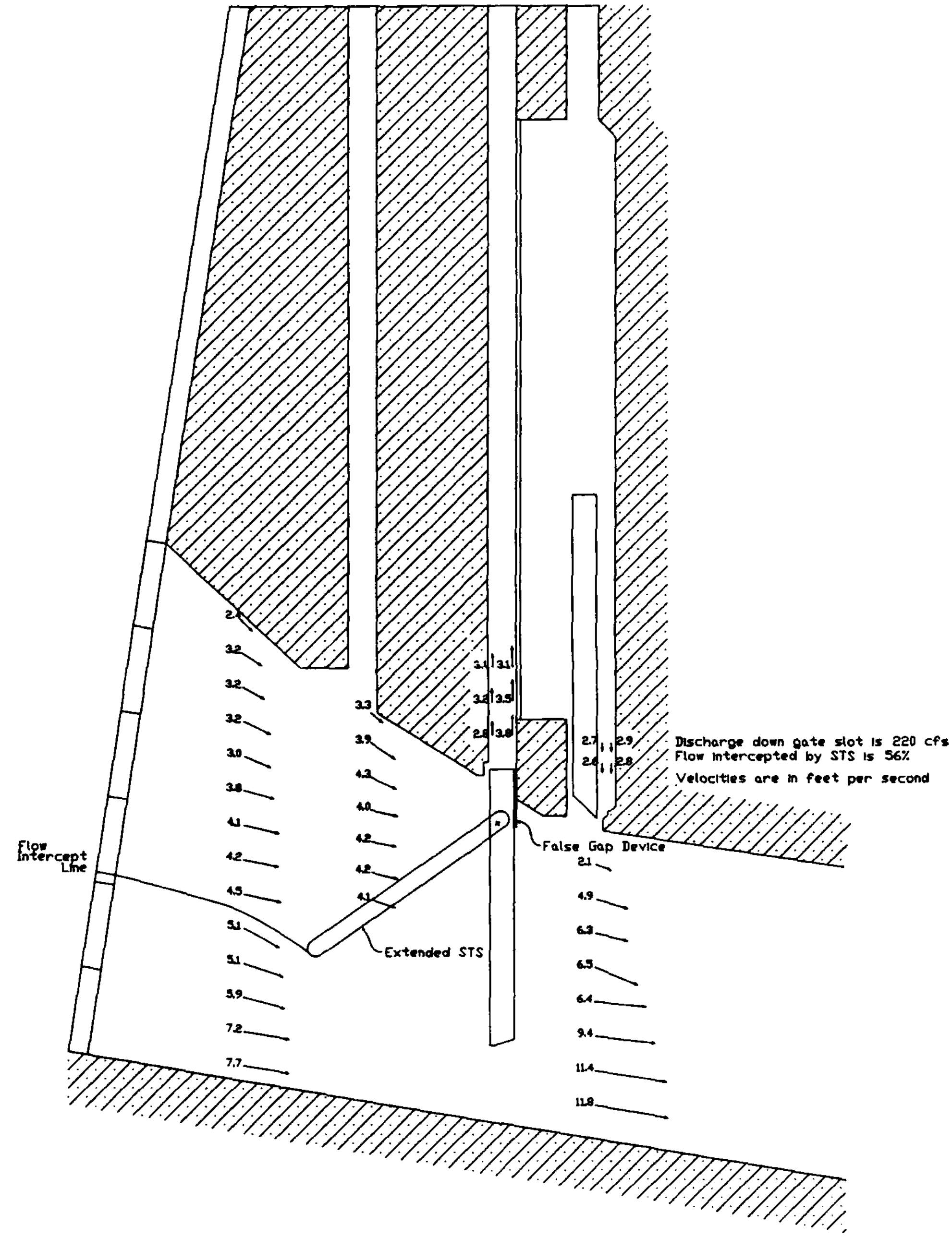


LOWER GRANITE FGE STUDY
Test 15 Velocities
55-deg Extended STS
Gate Raised 5 FT
Pivot El 636.4

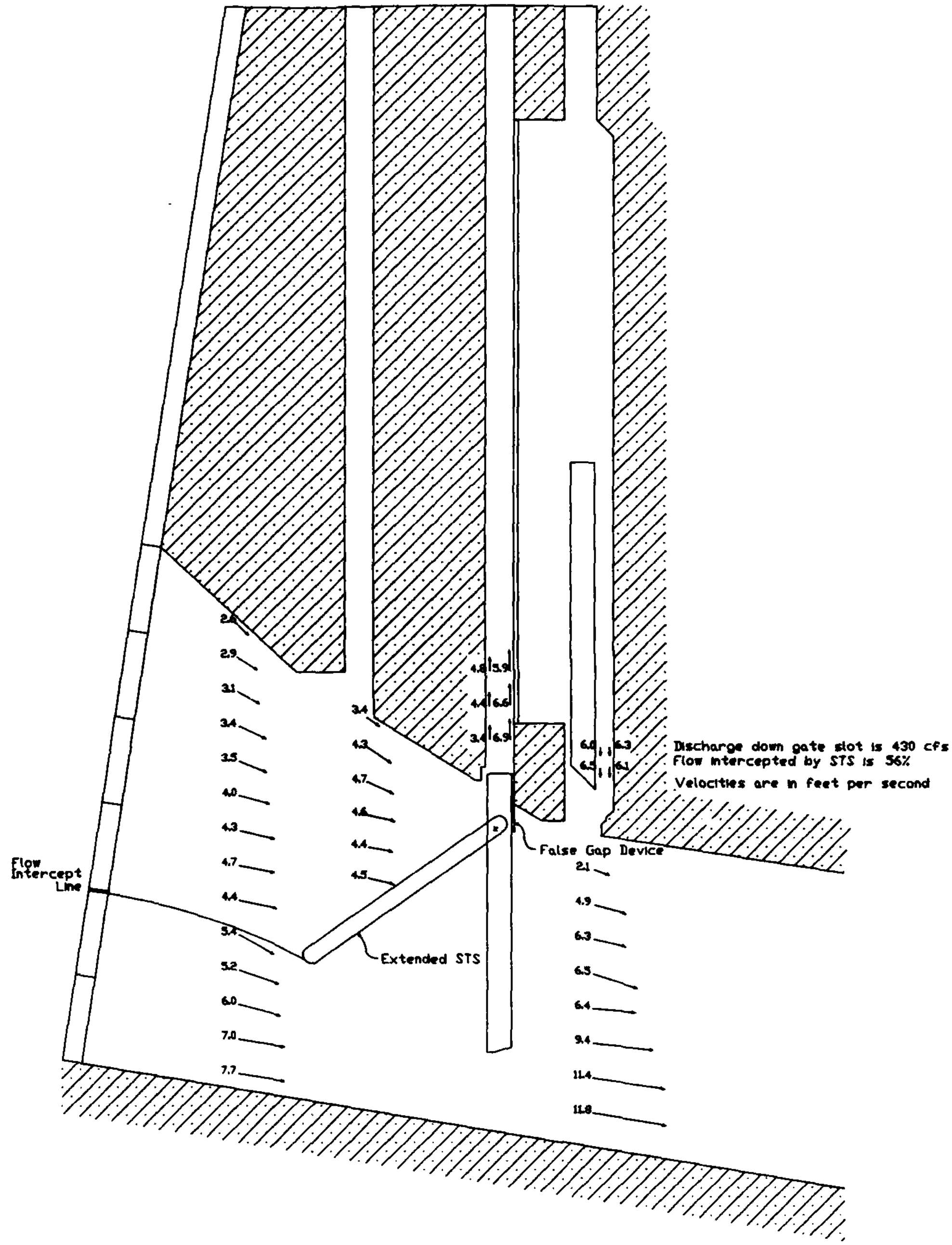
PLATE 24



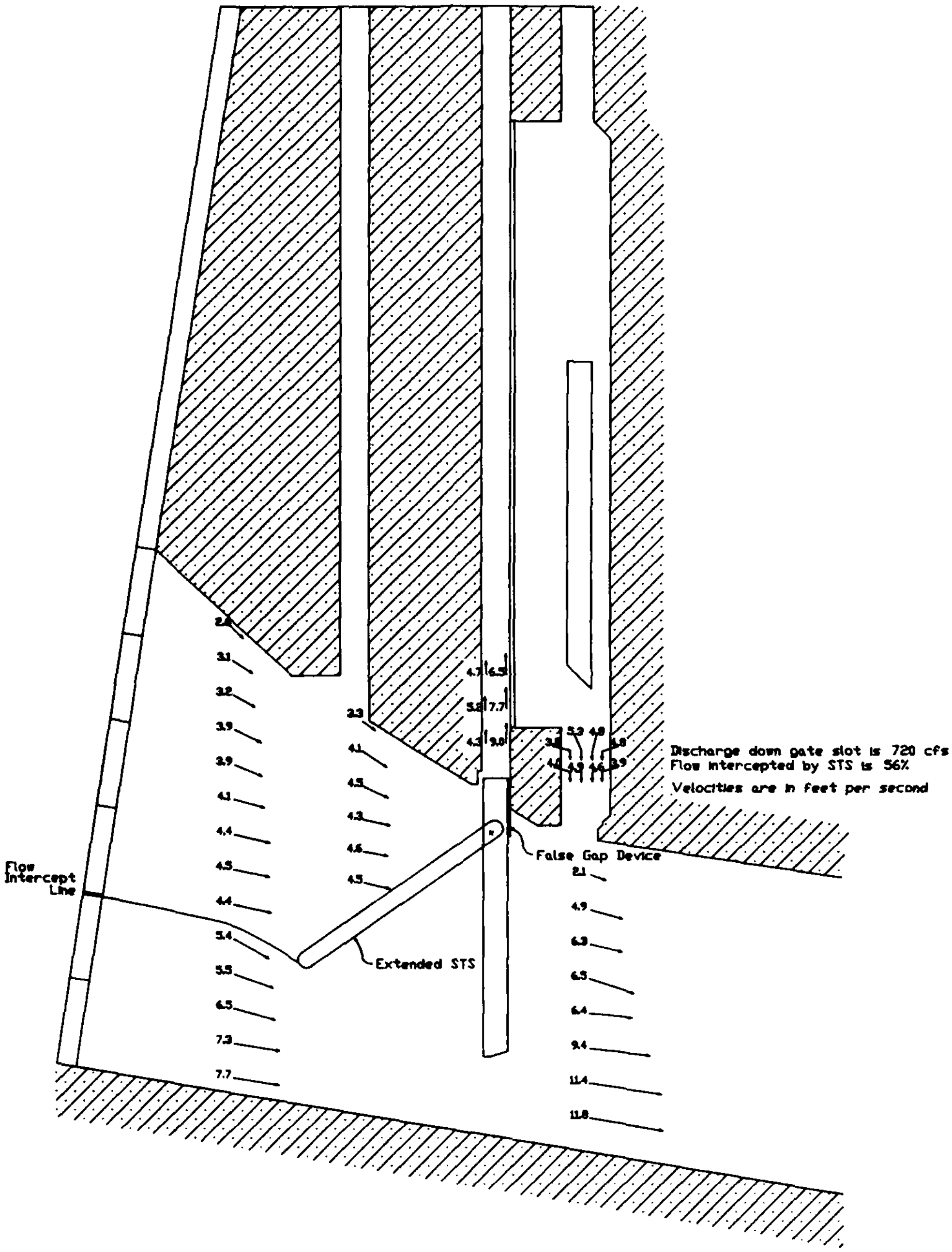
LOWER GRANITE FGE STUDY
Test 16 Velocities
55-deg Extended STS
Gate Raised 20 FT
Pivot El 636.4



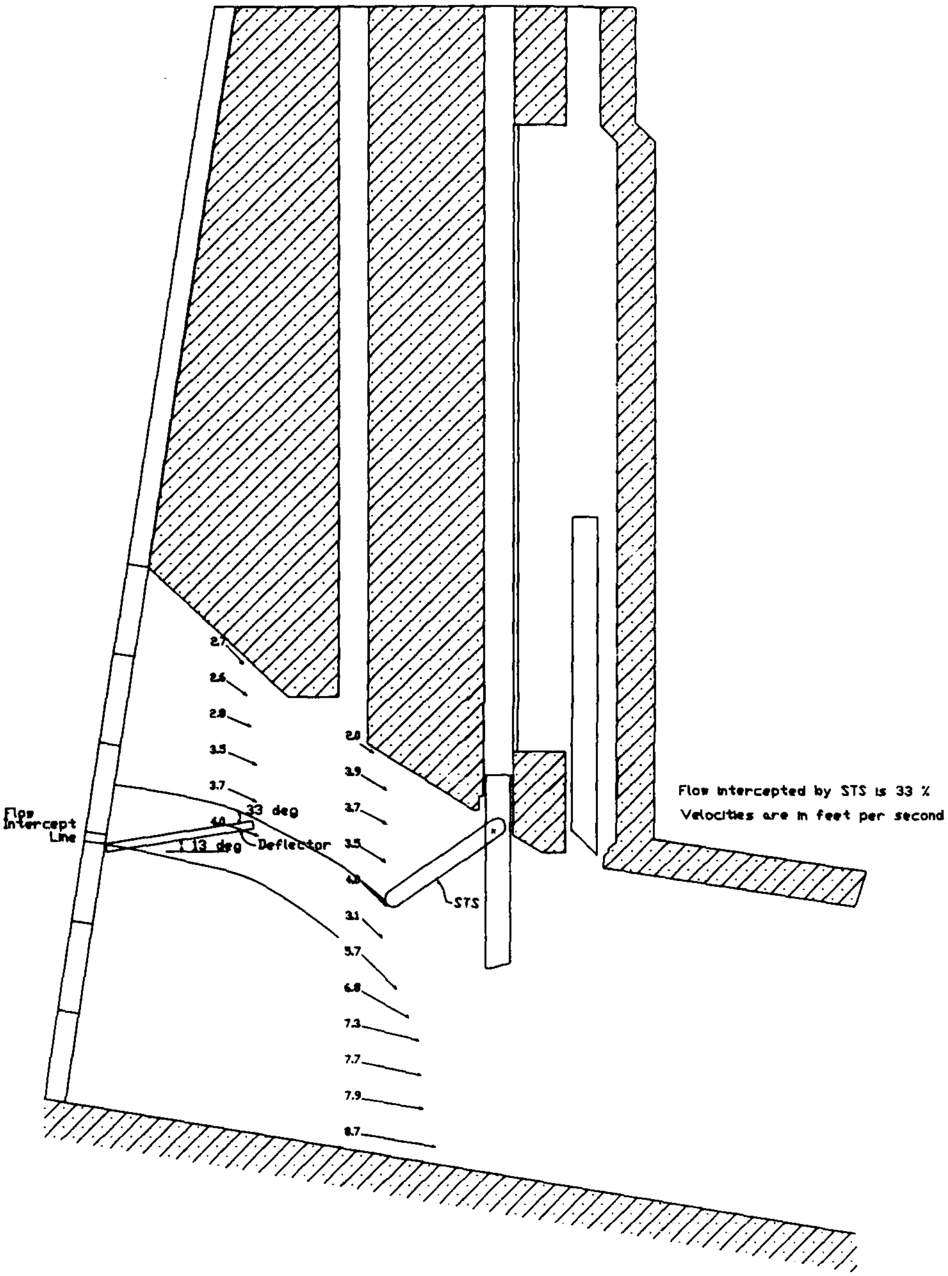
LOWER GRANITE FGE STUDY
Test 17 Velocities
55-deg Extended STS Lowered 4 FT
False Gap Device
Pivot El 632.4



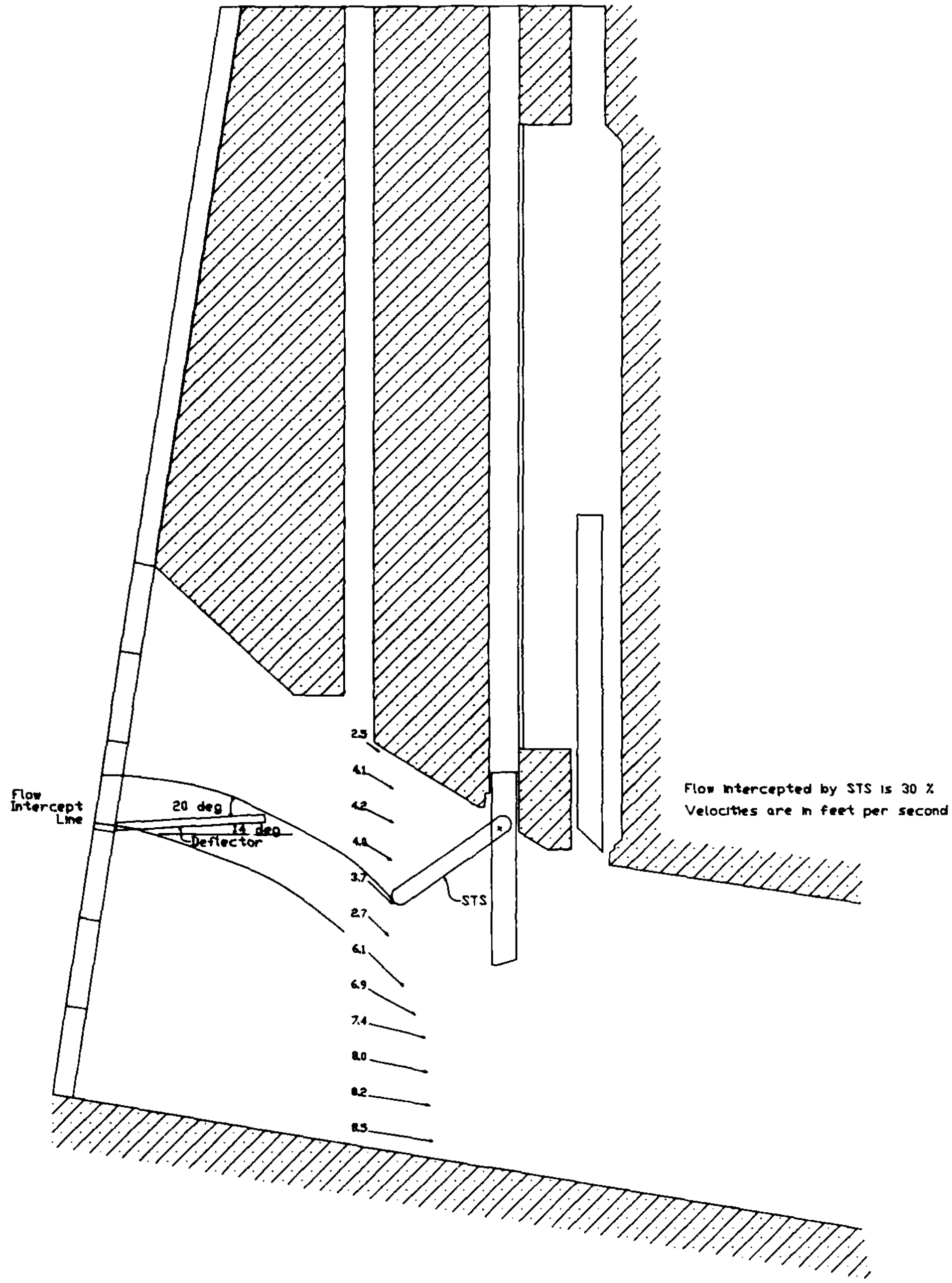
LOWER GRANITE FGE STUDY
Test 18 Velocities
55-deg Extended STS Lowered 4 FT
False Gap Device
Gate Raised 5 FT
Pivot El 632.4



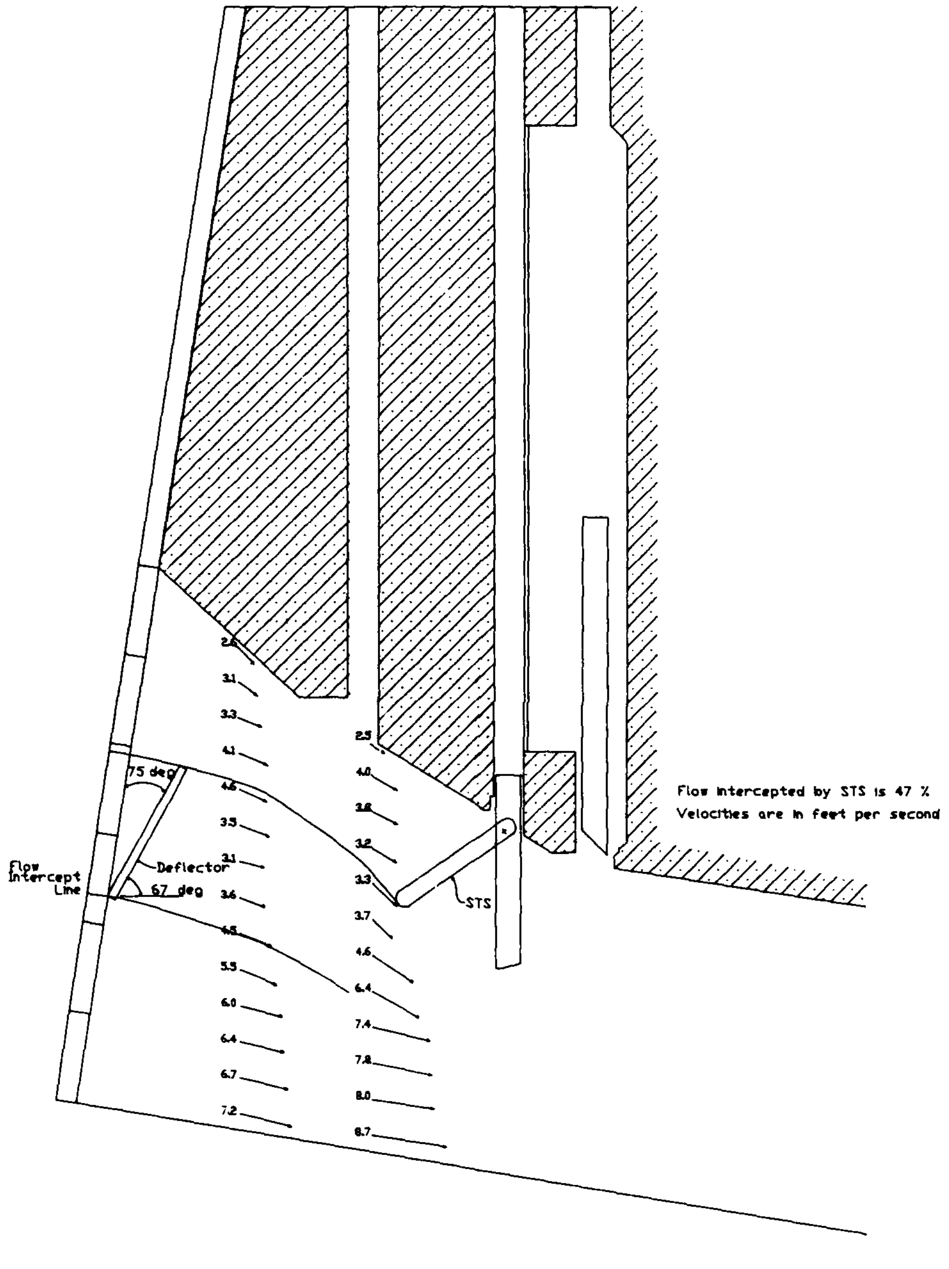
LOWER GRANITE FGE STUDY
Test 19 Velocities
55-deg Extended STS Lowered 4 FT
False Gap Device
Gate Raised 20 FT
Pivot El 632.4



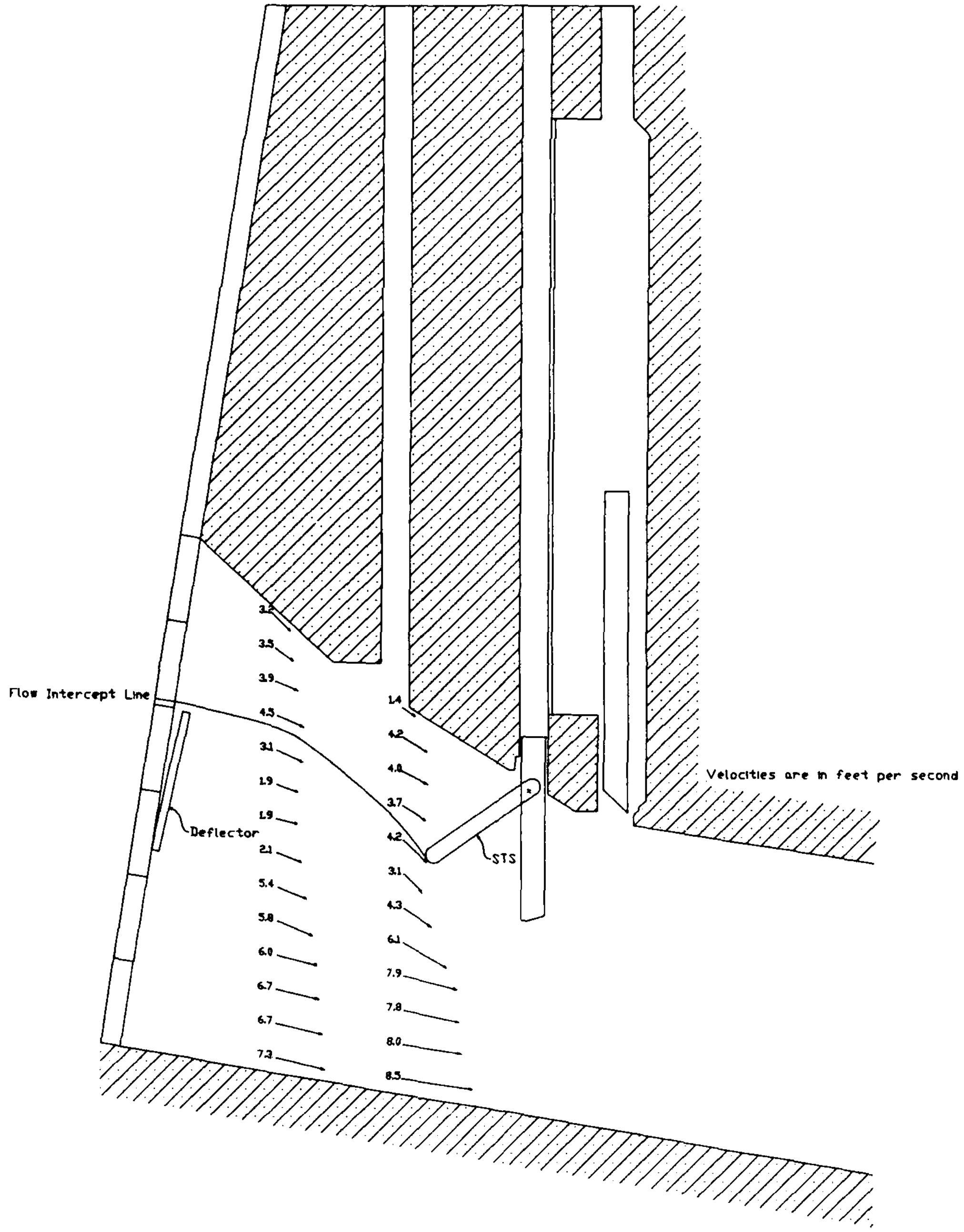
LITTLE GOOSE FGE STUDY
Test 20 Velocities
55-deg STS
Deflector Attached at El 636.4
Pivot El 636.4



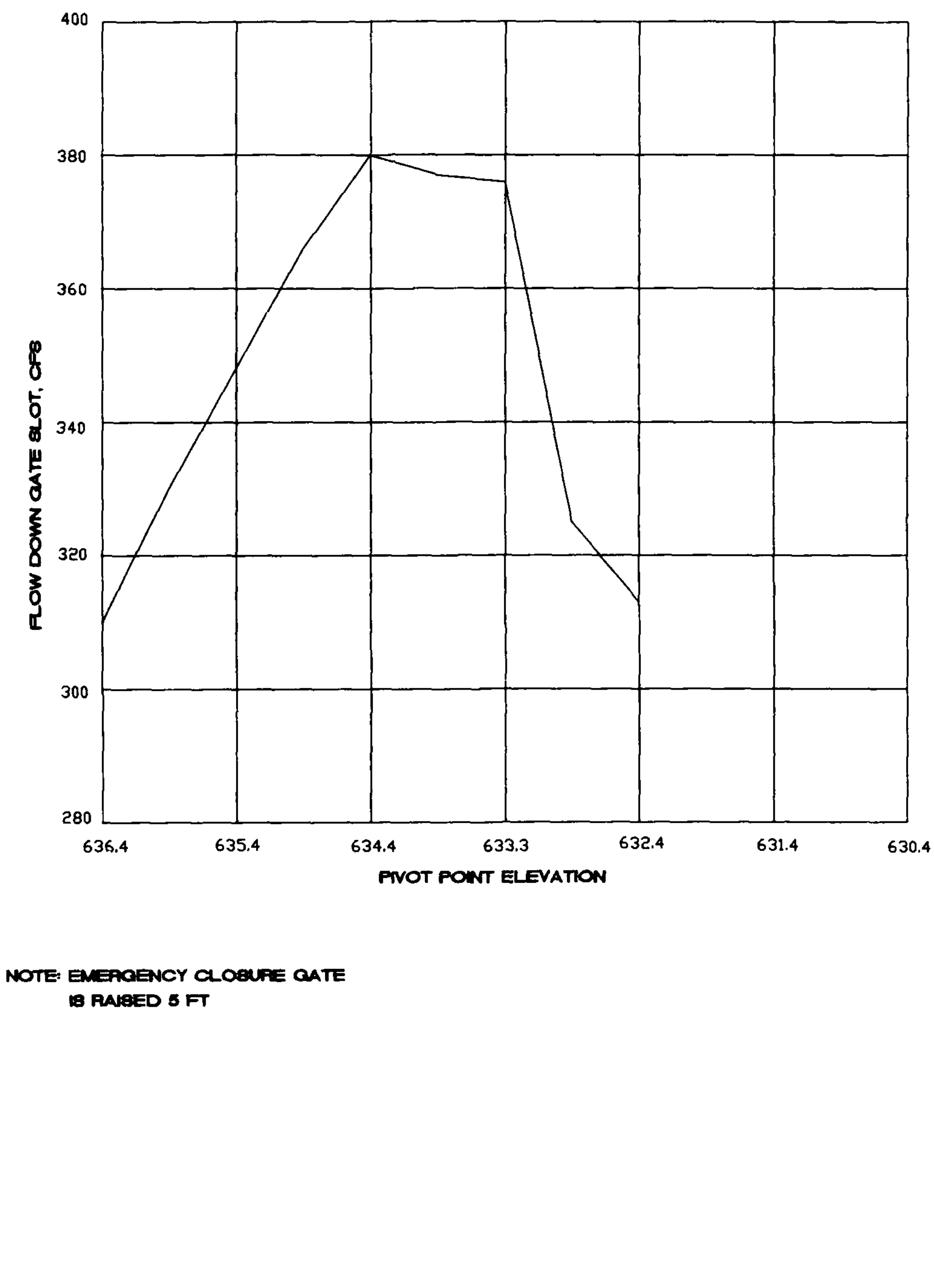
LITTLE GOOSE FGE STUDY
Test 21 Velocities
55-deg STS
Deflector Attached at El 638.3
Pivot El 636.4



LITTLE GOOSE FGE STUDY
Test 22 Velocities
55-deg STS
Deflector Attached at El 626.8
Pivot El 636.4



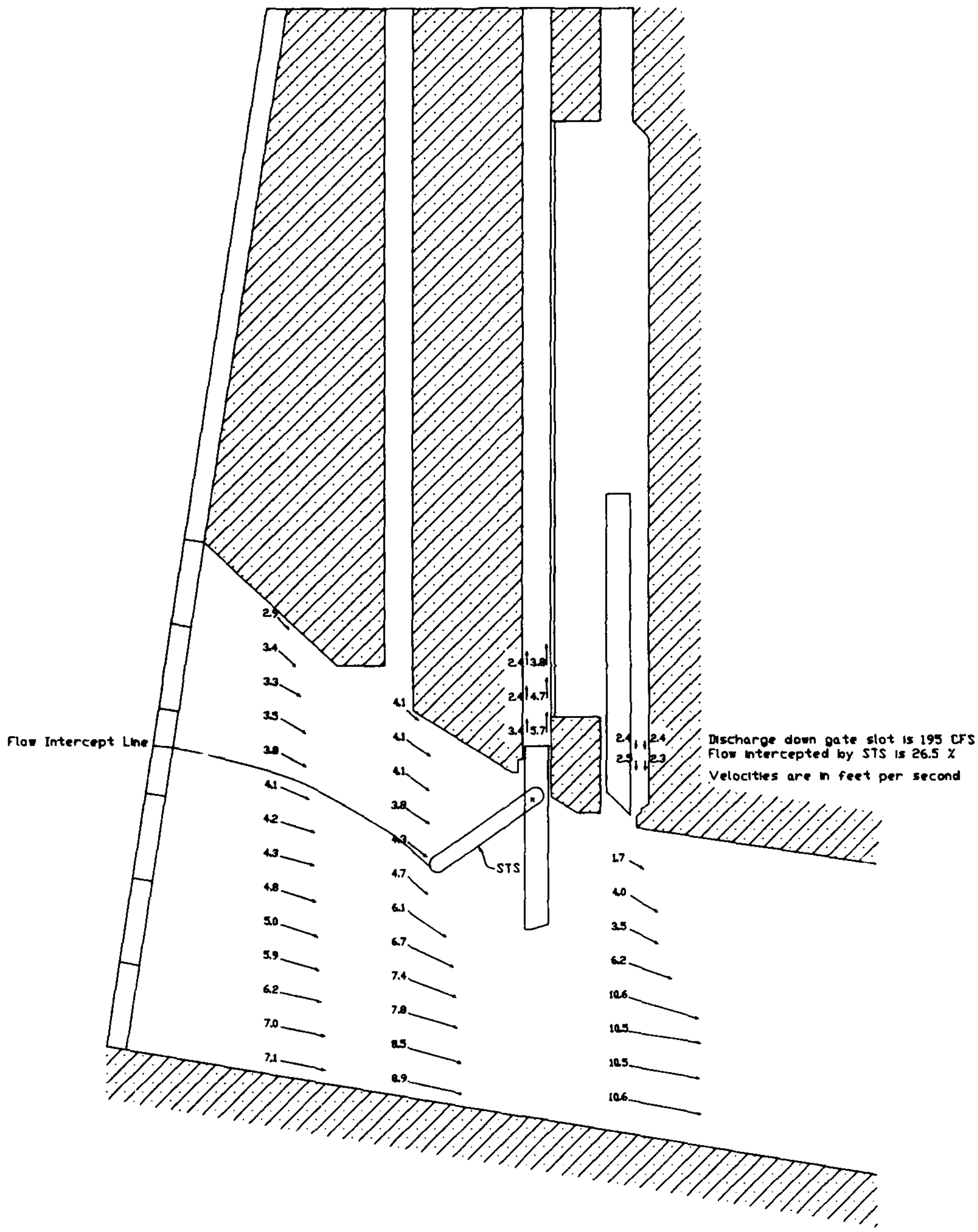
LITTLE GOOSE FGE STUDY
Test 23 Velocities
55-deg STS
30% Porosity Deflector Attached at El 627
Pivot El 636.4



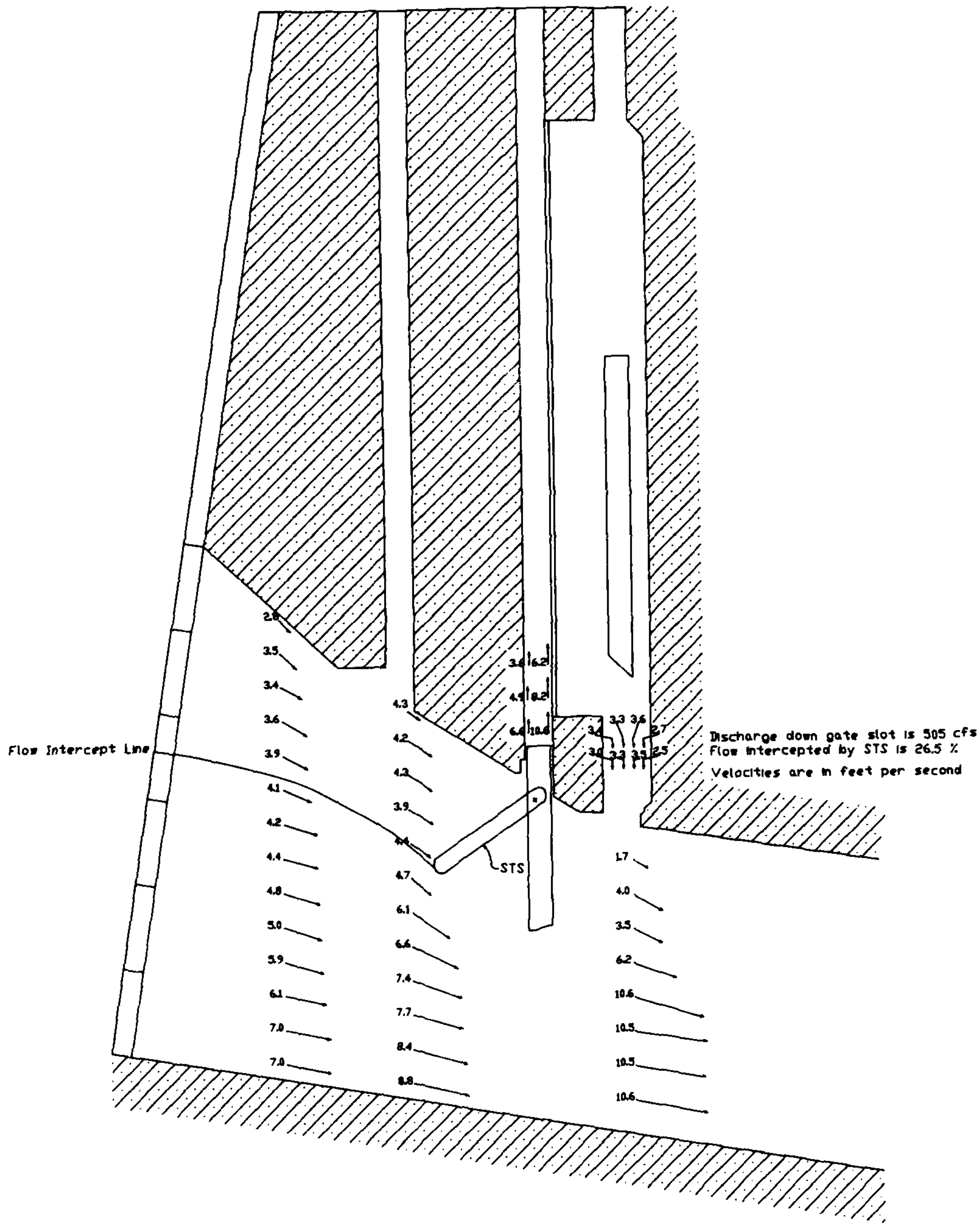
STS PIVOT POINT ELEVATION

Vs

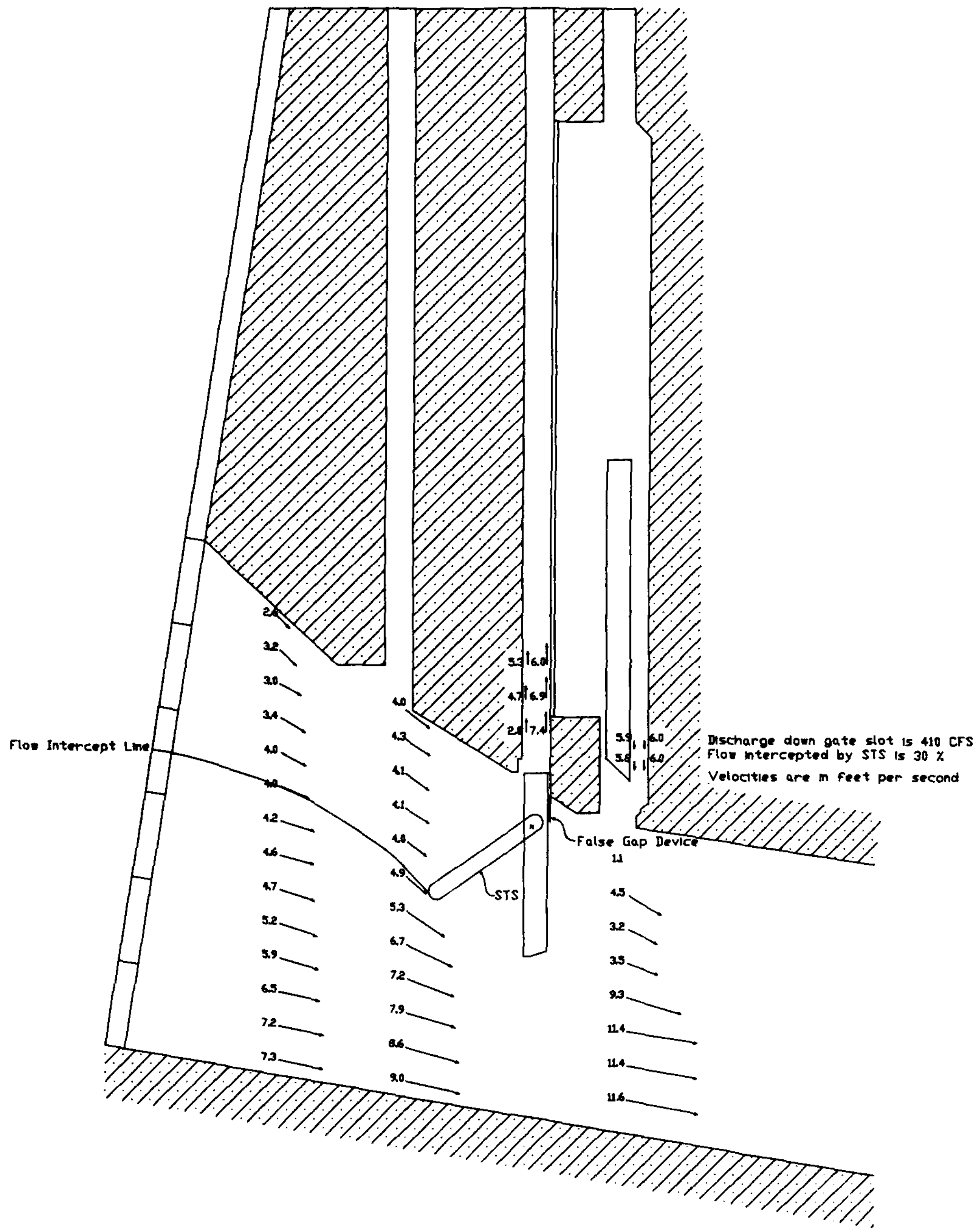
FLOW DOWN GATE SLOT



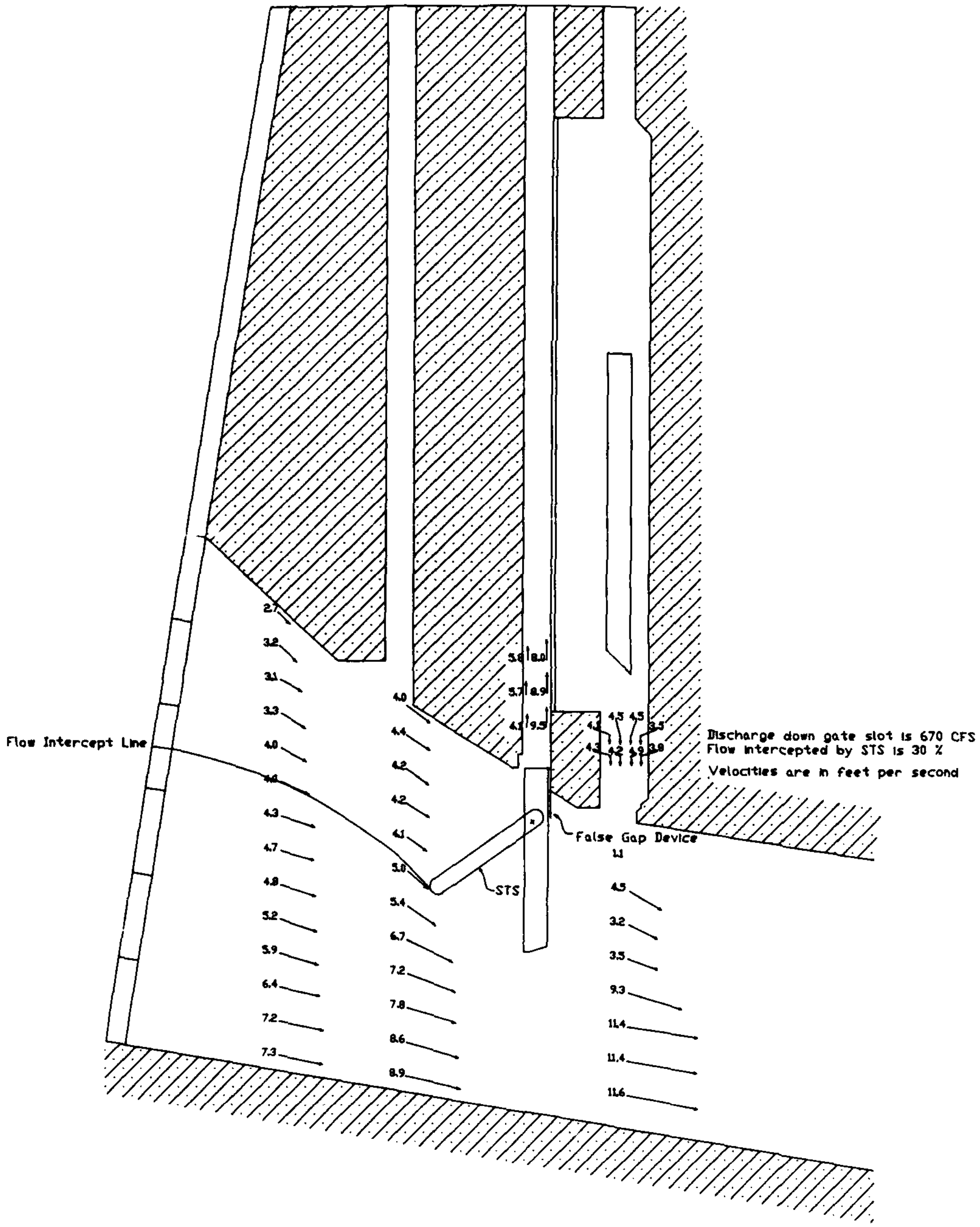
LOWER GRANITE FGE STUDY
Test 24 Velocities
55-deg STS Lowered 1 FT
Pivot El 635.4



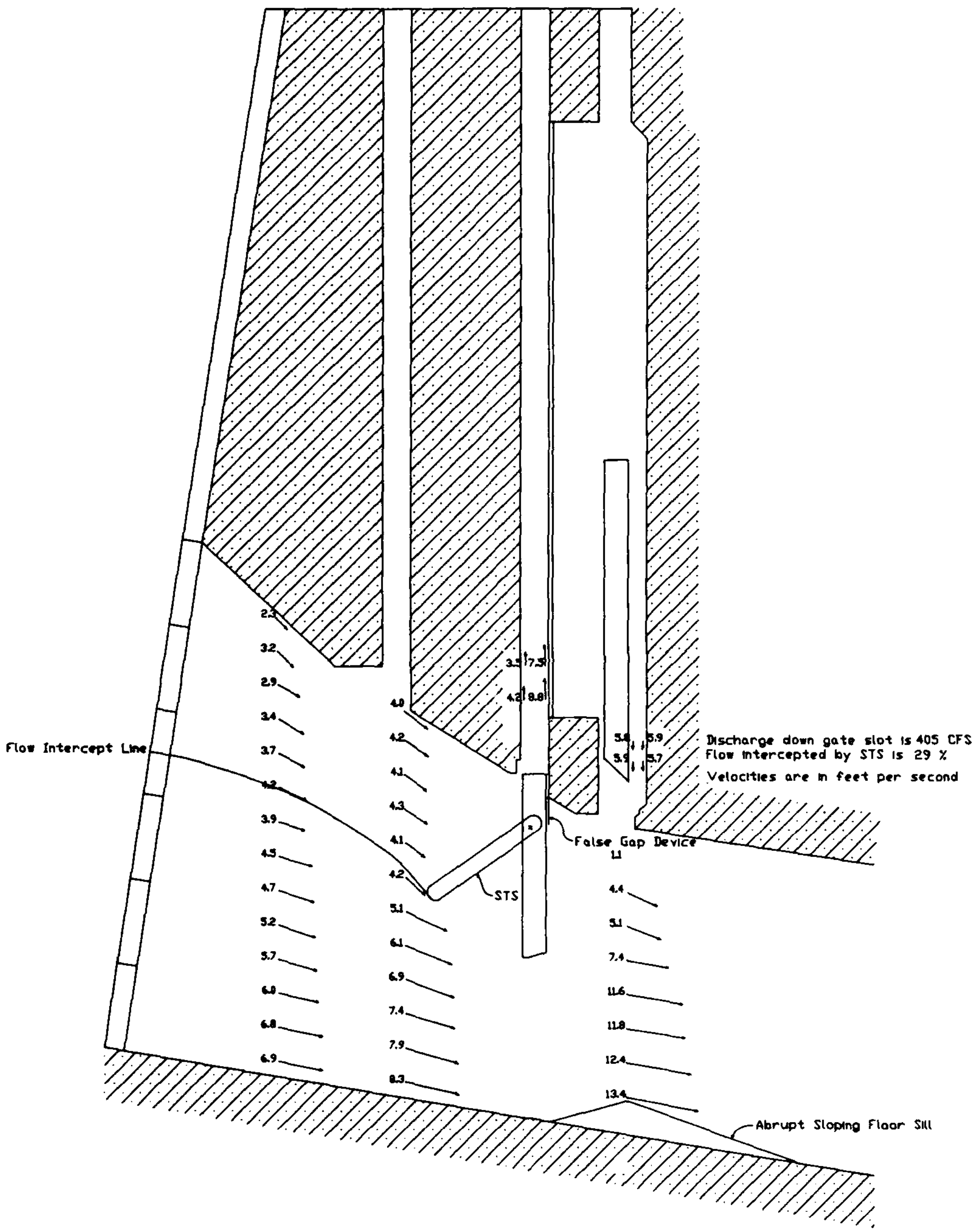
LOWER GRANITE FGE STUDY
Test 25 Velocities
55-deg STS Lowered 1 FT
Gate Raised 20 FT
Pivot El 635.4



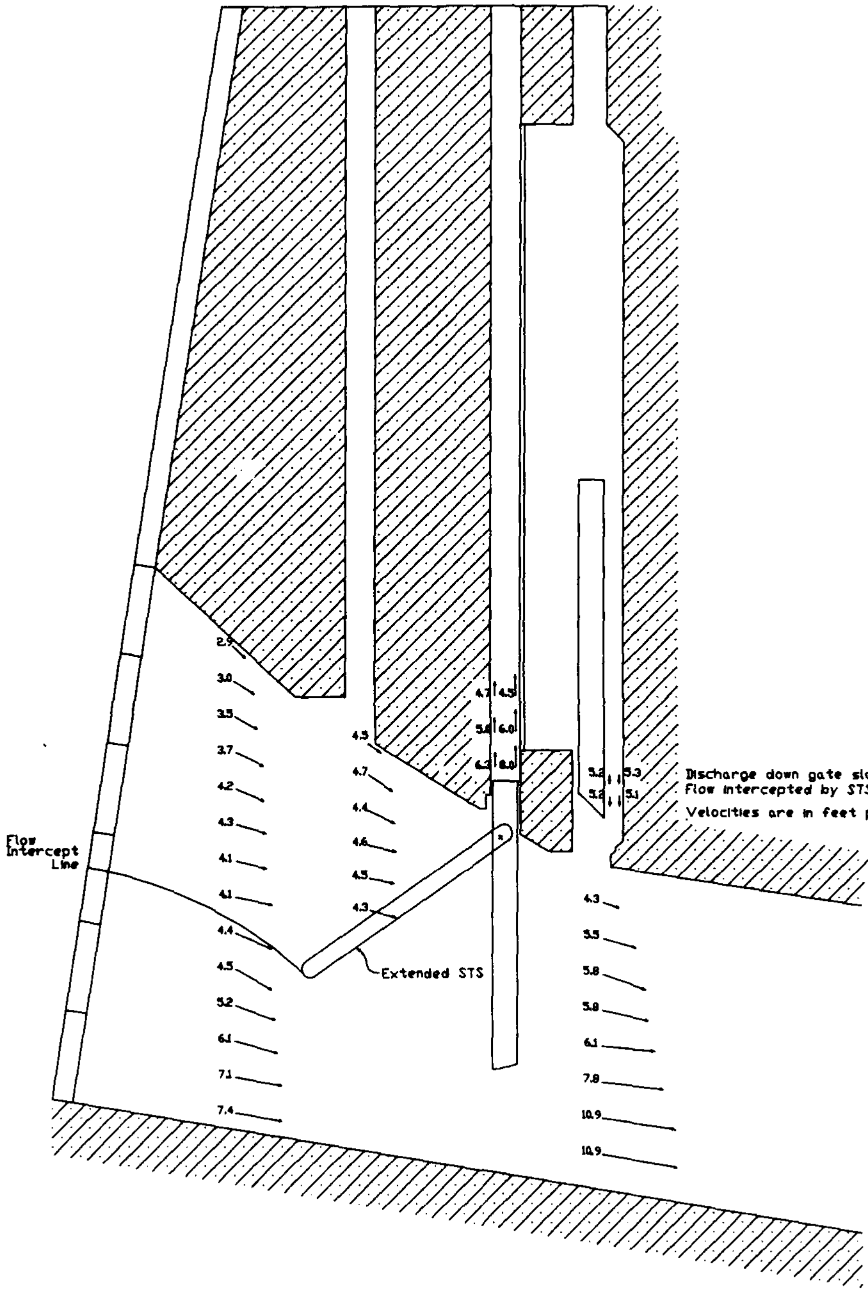
LOWER GRANITE FGE STUDY
Test 26 Velocities
55-deg STS Lowered 5 FT
False Gap Device
Gate Raised 5 FT
Pivot El 631.4



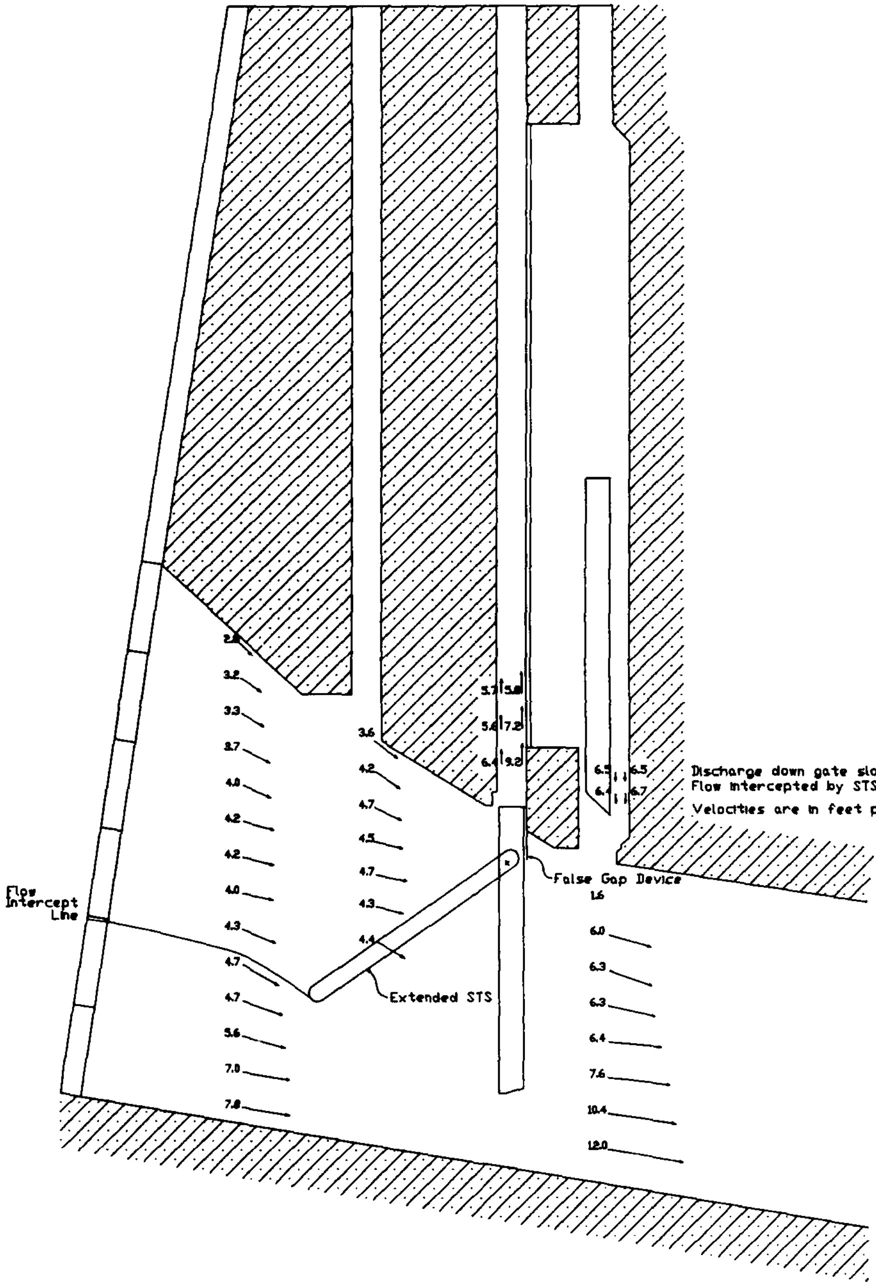
LOWER GRANITE FGE STUDY
Test 27 Velocities
55-deg STS Lowered 5 FT
False Gap Device
Gate Raised 20 FT
Pivot El 631.4



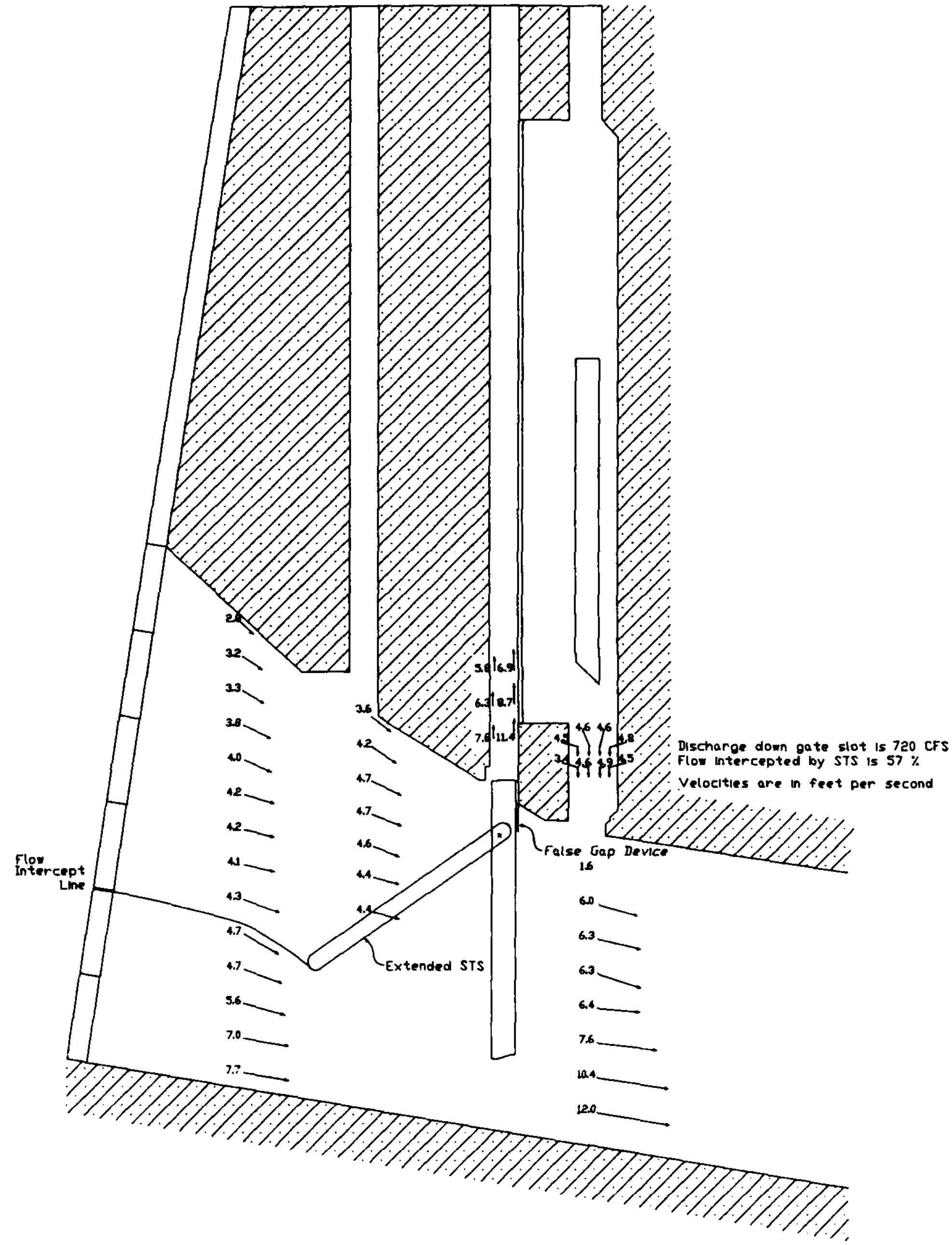
LOWER GRANITE FGE STUDY
Test 28 Velocities
55-deg STS Lowered 5 FT
Abrupt Sloping Floor Sill
False Gap Device
Gate Raised 5 FT
Pivot El 631.4



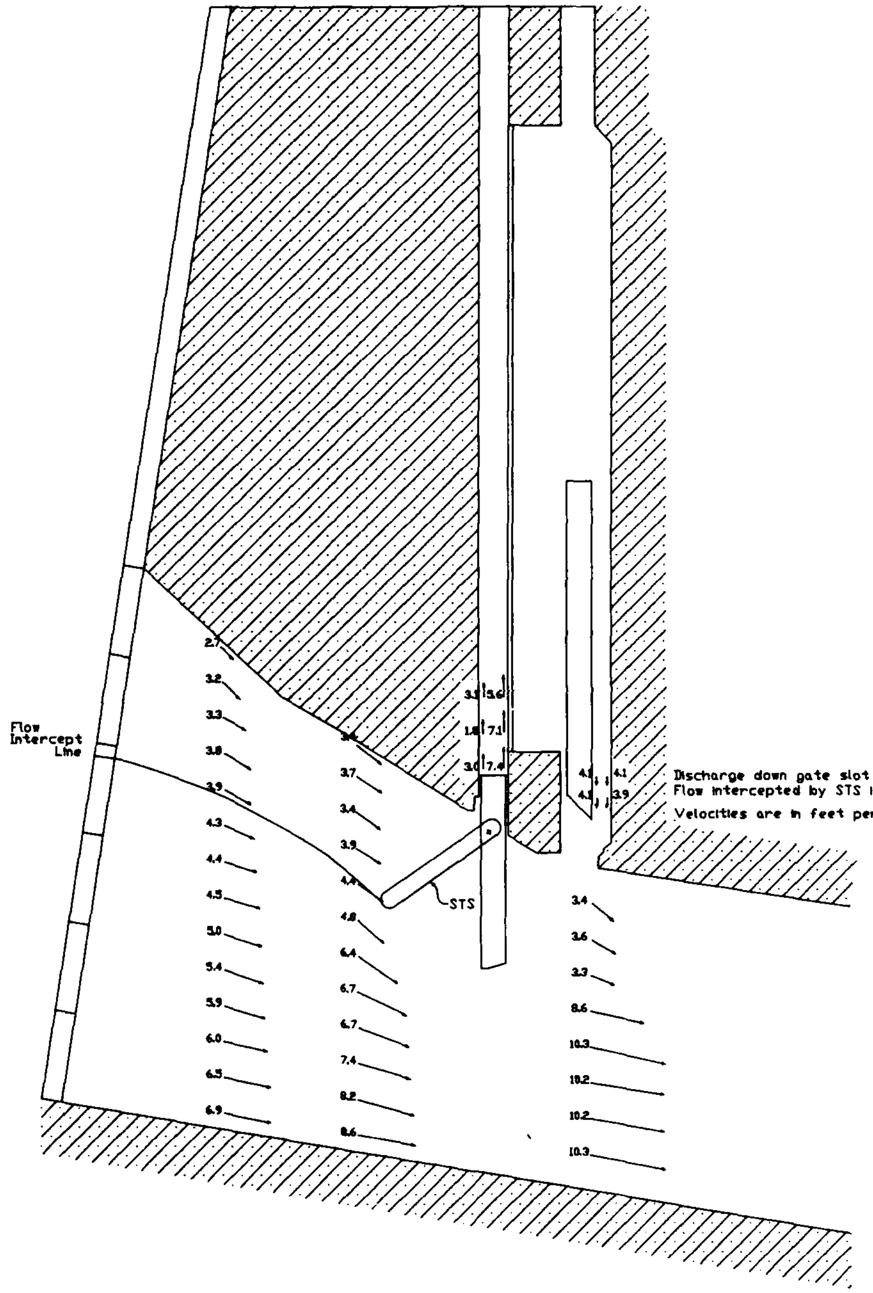
LOWER GRANITE FGE STUDY
Test 29 Velocities
55-deg Extended STS Lowered 1 FT
Gate Raised 5 FT
Pivot El 635.4



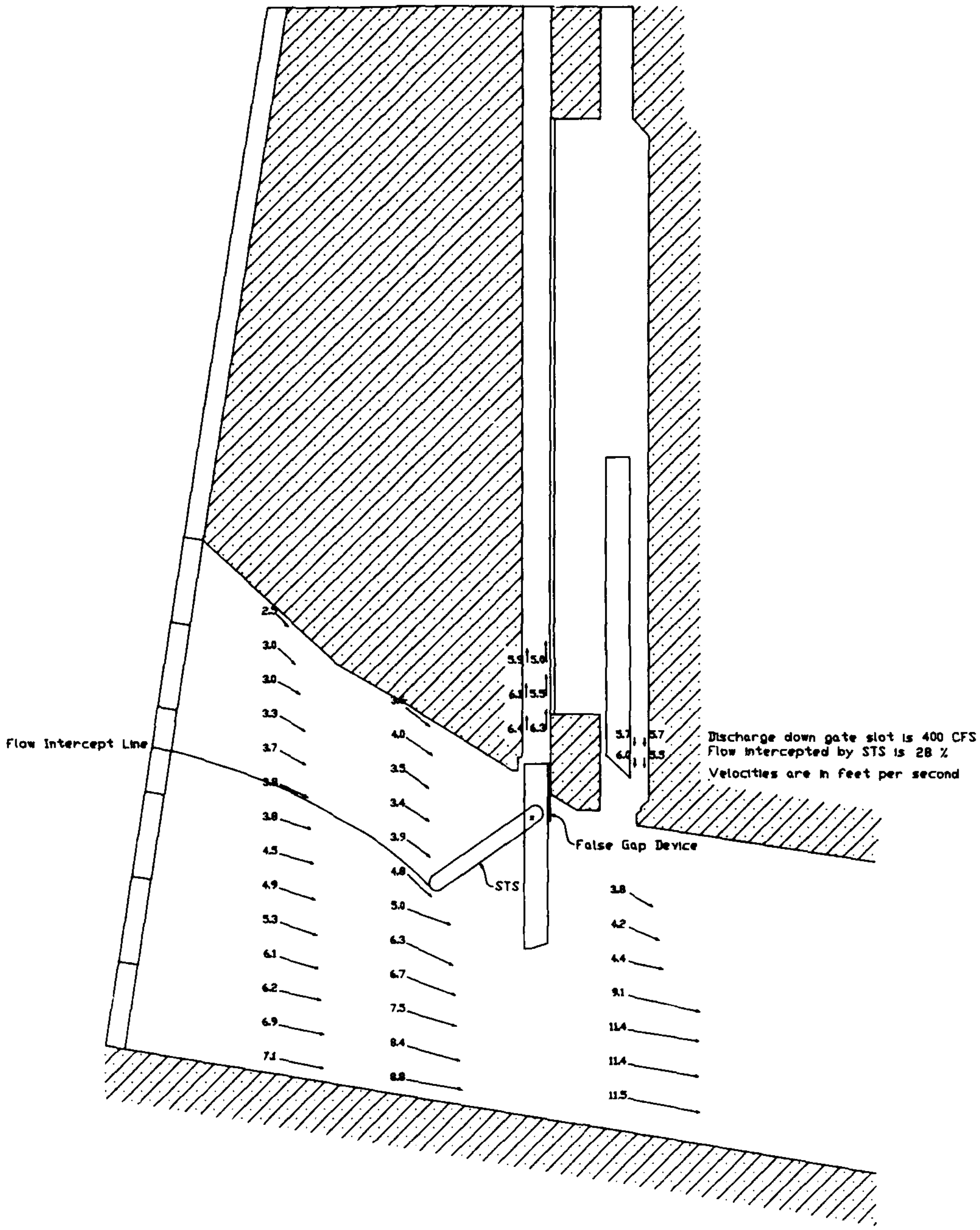
LOWER GRANITE FGE STUDY
Test 30 Velocities
55-deg Extended STS Lowered 5 FT
False Gap Device
Gate Raised 5 FT
Pivot El 631.4



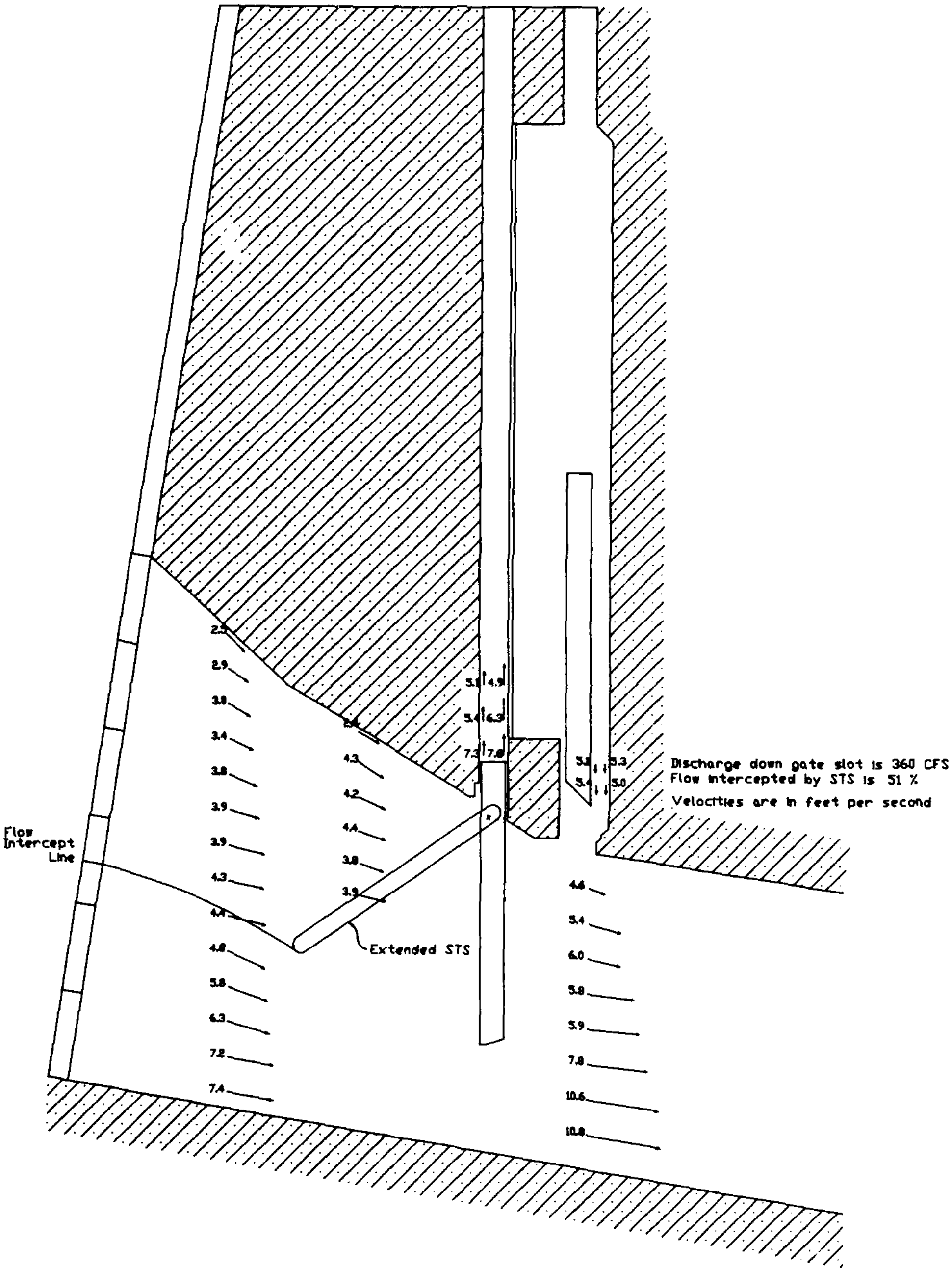
LOWER GRANITE FGE STUDY
Test 31 Velocities
55-deg Extended STS Lowered 5 FT
False Gap Device
Gate Raised 20 FT
Pivot El 631.4



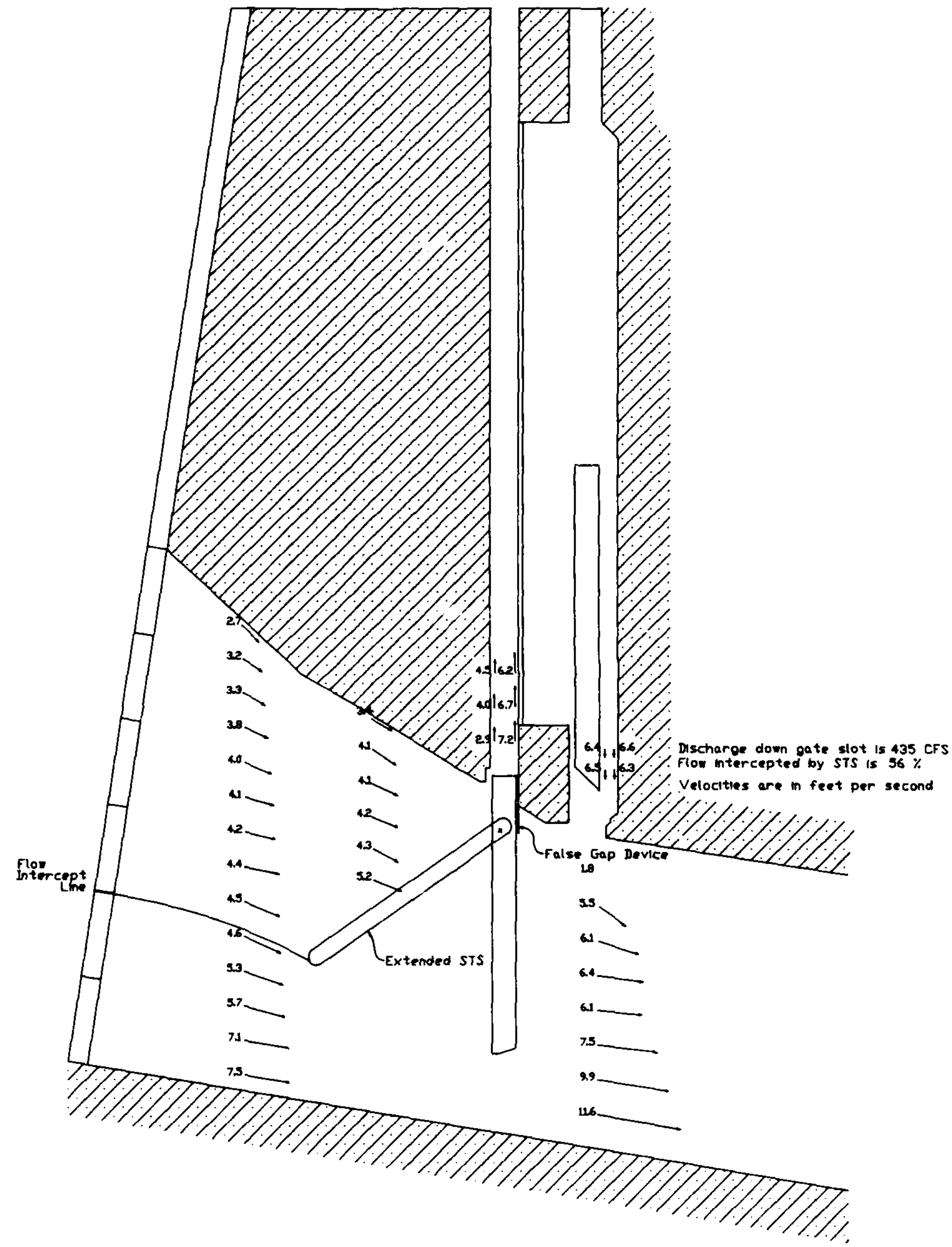
LITTLE GOOSE FGE STUDY
Test 32 Velocities
55-deg STS
Gate Raised 5 FT
Pivot El 636.4



LITTLE GOOSE FGE STUDY
Test 33 Velocities
55-deg STS Lowered 4 FT
False Gap Device
Gate Raised 5 FT
Pivot El 632.4



LITTLE GOOSE FGE STUDY
Test 34 Velocities
55-deg Extended STS
Gate Raised 5 FT
Pivot El 636.4



LITTLE GOOSE FGE STUDY
Test 35 Velocities
55-deg Extended STS Lowered 4 FT
False Gap Device
Gate Raised 5 FT
Pivot El 632.4