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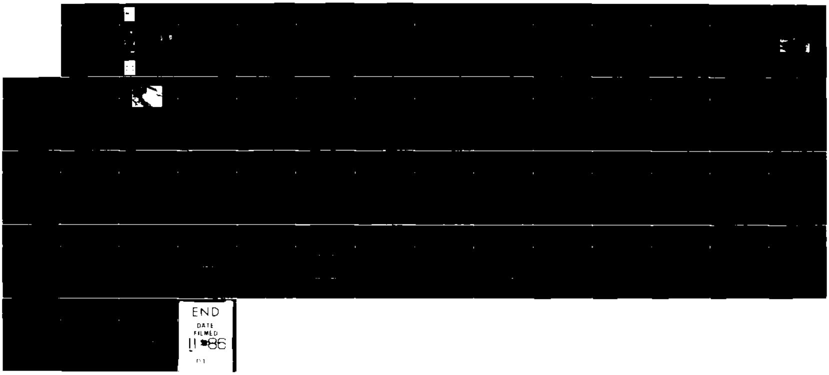

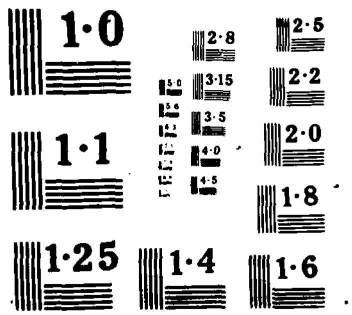
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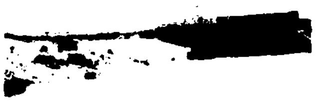

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MISCELLANEOUS PAPER HL-86-6

# ST. STEPHEN POWERHOUSE TAILRACE VELOCITY MEASUREMENT

by

T. L. Fagerburg

Hydraulics Laboratory

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



September 1986
Final Report



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


Tests were conducted to provide a prototype evaluation of the operating conditions of the project and to evaluate the adequacy of the repairs and remedial work performed in the channel downstream of the tailrace. Prototype measurements were made to define the relative magnitudes of velocities and the surface flow patterns in the channel downstream of the tailrace and the displacement, if any, of the stone protection material resulting from various turbine operations and tailwater conditions.

Results of the data collection included determination of (a) velocity distributions at various ranges across the channel; (b) velocity profiles at the toe of the slope and at the observed location of highest velocity; and (c) unusual surface flow patterns that are produced by different combinations of turbine operations. Recommendations for start-up and shut-down procedures for the turbine operations that would produce the most acceptable

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19. ABSTRACT (Continued).

velocity conditions in the repaired channel area downstream of the tailrace were made using these data.

The depth soundings revealed that the stone protection material was quite stable. (District surveys reveal that no appreciable displacement has occurred during the subsequent months of operation of the powerhouse.) The flow velocities were found to concentrate along the right side of the channel as a result of uneven flow distribution from the draft tube bays and the asymmetrical geometry along the left side of the tailrace. Return flows were observed and found to concentrate along the left side of the channel except when all three turbines were operating. Operating recommendations for the turbines are made based on tailwater conditions, length of time of nonoperation of the powerhouse, and the velocity data obtained from the tests.

## PREFACE

The prototype investigation described herein was conducted during August 1985 by the US Army Engineer Waterways Experiment Station (WES) under the sponsorship of the US Army Engineer District, Charleston.

Acknowledgment is made to the personnel of the Charleston District for their assistance in the investigation. Mr. T. L. Fagerburg, Engineer, Prototype Evaluation Branch, Hydraulic Analysis Division, Hydraulics Laboratory (HL), WES, and Mr. J. L. Grace, Jr., Chief of the Hydraulic Structures Division, HL, were coordinators of the investigation. This report was prepared by Mr. Fagerburg under the supervision of Mr. Grace; Mr. E. D. Hart, Chief, Prototype Evaluation Branch, Hydraulic Analysis Division; Mr. M. B. Boyd, Chief, Hydraulic Analysis Division; and Mr. F. A. Herrmann, Jr., Chief, HL. Additional assistance in the investigation was provided by Messrs. C. H. Tate, Jr., and J. E. Myrick of the Hydraulic Structures Division and Mr. J. E. Hall of the Hydraulic Analysis Division.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is 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 per second | 0.02831685 | cubic metres |
| feet | 0.3048 | metres |
| inches | 2.54 | centimetres |
| pounds (mass) | 0.4535924 | kilograms |

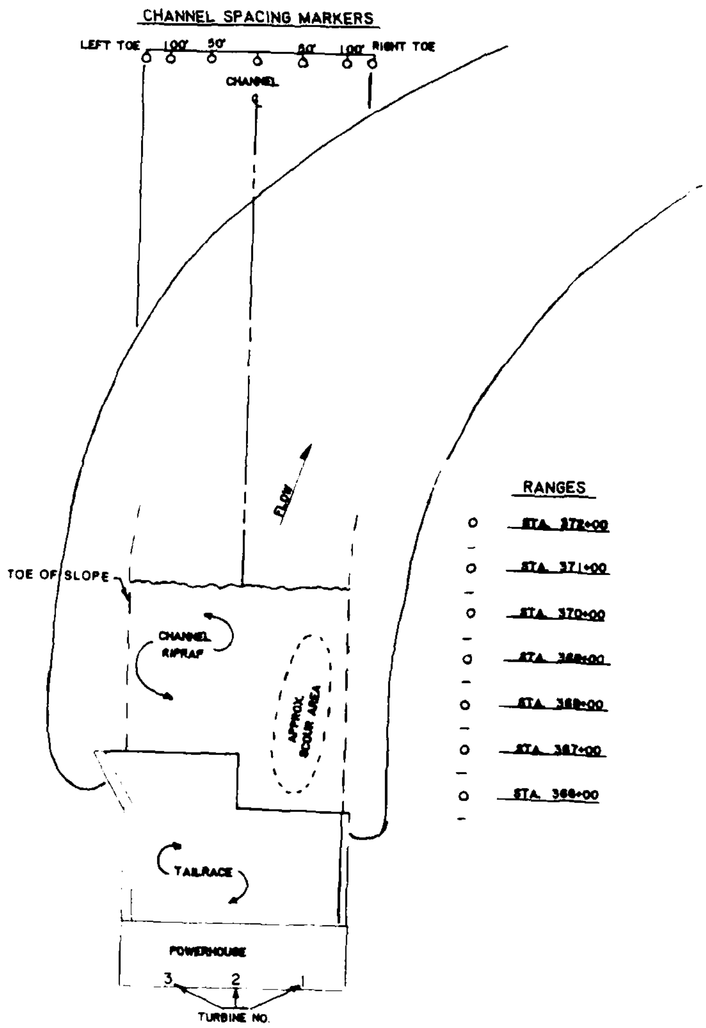


Figure 1. Range and channel spacing markers

## ST. STEPHEN POWERHOUSE TAILRACE VELOCITY MEASUREMENT

### PART I: INTRODUCTION

#### Pertinent Features of the Project

1. The St. Stephen Powerhouse is part of the Cooper River Rediversion Project which was constructed to reduce shoaling and restore the historic saline regimen to the Cooper River and Charleston Harbor. The project provides for rediversion of most of the Santee River waters from Lake Moultrie through a canal and the St. Stephen Powerhouse into the Santee River near St. Stephen, South Carolina. The powerhouse has three vertical-axis, fixed-blade turbines rated at 28 Mw each with a net head of 49 ft* and a total discharge of 24,500 cfs. The powerhouse was constructed by the US Army Corps of Engineers. Shortly after completion of the tests, power production was turned over to the South Carolina Public Service Authority. In this report the turbines will be referred to as units 1, 2, and 3. Unit 1 is located on the right bank side of the channel when facing downstream in the direction of flow with unit 2 located in the center of the channel and unit 3 located on the left bank side of the channel (Figure 1).

#### Background

2. The construction of the powerhouse started in the spring of 1983, and the first commercial operation began in March 1985. After only 5 days of operation, it was discovered that a large scour hole had developed in the tailrace channel (Figure 1). The major scour area was located on the right side (looking downstream) of the tailrace channel from the channel center line up to and including the existing toe and slope of the right bank. The length of the scour area extended from the edge of the concrete apron to a point 300 ft downstream. The scour depth was found to have reached a maximum of 21 ft below the original channel bottom elevation.

3. The operation of the powerhouse, including commercial power production, was immediately curtailed until repair work could be completed. The

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

repairs to the tailrace channel included excavating all the remaining bottom material above el -4.75 ft* from the edge of the concrete apron to sta 368+50, then removing all material above el -2.25 ft from sta 368+50 to sta 370+00 and using this material as fill for the scour area. Next a nonwoven filter fabric material, overlain with 9 in. of sand, and three sizes of riprap stone were placed, the largest of which was placed nearer the apron. The stone sizes used in the channel decreased with distance downstream of the powerhouse. In the areas where erosion extended into the existing side slope, additional layers of stone were added to increase the protection of the toe and slope. The following tabulations describe the extent and composition of the tailrace protection provided and the gradation of the various riprap and bedding stone used (see Figure 1 for location of station numbers):

| | |
|---|---|
| Apron to sta 367+00 (150 ft on right and 100 ft on left from tailrace edge) | 4-ft layer Type 1 riprap<br>9-in. layer sand<br>Nonwoven filter fabric |
| Sta 367+00 to sta 367+50 | 4-ft layer Type 2 riprap<br>9-in. layer sand<br>Nonwoven filter fabric |
| Sta 367+50 to sta 368+00 | 4-ft layer Type 3 riprap<br>9-in. layer sand<br>Nonwoven filter fabric |
| Sta 368+00 to sta 370+50 | 1.5-ft layer Type 3 riprap<br>9-in. layer sand<br>Nonwoven filter fabric |

| Stone Classification | Gradation: Percent Lighter By Weight | Gradation: Limits of Stone Weight, lb | Gradation: Limits of Stone Size, in. |
|---|---|---|---|
| Type 1 riprap | 100 | 1,638-655 | 32-24 |
| | 50 | 691-328 | 24-18 |
| | 10 | 346-102 | 18-12 |
| Type 2 riprap | 100 | 691-276 | 24-18 |
| | 50 | 292-128 | 18-12 |
| | 10 | 146-43 | 14-9 |
| Type 3 riprap | 100 | 86-35 | 12-9 |
| | 50 | 36-17 | 9-6 |
| | 10 | 18-5 | 6-4 |

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

4. Before completion of the repair work, the US Army Engineer District, Charleston, contacted the US Army Engineer Waterways Experiment Station (WES) about assisting in the conduct of field tests. The tests were to be made with various combinations of turbine operation to evaluate the tailrace flow conditions and the stability of the riprap provided to protect the tailrace including the area previously scoured. A test plan was formulated by WES personnel and forwarded to the Charleston District.

## Purpose and Scope of Work

### Purpose

5. The principal purposes of the tests described herein were to evaluate the adequacy of the repairs and remedial work performed, to define the relative magnitudes of velocities and the surface flow patterns in the channel downstream of the railrace, and to determine the displacement, if any, of stone protection material resulting from various turbine operations and tailwater conditions. The data obtained would then be used to determine (a) distribution of velocities at various ranges across the channel; (b) velocity profiles at the toe of the bank and at the observed location of highest velocity; (c) unusual surface flow patterns produced by different combinations of turbine operation; and to (d) recommend start-up and shut-down procedures for the turbine operations that would produce the most acceptable velocity conditions in the newly repaired scour area.

### Scope

6. On 26-28 August 1985, 22 tests were conducted at St. Stephen Powerhouse. Individual tests varied with respect to number of turbines being operated. A breakdown of the tests and conditions is listed in Table 1.

PART II: TEST EQUIPMENT AND PROCEDURES

## Test Equipment

7. The test equipment consisted of a Price current meter with a digital display indicator for direct velocity readings and a current direction indicator compass for determination of the direction of flow. A 22-ft MonArk boat belonging to the Hydraulic Structures Division, WES, was used as the instrumentation vessel during the test period. The current meter and compass were suspended from a boom arrangement mounted on the stern of the boat (Figure 2). A calibrated winch was used to raise and lower the current meter and compass

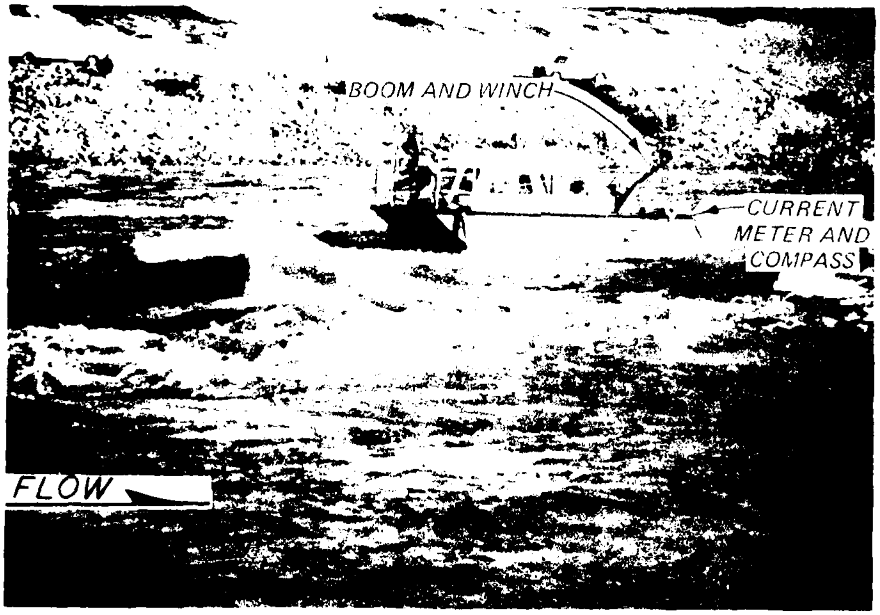



Figure 2. Boat and boom arrangement used for data collection

to the position desired. Prior to the tests, the Charleston District had crews survey the channel area and place range markers along the right bank (looking downstream) at 50-ft intervals. The survey crews also provided channel spacing markers to aid in determination of location within the channel. These markers were placed at 50-ft intervals to the right and left of the channel center line, with additional markers designating the right and left toe of the slopes (Figure 1). Charleston District personnel with their survey boat and equipment helped with distribution and collection of Styrofoam floats that were used to define surface current patterns, depth soundings throughout the tailrace and exit channel, procurement and repair activities required during equipment breakdowns, and safety of operations throughout the entire testing period. Video films as well as still photographs were used to record the surface flow patterns and the events of the field tests.

## Test Procedures

8. The combinations of turbines being operated varied from one unit on line to all three turbines at maximum power production. The first six tests were conducted with the turbines operating under no-load conditions for the determination of unusual surface flow patterns. No velocities were measured at this time. At the time of the testing, the reservoir pool elevation ranged from el 74.0 to 75.2 ft.

9. The system used to hold the boat in position at each cross section consisted of a 5/8-in. nylon rope stretched tight across the channel width and anchored to two large dump trucks, supplied by the contractor, which were situated at the top of the bank on either side of the channel. The instrument boat was then attached to this rope by a bow line. The instrument boat was disconnected from the rope and moved to the different channel spacings in the particular range and reattached. After completing a range, the instrument boat was disconnected from the rope and the trucks were moved simultaneously to the next range for the next series of measurements. A safety boat stood by during all operations and also conducted depth soundings before and after daily tests. This arrangement is shown in Figure 3. Initially, three ranges were monitored for each test, which required coordination in moving the anchoring system. However, the time required to obtain the desired measurements and rapid rise of the tailwater elevation, especially at the low tailwater conditions, forced the reduction of the number of ranges to be monitored to only two.

10. Velocity measurements were obtained at 0.6 depth and at 50-ft intervals across the width of the channel. It was assumed that the 0.6 depth was the point at which the average velocity occurred. Velocity profiles were obtained at the toe of both bank slopes and at the observed location of the highest velocity for each range. Initial observations of the surface flow

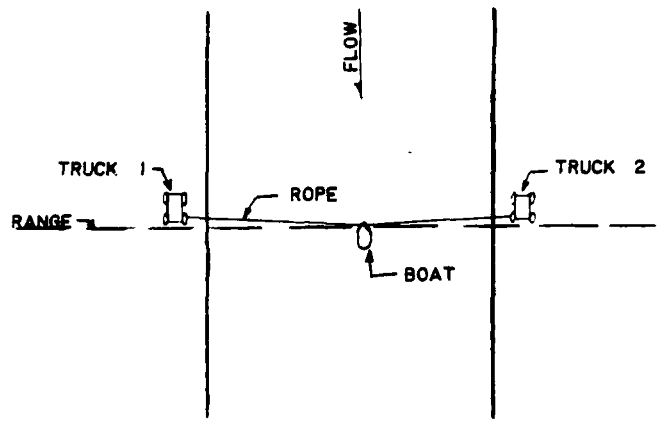



Figure 3. Boat anchoring and positioning arrangement

patterns after the first series of turbine operations indicated that the majority of the flow was concentrated along the area to the right of the channel center line and that return flows were concentrated along the left bank. In an effort to conserve time, the majority of the measurements were taken in the area to the right of the channel center line with some measurements in the area of the return flow. The observed location of the highest velocity was found to vary with the different turbine combinations but generally ranged from about 100 ft to the right of the channel center line to the toe of the slope of the right bank.

11. A few spot velocity measurements were attempted at a location immediately downstream of the right wing wall. Due to extreme turbulence, standing waves, and critical surface currents in this area, as shown in Figure 4, and difficulty in maintaining boat position, these efforts were discontinued after a few attempts. Therefore, the spot velocity information obtained in this area during the test period should be interpreted for determination of trends and not considered as absolute values. Velocity readings taken at all other locations are considered to be accurate to within ±0.2 fps.

12. Flow discharges were estimated from the turbine theoretical rating curves based on head and gate opening. The basic test data such as pool elevations, tailwater elevations, turbine combinations, gate openings, load output, and discharge are shown in Table 1.

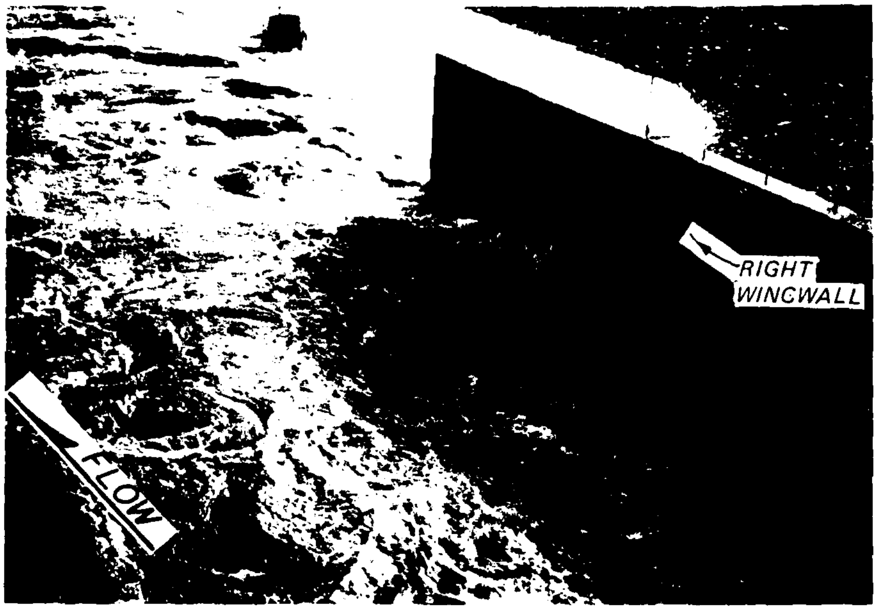



Figure 4. Flow turbulence in the area of the right wing wall

13. Depth soundings were used to determine if any stone displacement had occurred as a result of the turbine operations. A District survey crew, using a Raytheon DE 719 Depthsounder, conducted cross channel soundings of the tailrace channel at each 50-ft interval downstream from the end of the concrete apron to the end of the channel stone protection. These measurements were made prior to the start of the test period and after the completion of the testing for each day of the test period.

## PART III: TEST RESULTS

### Velocity Measurements

14. Velocities for the different turbine combinations were obtained for the various tailwater elevations, which were designated as low, intermediate, and high. The low tailwater elevations ranged from 7.0 to 14.5 ft, the intermediate tailwater elevations ranged from 14.5 to 17.0 ft, and the high tailwater elevations ranged from 19.8 to 21.3 ft. The velocities observed at 0.6 depth for all locations measured along each range are given in Table 2. These values were then plotted to illustrate the velocity distribution patterns over the width of the channel at the various ranges, as shown in Plates 1-13. The highest velocities observed at the 0.6 depth, as illustrated in Table 2 and Plates 1-13, occurred in all the turbine combinations during the low tailwater tests and were concentrated in an area from 100 ft to the right of center line to the right bank toe of the slope. Return flow velocities (in the upstream direction) were measured and found to concentrate along the left side of the channel. No return flow velocities were present when all three turbines were operating. The maximum spot velocities shown in Table 2, 10.8 fps (at 0.6 depth) and 10.2 fps (at 0.3 depth), were obtained immediately downstream of the right wing wall for turbine combinations of 2-1 and 3-1, respectively.

### Velocity Profiles

15. The velocity profiles obtained at each of the ranges are given in Plates 14-32. Two of the profiles were taken at locations that were a considerable distance downstream of the powerhouse. Plate 28 shows profiles (designated sta D-2) taken across from a baffled chute spillway or drop structure located in a side channel approximately 4,450 ft downstream of the powerhouse. Plate 29 is the velocity profile obtained at the center span of the railroad bridge which is located approximately 5,200 ft downstream of the powerhouse. The profiles shown in Plates 26, 30, and 32 (at sta 368+50 and 100 ft right of the channel center line) display unusual velocity profiles with the highest velocity observed occurring near the 0.6 depth rather than nearer the surface. This indicates that a submerged jet may be present at this depth, possibly due

to the large depth of tailwater (19.8-20.6 ft) relative to the elevation of the draft tube and initial jet center line (14.67 ft). Flow distribution is easily distorted by only minor differences in geometric characteristics due to structural and/or operational features particularly with tailwater to jet depths greater than or equal to 1.1. Also, it is important to recognize that the formation of vertical and/or horizontal eddies which concentrate flow of a submerged jet rather than dissipate the energy of flow increases with increasing depth of tailwater or submergence.

16. The unit discharge and velocity of the submerged jet appear to have increased due to entrainment of return flow into that of the initial submerged jet. The transverse distributions of flow indicated by the velocities measured at 0.6 depth indicate apparent entrainment coefficients on the order of 0.67. This value was determined by comparing the assumed correct turbine rating curve discharges with those calculated by the transverse velocities at 0.6 depth and the width and depth of the flow downstream. Thus, the discharge of the submerged jet flowing downstream appears to be 1.67 times the powerhouse discharge.

## Flow Distribution

17. An unexpected and significant occurrence which was noted during the operation of the turbines, particularly at low and intermediate tailwater elevations, was that the majority (approximately 75 percent) of the flow leaving the two draft tube bays of each turbine exited the rightmost bay (looking downstream). This distribution caused the flow to be concentrated in an area to the right of the channel center line. The asymmetrical geometry of the tailrace (Figure 1), particularly the left side of the tailrace that was provided to accommodate the fish lift facility, also caused the downstream flows to concentrate to the right of the channel center line. This combination of factors resulting in the concentration of flow to the right side of the channel also produced flow separation in the form of a large return flow eddy which became established along the left bank. The uneven distribution of flow from the draft tube bays was not as evident during the high tailwater conditions, and no return flow eddy was observed to be present when all three turbines were operating. However, as previously discussed, the velocity profiles at sta 368+50, at a position 100 ft right of the channel, have the appearance

of a submerged jet. In the majority of the tests, the highest velocity was found to exist in the area to the right of the channel center line, as documented in the tables and figures.

## Depth Soundings

18. As indicated earlier, the depth soundings were used to determine the displacement of the stone protection material on the channel bottom after each day of testing. Particular emphasis was placed on obtaining soundings along the right bank which had recently undergone extensive work to repair the large scour hole. The approximate location of the scour hole is shown in Figure 1. The scour occurred after a relatively short duration of commercial power production. The depth soundings were made across the width of the tailrace channel at each 50-ft interval downstream from the concrete apron. These recordings were compared to the baseline soundings which were made prior to the beginning of the tests. The comparisons revealed that little or no movement of the stone protection material occurred other than settlement of the stone due to removal of the underlying sand placed between the filter fabric and the stone. The only significant scour that was evident from the soundings occurred immediately downstream of the stone-protected channel area (approximately sta 370+50); however, this scour was anticipated as it will invariably occur at the termination of a riprap blanket in a channel excavated in erodible material. The depth of the scour was approximately 4.0 ft below the channel bottom elevation, 0.0 ft. The width of this scour area was found to extend from the channel center line to a point 100 ft to the right of the center line. The length of the scour extended in the downstream direction for approximately 150 to 200 ft.

19. Another series of depth soundings was made by the Charleston District 10 days after the powerhouse went into continuous commercial operation. The soundings indicated that virtually no displacement of the stone protection material had occurred. The scour area immediately downstream of the protected channel bottom had not increased appreciably in depth but had expanded in the downstream direction. The Charleston District has made provisions to monitor routinely the tailrace channel stone protection, the downstream scour area, and other areas in the channel downstream of the project. The 19 February

1986 survey data indicate that the depth of scour in the channel bottom downstream of the end of the riprap protection has increased to 9 ft.

## PART IV: CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

20. The following conclusions result from the data analysis and observations of the St. Stephen Powerhouse field study:

- a. The higher velocities observed at the 0.6 depth during low tailwater were concentrated in an area to the right (looking downstream) of the channel center line. In almost all tests, the highest velocities occurred to the right of the channel center line.
- b. The return flow velocities were found to concentrate along the left side of the channel. No return flow was observed to be present when all three turbines were operating.
- c. The concentration of the downstream flow velocities along the right side of the channel is probably due in part to the uneven distribution of the flow exiting the draft tube bays but more so to the asymmetrical geometry along the left side of the tailrace that was provided to accommodate the fish lift facility. This distribution results in flow separation and permits the formation of a return eddy located to the left of the channel center line.
- d. The continuing depth soundings of the tailrace channel indicate that the stone protection material is stable and that no appreciable displacement has occurred during the subsequent months of operation of the powerhouse.

### Recommendations

21. The following start-up and shut-down procedures are recommended for turbine operations:

- a. Tailwater less than or equal to el 7.0 ft. A review of the operating logsheets indicates that if power production is halted, the tailwater level is greater than el 20, and the powerhouse is not operated for a period exceeding 36 hr, the tailwater level will return to el 7.0. When this condition occurs, the recommended mode of operation for start-up of the turbines is as follows:
  - (1) For a single-turbine operation, use turbine 2.
  - (2) For a two-turbine operation, begin with turbine 2 followed by turbine 3 (left turbine looking downstream). The tailwater elevation should be equal to or greater than el 9.0 before turbine 3 is started.

(3) For a three-turbine operation, follow the sequences previously described to start turbines 2 and 3, then add turbine 1 when the tailwater elevation is equal to or greater than el 12.0.

(4) For termination of power production, if the tailwater level is below el 12.0, the recommended sequence would be to stop turbine 1 first, followed by turbines 3 and 2, respectively.

The observed rate of rise in the tailwater elevation during the test period was quite rapid; therefore, these recommended procedures should not present any substantial delays in the sequential start-up operations of the turbines. However, to ensure that sufficient tailwater levels exist for the start-up procedures (particularly for the low tailwater, el 7.0 ft), it is recommended that the units be operated as described in these procedures and that only one turbine at a time be brought on line (total time required should be approximately 15 min per turbine) and that the power output of each turbine should be 90 percent or greater (25-28 Mw).

b. Tailwater greater than el 7.0 ft. If power production is halted while the tailwater elevation is greater than el 20 and the powerhouse is not operated for a period of 8-24 hr, the tailwater should fall to a level of approximately el 13.0. When this condition occurs, the recommended mode of operation of the turbines is as follows:

(1) For one-, two-, or three-turbine operation, use the same sequence as described for a low tailwater condition excluding the time and tailwater elevation constraints.

(2) For termination of power generation, if the tailwater elevation is greater than el 20 ft, the recommended sequence to follow is to stop turbine 2 first, followed by turbines 1 and 3, respectively. An alternative sequence that may be used is to stop turbine 1 first, followed by turbines 2 and 3, respectively.

Table 1

St. Stephen Powerhouse

Operating Log

| Test No. | Time | Unit No. 1 Power Mw | Unit No. 1 Gate Position % | Unit No. 1 Discharge cfs | Unit No. 2 Power Mw | Unit No. 2 Gate Position % | Unit No. 2 Discharge cfs | Unit No. 3 Power Mw | Unit No. 3 Gate Position % | Unit No. 3 Discharge cfs | Water Elevation, ft Pool | Water Elevation, ft Tail | Water Elevation, ft Head | Water Elevation, ft Tailrace Staff Gage | Totals Power Mw | Totals Discharge cfs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 8-26-85 | | | | | | | | |
| 1 | 0930 | | | | | | | 0 | -- | 1,000 | 74.45 | 7.0 | 67.45 | 7.0 | 0 | 1,000 |
| 2 | 0945 | | | | | | | 0 | -- | 2,000 | 74.45 | 7.0 | 67.45 | 7.0 | 0 | 2,000 |
| 3 | 1030 | | | | 0 | -- | 1,000 | | | | 74.45 | 7.0 | 67.45 | 7.0 | 0 | 1,000 |
| 4 | 1045 | | | | 0 | -- | 2,000 | | | | 74.45 | 7.0 | 67.45 | 7.0 | 0 | 2,000 |
| 5 | 1110 | 0 | -- | 1,000 | | | | | | | 74.45 | 7.0 | 67.45 | 7.0 | 0 | 1,000 |
| 6 | 1130 | 0 | -- | 2,000 | | | | | | | 74.45 | 7.1 | 67.35 | 7.0 | 0 | 2,000 |
| 7 | 1404 | | | | | | | | | | | | | 8.5 | | |
| | 1500 | | | | | | | 28 | -- | 6,400 | 74.47 | 8.83 | | | 28 | 6,400 |
| | 1519 | | | | | | | | | | | | | 9.6 | | |
| 8 | 1545 | | | | | | | | | | | | | 10.5 | | |
| | 1600 | 7 | -- | 1,650 | | | | 28 | -- | 6,500 | 74.83 | 11.43 | 63.40 | | 35 | 8,150 |
| | 1620 | | | | | | | | | | | | | 11.4 | | |
| | | | | | | | | 8-27-85 | | | | | | | | |
| 9 | 0800 | | | | | | | | | | 74.85 | 7.34 | 67.50 | 7.3 | 0 | 0 |
| | 0900 | 22 | -- | 5,420 | | | | | | | 74.90 | 9.40 | 65.50 | | 22 | 5,420 |
| | 1000 | 26 | -- | 5,720 | | | | | | | 74.98 | 9.00 | 65.98 | | 26 | 5,720 |
| | 1050 | | | | | | | | | | | | | 9.4 | | |
| 10 | 1055 | | | | | | | | | | | | | 10.0 | | |
| | 1100 | | | | 16 | -- | 3,350 | | | | 74.70 | 9.80 | 64.90 | | 16 | 3,350 |
| | 1155 | | | | | | | | | | | | | 10.0 | | |
| 11 | 1200 | 10 | -- | 2,220 | 10 | -- | 2,220 | | | | 74.98 | 10.08 | 64.90 | 10.0 | 20 | 4,440 |
| | 1230 | 0 | | 0 | 0 | | 0 | | | | | | | 10.0 | 0 | 0 |
| | 1300 | | | | | | | | | | 74.98 | 9.70 | 65.28 | | 0 | 0 |
| | 1400 | | | | | | | | | | 74.64 | 9.40 | 65.24 | | 0 | 0 |
| 12 | 1401 | | | | | | | | | | | | | 9.4 | | |
| | 1500 | | | | 20 | -- | 4,950 | 24 | -- | 5,550 | 74.72 | 11.72 | 63.00 | | 44 | 10,450 |
| | 1517 | | | | | | | | | | | | | 12.3 | | |

(Continued)

Note: -- indicates that no reading was recorded.

Table 1 (Concluded)

| Test No. | Time | Unit No. 1 Power Mw | Unit No. 1 Gate Position % | Unit No. 1 Discharge cfs | Unit No. 2 Power Mw | Unit No. 2 Gate Position % | Unit No. 2 Discharge cfs | Unit No. 3 Power Mw | Unit No. 3 Gate Position % | Unit No. 3 Discharge cfs | Water Elevation, ft Pool | Water Elevation, ft Tail | Water Elevation, ft Head | Water Elevation, ft Tailrace Staff Gage | Totals Power Mw | Totals Discharge cfs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 1530 | | | | | | | | | | | | | 13.0 | | |
| | 1600 | 16 | -- | 3,350 | 30 | -- | 6,700 | 14 | -- | 3,350 | 74.30 | 13.80 | 60.50 | | 60 | 13,400 |
| | 1655 | | | | | | | | | | | | | 13.8 | | |
| 14 | 1700 | 28 | -- | 6,900 | 28 | -- | 6,900 | 3 | -- | 1,150 | 74.00 | 15.60 | 58.40 | 13.8 | 59 | 14,950 |
| | 1755 | | | | | | | | | | | | | 14.5 | | |
| 15 | 1800 | 31 | -- | 6,650 | 8 | -- | 1,660 | 7 | -- | 1,660 | 75.00 | 15.00 | 60.00 | 14.5 | 46 | 9,970 |
| | 1900 | 29 | -- | 6,650 | | | | | | | 74.70 | 14.70 | 60.00 | | 29 | 6,650 |
| | 1924 | | | | | | | | | | | | | 14.5 | | |
| 16 | 1924 | | | | | | | | | | | | | 14.5 | | |
| | 2000 | 11 | -- | 2,790 | 19 | -- | 3,910 | | | | 74.90 | 14.40 | 60.50 | 14.5 | 30 | 6,700 |
| | 2100 | | | | 6 | -- | 1,670 | | | | | | | | 6 | 1,670 |
| | | | | | | | | 8-28-85 | | | | | | | | |
| 17 | 0800 | | | | | | | | | | 74.70 | 9.90 | 64.80 | 9.9 | 0 | 0 |
| | 0900 | | | | | | | | | | 74.70 | 10.10 | 64.60 | | 0 | 0 |
| | 1000 | 28 | 58 | 6,055 | | | | 30 | 58 | 6,600 | 74.90 | 12.80 | 62.10 | | 58 | 12,715 |
| | 1100 | 28 | 60 | 6,750 | | | | 28 | 58 | 6,600 | 74.40 | 14.10 | 60.30 | | 56 | 13,350 |
| | 1200 | 28 | 60 | 6,800 | | | | 28 | 59 | 6,800 | 74.70 | 15.00 | 59.70 | 14.7 | 56 | 13,600 |
| 18 | 1201 | | | | | | | | | | | | | 14.0 | | |
| | 1300 | | | | | | | 29 | 59 | 6,800 | 74.30 | 14.10 | 60.20 | 14.0 | 29 | 6,800 |
| | 1325 | | | | | | | | | | | | | 15.5 | | |
| 19 | 1325 | | | | | | | | | | | | | 15.5 | | |
| | 1400 | 22 | 65 | 5,250 | 20 | 66 | 4,670 | 28 | 63 | 7,000 | 73.90 | 17.00 | 56.90 | 16.7 | 70 | 16,920 |
| | 1422 | | | | | | | | | | | | | 17.2 | | |
| | 1500 | 29 | 66 | 7,100 | 29 | 67 | 7,150 | 29 | 64 | 7,100 | 74.00 | 18.40 | 55.60 | | 87 | 21,350 |
| | 1600 | 29 | 68 | 7,200 | 28 | 70 | 7,400 | 28 | 65 | 6,900 | 74.00 | 19.40 | 54.60 | | 85 | 21,500 |
| 20 | 1700 | 29 | 70 | 7,350 | 29 | 71 | 7,500 | 28 | 67 | 7,100 | 73.90 | 20.10 | 53.80 | | 86 | 21,950 |
| | 1800 | 29 | 71 | 7,400 | 29 | 73 | 7,550 | 28 | 68 | 7,150 | 73.90 | 20.80 | 53.10 | 20.6 | 86 | 22,100 |
| 21 | 1900 | 29 | 72 | 7,500 | 29 | 75 | 7,600 | 28 | 69 | 7,200 | 73.80 | 21.30 | 52.50 | | 86 | 22,300 |
| | 2000 | 30 | 71 | 7,350 | 29 | 73 | 7,550 | 3 | -- | 1,200 | 74.20 | 20.80 | 53.40 | 20.4 | 62 | 16,100 |
| 22 | 2040 | | | | | | | | | | | | | 20.4 | | |
| | 2100 | 19 | -- | 4,950 | 2 | -- | 650 | | | | 75.10 | 19.00 | 56.10 | 19.5 | 21 | 5,600 |
| | 2200 | | | | | | | | | | 74.50 | 18.30 | | | 0 | 0 |

Table 2

St. Stephen Powerhouse Velocity Readings

| Test No. | Date | Station | Tailwater El, ft | Maximum Velocity at 0.6 Depth, fps Right Toe | 100 ft R/CL | 50 ft R/CL | Channel CL | 50 ft L/CL | 100 ft L/CL | Left Toe | Turbines Operating |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 8/26 | 367+00 | 7.0 | 2.8 | 7.6 | 7.0 | 3.1 | -1.1 | -- | -1.3 | 3 |
| 7 | ↓ | 369+00 | 9.0 | 6.0 | 6.3 | 3.7 | 1.6 | -2.0 | -1.9 | -- | 3 |
| 7 | ↓ | 371+00 | 9.6 | 5.5 | 5.7 | 3.2 | 1.9 | -0.8 | -- | -- | 3 |
| 8 | ↓ | 371+00 | 9.6 | -- | 5.6 | 5.3 | -- | -- | -- | -- | 3&1 |
| 8 | ↓ | 367+00 | 9.6 | -- | 10.2 (taken 3 ft below water surface)* | | | | | -- | 3&1 |
| 9 | 8/27 | 367+00 | 7.3 | 4.6 | 9.2 | 5.6 | 3.1 | -0.8 | -- | -- | 1 |
| 9 | ↓ | Boat ramp | 7.3 | 5.4 | 4.0 | -- | -- | -- | -- | -- | 1 |
| 9 | ↓ | 369+00 | 8.8 | 8.5 | 6.7 | 4.0 | 2.4 | -- | -0.5 | -- | 1 |
| 9 | ↓ | 371+00 | 9.8 | 6.6 | 5.2 | 3.9 | 2.0 | -1.2 | -- | -- | 1 |
| 10 | ↓ | 371+00 | 9.2 | 5.3 | 5.7 | 4.1 | 3.2 | -- | -- | -- | 2 |
| 10 | ↓ | 366+00 | 9.2 | -- | 9.6* | -- | -- | -- | -- | -- | 2 |
| 12 | ↓ | 368+50 | 9.4 | 4.9 | 5.1 | 4.7 | 6.6 | -- | 3.9 | -- | 2&3 |
| 12 | ↓ | 370+50 | 11.8 | 5.0 | 4.0 | 4.8 | 4.3 | -- | 2.2 | -- | 2&3 |
| 13 | ↓ | 370+50 | 12.5 | 5.6 | 7.4 | 4.8 | 3.6 | -- | -1.2 | -- | 1&2 |
| 13 | ↓ | 366+50 | 12.5 | -- | 10.8* | -- | -- | -- | -- | -- | 1&2 |
| 13 | ↓ | 368+50 | 13.8 | 7.2 | 7.6 | 5.2 | 4.1 | -0.6 | -- | -- | 1&2 |

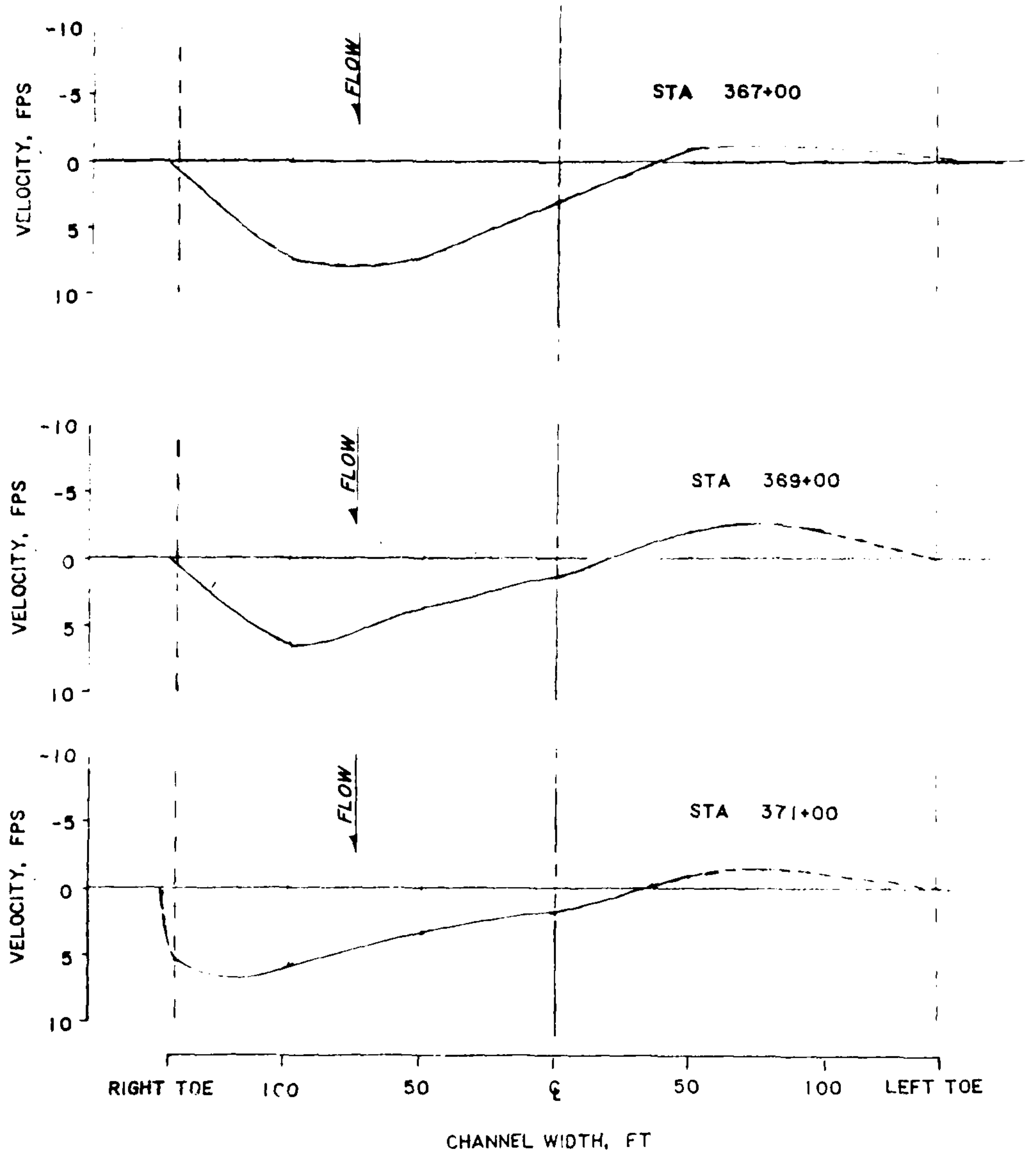
(Continued)

Note: R/CL: Distance to the right of channel center line looking downstream.
L/CL: Distance to the left of channel center line looking downstream.
Toe: The toe of the slope of the respective banks.
Negative sign indicates return flow back toward powerhouse.
-- no data taken at this point.
* Spot velocity measurements taken immediately downstream of right wing wall.

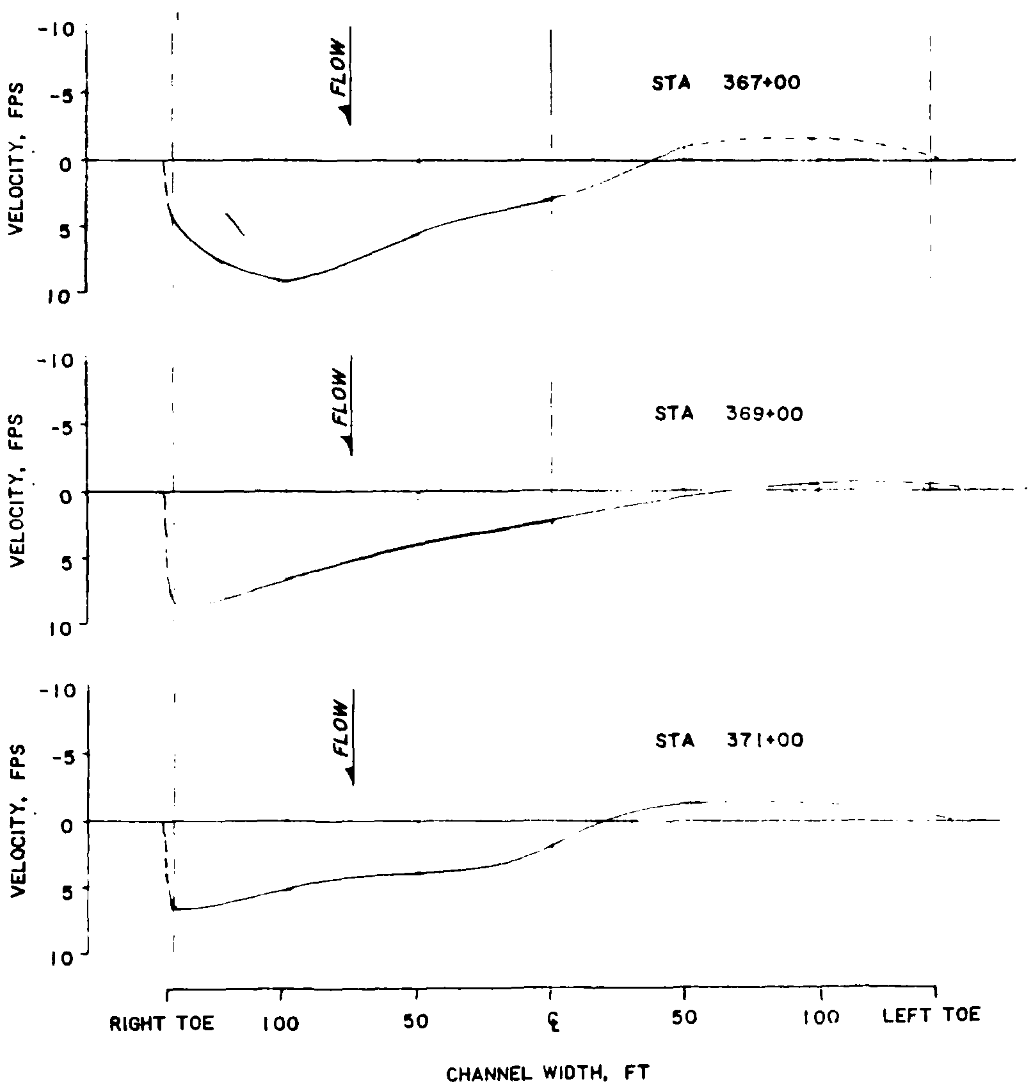
Table 2 (Concluded)

| Test No. | Date | Station | Tailwater El, ft | Maximum Velocity at 0.6 Depth, fps: Right Toe | 100 ft R/CL | 50 ft R/CL | Channel CL | 50 ft L/CL | 100 ft L/CL | Left Toe | Turbines Operating |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 8/27 | 368+50 | 15.4 | 7.2 | 6.6 | 5.0 | 5.3 | 4.5 | -- | -- | 1,2,&3 |
| 14 | | 366+25 | 15.4 | -- | 5.6* | -- | -- | -- | -- | -- | 1,2,&3 |
| 15 | | 368+50 | 14.7 | 7.3 | 6.6 | 2.2 | 1.0 | -- | -2.3 | -- | 1 |
| 15 | | 370+50 | 14.5 | 7.0 | 5.4 | 2.4 | 1.0 | -1.7 | -2.6 | -- | 1 |
| 16 | | 370+50 | 14.5 | 3.6 | 4.3 | 1.4 | 1.1 | -1.9 | -- | -- | 2 |
| 16 | | 366+00 | 14.5 | -- | 6.5* | -- | -- | -- | -- | -- | 2 |
| 16 | | 368+50 | 14.4 | 4.7 | 4.4 | 3.7 | 1.7 | -0.9 | -- | -- | 2 |
| 17 | 8/28 | 368+50 | 9.8 | 6.9 | 6.8 | 7.0 | 6.5 | -- | -1.7 | -- | 3&1 |
| 17 | | 370+50 | 13.8 | 6.4 | 6.0 | 5.4 | 3.6 | -- | -1.4 | -- | 3&1 |
| 17 | | 368+50 | 14.5 | 6.2 | 6.2 | 5.6 | 4.0 | -- | -1.4 | -- | 3&1 |
| 18 | | 368+50 | 14.0 | 5.0 | 5.2 | 3.0 | 1.2 | -- | -1.4 | -- | 3 |
| 18 | | 370+50 | 14.0 | 4.9 | 4.8 | 2.8 | 1.8 | -- | -1.7 | -- | 3 |
| 19 | | 370+50 | 16.0 | 5.6 | 5.8 | 4.0 | 4.0 | -- | 2.4 | -- | 1,2,&3 |
| 19 | | 368+50 | 16.8 | 4.6 | 6.2 | 4.8 | 5.0 | -- | 2.1 | -- | 1,2,&3 |
| 20 | | 368+50 | 20.6 | 2.8 | 6.6 | 4.4 | 4.8 | -- | 1.8 | -- | 1,2,&3 |
| 20 | | 370+50 | 21.22 | 4.2 | 5.0 | 3.4 | 4.0 | -- | 0.8 | -- | 1,2,&3 |
| 20 | | D-2 | 21.2 | 1.8 | -- | 2.4 | 2.6 | 2.4 | -- | 2.2 | 1,2,&3 |
| 20 | | Bridge | 21.2 | -- | -- | -- | 3.6 | -- | -- | -- | 1,2,&3 |
| 21 | | 370+50 | 20.7 | 2.8 | 5.2 | 2.6 | 2.2 | -- | -0.8 | -- | 1&2 |
| 21 | | 368+50 | 20.6 | 3.5 | 6.4 | 3.0 | 2.2 | -- | -1.8 | -- | 1&2 |
| 22 | | 368+50 | 19.8 | 1.6 | 5.6 | 4.0 | 3.0 | -- | -2.8 | -- | 1 |

* Spot velocity measurements taken immediately downstream of right wing wall.

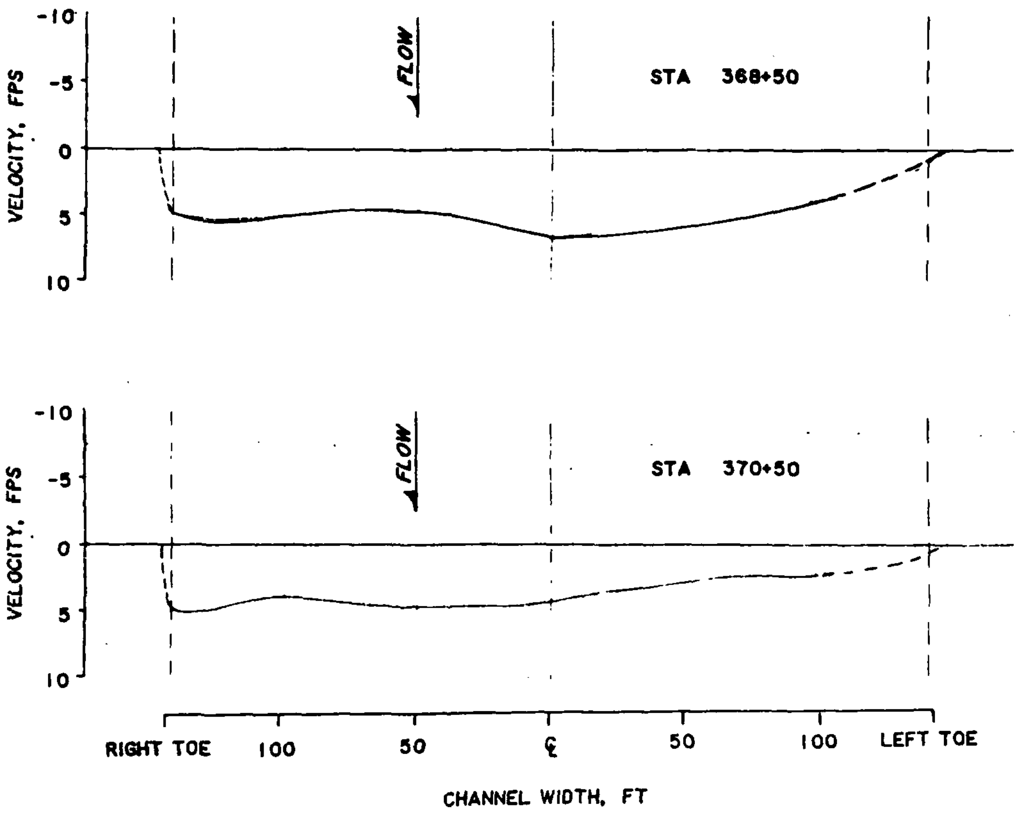



CHANNEL
VELOCITY DISTRIBUTION
TEST 7

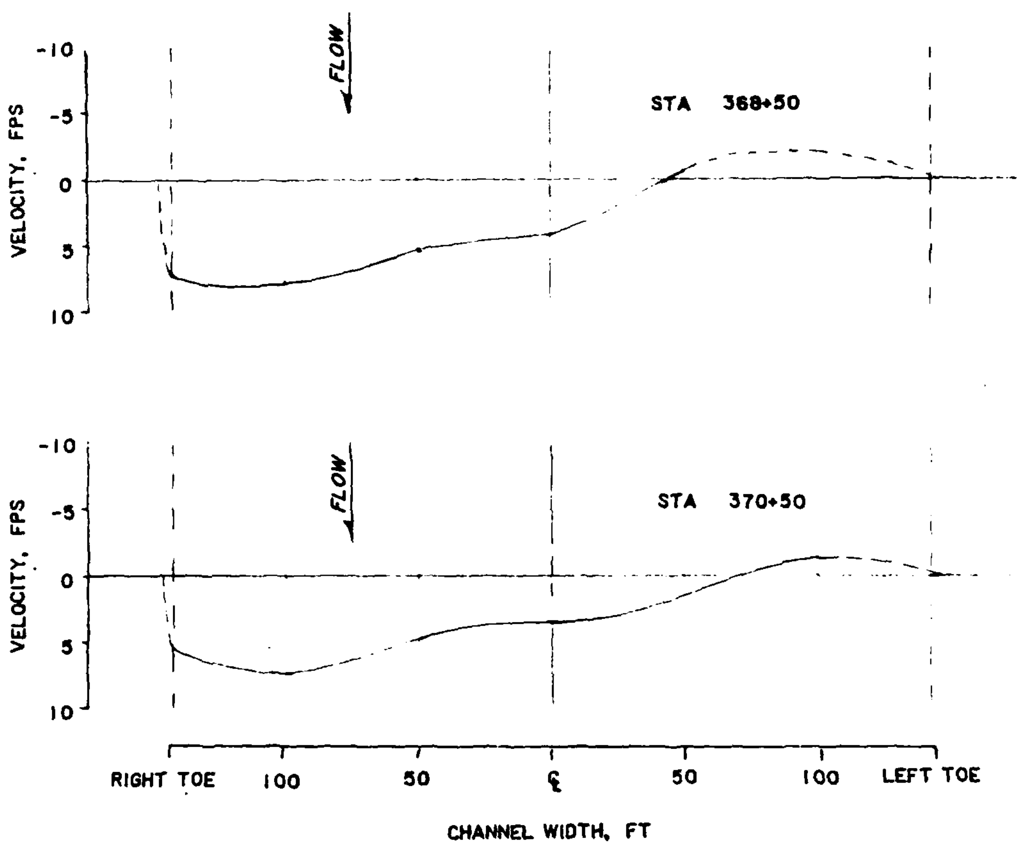



CHANNEL
VELOCITY DISTRIBUTION
TEST 9

PLATE 2

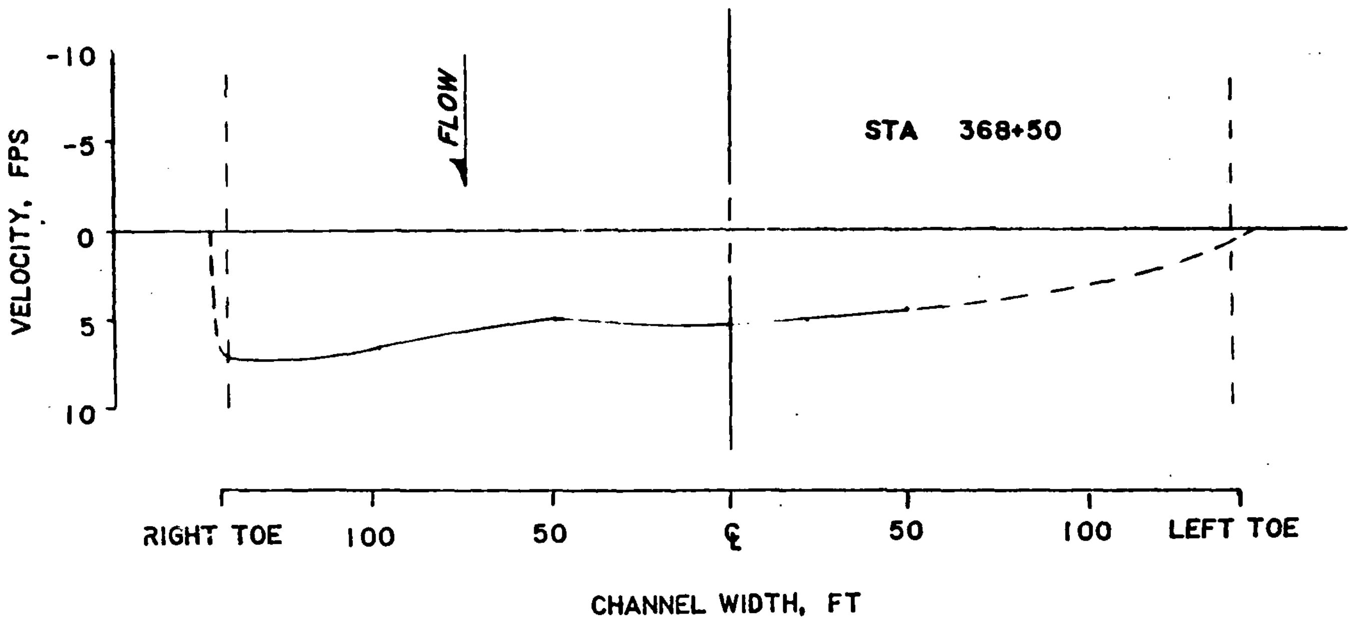



CHANNEL
VELOCITY DISTRIBUTION
TEST 12

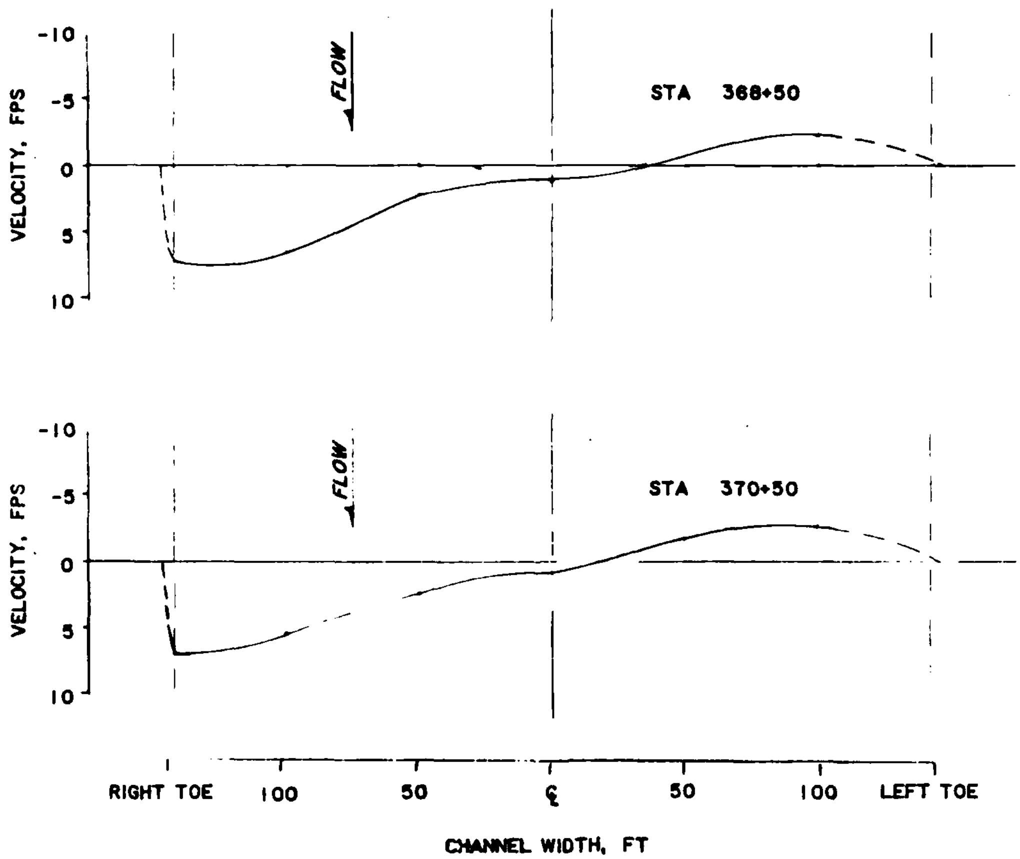



CHANNEL
VELOCITY DISTRIBUTION
TEST 13

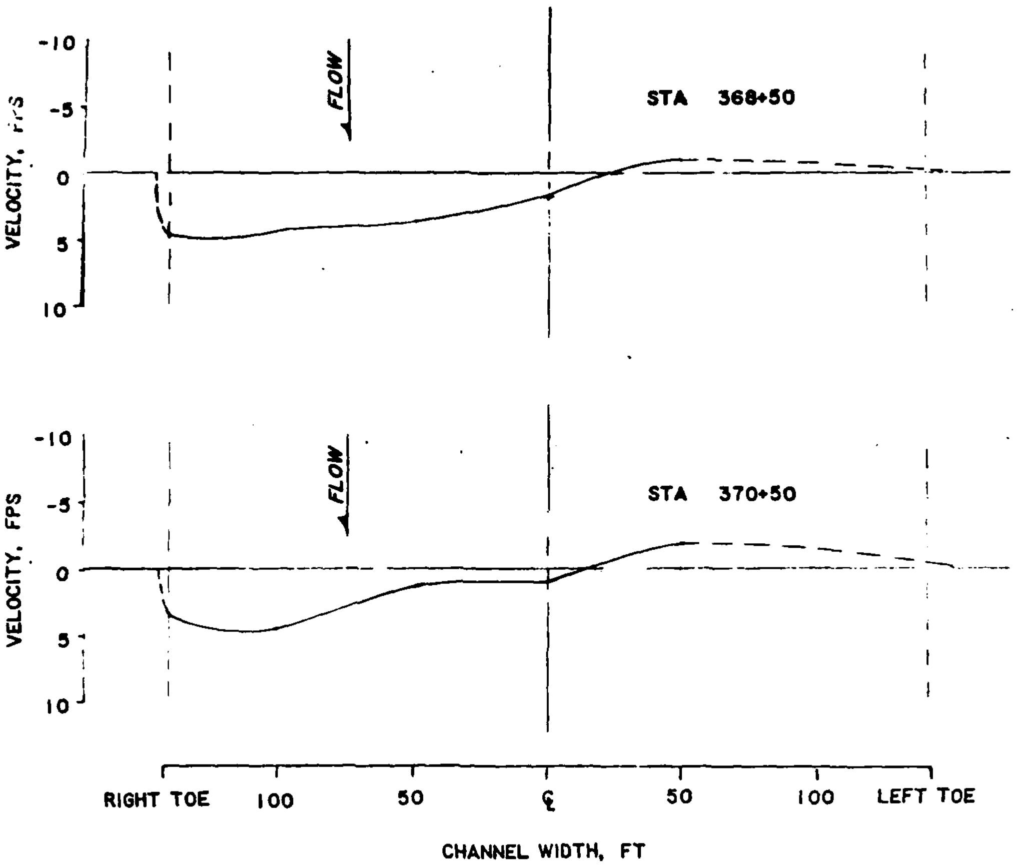
PLATE 4



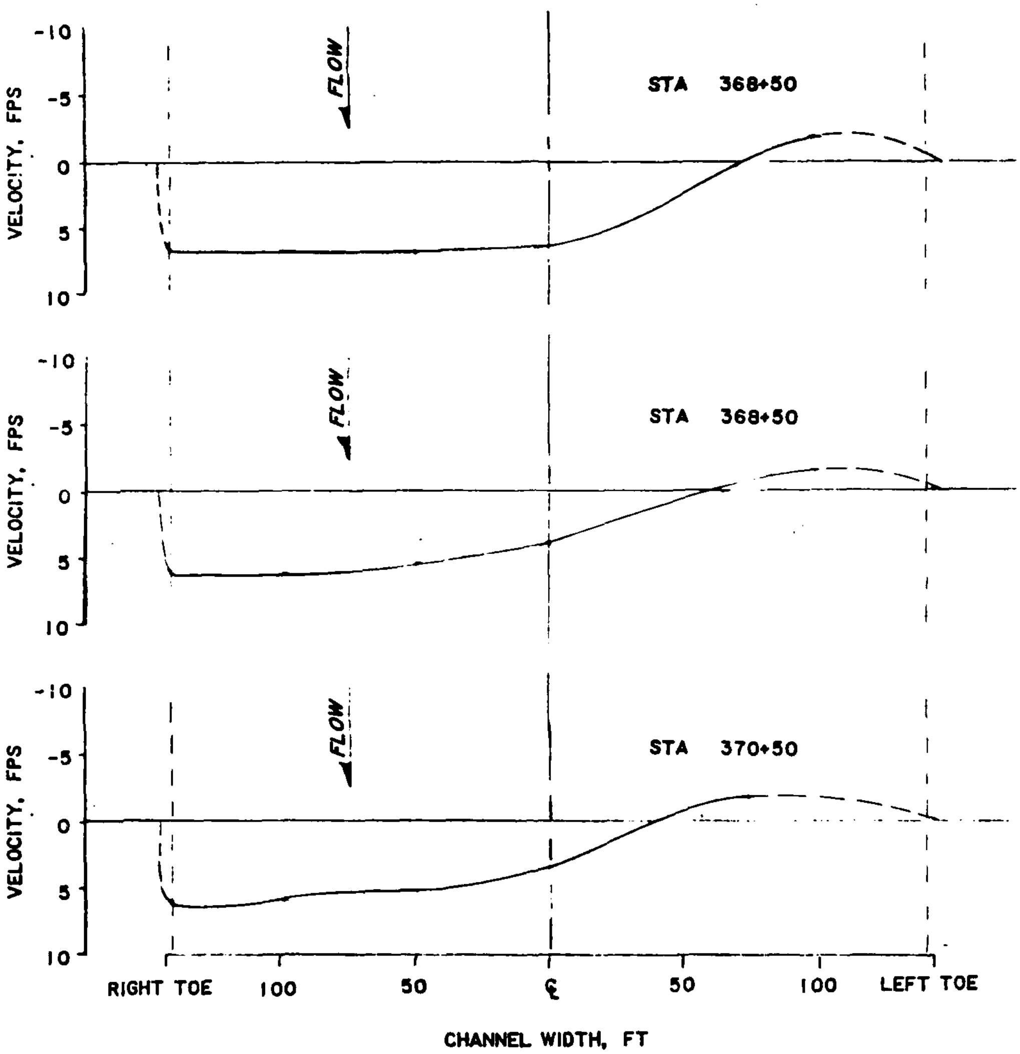

CHANNEL
VELOCITY DISTRIBUTION
TEST 14



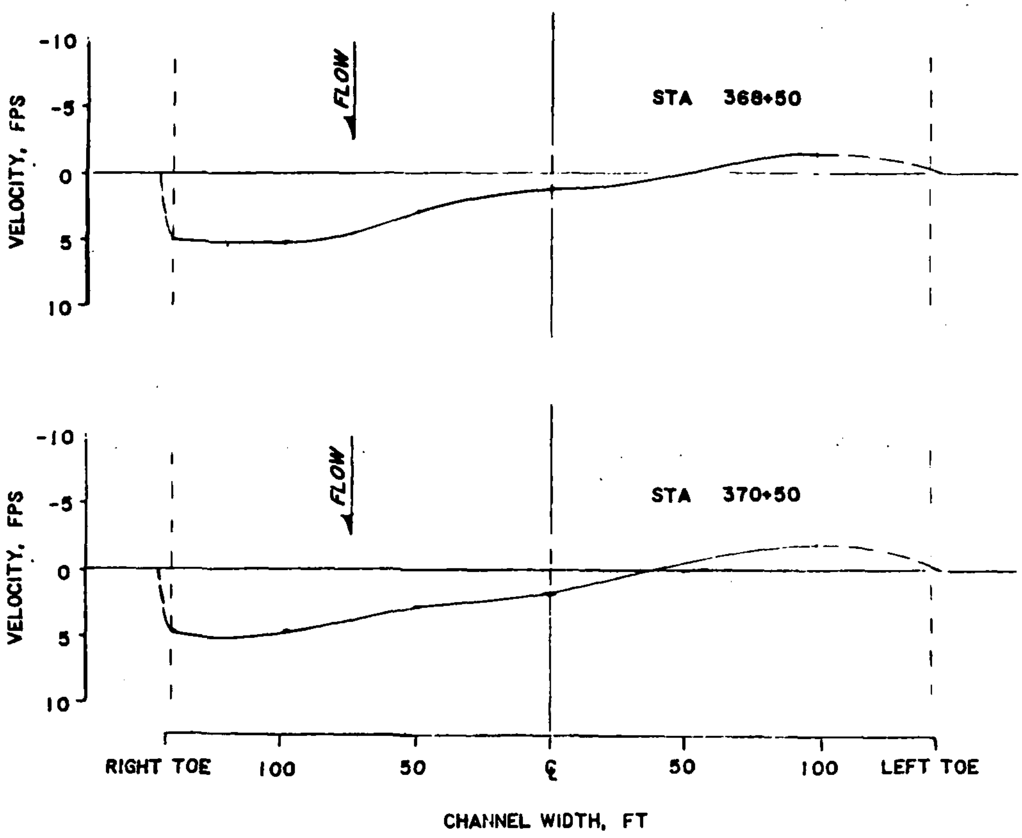

CHANNEL
VELOCITY DISTRIBUTION
TEST 15



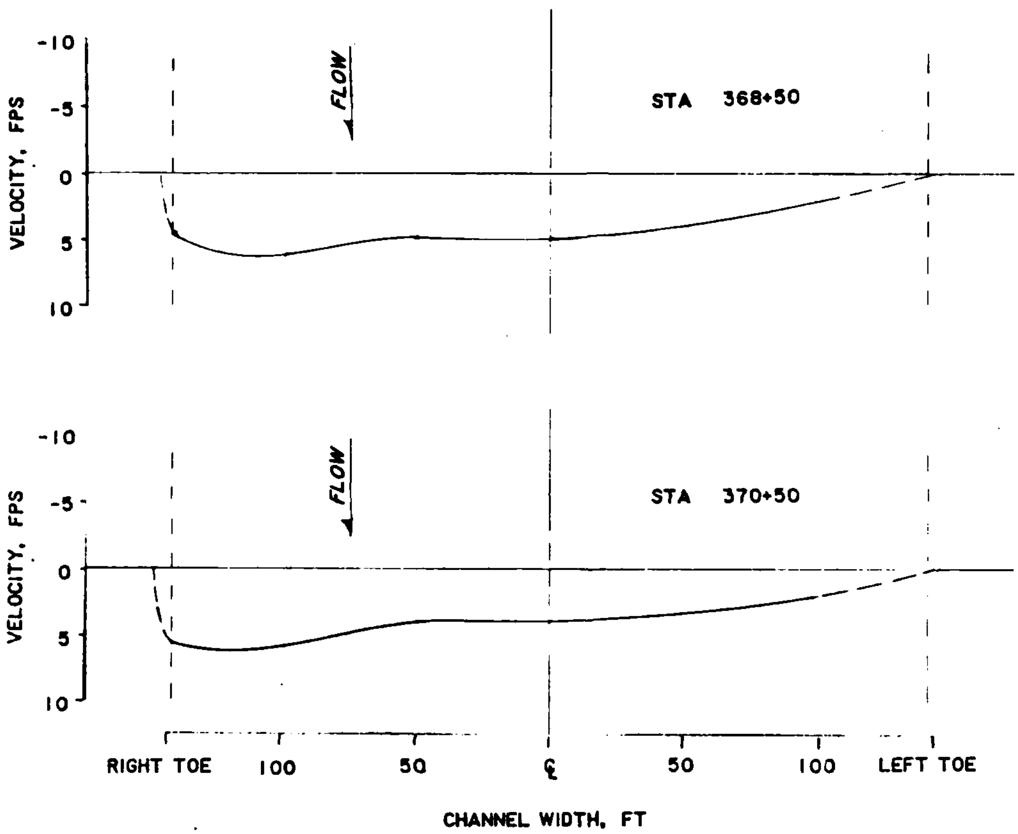

CHANNEL
VELOCITY DISTRIBUTION
TEST 16



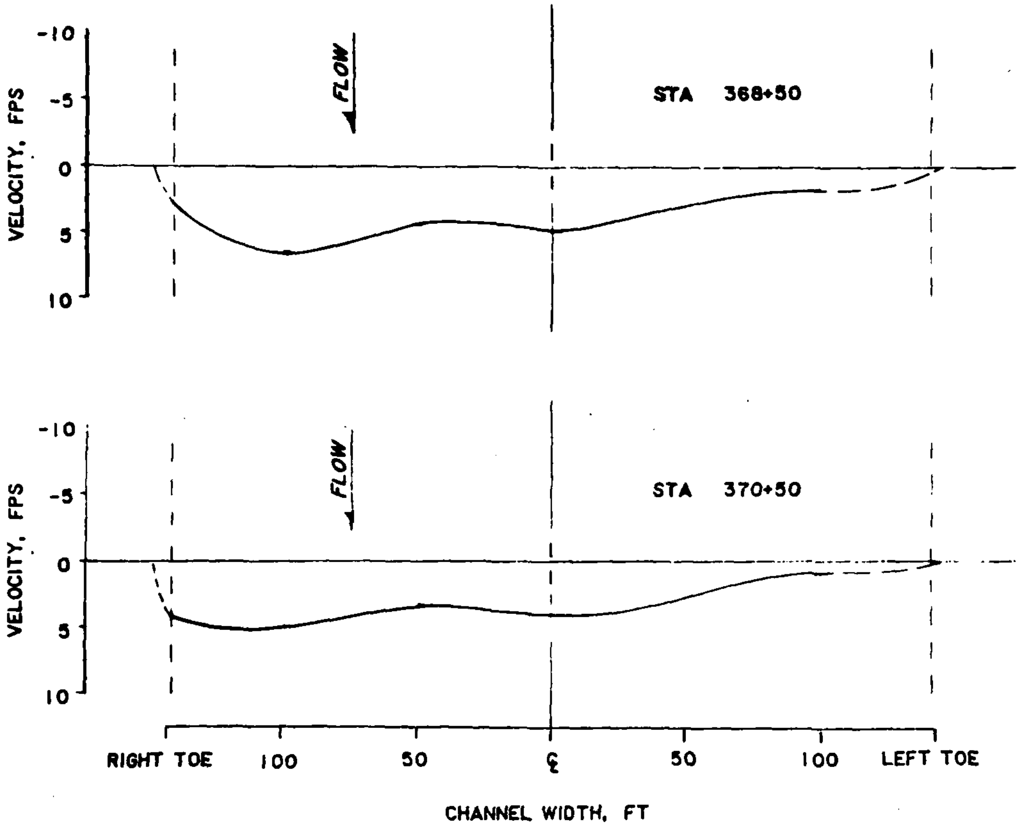

CHANNEL
VELOCITY DISTRIBUTION
TEST 17



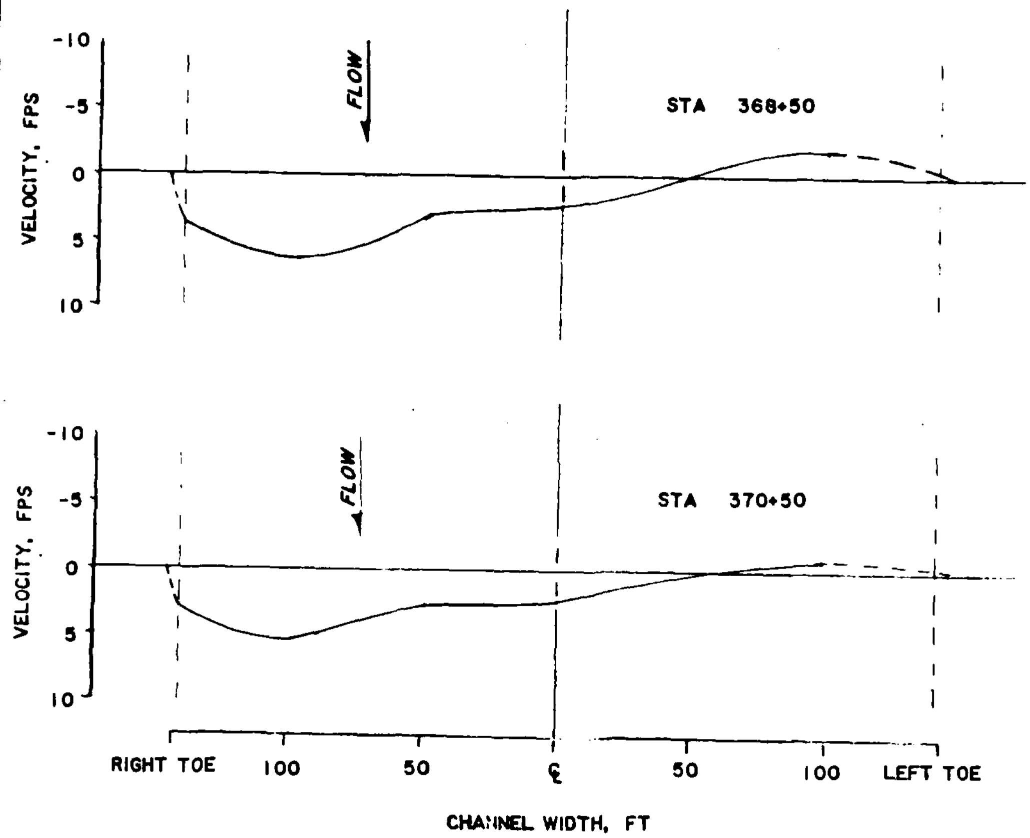

CHANNEL
VELOCITY DISTRIBUTION
TEST 18



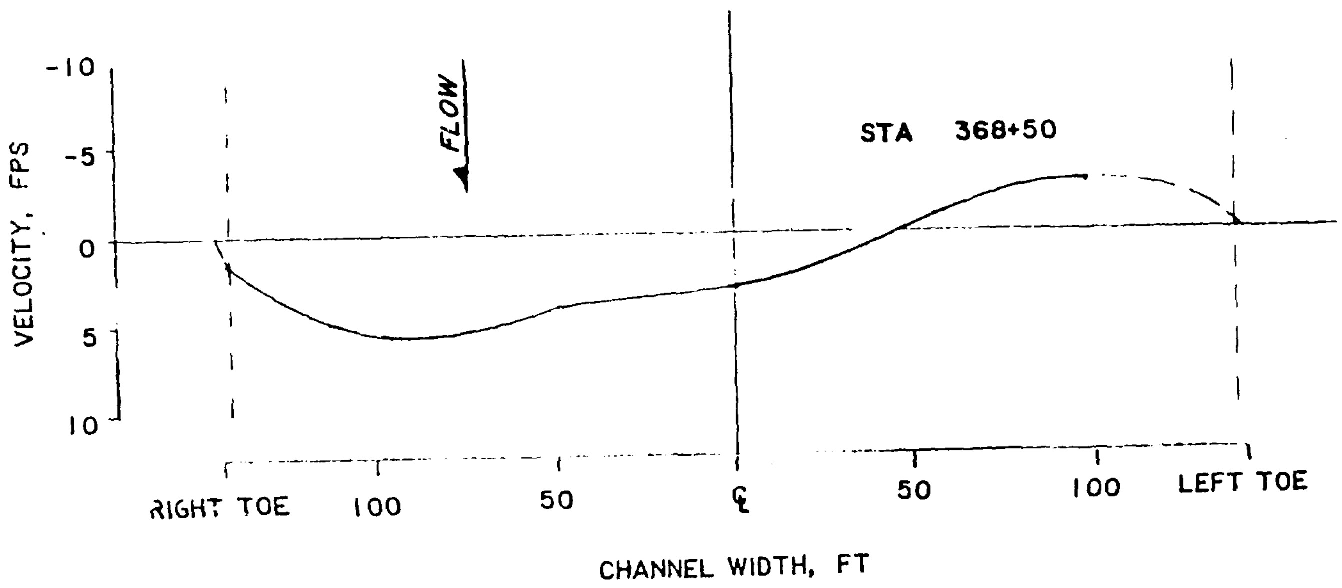

CHANNEL
VELOCITY DISTRIBUTION
TEST 19



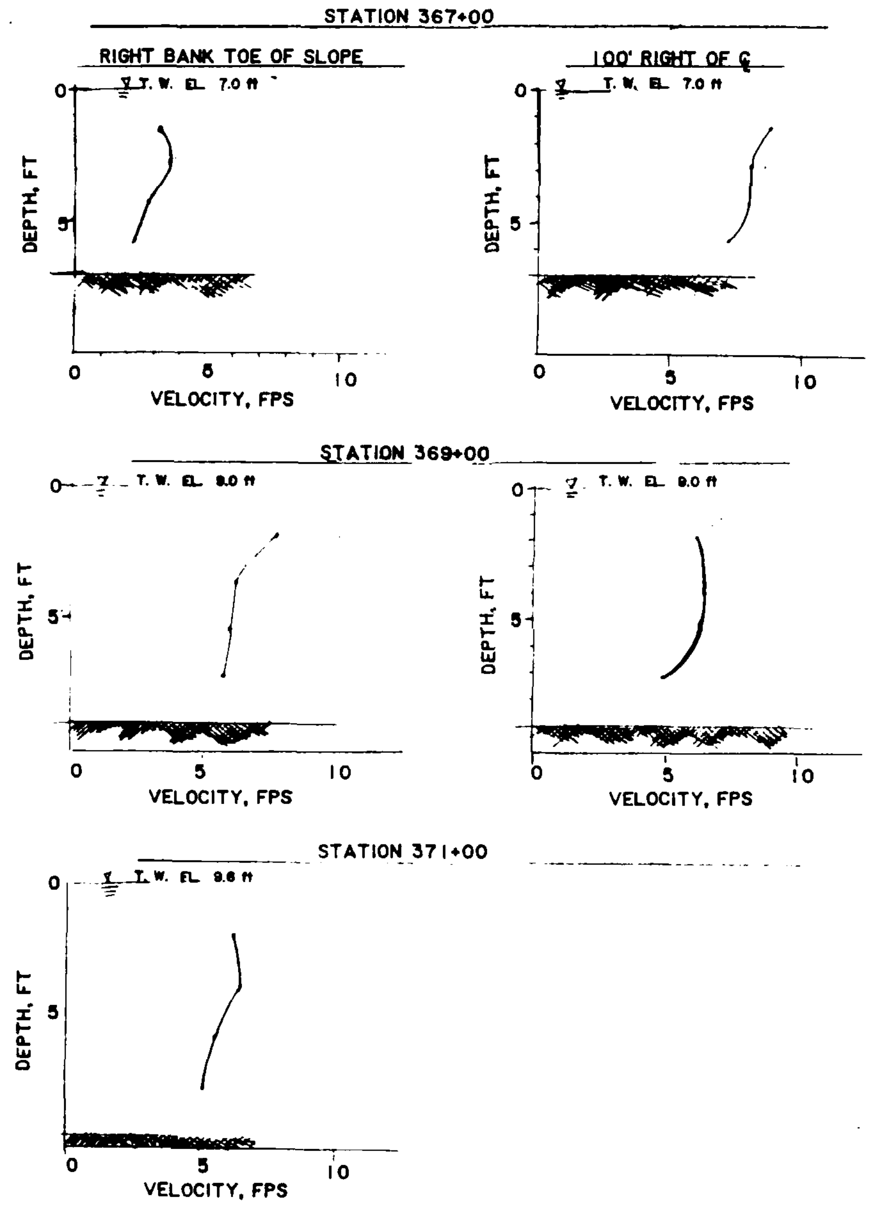

CHANNEL
VELOCITY DISTRIBUTION
TEST 20




CHANNEL
VELOCITY DISTRIBUTION
TEST 21

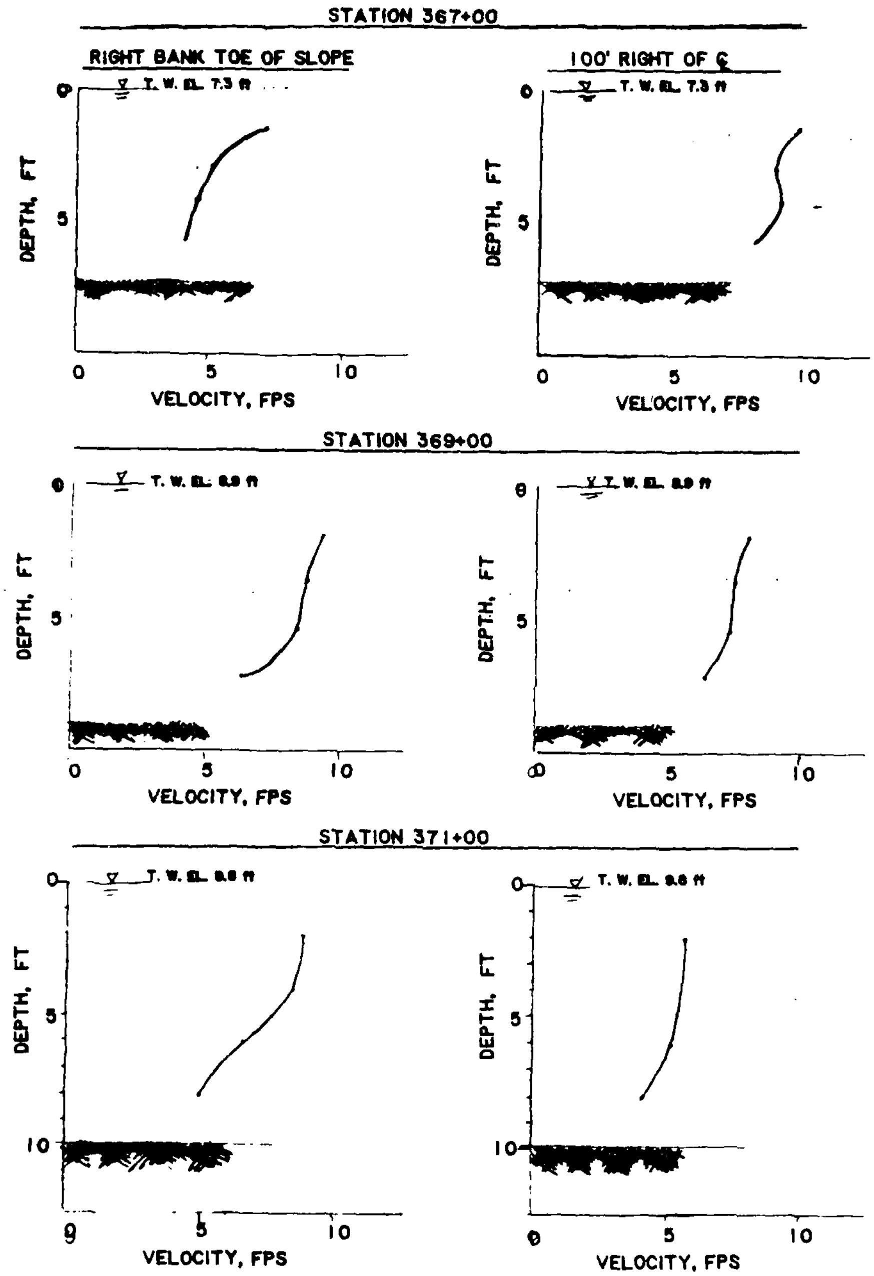



CHANNEL
VELOCITY DISTRIBUTION
TEST 22

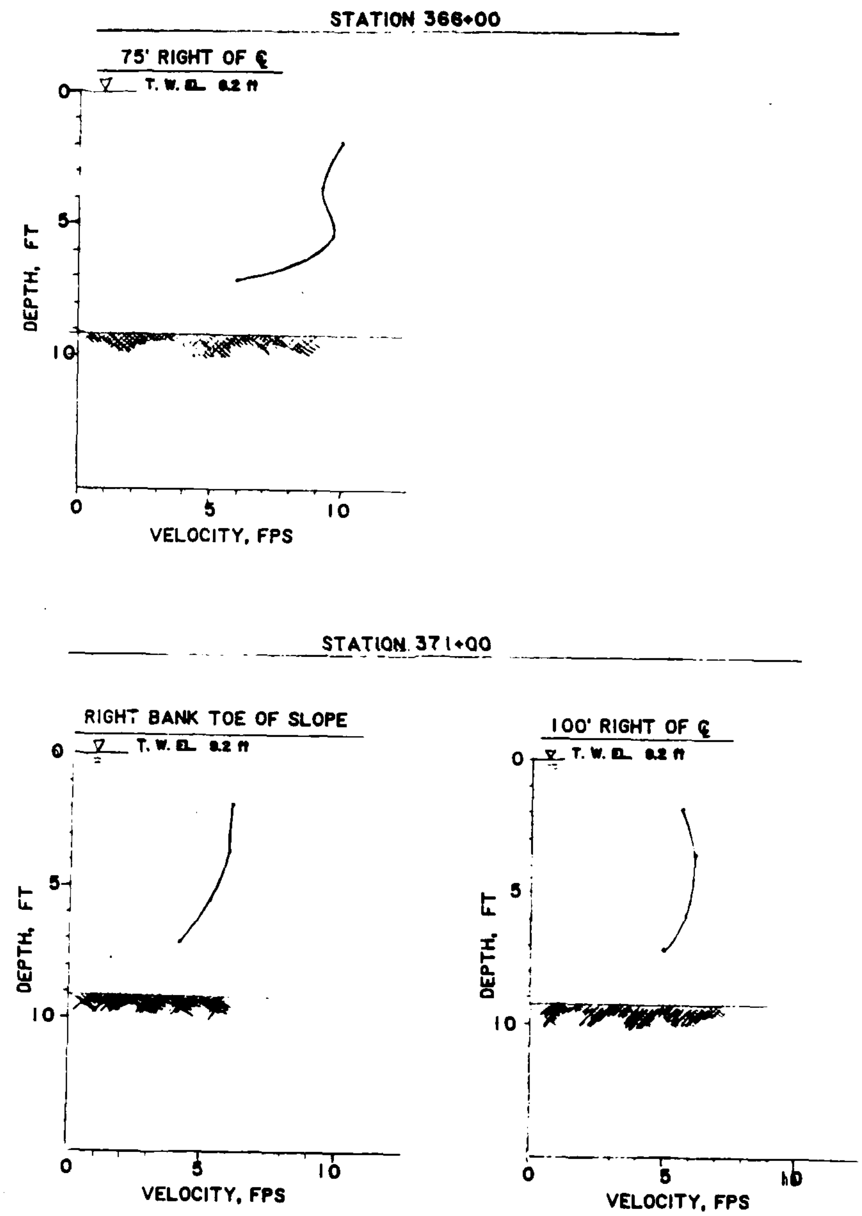



VELOCITY PROFILES

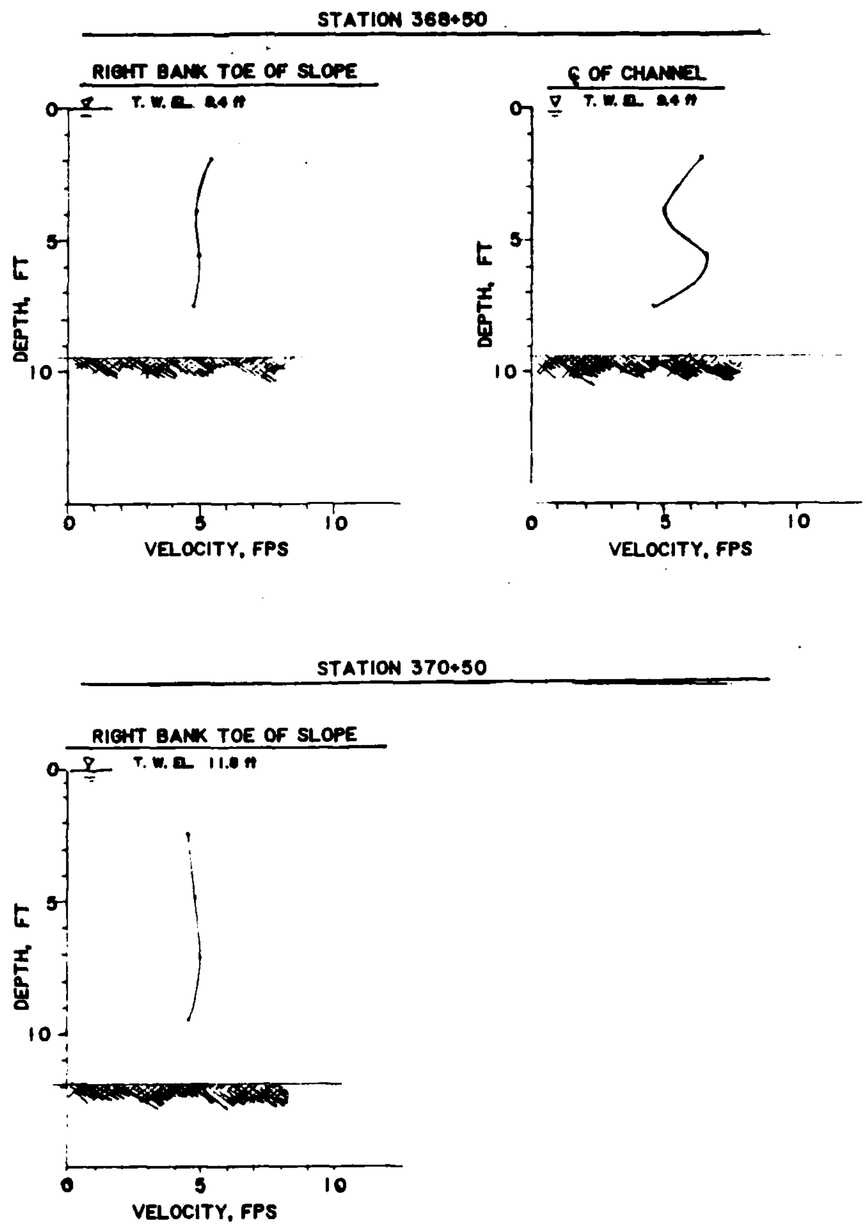
TEST 7, UNIT 3
LOW TAILWATER



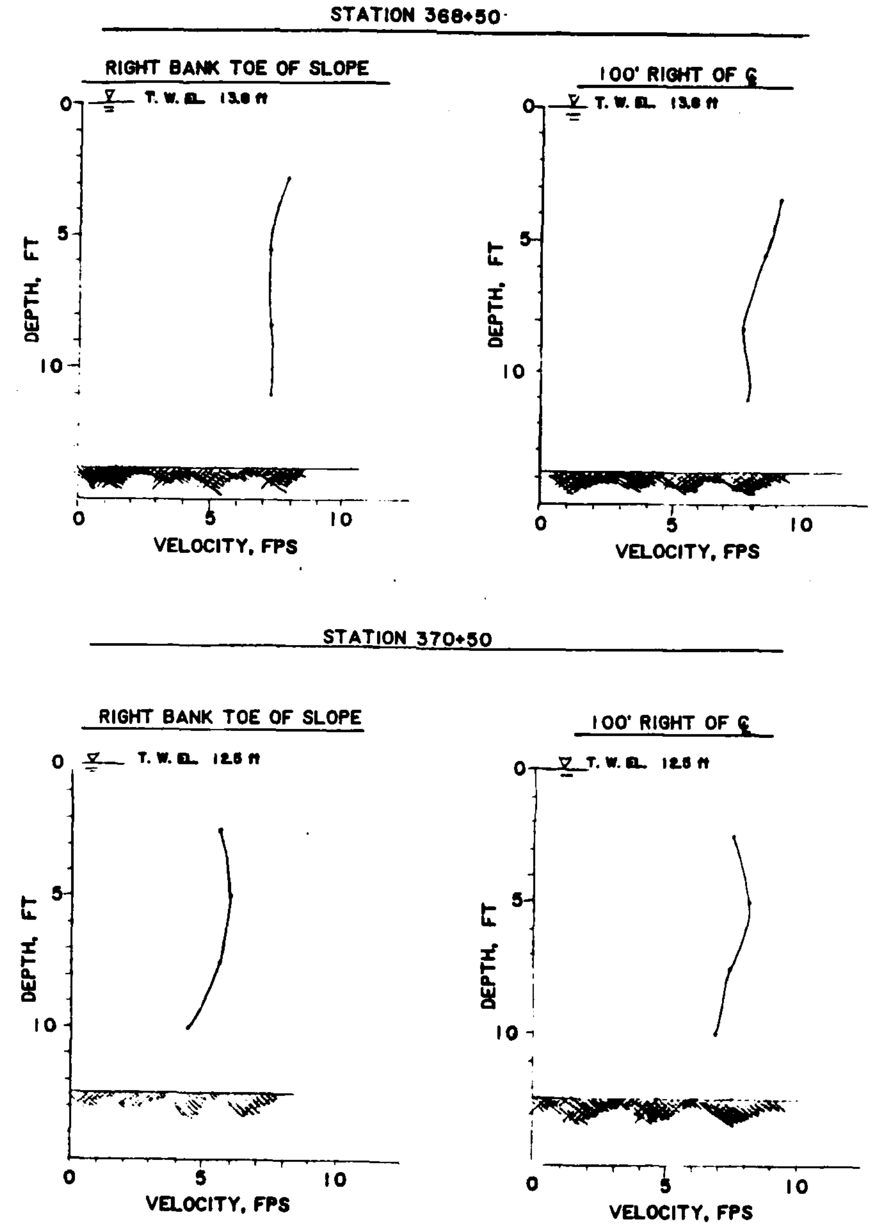

VELOCITY PROFILES
TEST 9, UNIT 1
LOW TAILWATER



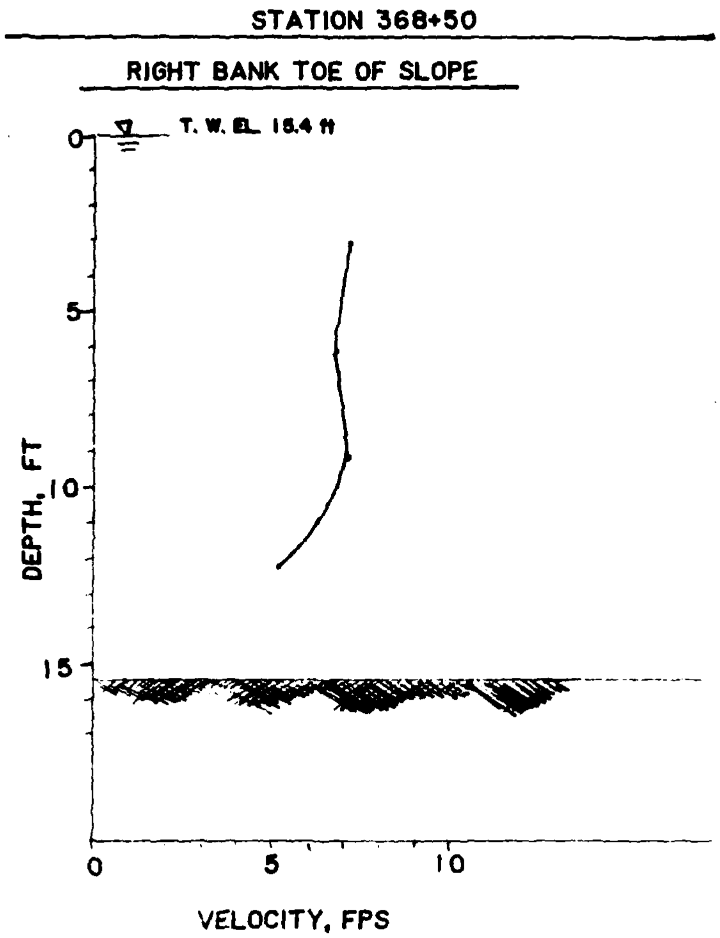

VELOCITY PROFILES
TEST 10, UNIT 2
LOW TAILWATER




VELOCITY PROFILES
TEST 12, UNITS 2 & 3
LOW TAILWATER

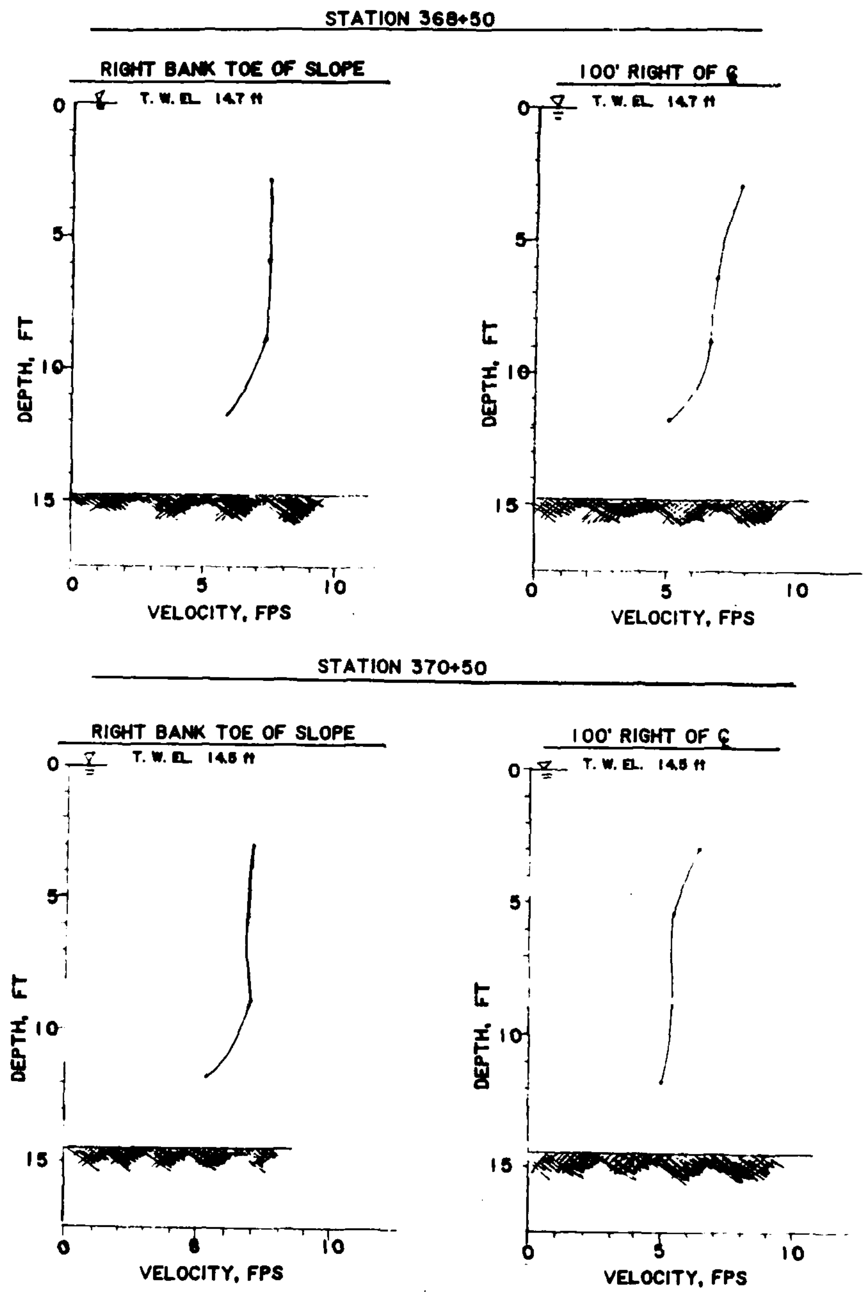



VELOCITY PROFILES
TEST 13, UNITS 1 & 2
LOW TAILWATER

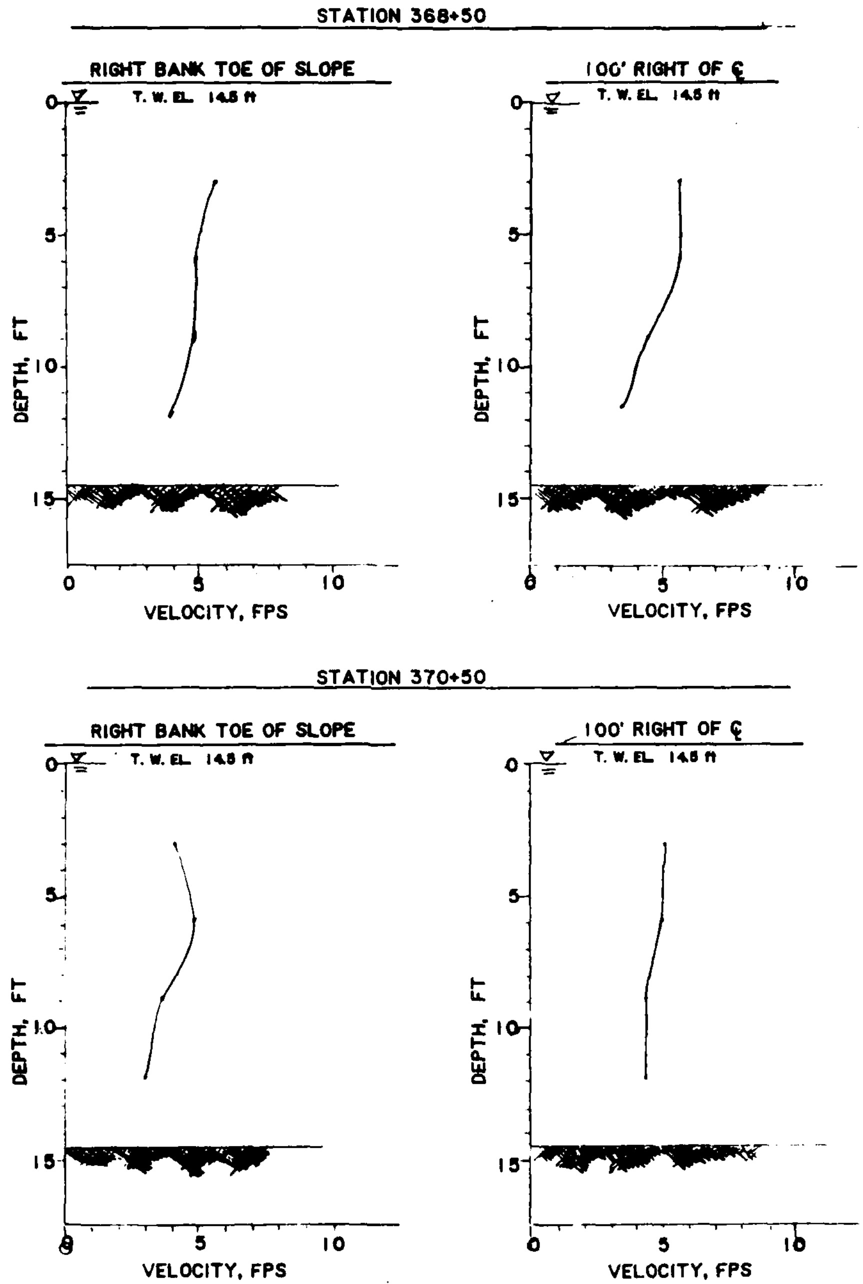



VELOCITY PROFILES

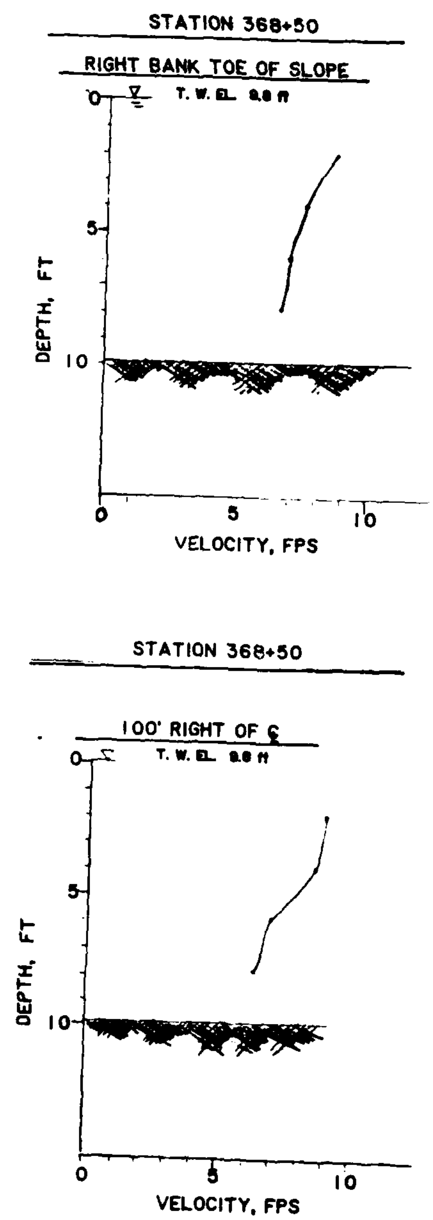
TEST 14, UNITS 1, 2, & 3
LOW TAILWATER
STA 368+50



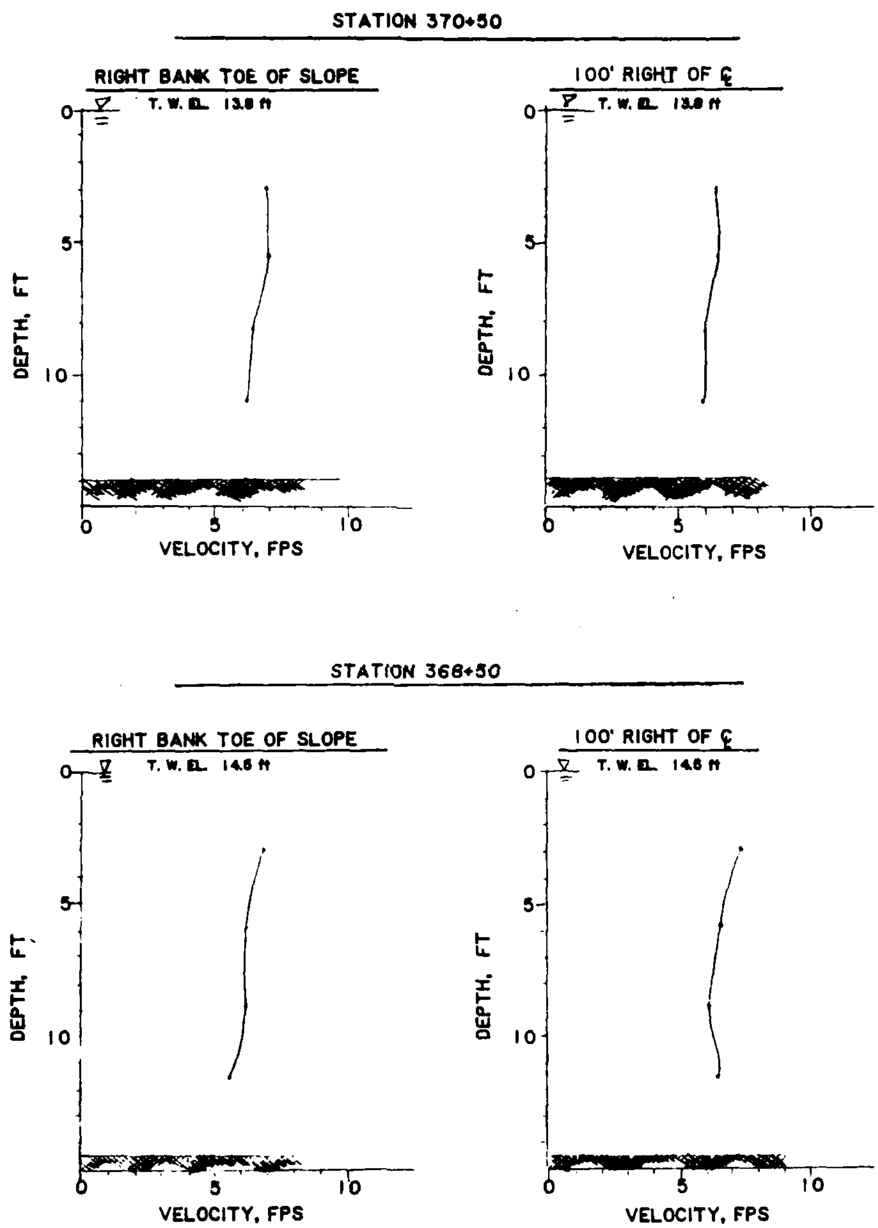

VELOCITY PROFILES
TEST 15, UNIT 1
INTERMEDIATE TAILWATER



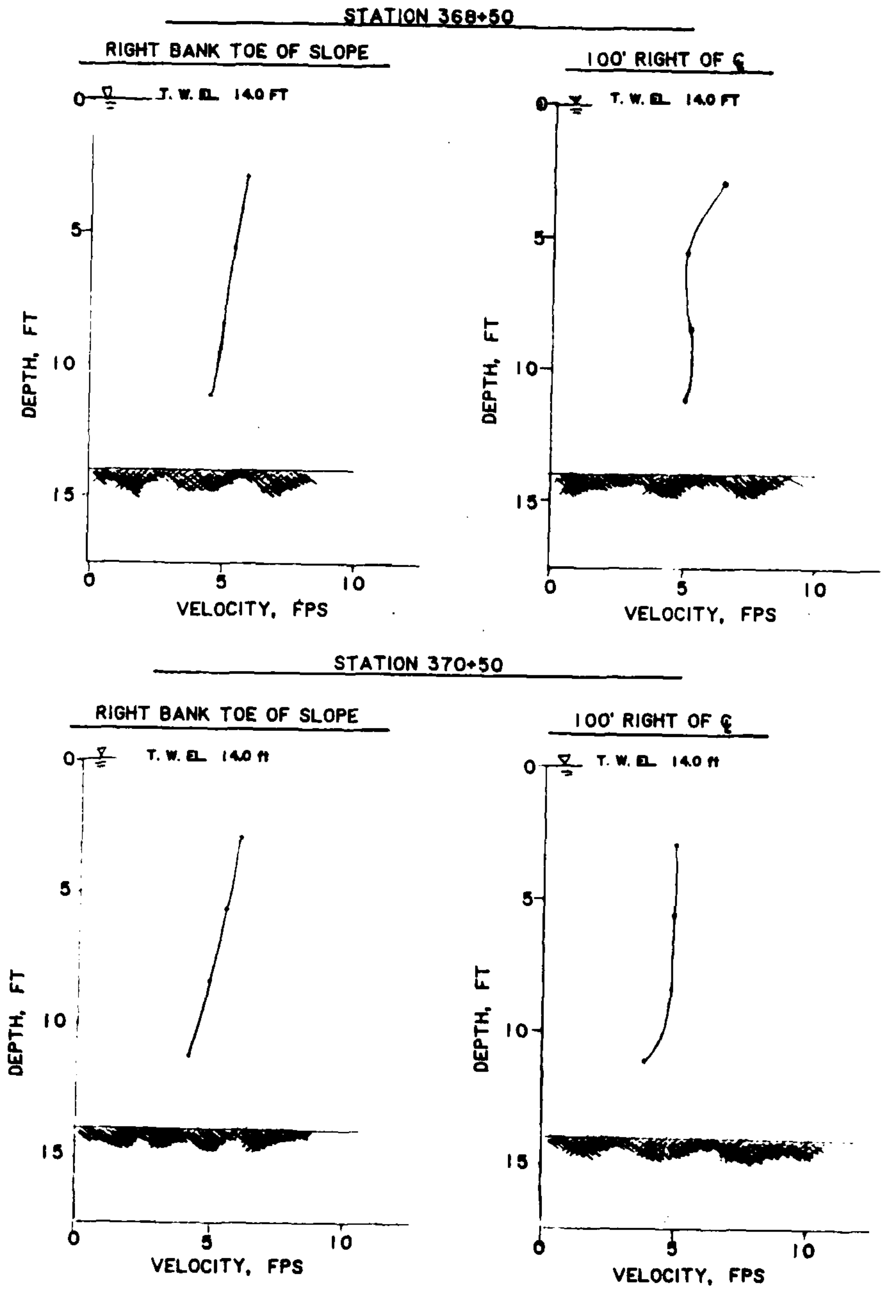

VELOCITY PROFILES
TEST 16, UNIT 2
INTERMEDIATE TAILWATER



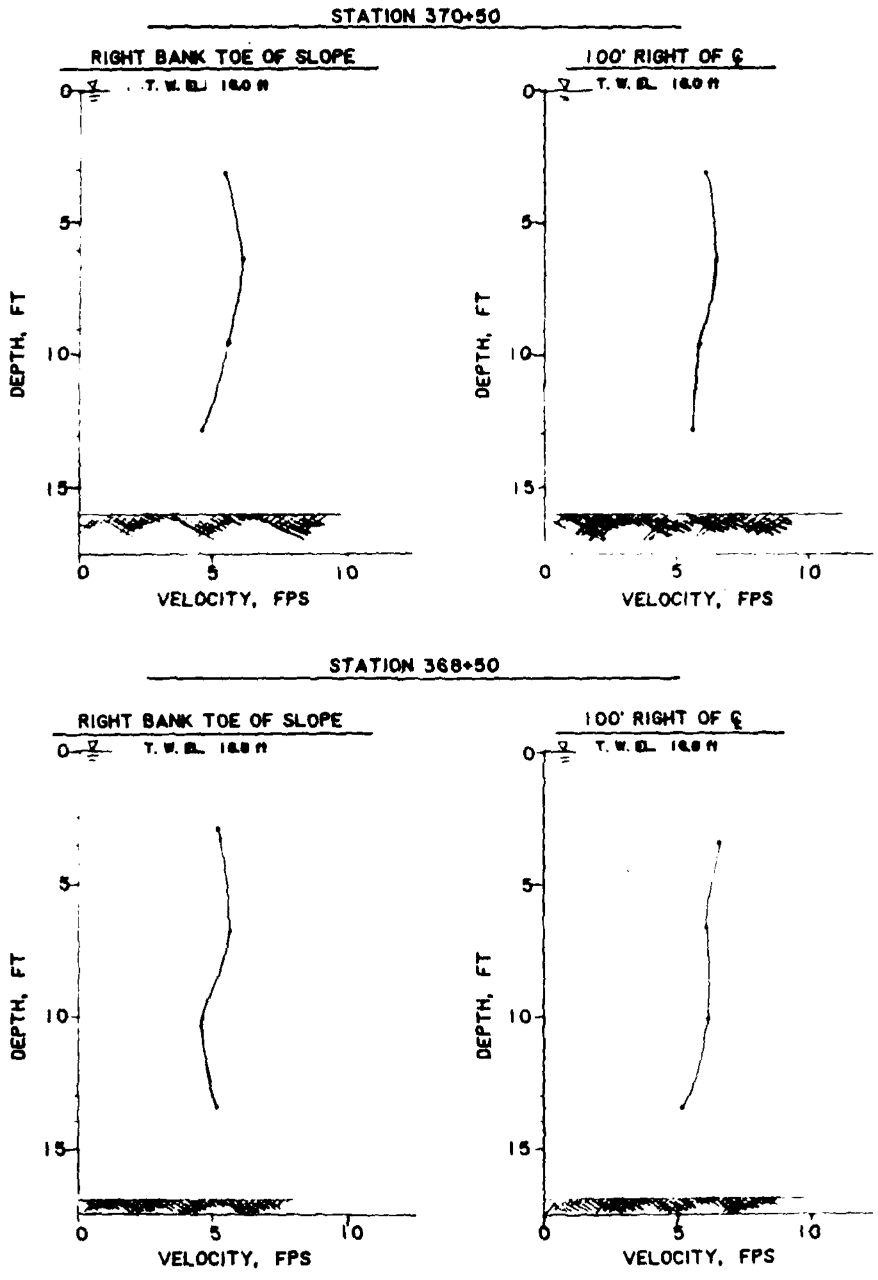

VELOCITY PROFILES
TEST 17, UNITS 1 & 3
LOW TAILWATER
STA 368+50



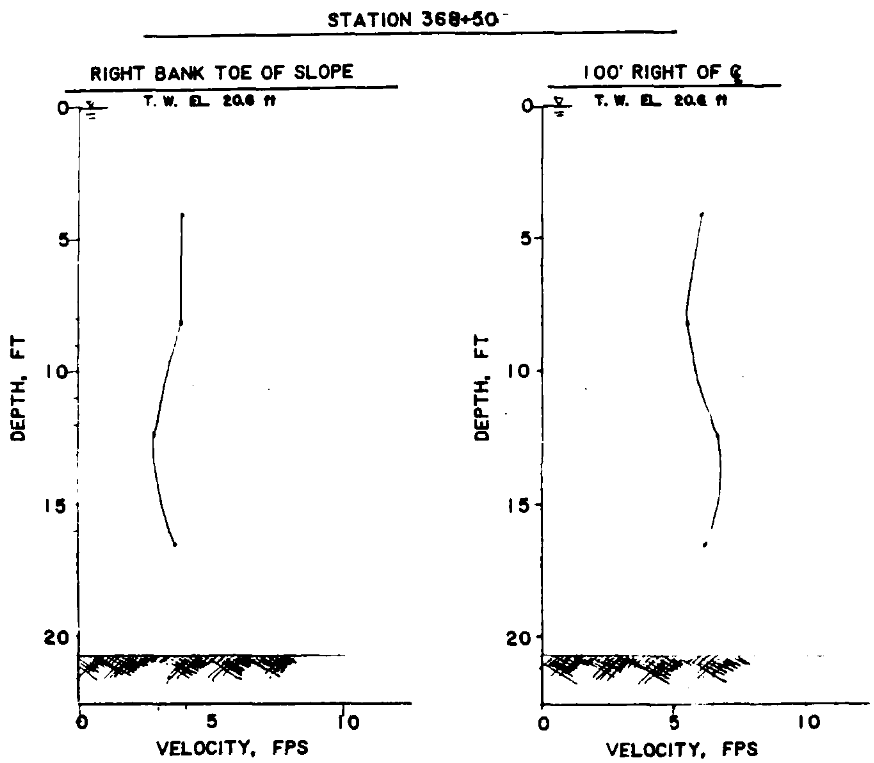

VELOCITY PROFILES
TEST 17, UNITS 1 & 3
INTERMEDIATE TAILWATER



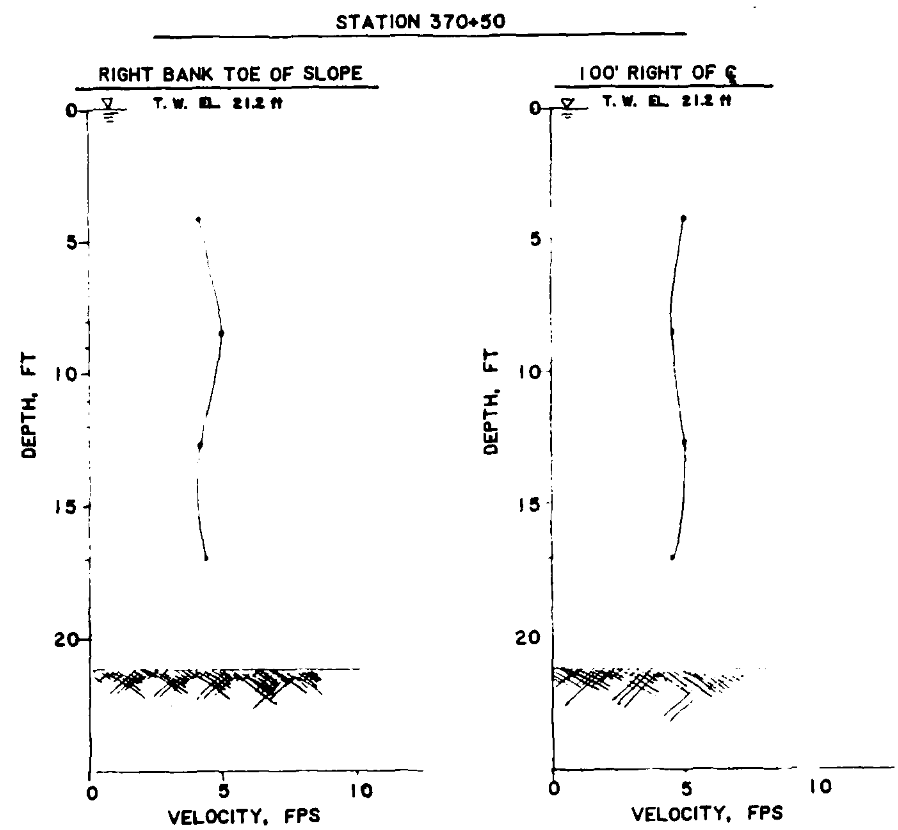

VELOCITY PROFILES
TEST 18, UNIT 3
INTERMEDIATE TAILWATER



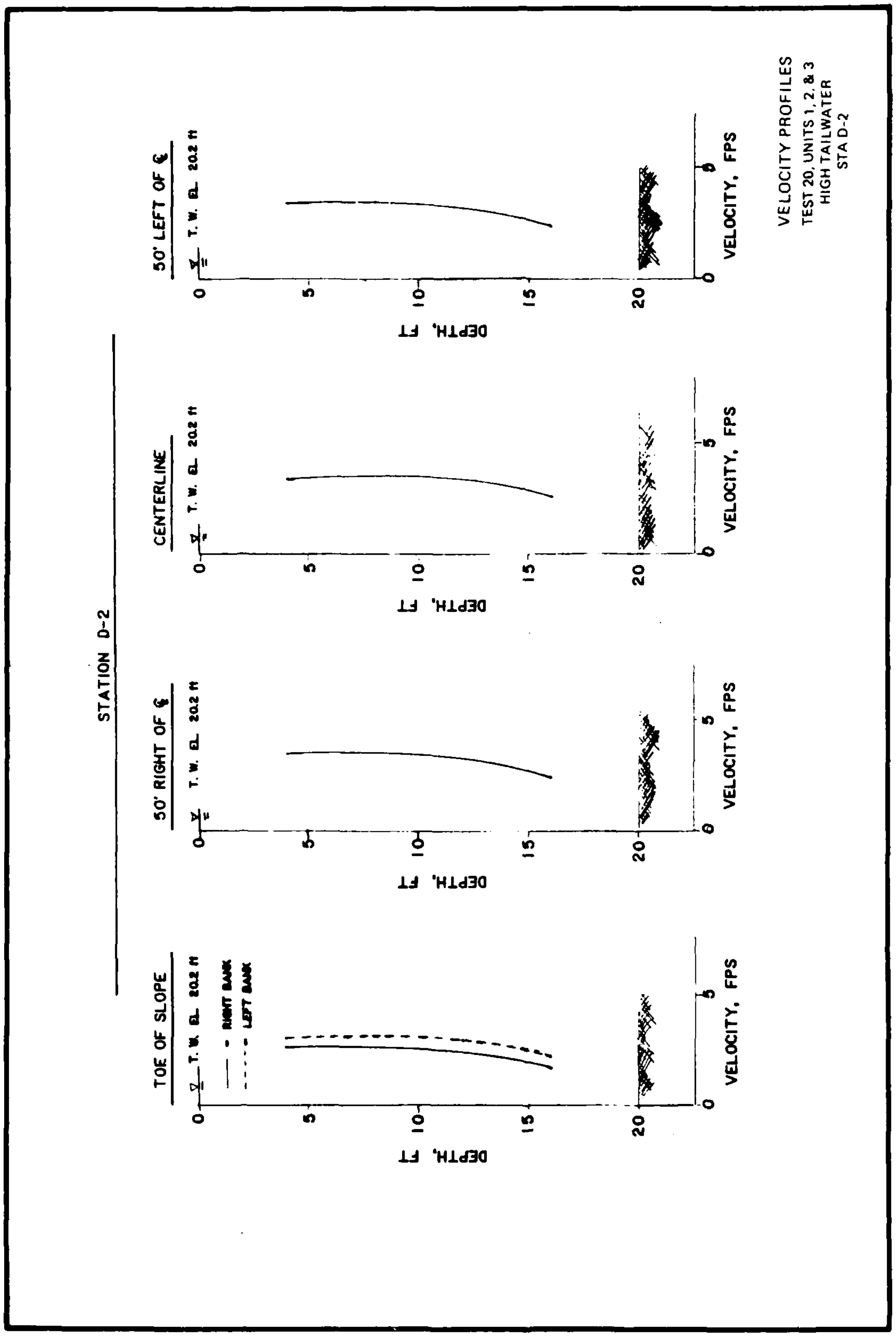

VELOCITY PROFILES
TEST 19, UNITS 1, 2, & 3
INTERMEDIATE TAILWATER

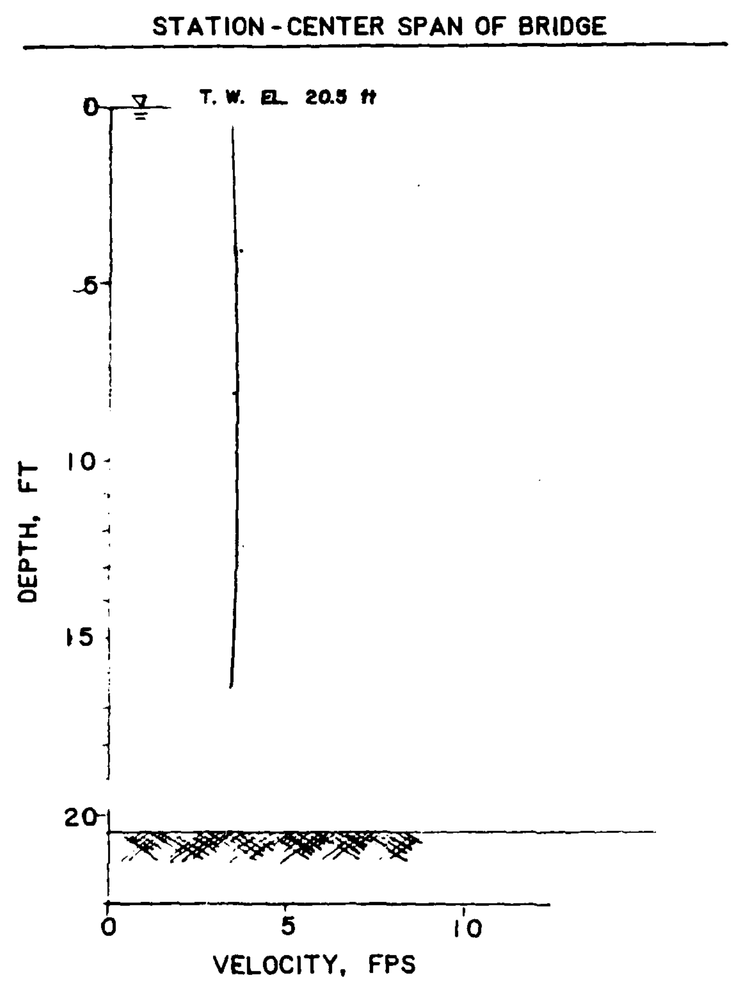



VELOCITY PROFILES
TEST 20, UNITS 1, 2, & 3
HIGH TAILWATER
STA 368+50



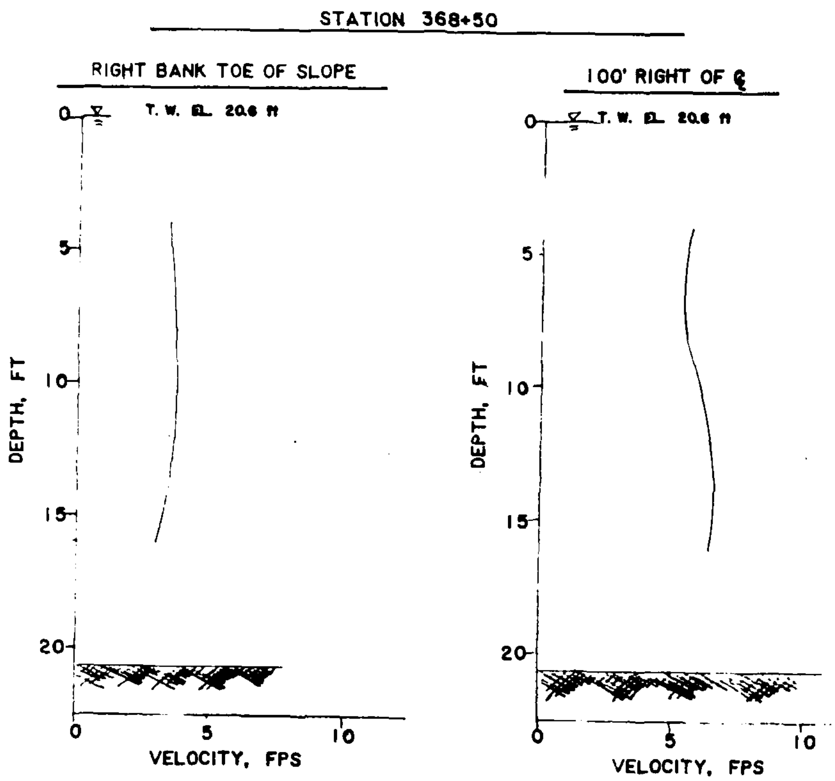

VELOCITY PROFILES
TEST 20, UNITS 1, 2, & 3
HIGH TAILWATER
STA 370+50


STATION D-2
TOE OF SLOPE
T. W. EL 20.2 ft
RIGHT BANK
LEFT BANK
50' RIGHT OF ℄
CENTERLINE
50' LEFT OF ℄
DEPTH, FT
VELOCITY, FPS
VELOCITY PROFILES
TEST 20, UNITS 1, 2, & 3
HIGH TAILWATER
STA D-2

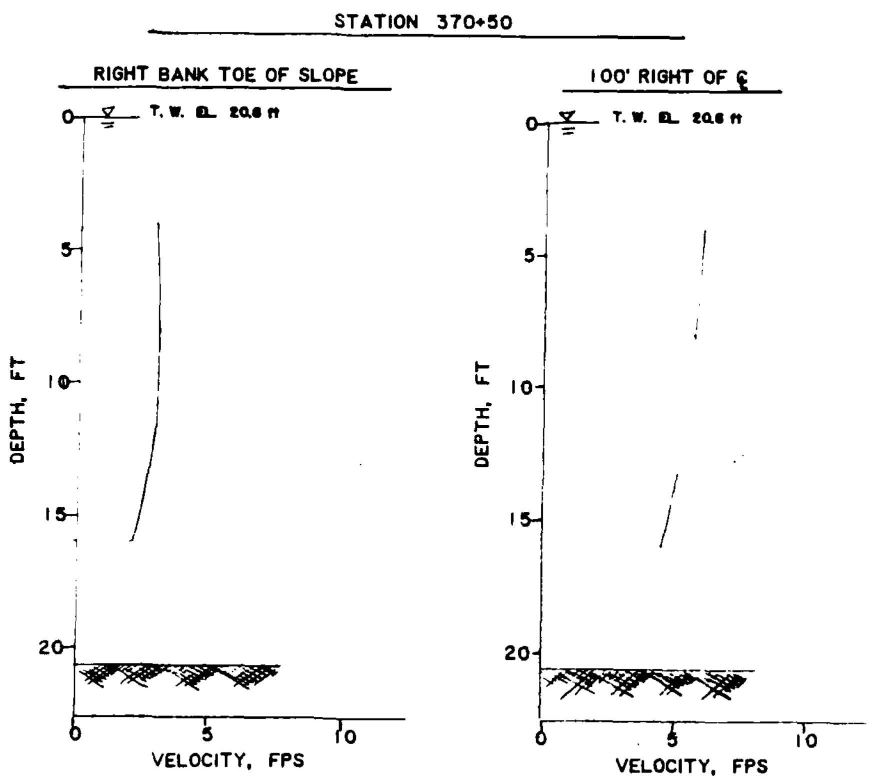



VELOCITY PROFILES

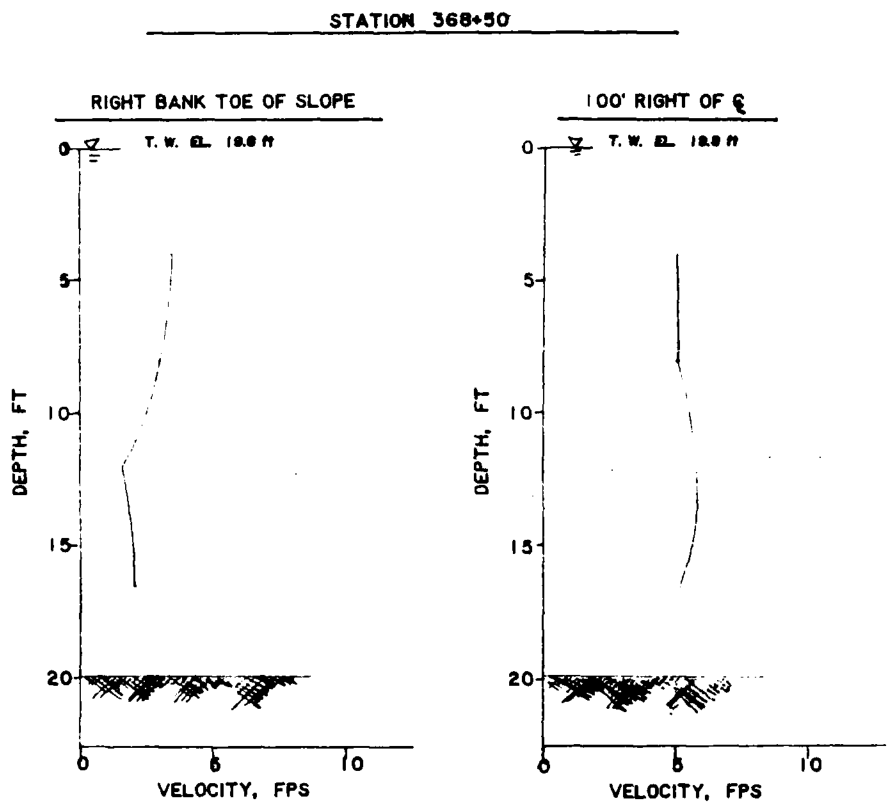
TEST 20, UNITS 1, 2, & 3
HIGH TAILWATER
CENTER SPAN OF BRIDGE




VELOCITY PROFILES
TEST 21, UNITS 1 & 2
HIGH TAILWATER
STA 368+50




VELOCITY PROFILES
TEST 21, UNITS 1 & 2
HIGH TAILWATER
STA 370+50




VELOCITY PROFILES
TEST 22, UNIT 1
HIGH TAILWATER
STA 368+50

DATE
ILMED
8