AD-A169 607 CALIBRATION AND STABILITY CHARACTERISTICS OF THE BAYLOR STAFF WAVE GAGE(U) COASTAL ENGINEERING RESEARCH CENTER VICKSBURG MS W E GROGG MAY 86 CERC-MP-86-7 1/1

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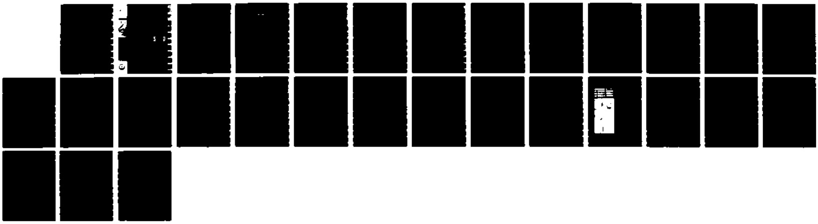

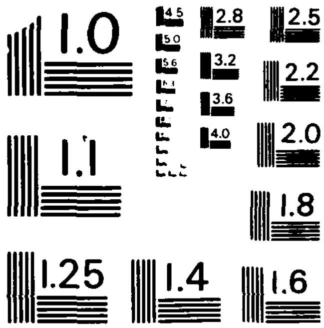
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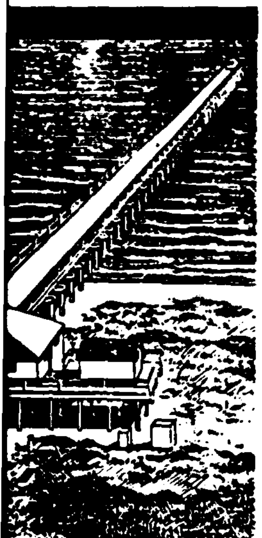

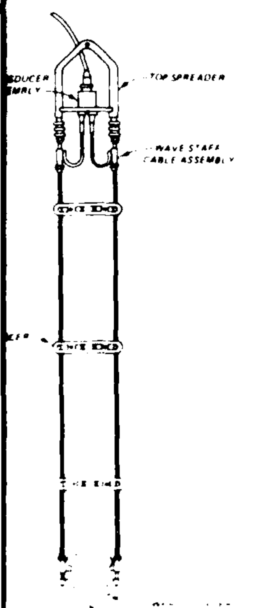

MISCELLANEOUS PAPER CERC-86-7

# CALIBRATION AND STABILITY CHARACTERISTICS OF THE BAYLOR STAFF WAVE GAGE

by


William E. Grogg, Jr.

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Waterways Experiment Station, Corps of Engineers
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May 1986

Final Report

Approved For Public Release; Distribution Unlimited


Prepared for

DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

## REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Miscellaneous Paper CERC-86-7

2. GOVT ACCESSION NO.: AD-A169 607

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): CALIBRATION AND STABILITY CHARACTERISTICS OF THE BAYLOR STAFF WAVE GAGE

5. TYPE OF REPORT & PERIOD COVERED: Final report

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): William E. Grogg, Jr.

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
US Army Engineer Waterways Experiment Station
Coastal Engineering Research Center
PO Box 631, Vicksburg, Mississippi 39180-0631

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS:
DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

12. REPORT DATE: May 1986

13. NUMBER OF PAGES: 25

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ocean Waves--Measurement (LC)
Water Waves--Measurement (LC)
Baylor Staff Wave Gage (WES)

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

The Coastal Engineering Research Center has used Baylor staff wave gages to gather prototype wave data at their Field Research Facility since 1978. This paper describes the theory of operation, calibration techniques, salinity effects, and suggested precautions to improve the reproducibility of long-term wave height measurements.

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## PREFACE

This report was prepared at the US Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center's (CERC's) Field Research Facility (FRF) in Duck, N. C. The report was prepared by Mr. William E. Grogg, Jr., Electronics Technician, under direct supervision of Mr. Curtis Mason, Chief, FRF Group, Research Division and under general supervision of Dr. James R. Houston, former Chief, Research Division, and present Chief, CERC.

Messrs. Eugene W. Bichner, Civil Engineering Technician; Stephen C. Wheeler, Computer Specialist; Robert T. Battalio and David A. Bradley, Summer Aides, assisted with data collection. This report was edited by Ms. Shirley A. J. Hanshaw, Publications and Graphic Arts Division, WES.

Director of WES during publication of this report was COL Allen F. Grum, USA. Technical Director was Dr. Robert W. Whalin.

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 |
|---|---|---|
| feet | 0.3048 | metres |
| inches | 2.54 | centimetres |

# CALIBRATION AND STABILITY CHARACTERISTICS OF THE BAYLOR STAFF WAVE GAGE

## PART I: INTRODUCTION

1. Since 1977, the Coastal Engineering Research Center (CERC) has used Baylor wave staffs to collect data at CERC's Field Research Facility (FRF) in Duck, North Carolina (Birkemeier, et al. 1985).* Based on CERC's subsequent experience with these instruments, this paper has been developed to assist users of the gages in determining their operating characteristics, maintenance requirements, and accuracy.

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* Birkemeier, et al., 1985. "A User's Guide to the Coastal Engineering Research Center's (CERC's) Field Research Facility, Instruction Report CERC-85-1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

## PART II: GAGE DESCRIPTION

### General

2. Baylor staff wave gages are parallel inductive cable gages manufactured by the Baylor Company in Houston, Texas. The basic system consists of a twin wire rope staff, power supply, transducer element, and amplifier.

3. The wire rope staff consists of two parallel 0.5-in.* wire cables held under tension at a distance of 9 in. apart (Figure 1). At the FRF, the upper spreader is supported under a concrete and steel research pier, and the lower spreader is connected to an anchoring system in the ocean bottom (Figure 2). The power supply is regulated at 24 V direct current (VDC) and supplies input power to the transducer. The transducer element utilizes the wire rope staff as an inductor in a circuit excited at a fixed frequency.

4. The change in inductance produced by a variation in the water level on the gage causes a linear change of output voltage. The output of the transducer element is directly proportional to the exposed (unsubmerged) portion of wire rope and is approximately 0.05 V/ft of unsubmerged staff. Therefore, a fully submerged staff would produce 0 VDC; 30 ft of staff above the water would produce 1.5 VDC. An amplifier fabricated by CERC is utilized to amplify and convert the signal to 0 VDC for minimum water level (bottom of gage) and +5 VDC for maximum water level (top of gage). A fully submerged staff would produce an output of 5 VDC, and 30 ft of staff above the water would produce an output of 0 VDC.

### Calibration Procedures

5. Since each transducer's output characteristics are different, the transducer must be calibrated in the laboratory prior to installation into any Baylor gage system. For gages installed on the FRF pier, the calibration setup consists of a 31-ft staff wave gage held horizontally between two supports marked at 1-ft intervals. The transducer is mounted on a plate in a configuration identical to that used in the field. A shorting bar is then

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

installed between the cables at the marked points, and the voltage of each point is recorded. The output of a typical calibration is shown in Table 1.

## PART III: GAGE SENSITIVITY ANALYSIS

6. Seven transducers were used with four different wave staffs to determine the sensitivity of the gage output to the following potential sources of error:

- a. Input voltage versus output. The effects on transducer output voltage versus changes in input voltage due to power supply drift or losses due to cable length.
- b. Transducer drift. Drift due to changes from component aging and stability.
- c. Power supply. Drift variation in input voltage due to power supply drift.
- d. Transmission line losses. Losses in input voltage at the transducer due to cable length from regulated power supply to transducer.
- e. Variance in wave staff cables. Errors due to differences between wire rope staffs.
- f. Input cable orientation. Changes in output voltage due to cable mounting orientation at the transducer between wire rope staff and transducer.
- g. Amplifier drift. Changes in output over time from the CERC amplifier.

## PART IV: TEST RESULTS

### Input Voltage Versus Output

7. Prior to 1981, all transducers were calibrated using an input voltage of 24 VDC. This did not take into consideration the voltage loss due to the cable which connects the power supply to the transducer. This loss is constant and should not change. Table 2 shows the voltage loss for each gage installed at the FRF. To determine the gage's performance under variable power supply voltages, the output from each of the seven transducers was measured as the input voltage was varied from 22 to 24.5 VDC at 0.2-VDC increments. For each voltage, the cable was shorted every 5 ft between 0 and 30 ft using a 9-in. shorting bar. Table 3 and Figure 3 show the output voltages obtained for one of the transducers over the typical range of power supply input voltages. The other transducers showed similar results. Table 3 and a graph of the cable length versus output voltages for input voltages between 22.059 and 23.054 VDC (Figure 3) show that a greater range in output voltages occurs at the 30-ft end than at the 0-ft end of the cable. These data also indicate a change of 8 percent in V/ft which is the calibration used at the FRF. Therefore, for greatest reproducibility, the transducers should be operated using exactly the same input voltage as that supplied to the transducer during calibration.

### Transducer Drift

8. To test the stability of the transducer output over a long time period, the seven transducers were calibrated on 8 and 9 December 1980 and checked again approximately 3 months later. Figure 4 shows the results for one of these transducers. A small change in output (less than 0.5 percent voltage) compared to other sources of error was observed. Note that the transducer's linearity did not change.

### Power Supply Drift

9. To determine the stability of the power supplies (nominally 24 VDC), their output was measured over a period of time. As shown in Table 4, the

24 VDC-regulated power supply outputs were very stable, and variation would have produced less than 0.5 percent difference in gage output.

## Transmission Line Losses

10. The effect of line loss from power supply to transducer was evaluated by measuring the power supply voltage at each of the transducer inputs (Table 2). These data show a decrease of 0.3 VDC for every 500 ft of cable due to electrical losses within the cable.

## Variance in Wave Staff Cables

11. Four different sets (three sets of 30-ft and one set of 28-ft cable) of 0.5-in. diam wave staff cables were tested on two transducers. Results of this test for one of the transducers (Table 5) indicate that all cables gave similar values, though one deviated about 0.7 percent from the others. The other transducer showed similar results.

## Input Cable Orientation

12. The orientation of the two leads connecting the wave staff to the transducer was varied using the configurations shown in Figure 5. The wave staff was shorted at 0 ft, and the output from the transducer was measured for each one of the configurations. Figure 5 shows a maximum of 1 percent change in the gage output at 0 ft. This is due to the change in lead separation. To eliminate this potential source of error, the leads should be installed as shown in Figure 5g. A 9-in. spacer should also be used on the leads to assure proper separation.

## Amplifier Drift

13. The wave gage amplifiers installed at the FRF on 11 September 1979 were continuously checked for drift between March 1980 and April 1984.

14. Initially, a voltage corresponding to the 0-ft level on the gage was input to the amplifier, and the amplifier output was set at 0 V affecting only the mean water level. Then at twice-a-week intervals the same input

voltages were applied, the corresponding amplifier outputs measured and recorded, and the amplifier output reset to zero. Figures 6a and 6b show the time variation of these outputs for the 4-year period. Note that after November 1980 the drift was very close to zero. At that time it was determined that some of the integrated circuits of the amplifiers were drifting. By replacing the integrated circuits and calibrating at regular intervals, the drift was greatly reduced.

15. The output drift of the amplifier was also determined by measuring changes in the maximum output voltage, nominally 5 VDC. Figures 7a and 7b show that over the 4-year period there was less than a 0.5 percent change in maximum output values due to amplifier drift.

## PART V: SALINITY EFFECTS ON GAGE PERFORMANCE

16. An inductance wave staff such as the Baylor gage is dependent on salinity variations in the surrounding water. As part of a study to determine wave characteristics in a low-salinity environment, a special Baylor gage calibration facility was constructed, and salinity effects were investigated.

17. A 15-ft-deep, 12-in.-diam fiberglass well was filled with salt water, and a 10-ft wave staff was inserted into the well in 1-ft increments. Calibration runs were made at about 5 ppt increments from 5 to 35.5 ppt. Power from a single source was used for all calibrations.

18. Early in these salinity tests it was found that little change in gage output occurred within the lower 3 ft of cable. It was determined that the lower spreader connecting the bottom ends of the cables was affecting this part of the gage. Additional experience gained with gages installed on the FRF pier confirms that data from the bottom 3 ft of gage are unusable.

19. Subsequent tests of gage output versus water elevation were conducted over a wide range of salinities. Figure 8 shows the previously mentioned nonlinearity in response to the lower 3 ft of gage (i.e. between 7 and 10 ft) and the variation in gage linearity as a function of salinity. The output voltage as a function of distance along the gage usually decreased with a decrease in salinity. For example, a 10-ft wave height in water having 35.5 ppt salinity would appear as a 9.6-ft wave in salinity of 25.5 (i.e. 4 percent error). Within the range of salinities measured, as much as a 20 percent error (Table 6) in wave height could result from this effect.

20. Note also the differences between the shorting bar calibration recommended by the manufacturer and the actual values for various salinities. Apparently, using gage output factors based on the shorting bar calibration may induce errors of at least 4 percent under normal seawater salinity conditions. Additional tests were made using three 28-ft and two 31-ft cables in a 30-ft well filled with seawater at a salinity of 32.5 ppt. Nine transducers were used to determine the operational differences between calibration in seawater versus the shorting bar technique. Results of these tests showed a difference of only 0.5 percent in wave height measurement, but the gage 0 value shifted as much as 6 percent from the shorting technique to actual calibration in seawater. This error is critical only when using the gages for

mean water level. Additional tests are being conducted to determine the accuracies of these gages for measuring mean water level.

## PART VI: CONCLUSIONS

21. From these tests, the following conclusions can be made regarding the operation and calibration of a Baylor wave gage:

a. When installing a transducer, it is important to calibrate the transducer using the exact input voltage that will be applied to the transducer during operation. The same wave staff configuration should also be used, including spacing, length of lead from wave staff to transducer, and shorting bar used during calibration.

b. The transducers should be calibrated every 6 months.

c. Unless special precautions are taken, amplifier drift will reduce gage accuracy. By calibrating amplifiers each month and replacing integrated circuits (IC's) that drift, errors due to drift have been reduced to less than 0.5 percent at the FRF.

d. The power supply should be checked for drift every 6 months (depending on the type of power supply used).

e. Over the normal range of seawater salinities (30 to 35 ppt), gage output may vary as much as 2.0 percent. The gages can be used in variable salinity environments, provided they are calibrated for the expected salinity range.

f. When all possible precautions have been incorporated to ensure gage reproducibility, repetitive long-term wave height measurements can be obtained within a reproducibility of 4.8 percent (Table 7).

Table 1

Baylor Sensing Cable Calibration Table, Feet of Sea Water Versus Transducer Output Voltage

| Sensing Cable ft | Output V | Gage Calibration Factor mv/ft |
|---|---|---|
| 0 | 0.682 | |
| 1 | 0.708 | 26 |
| 2 | 0.741 | 33 |
| 3 | 0.775 | 34 |
| 4 | 0.807 | 32 |
| 5 | 0.840 | 33 |
| 6 | 0.873 | 33 |
| 7 | 0.906 | 33 |
| 8 | 0.940 | 34 |
| 9 | 0.973 | 33 |
| 10 | 1.006 | 33 |
| 11 | 1.039 | 33 |
| 12 | 1.073 | 34 |
| 13 | 1.105 | 32 |
| 14 | 1.138 | 33 |
| 15 | 1.171 | 33 |
| 16 | 1.204 | 33 |
| 17 | 1.239 | 35 |
| 18 | 1.271 | 32 |
| 19 | 1.303 | 32 |
| 20 | 1.338 | 35 |
| 21 | 1.370 | 32 |
| 22 | 1.404 | 34 |
| 23 | 1.437 | 33 |
| 24 | 1.469 | 32 |
| 25 | 1.502 | 33 |
| 26 | 1.536 | 34 |
| 27 | 1.569 | 33 |
| 28 | 1.602 | 33 |
| 29 | 1.634 | 33 |
| 30 | 1.667 | 33 |
| 31 | 1.700 | 33 |

Table 2

Input Voltage Loss

| Gage No. | Power Supply Output V | Approximate Line Distance ft | Gage Input V | Loss V | Loss mv/ft |
|---|---|---|---|---|---|
| 615 | 23.8 | 520 | 23.2 | 0.5 | 0.96 |
| 635 | 23.7 | 595 | 23.3 | 0.4 | 0.67 |
| 645 | 23.8 | 668 | 23.4 | 0.4 | 0.60 |
| 655 | 23.8 | 780 | 23.3 | 0.5 | 0.65 |
| 665 | 23.7 | 930 | 23.1 | 0.6 | 0.65 |
| 675 | 23.7 | 1,265 | 22.9 | 0.8 | 0.63 |
| 625 | 23.6 | 1,710 | 22.7 | 0.9 | 0.53 |

Table 3

Input Volts Versus Output

| Input V | Cable Length, ft | | | | | | | V/ft* |
|---|---|---|---|---|---|---|---|---|
| | 0 | 5 | 10 | 15 | 20 | 25 | 30 | |
| 22.059 | 0.756 | 0.949 | 1.146 | 1.344 | 1.543 | 1.741 | 1.945 | 0.0396 |
| 22.256 | 0.763 | 0.958 | 1.158 | 1.356 | 1.557 | 1.751 | 1.958 | 0.0398 |
| 22.456 | 0.770 | 0.966 | 1.169 | 1.369 | 1.572 | 1.774 | 1.976 | 0.0402 |
| 22.655 | 0.777 | 0.975 | 1.179 | 1.381 | 1.586 | 1.790 | 1.994 | 0.0406 |
| 22.854 | 0.784 | 0.984 | 1.190 | 1.394 | 1.601 | 1.806 | 2.012 | 0.0409 |
| 23.054 | 0.791 | 0.993 | 1.200 | 1.407 | 1.615 | 1.823 | 2.030 | 0.0413 |
| 23.256 | 0.798 | 1.002 | 1.211 | 1.420 | 1.630 | 1.839 | 2.041 | 0.0414 |
| 23.453 | 0.805 | 1.011 | 1.222 | 1.432 | 1.644 | 1.855 | 2.061 | 0.0419 |
| 23.660 | 0.812 | 1.020 | 1.232 | 1.445 | 1.658 | 1.872 | 2.087 | 0.0425 |
| 23.852 | 0.819 | 1.028 | 1.243 | 1.457 | 1.673 | 1.888 | 2.104 | 0.0428 |
| 24.051 | 0.826 | 1.037 | 1.254 | 1.470 | 1.688 | 1.905 | 2.122 | 0.0432 |
| | Range | | | | | | | |
| | 0.070 | 0.088 | 0.108 | 0.126 | 0.145 | 0.164 | 0.158 | 0.0036 |

* Voltage per foot is derived by taking the maximum voltage (30-ft cable length) minus the minimum voltage (0-ft cable length) and dividing by length of cable (ft).

Table 4

Variation in Output from 24V Power Supplies

| Date | Gage No. 615 | 635 | 645 | 655 | 665 | 675 |
|---|---|---|---|---|---|---|
| 21 Jan 81 | 23.803 | 23.726 | 23.810 | 23.804 | 23.711 | 23.711 |
| 4 Feb 81 | 23.809 | 23.735 | 23.806 | 23.792 | 23.756 | 23.714 |
| 13 Feb 81 | 23.809 | 23.735 | 23.806 | 23.792 | 23.756 | 23.714 |
| 25 Feb 81 | 23.799 | 23.718 | 23.782 | 23.759 | 23.684 | 23.696 |
| 12 Mar 81 | 23.770 | 23.730 | 23.771 | 23.824 | 23.782 | 23.712 |
| 16 Apr 81 | 23.794 | 23.745 | 23.793 | 23.814 | 23.712 | 23.718 |
| Range | 0.039 | 0.027 | 0.039 | 0.065 | 0.098 | 0.022 |

Table 5

Voltage Variance in Wave Staff Cables

| Distance Along Gage Cable ft | Output of Cable No. 1 V | Output of Cable No. 2 V | Output of Cable No. 3 V | Output of Cable No. 4 V |
|---|---|---|---|---|
| 0 | 0.750 | 0.756 | 0.749 | 0.866 |
| 1 | 0.786 | 0.790 | 0.784 | 0.900 |
| 2 | 0.827 | 0.830 | 0.820 | 0.938 |
| 3 | 0.870 | 0.869 | 0.858 | 0.978 |
| 4 | 0.911 | 0.907 | 0.896 | 1.017 |
| 5 | 0.951 | 0.946 | 0.936 | 1.055 |
| 6 | 0.992 | 0.985 | 0.974 | 1.095 |
| 7 | 1.033 | 1.024 | 1.014 | 1.134 |
| 8 | 1.074 | 1.062 | 1.054 | 1.172 |
| 9 | 1.116 | 1.102 | 1.092 | 1.212 |
| 10 | 1.156 | 1.142 | 1.131 | 1.250 |
| 11 | 1.198 | 1.180 | 1.171 | 1.291 |
| 12 | 1.239 | 1.219 | 1.212 | 1.329 |
| 13 | 1.280 | 1.258 | 1.248 | 1.368 |
| 14 | 1.322 | 1.298 | 1.287 | 1.408 |
| 15 | 1.363 | 1.336 | 1.326 | 1.446 |
| 16 | 1.404 | 1.375 | 1.366 | 1.484 |
| 17 | 1.447 | 1.414 | 1.406 | 1.524 |
| 18 | 1.487 | 1.453 | 1.447 | 1.563 |
| 19 | 1.528 | 1.492 | 1.485 | 1.602 |
| 20 | 1.570 | 1.531 | 1.524 | 1.641 |
| 21 | 1.612 | 1.571 | 1.563 | 1.680 |
| 22 | 1.652 | 1.608 | 1.603 | 1.719 |
| 23 | 1.694 | 1.647 | 1.642 | 1.759 |
| 24 | 1.735 | 1.684 | 1.681 | 1.798 |
| 25 | 1.776 | | 1.720 | 1.836 |
| 26 | 1.816 | | 1.760 | 1.874 |
| 27 | 1.858 | | 1.798 | 1.914 |
| 28 | 1.898 | | 1.837 | 1.951 |
| 29 | 1.940 | | 1.874 | 1.988 |
| 30 | 1.977 | | 1.911 | |

Table 6

Salinity Versus Calibration Factor

| Salinity ppt | Gage Linearity (V/ft) | Difference from Shorting Bar % |
|---|---|---|
| 5.0 | 0.0283 | 25.5 |
| 10.0 | 0.0297 | 21.8 |
| 14.2 | 0.0332 | 12.6 |
| 19.0 | 0.0348 | 8.4 |
| 25.5 | 0.0357 | 6.1 |
| 30.0 | 0.0365 | 3.9 |
| 35.5 | 0.0373 | 1.8 |
| | Shorting Bar | |
| | 0.0380 | 0.0 |

Table 7

Worst Case Error Analysis

| Source | Pre-1981 % | Post-1981 % |
|---|---|---|
| Input voltage versus output voltage | 8.0 | 0.5 |
| Transducer drift | 0.5 | 0.5 |
| Power supply drift | 0.5 | 0.5 |
| Wave staff cables | 0.7 | 0.7 |
| Amplifier drift | 3.5 | 0.5 |
| Salinity | 2.1 | 2.1 |
| Total | 15.3 | 4.8 |

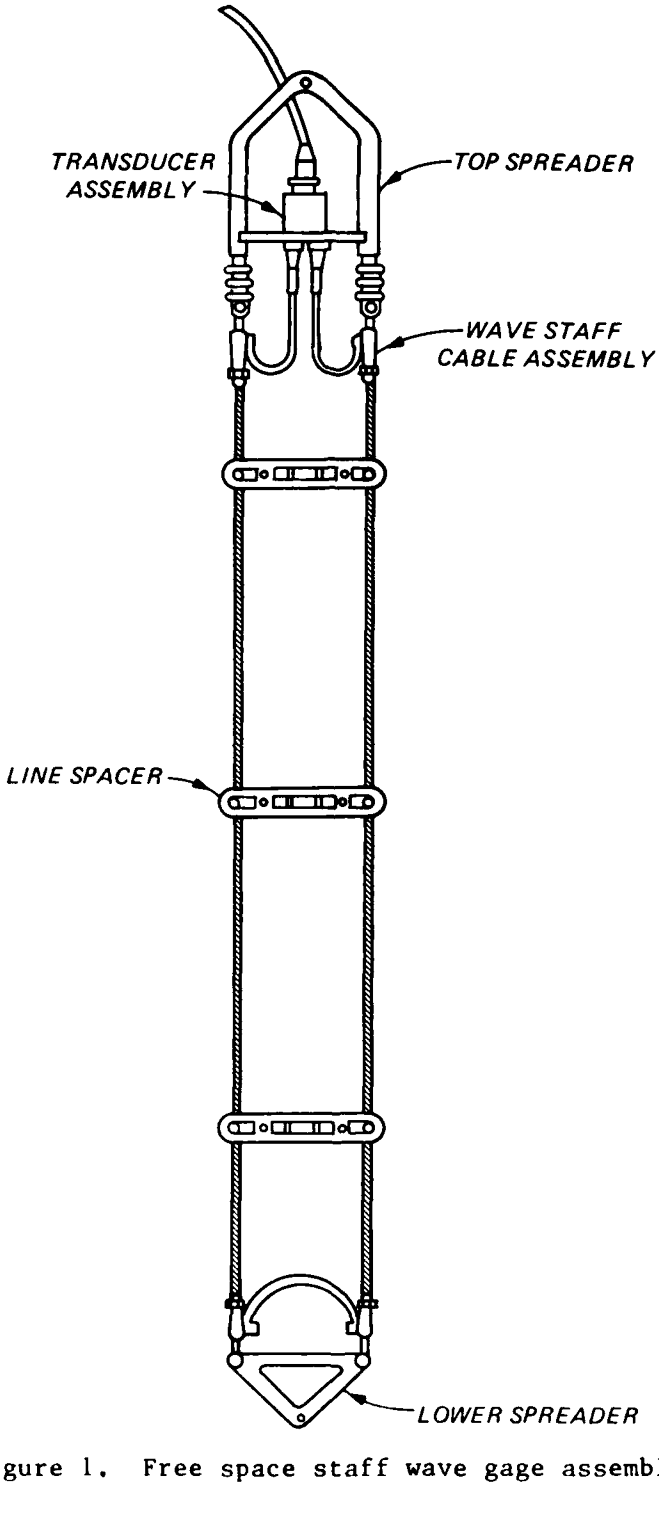



Figure 1. Free space staff wave gage assembly

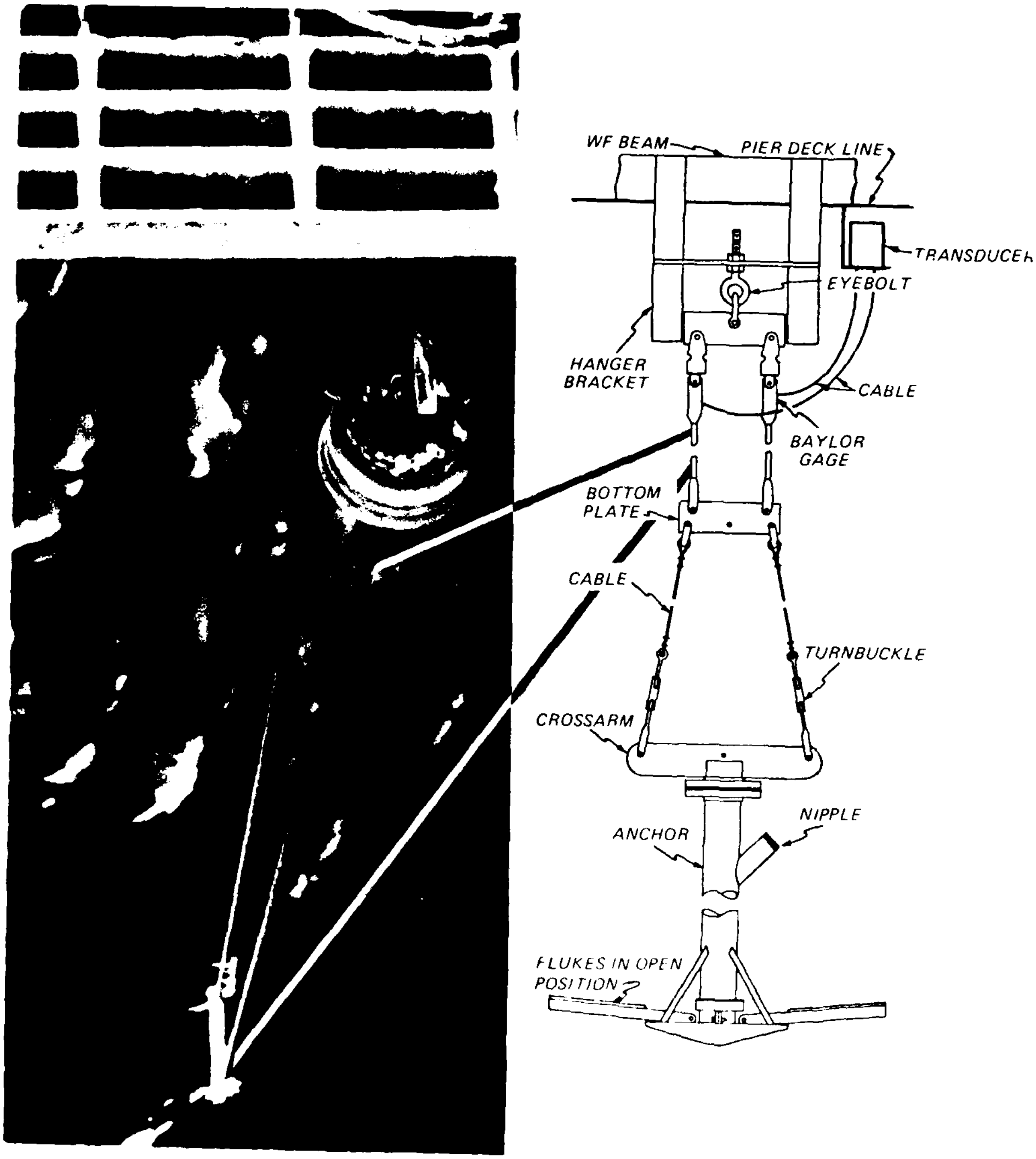



Figure 2. Baylor staff wave gage and support system

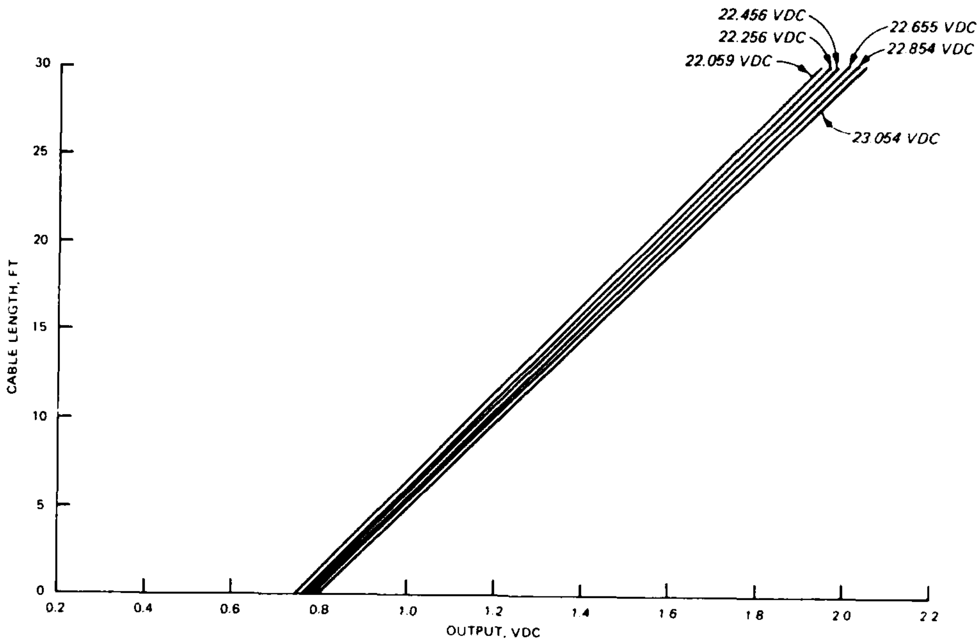



Figure 3. Input voltage versus output voltage, Baylor transducer

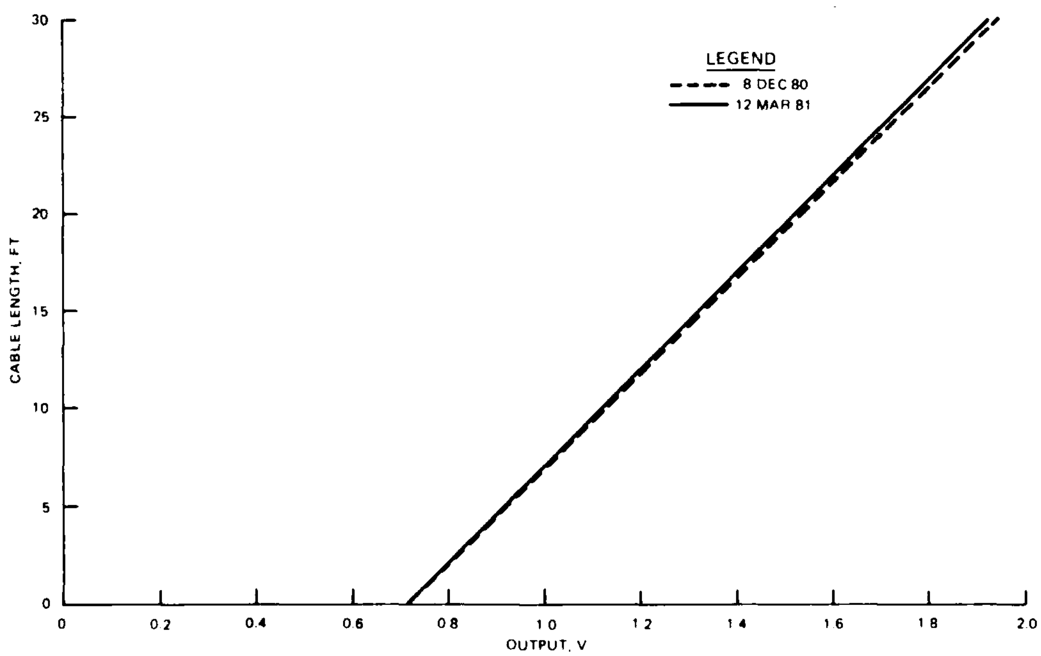



Figure 4. Transducer stability results

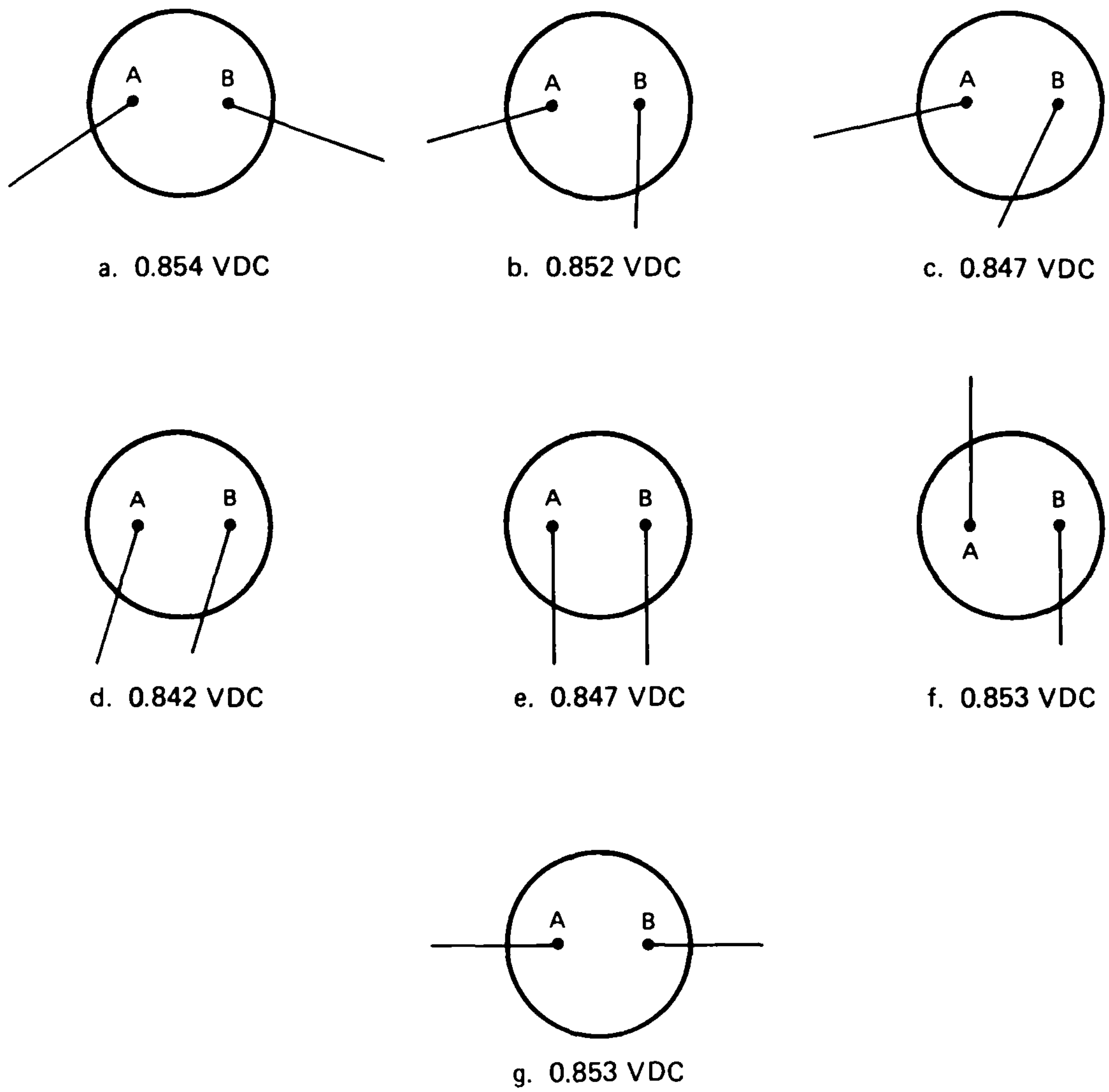
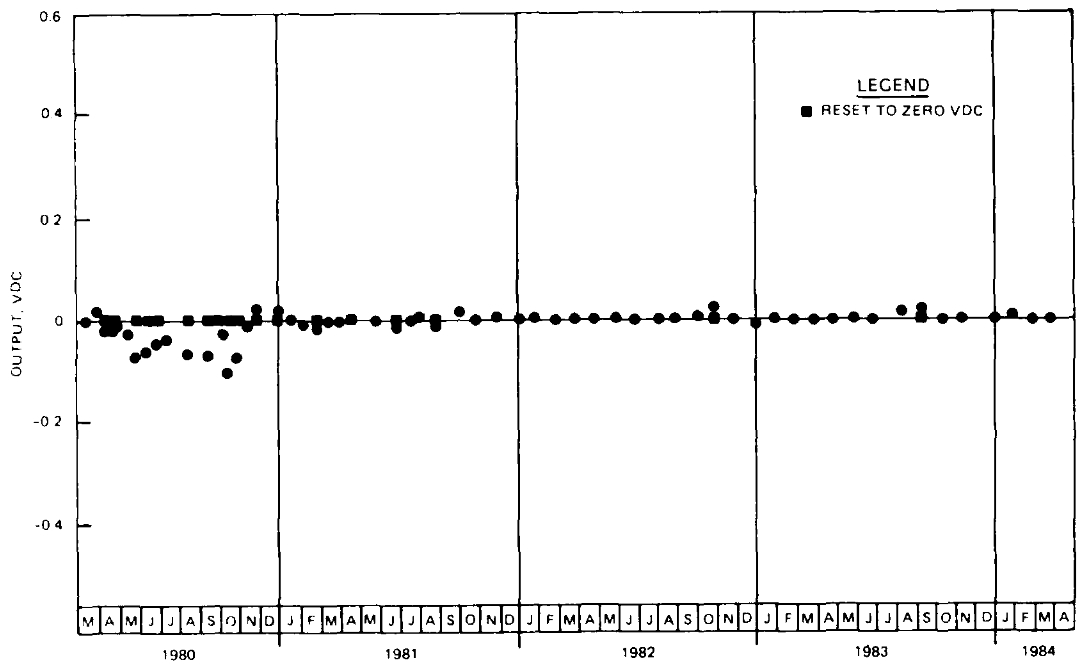
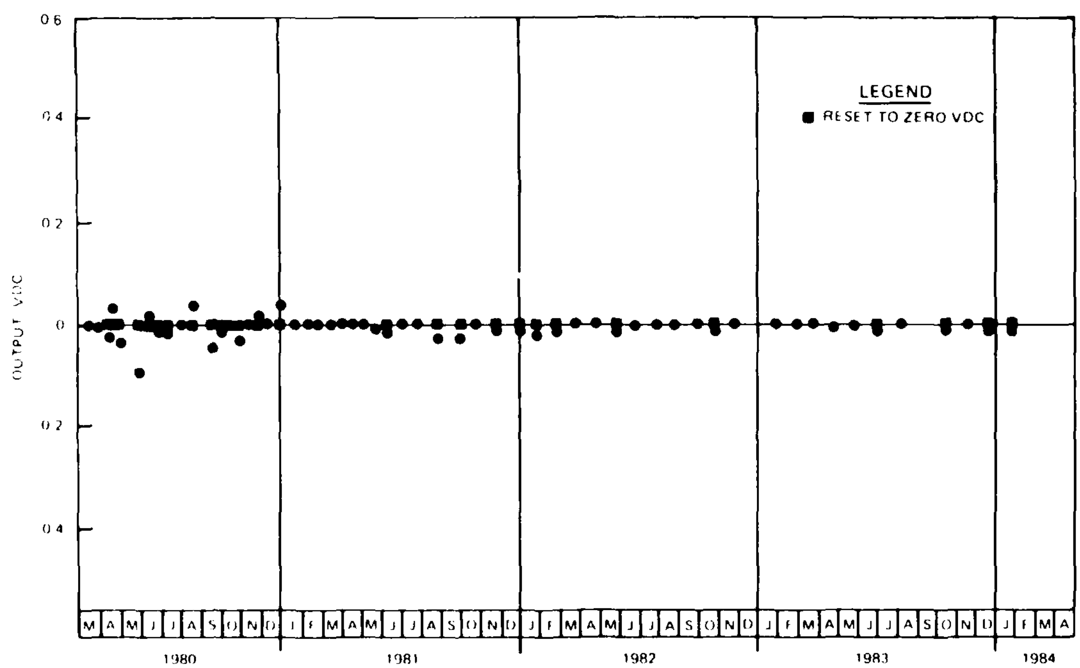



Figure 5. Configuration for transducer lead orientation

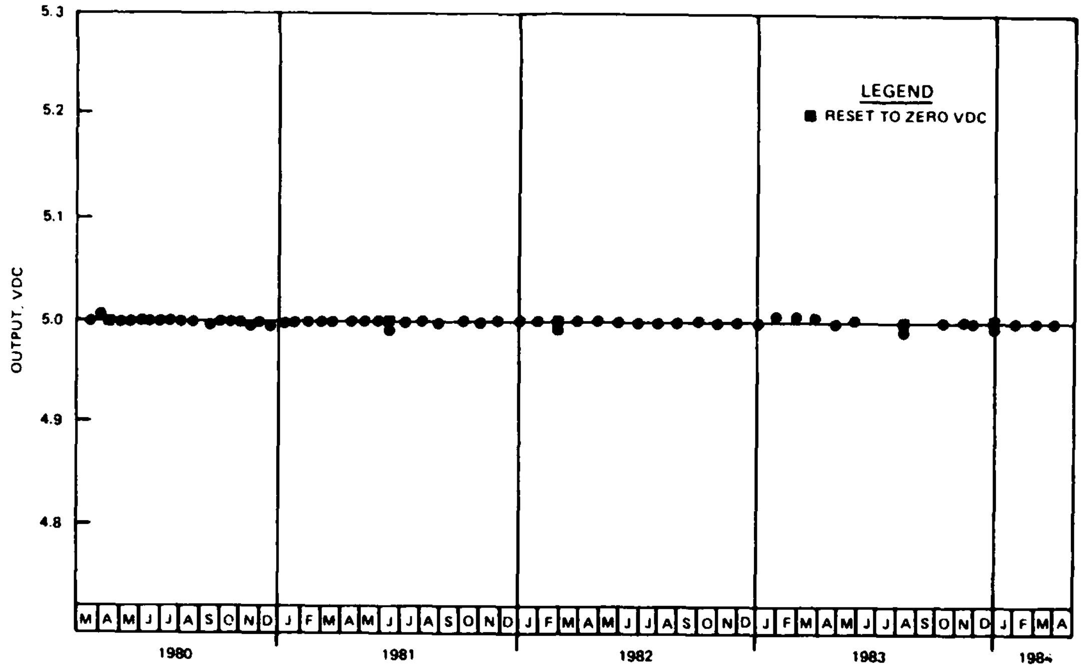



a. Gage 615

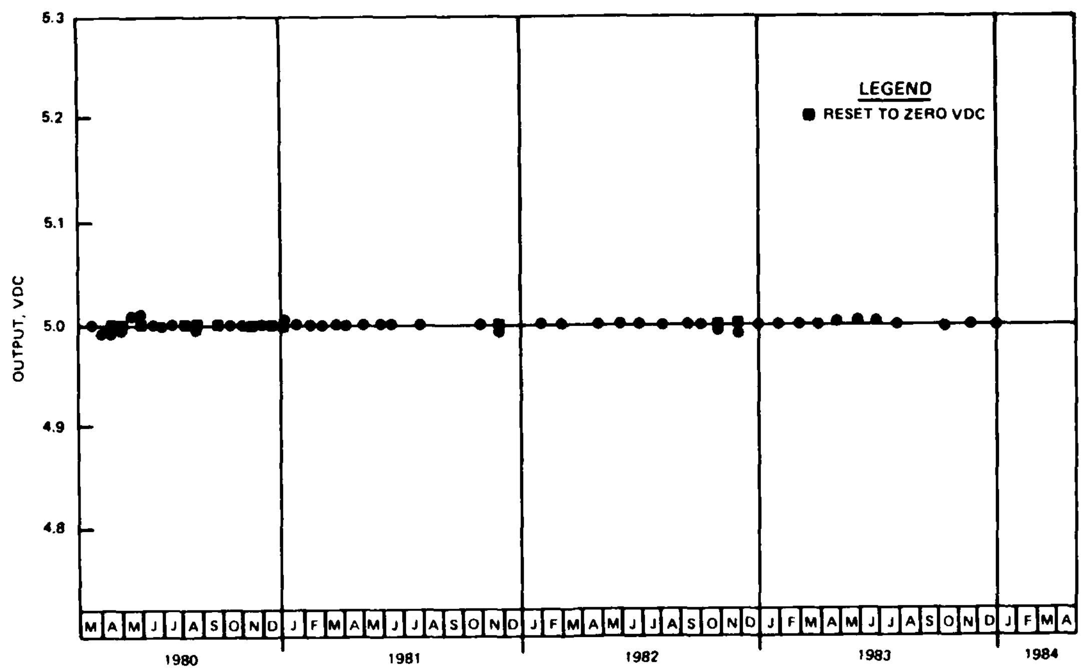



b. Gage 625

Figure 6. Ampli ier zero stability




a. Gage 615




b. Gage 625

Figure 7. Full-scale drift

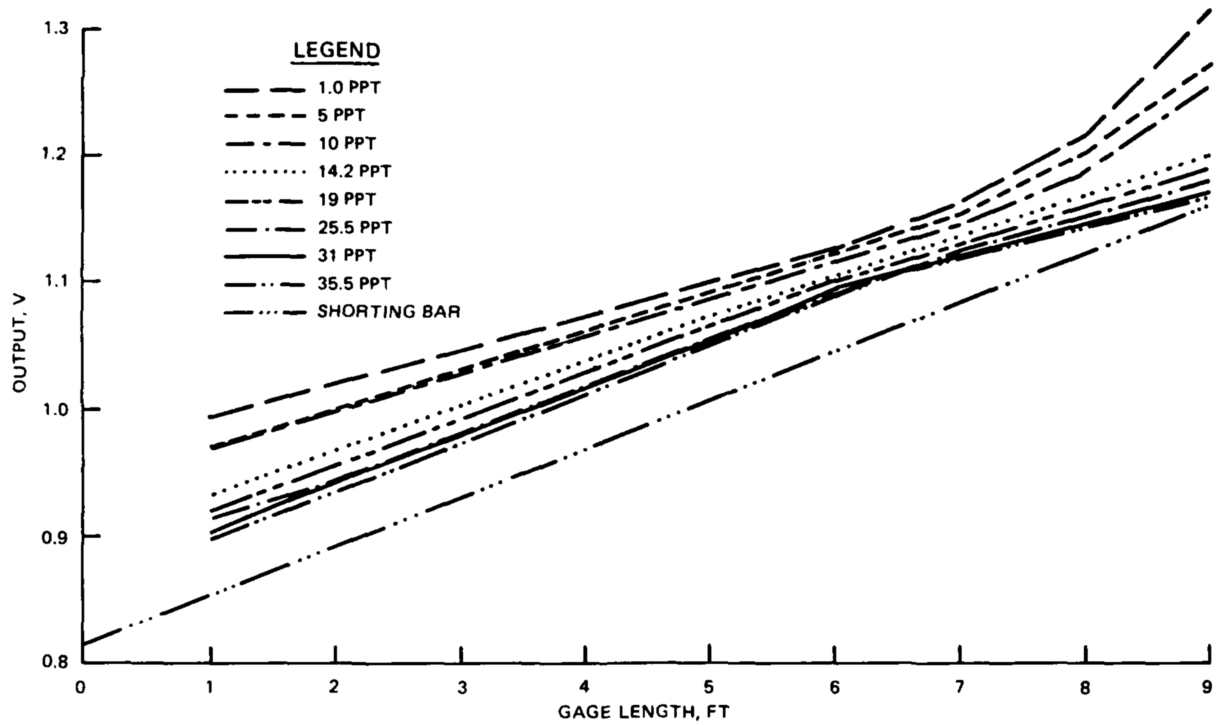



Figure 8. Variation in gage linearity as a function of salinity

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