N 69 13160

NASA CONTRACTOR REPORT

NASA CR-61244

November 29, 1968

NASA CR-61244

CASE FILE COPY

200-INCH MULTICELL TANK SLOSH TESTS

Prepared under Contract No. NAS 8-20073 by
Francis H. Cooper

BROWN ENGINEERING COMPANY

For

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama

November 29, 1968 NASA CR-61244

200-INCH MULTICELL TANK SLOSH TESTS

By

Francis H. Cooper

Prepared under Contract No. NAS 8-20073 by

BROWN ENGINEERING COMPANY
Huntsville, Alabama

For

Propulsion and Vehicle Engineering Laboratory

Distribution of this report is provided in the interest of information exchange. Responsibility for the contents resides in the author or organization that prepared it.

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

200-INCH MULTICELL TANK SLOSH TESTS

By

Francis H. Cooper

BROWN ENGINEERING COMPANY
C1-SST-4-006

ABSTRACT

This test was conducted to determine the first resonant slosh frequency and related data with water levels at 1/2 and 3/4 full.

Data obtained include horizontal shaker loads and displacements, vertical load changes on the 10 supports, and pressures and strains on the cell walls.

TABLE OF CONTENTS

Page

INTRODUCTION 1

TEST DESCRIPTION

A. SPECIMEN 2

B. REQUIREMENTS 2

C. SETUP 2

D. INSTRUMENTATION 4

E. PROCEDURE 5

TEST RESULTS

A. DATA 9

B. DISCUSSION 10

LIST OF ILLUSTRATIONS

Figure		Page
1	Multicell Tank Front View	12
2	Multicell Tank Top View	13
3	Multicell Tank Angle View	14
4	Typical Oil Bearing Arrangement	15
5	Power Unit and Sump Pump for Oil Bearings	16
6	Hydraulic Shaker Connections	17
7	Ring Displacement Guide	18
8	Displacement Transducers	19
9	Multicell Tank Side View	20
10	Instrumentation Drawing for Multicell Tank	21
11	Cell 3 View of Instrumented Web	22
12	Cell 4 View of Instrumented Web	23
13	Cable Arrangement from Web	24
14	Instrumentation Drawing for Multicell Tank	25
15	Cell 1 External View	26
16	Cell 1 View from Top at 1/2 Full Level	27
17	Cell 2 View from Top at 1/2 Full Level	28
18	Cell 3 View from Top at 1/2 Full Level	29
19	Support Ring and Bearing Arrangement Top View	30
20	Instrumentation Hookup	31
21	T. V. Units and Frequency Generator	32

LIST OF ILLUSTRATIONS (Continued)

Figure		Page
22	Beckman Recorders 1 and 2	33
23	CEC Oscillograph 2	34
24	CEC Oscillographs 1, 4, and 5	35
25	CEC Oscillograph 3 and "D" System	36
26	Cell 1 at 1/2 Full Water Level	37
27	Cell 1 at Resonance	38
28	Cell 1 at Resonance	39
29	Cell 2 at 1/2 Full Water Level	40
30	Cell 2 at Resonance	41
31	Cell 2 at Resonance	42
32	Cell 3 at 1/2 Full Water Level	43
33	Cell 3 at Resonance	44
34	Cell 3 at Resonance	45
35	Cell 1 at 3/4 Full Water Level	46
36	Cell 1 at Resonance	47
37	Cell 1 at Resonance	48
38	Cell 2 at 3/4 Full Water Level	49
39	Cell 2 at Resonance	50
40	Cell 2 at Resonance	51
41	Cell 3 at 3/4 Full Water Level	52
42	Cell 3 at Resonance	53
43	Cell 3 at Resonance	54

LIST OF ILLUSTRATIONS (Concluded)

Figure		Page
44	Cell 1 at Resonance 1/2 Full Water Level	55
45	Cell 1 at Resonance 1/2 Full Water Level	56
46	Cell 1 at Resonance 1/2 Full Water Level	57
47	Cell 1 at Resonance 1/2 Full Water Level	58
48	Cell 1 at Resonance 1/2 Full Water Level	59
49	Cell 1 at Resonance 1/2 Full Water Level	60
50	Cell 1 at Resonance 1/2 Full Water Level	61

LIST OF TABLES

Table	Title	Page
I	Transducer Output When Tank 1/2 Full.	62
II	Transducer Output When Tank 3/4 Full	65
III	Slosh Movement and Timing Data From Movies	68
IV	Basic Dimensional and Timing Data From Movies . .	69
V	Oscillograph Movements When Tank 1/2 Full	70
VI	Oscillograph Movements When Tank 3/4 Full	73
VII	Calibration for Oscillograph Movements.	76
VIII	Data Reduction Examples	77

UNITS, CONVERSION FACTORS, AND DEFINITIONS

A. UNITS

Pressures are in pounds per square inch. Strains are in micro-inches per inch (1 micro-inch = 1 inch $\times 10^{-6}$). Dimensions are in inches.

B. CONVERSIONS

To convert pounds per square inch to Newtons per square meter, multiply by 6.894×10^{-3}. To convert inches to centimeters, multiply by 2.54.

C. DEFINITIONS

Biaxial strain gage - The symbol $\overset{1(3)}{\urcorner}$ represents a strain gage with two legs perpendicular to each other. The number represents the horizontal leg. The vertical leg is one digit greater. A number enclosed by parentheses designates a strain gage that is located on the opposite side.

Single strain gage - The symbol $\overset{5(6)}{—}$ represents a single element gage and measures strain in the direction of orientation. A number enclosed by parentheses designates a strain gage that is located on the opposite side.

The symbol μ represents the word micro.

INTRODUCTION

The multicell tank has a shape that requires a complex theoretical determination of the resonant slosh frequency.

The primary purpose of the slosh test was to determine the first mode resonant slosh frequency at the 1/2 and 3/4 full level. Secondary objectives were to determine pressures generated against the webs and cylindrical sections of the tank, shaker loads and displacements, vertical load changes on the 10 supports, and strains produced in the webs and cylindrical sections.

Because loads, strains, and pressures are dependent upon shaker displacement, two displacements were selected: one was the displacement which would produce the maximum non-splash slosh height. This is defined as the maximum height reached by the slosh wave without a portion of the wave peak separating from the main wave. This particular displacement was selected because the resulting slosh condition is one that is readily determined. The second displacement selected was double the first displacement unless good reasons necessitated a smaller displacement.

The resonant frequency was determined for three cells adjacent to each other.

TEST DESCRIPTION

A. SPECIMEN

The multicell tank is a 10-celled aluminum structure 200 inches in diameter and 122 inches high, per MSFC drawing 09-D-X-520. Front and top views are shown in Figures 1, 2, and 3.

B. REQUIREMENTS

It was specified that the first resonant slosh frequency be determined for cells 1, 2, and 3 at the 1/2 full level and at the 3/4 full level while shaking in a line parallel with the web separating cells 1 and 10. Initial requirements also specified that the multicell would be shifted so that the shaker direction passed through the center of cell, but that requirement was later rescinded.

The type of instrumentation, quantity, and location was also specified. The overall number of data channels available for the test was limited by the number of oscillograph recorders available in the Test Laboratory.

C. SETUP

The multicell tank was bolted to the top of a support ring which was supported by 10 load feet which were instrumented like load cells. Each of the load feet rested upon an oil bearing which floated on a film of oil forced out under pressure between the movable oil bearing, and a fixed bearing pad (Figure 4).

The hydraulic oil for the bearings was provided by a Dennison hydraulic power unit (Figure 5) which provided oil at 5000 psi to a manifold. Each oil bearing was connected to the manifold through steel tubing 1/8 inch outside diameter, 37 feet long. Experiments indicated that with these dimensions, an adequate oil supply would be supplied to each bearing.

Oil from the bearings drained by gravity into a sump from which it was pumped back to the Dennison power unit by a Worthington pump (Figure 5).

The support ring was attached by 4 spokes to a center plate which was connected to a Thompson servo-controlled hydraulic shaker by a 10-kip load cell (Figure 6). Hydraulic oil at 5000 psi and 25 GPM was available to the shaker.

Ring displacement guides (Figure 7) on opposite sides of the ring were

required for preventing a sideways movement of the ring as the shaker moved it back and forth.

Two Research Inc. Model 4040 displacement transducers with a two-foot range were attached to the shaker rod as shown in Figure 8. Transducer 166 was connected to an oscillograph to record the shaker displacement. Transducer 167 was connected to the servo-control system of the shaker.

Potable water was used in the slosh tests in order to eliminate the problem of silt depositing out on the pressure transducer, and slosh sensors when industrial water is used for slosh tests. An individual water meter was used for determining the gallons of water used.

A water level gage consisting of plastic tubing and a steel measuring tape was attached to the side of the tank (Figure 9).

D. INSTRUMENTATION

The web joining cells 3 and 4, being an area of primary interest, received the most attention for instrumentation. Twenty-four (24) biaxial strain gages, 14 single gages, and 24 pressure transducers were located on the web as shown in Figures 10, 11, and 12. The cable arrangement emanating from this instrumentation is shown in Figure 13.

The outer wall of cell 1 was instrumented with four biaxial strain gages, two pressure transducers, and two slosh sensors (Figures 14, 15, and 16).

Cells 1 and 2 each had two slosh sensors attached to the inner wall, and located so that one sensor would be in the most sensitive position for recording slosh motion for the particular direction of slosh motion (Figures 16 and 17). Cell 3 had only one slosh sensor, and that was located in the corner of the cell, because that was the best available location (Figure 18). Because one direction of slosh was later cancelled, only the data from slosh sensors 160 in cell 1, 162 in cell 2, and 164 in cell 3 was used.

Each slosh sensor consisted of a four-strand flex print cable with only one side insulated. The strands on the exposed side were exposed to the water. A flash coating of gold was applied to the copper strands, in order to protect against copper oxide formation. Slosh sensor operation is based upon a reduction of resistance between adjacent strands as a rising water level bridges more of the gap separating the strands.

Each load foot was instrumented with two biaxial strain gages as indicated in Figure 19. The output of the gages was combined such that the compression load was measured, but bending strains were cancelled out.

The instrumentation was connected to recording equipment as indicated in Figure 20. The recording equipment is shown in Figures 21 through 25.

E. PROCEDURE

1. Test Setup

The fixed bearing pads were leveled with an 18-inch-long precision level and were fixed in position by welding strips between the pads and the support structure. The four adjustment screws of each pad were then tightened securely so that a compression load applied to the top of the pad would be transmitted through the adjustment screws (Refer to Figure 4.)

The 10 load feet were calibrated individually by loading in 5-kip increments to 20-kips in compression in a universal test machine. For each increment, the strain gage changes were indicated on a Budd Instrument Company strain indicator Model P-350.

The support ring was positioned above the 10 bearing pads and was supported by four jacks spaced approximately 90^{o} apart. The ring was adjusted so that the three highest points on the top surface, which was warped, were in a level plane, and also was adjusted vertically so that the center of the ring center plate was at the same level as the shaker rod. A level was used for this purpose. While holding the ring in position with jacks, a no-load strain gage reading was obtained for each foot. The feet were then adjusted hand-tight and the jacks were unloaded. Another strain gage reading was obtained

for each foot and the corresponding load was computed. Small adjustments were made to the highest-loaded and smallest-loaded screws and then a new set of loads was obtained. This procedure was repeated until an equal load was obtained $\pm 10\%$.

The multicell tank was then bolted to the ring. Shims were used to fill gaps between ring and tank in order to avoid distorting the tank flange. The tank was positioned such that the line of shaking corresponded with the web joining cells 1 and 10 and cells 5 and 6.

2. Tests at the 1/2 Full Level

6716 gallons of potable water were added to the tank using an industrial water meter to measure the flow. This amount of water was 1/2 the tank capacity.

Potable water was used instead of industrial water because the silt contained in industrial water tends to deposit on pressure transducer diaphragms and slosh sensor strands with adverse effects on the data.

The recording equipment was then calibrated and aligned. Television cameras and lights were installed in the top manholes of cells 1, 2, and 3. The neutral position on the oscillographs thus represented the statically loaded condition. Dynamic testing caused sine-wave-like patterns to form which represented increases and decreases from the static condition.

The servac control unit was set to provide a shaker stroke of approximately 1/4 inch. The frequency generator was then slowly and steadily increased

from .1 Hz to 1 Hz while recording on Beckman Recorders 1 and 2, and CEC oscillograph 5. These instruments recorded loads on the feet, load cell, and slosh sensors. Because of low sensitivity recording equipment, the slosh sensor recordings were not effective in revealing differences in slosh height for small changes in frequency. The Beckman recorders proved more useful. By a careful examination of these recordings, the peak activity was pin-pointed. The approximate slosh resonant frequency was determined by counting the number of oscillations occurring in a known period of time.

To pin-point the resonant frequency more closely, the frequency was set at the value just determined and activity was observed in the cell showing the most activity by using a television camera with a zoom lens (Ref. Fig. 3). The frequency was increased and decreased by small amounts until peak activity was determined.

After determining the resonant slosh frequency for each cell for a small amplitude, the shaker displacement was slowly increased until the camera indicated impending separation of droplets from the crest of the wave. This condition, which is referred to as the maximum non-splash slosh condition, is the only distinct slosh condition occurring that can be determined readily by experiment.

Next the shaker displacement was approximately doubled unless action became so violent that it became unsafe in which case a smaller displacement was accepted. Test data was recorded for both conditions in each

of the 3 cells. Movies were also taken at 24 frames per second and at 100 frames per second.

An effort was made to calibrate the slosh sensors by raising and lowering the water level in 2-inch steps to 6 inches. The effort was a failure because the amplifier became overloaded at smaller level changes than those occurring during tests. Therefore no correlation could be made between test results and calibration attempts.

Water was then added to make the tank 3/4 full and tests were run again in the same manner as those run for the 1/2 full condition, and movies were also taken.

The movies were submitted to the calibration laboratory for analysis. Information desired from the movies included changes in water level on the slosh sensors during slosh, and time differences between slosh peaks and troughs occurring in one cell and those occurring in the other cells.

Also still photographs were taken of selected movie scenes depicting the static water level, peaks, and troughs for those cells which were at resonance. These are shown in Figures 26 through 43.

TEST RESULTS

A. DATA

The oscillograph recordings from the CEC equipment fade when exposed to light. Therefore, it was necessary to obtain Zerox copies before the records could be studied. However, the copies were too weak to include in a report without tracing in ink. Therefore, the transducer outputs are tabulated in Table I for the 1/2 full tests and in Table II for the 3/4 full tests.

Output is arranged in two columns for each cell. The first column presents the data for the maximum non-splash slosh condition. The second column presents data for slosh with splash. It was intended to double the shaker displacement for slosh with splash over that required for maximum non-splash. However, it was necessary to settle for less in some cases to prevent splashing water on television camera lights, or for other pertinent reasons.

Table III presents reduced data on slosh movement and time differences between peaks and troughs as they occurred at slightly different times in the three cells. This information was derived from the data recorded in Table IV. Tables V and VI present the oscillograph movements as measured with a measuring tape. Table VII provides calibration data for converting scale measurements of Tables V and VI into data as recorded in Tables I and II. A typical set of oscillographs is shown in Figures 44 through 50. Table VIII provides data reduction examples to show how data in Tables I and II are derived from data in Tables V, VI, and VII.

B. DISCUSSION

Several problems were encountered in running the slosh test which prevented the results from being as good as desired. The fine-resolution displacement transducers ordered for the test several months earlier were not received in time to be used. A coarse-resolution displacement transducer had to be substituted and its use caused a slightly jerky shaker movement. Its effect was especially noticeable where very small shaker displacements were needed. The irregularity is believed to have exerted a damping effect on the slosh wave and prevented the slosh resonant frequency from being sharply defined. It also caused some oscillograph recordings to be irregular and complex in wave form.

Because of a short maintenance-free life, it was almost impossible to run a series of tests for a given calibration without a failure occurring in one or more recorder channels.

The slosh sensors were flash-coated with gold to prevent copper oxide from forming on its surface. However, the gold coating apparently was not thick enough, because resistance between adjacent elements of the sensors continued to increase with time. This factor made it impossible to calibrate the sensors by raising and lowering the water level because in the several hours required to complete the water level changes, the resistance at the starting water level changed significantly.

A comparison between oscillograph movement and the corresponding peak to trough movement derived from a study of the movie frames (Table I)

showed that the oscillograph movement is not linearly proportional to the slosh movement. For example, slosh sensor 160 had an oscillograph movement of .375 inches representing a peak-to-trough movement of 9 1/4 inches, or 24.7 inches per chart inch, and an oscillograph movement of .450 inches representing a peak-to-trough movement of 15 1/2 inches, or 34.4 inches per chart inch.

The instability of the slosh sensor system was not a serious factor in this test, because the T.V. camera system proved to be superior in indicating the changes in slosh height. However, where T.V. can not be used, a sensitive slosh sensor system is imperative.

The tests were very effective in determining the resonant frequencies and loads on the feet and shaker. The strain gage data was small or negligible in all cases, indicating a high degree of stiffness in the structure. However, Table VII shows a lack of uniformity in calibration output for the same input. For example, for an input of 2K micro-inches, the oscillograph movement for gage 32 was .70 inch and for gage 6 it was .06 inches, yet the amplifier gains were identical. A strain output of 300 micro-inches would probably be recorded as zero for gage 6 since the chart movement would be less than .010 inch, but for gage 32 the movement would exceed .10 inch.

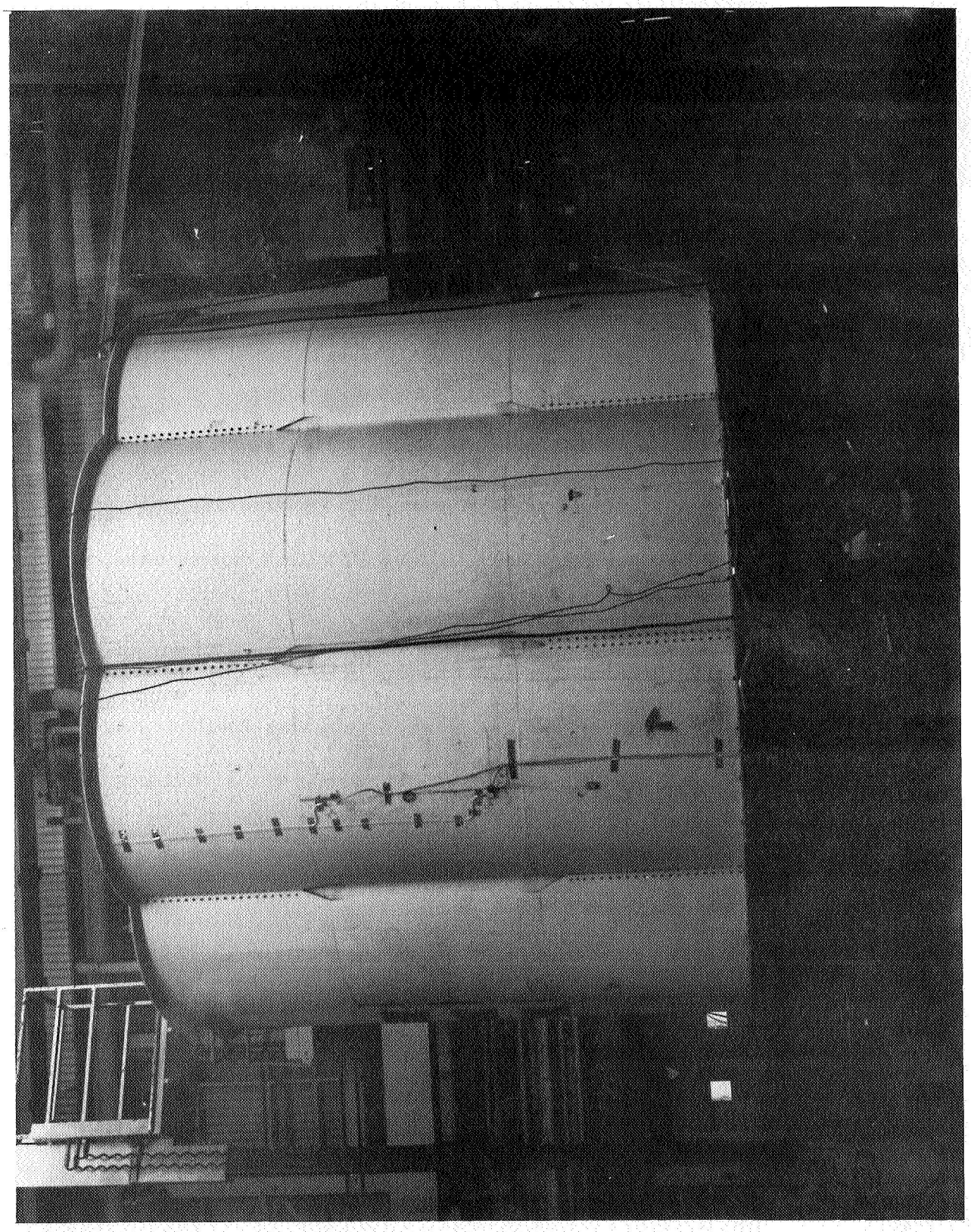


FIGURE 1 MULTICELL TANK FRONT VIEW

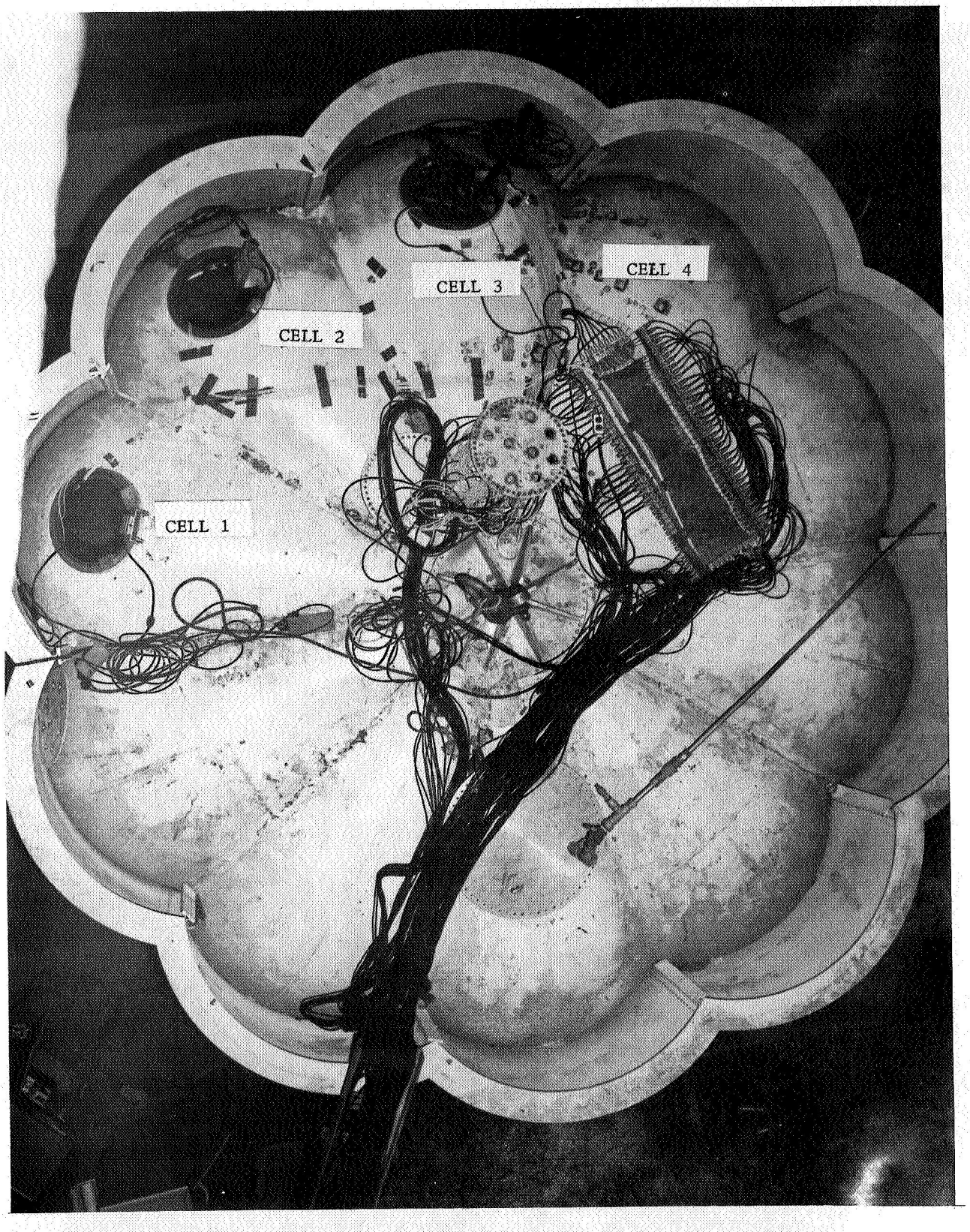


FIGURE 2 MULTICELL TANK TOP VIEW

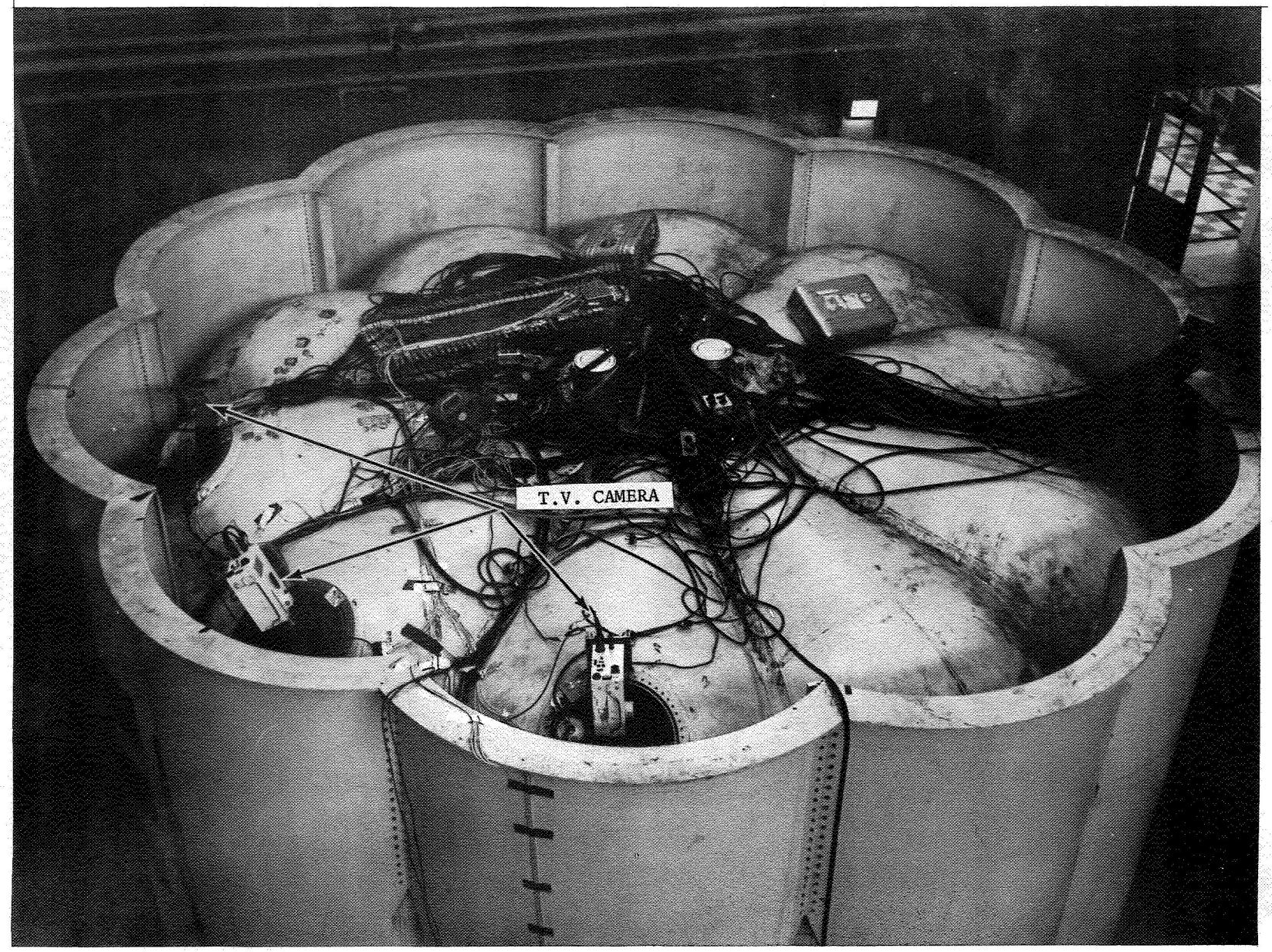


FIGURE 3 MULTICELL TANK-ANGLE VIEW

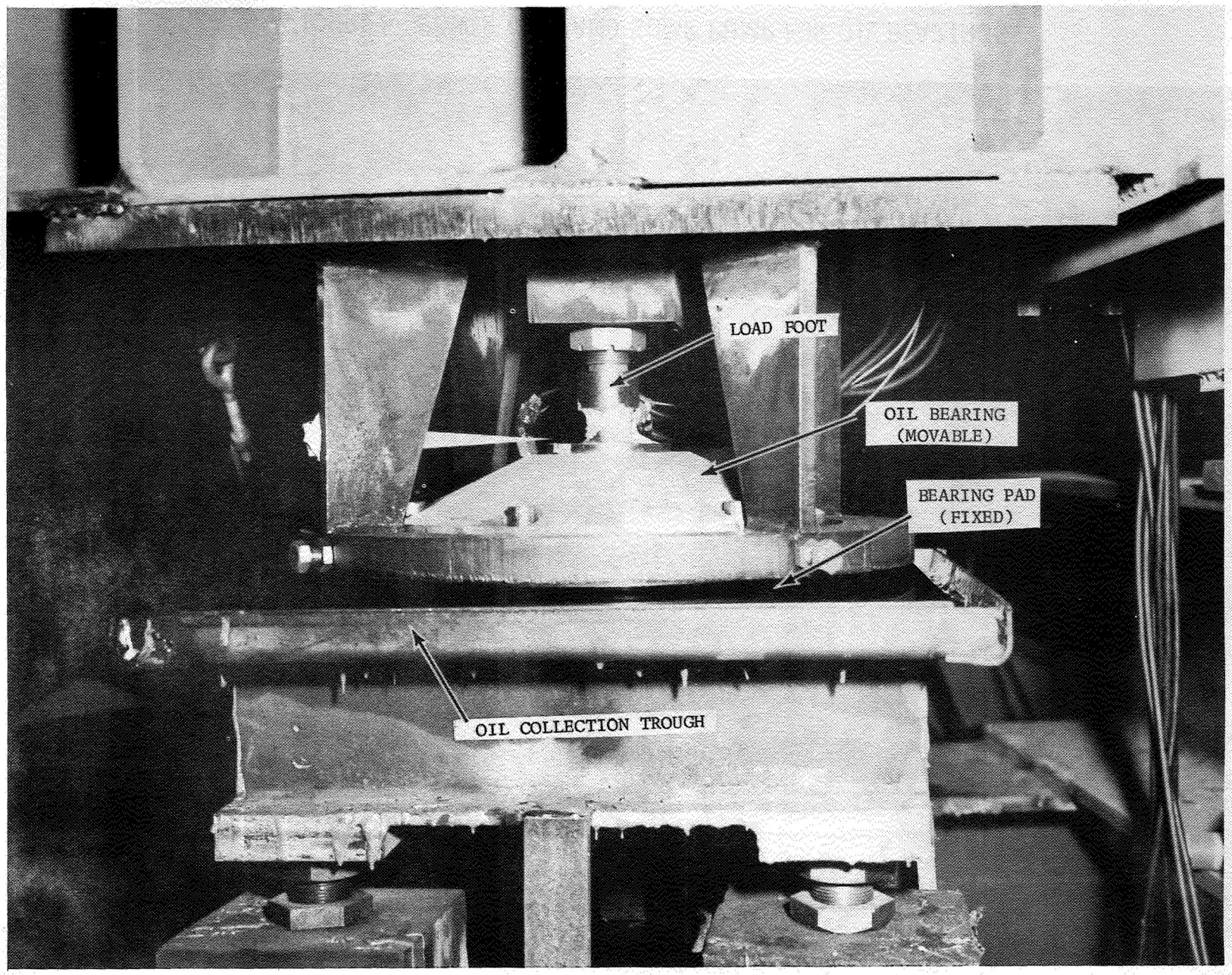


FIGURE 4 TYPICAL OIL BEARING ARRANGEMENT

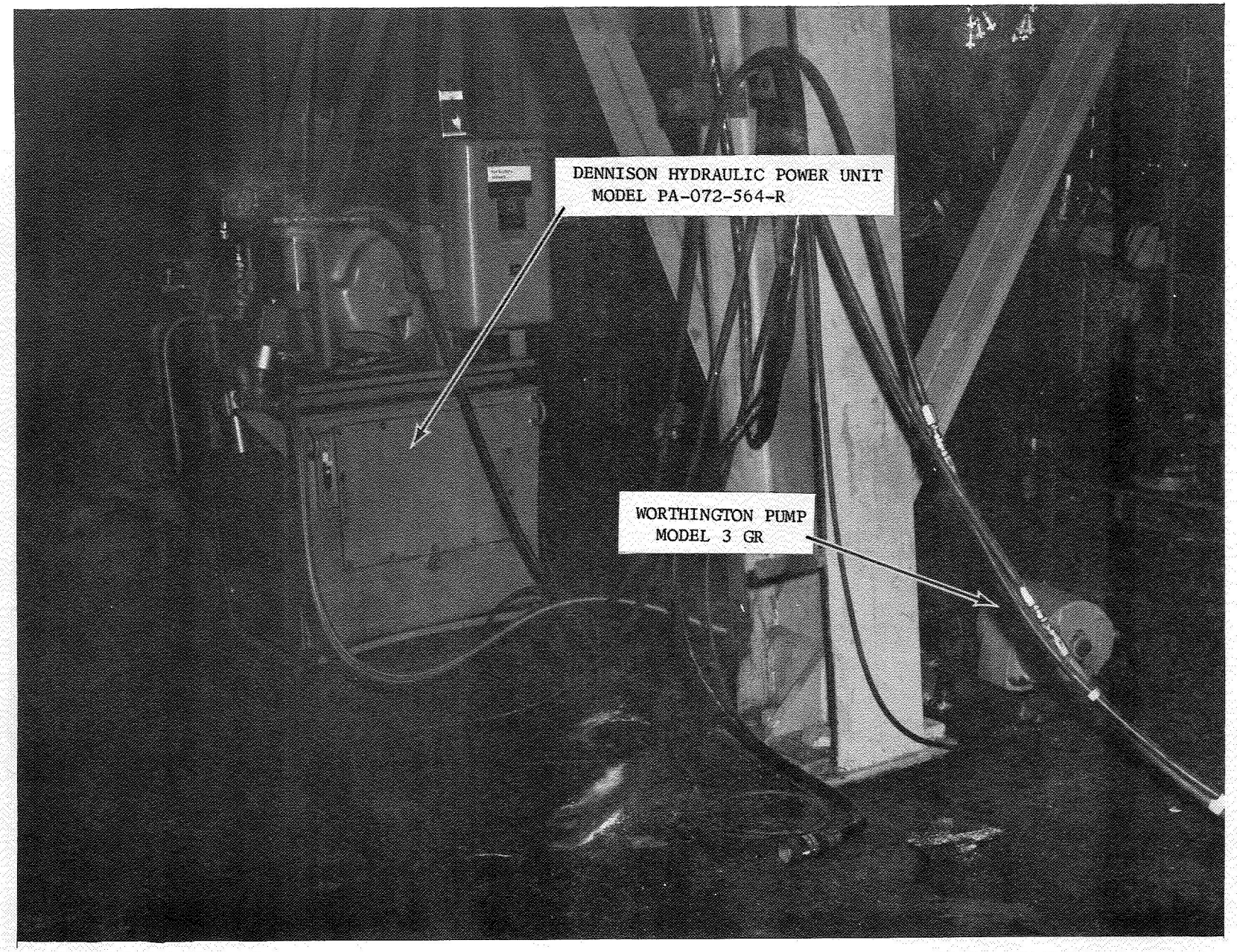


FIGURE 5 POWER UNIT AND SUMP PUMP FOR OIL BEARINGS

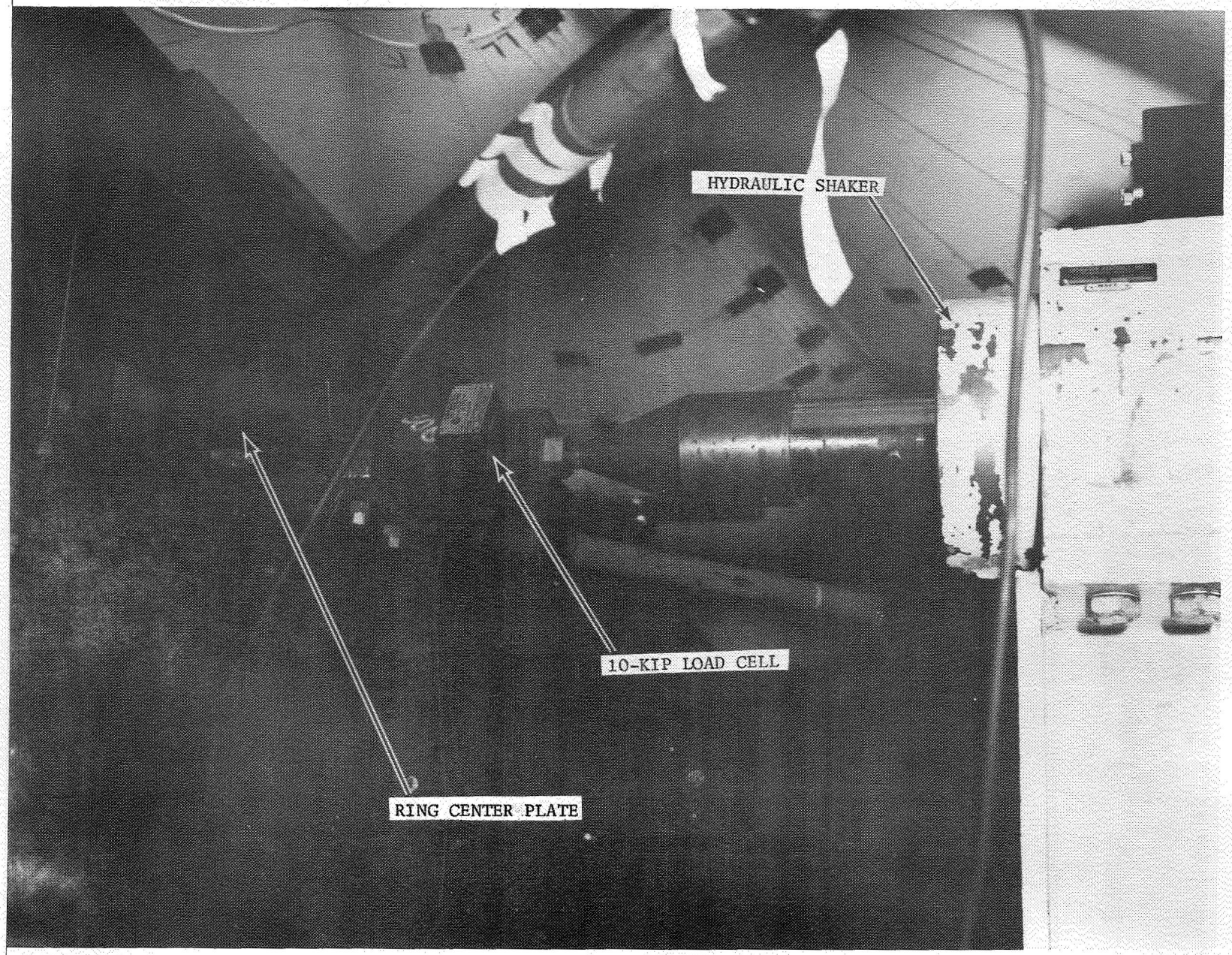


FIGURE 6 HYDRAULIC SHAKER CONNECTIONS

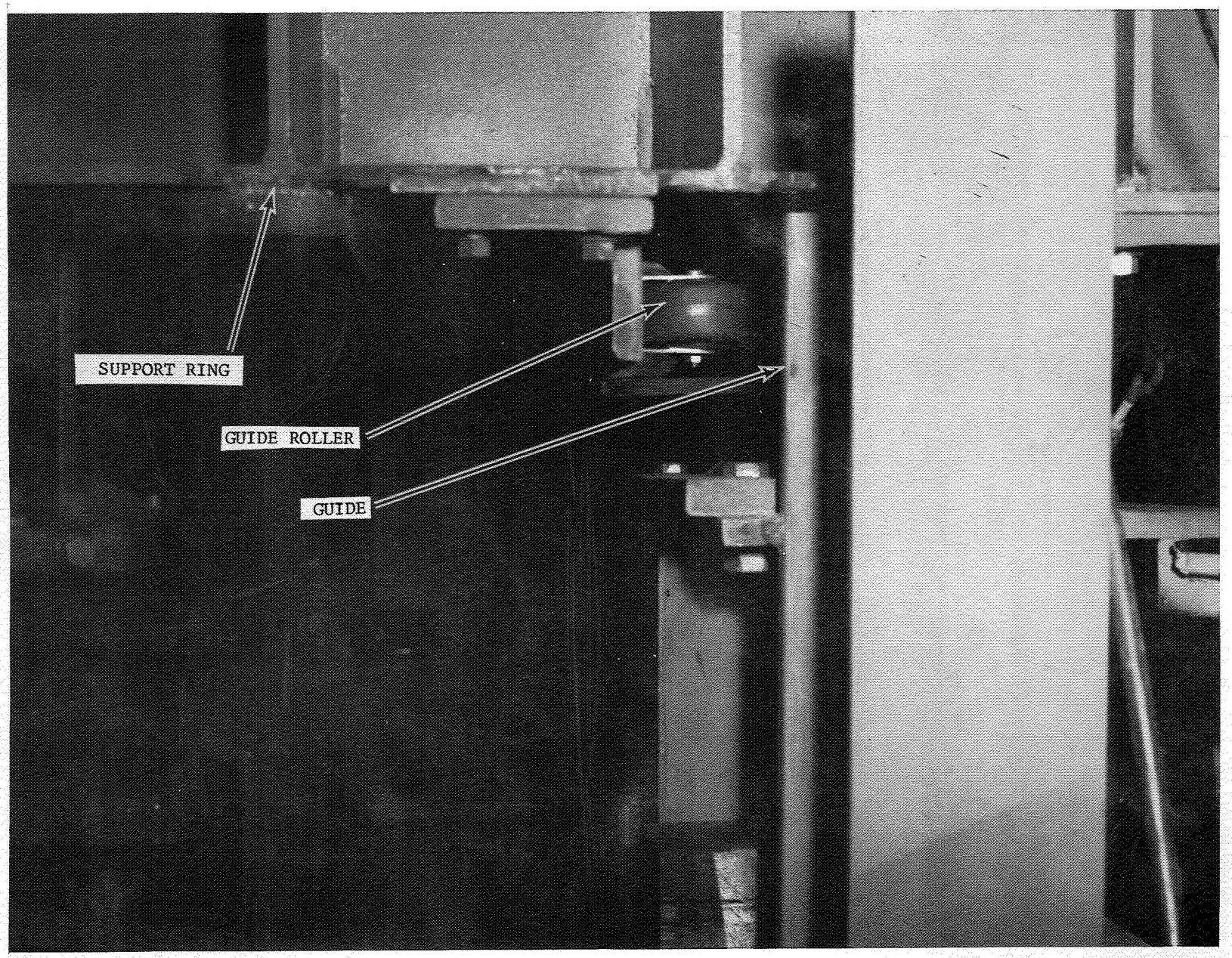


FIGURE 7 RING DISPLACEMENT GUIDE

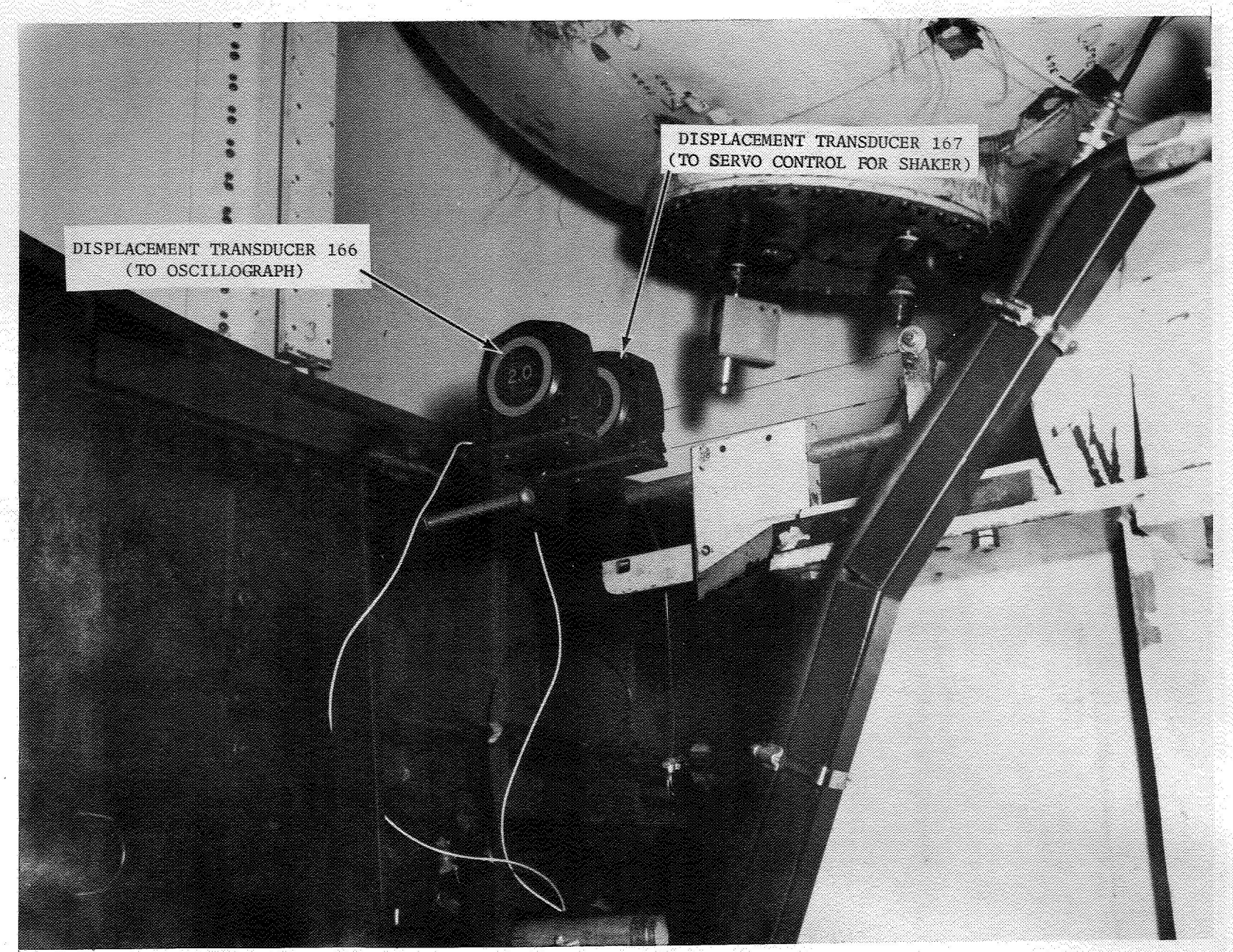


FIGURE 8 DISPLACEMENT TRANSDUCERS

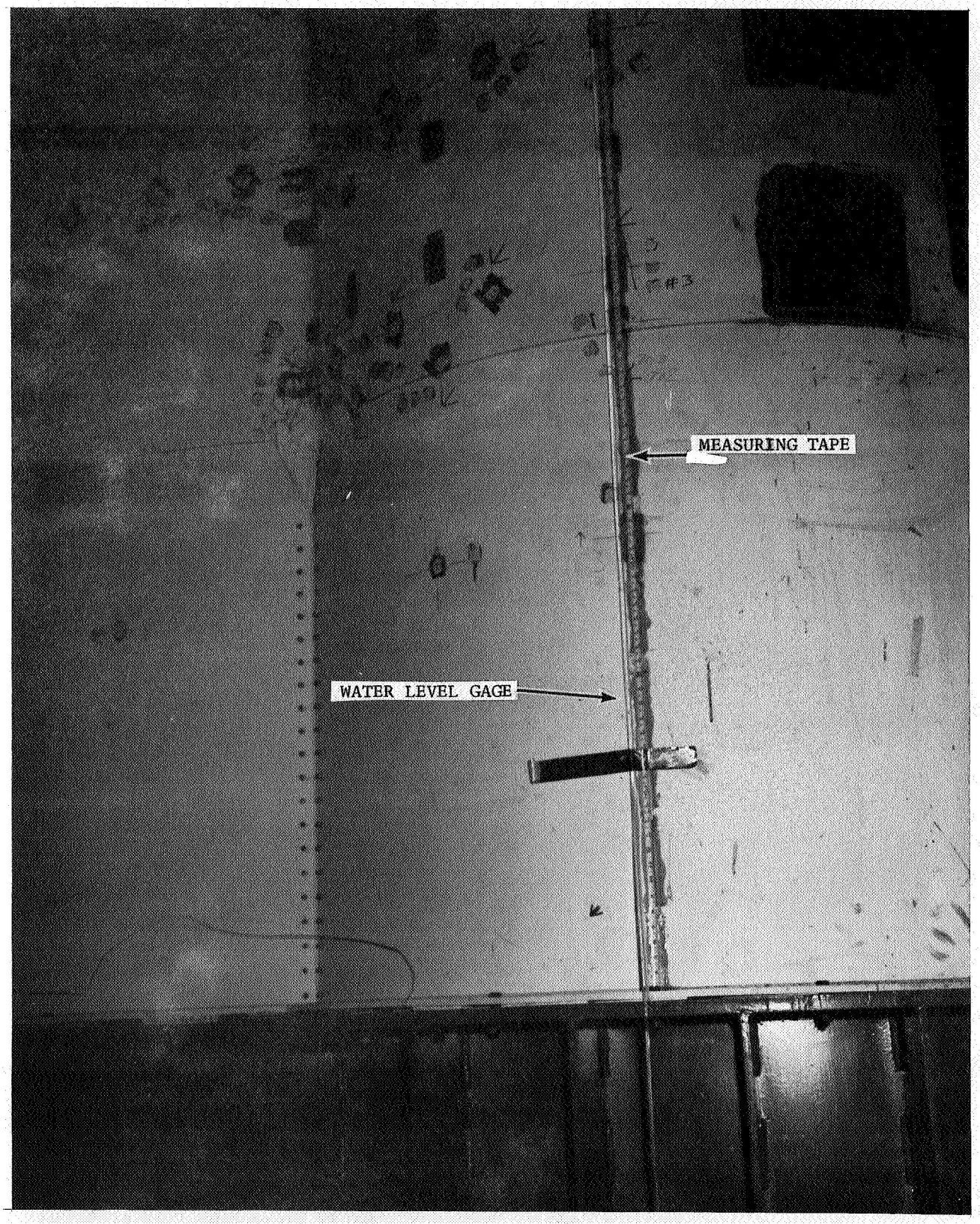


FIGURE 9 MULTICELL TANK SIDE VIEW

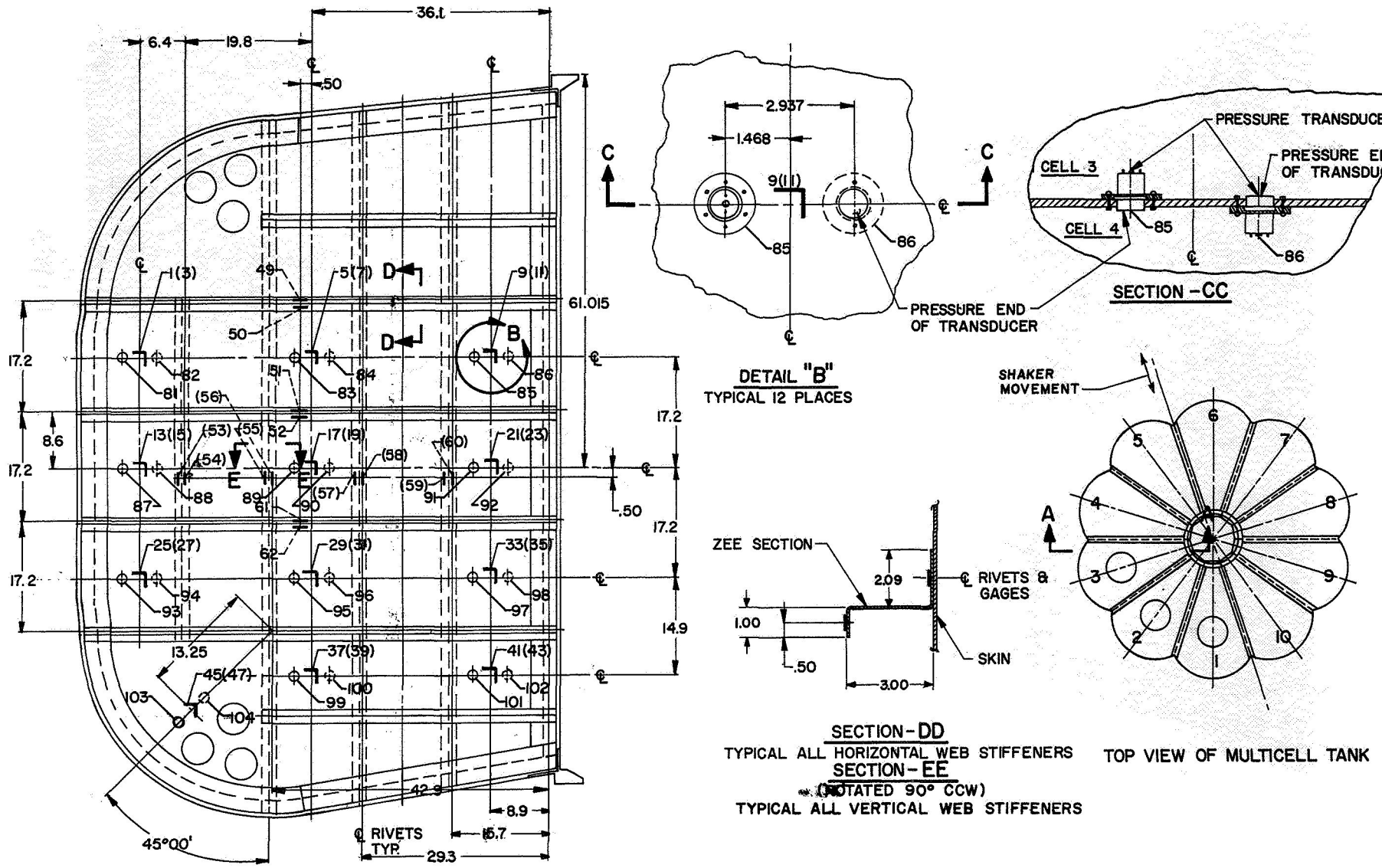


FIGURE 10 INSTRUMENTATION DRAWING FOR MULTICELL TANK

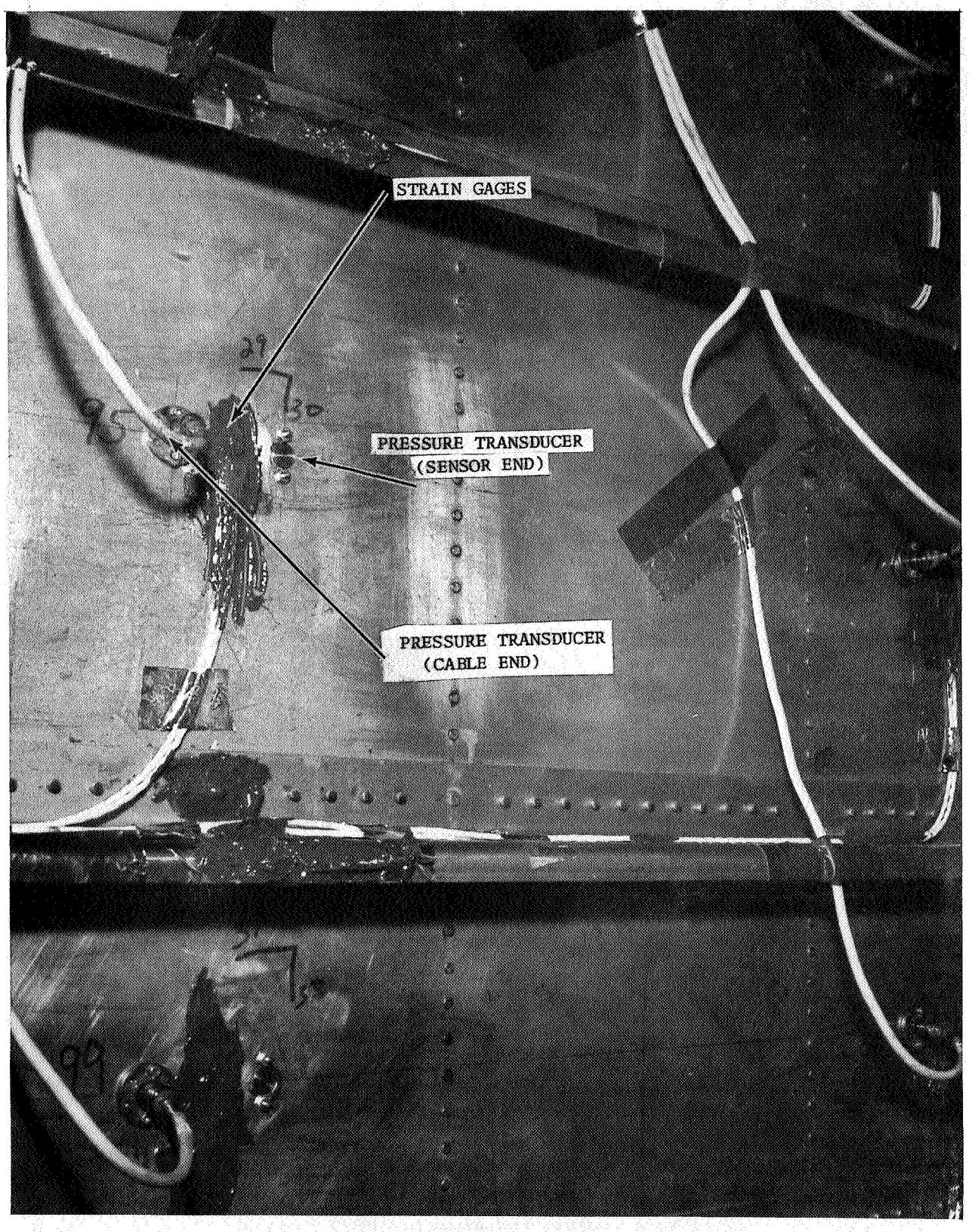


FIGURE II CELL 3 VIEW OF INSTRUMENTED WEB

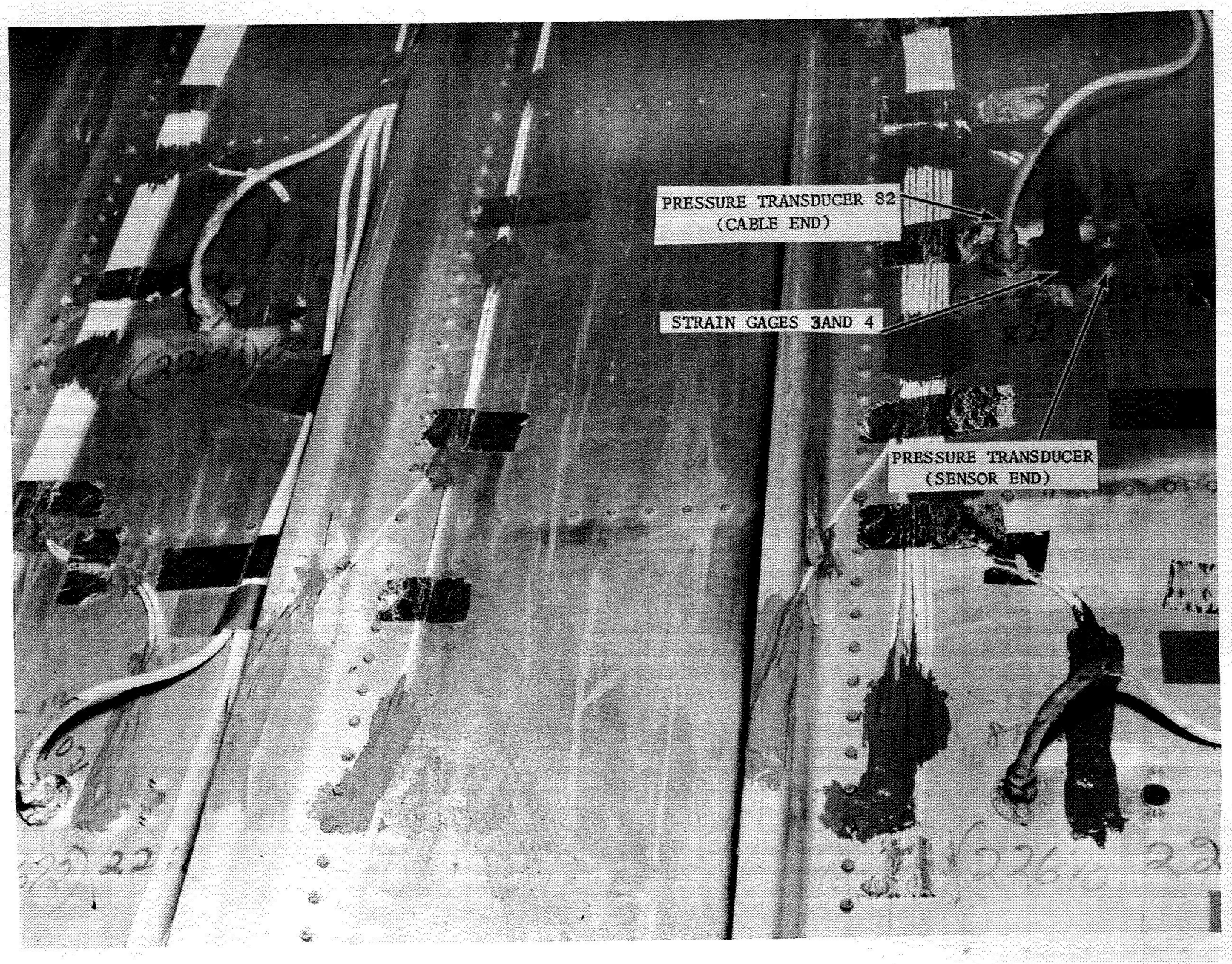


FIGURE 12 CELL 4 VIEW OF INSTRUMENTED WEB

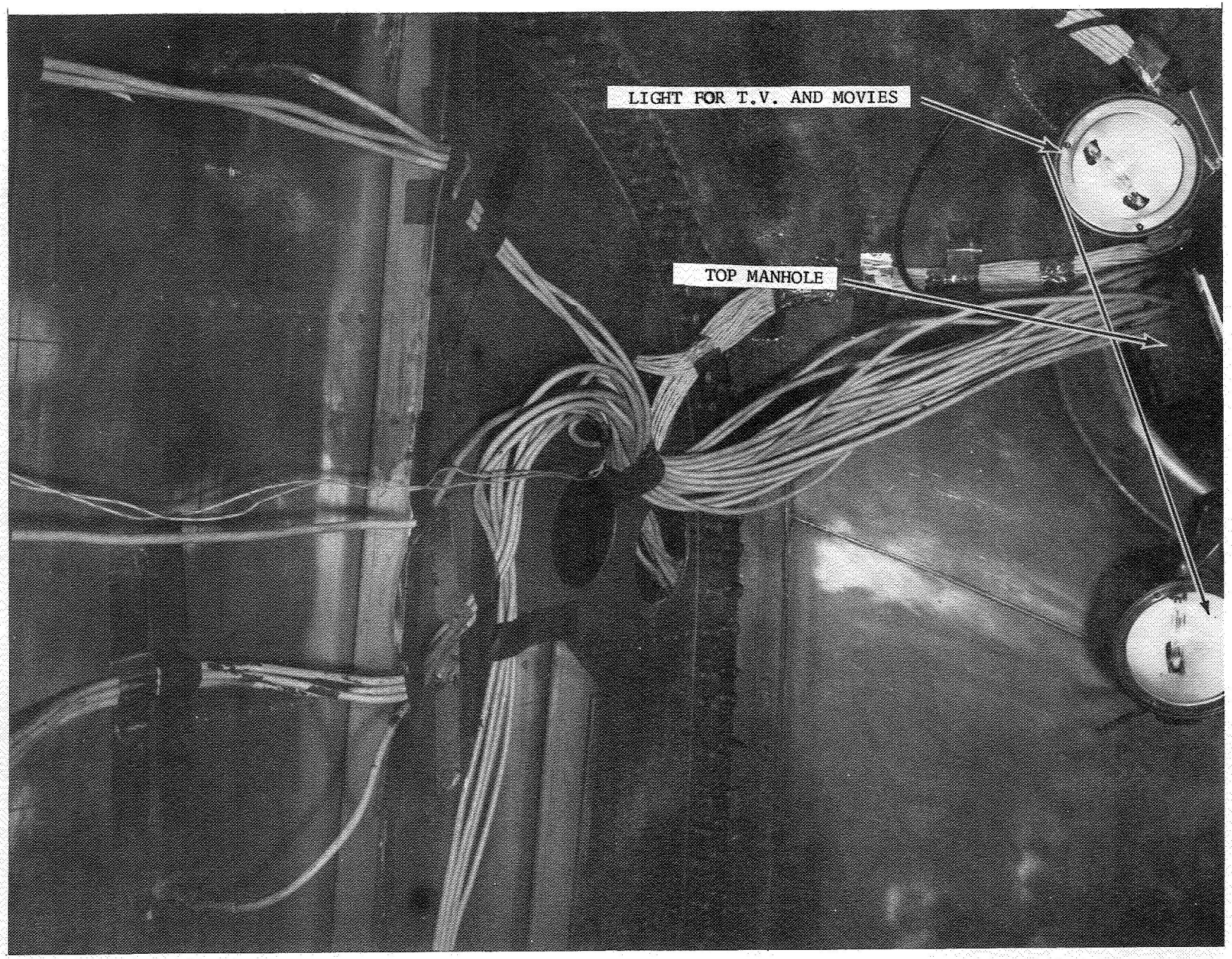
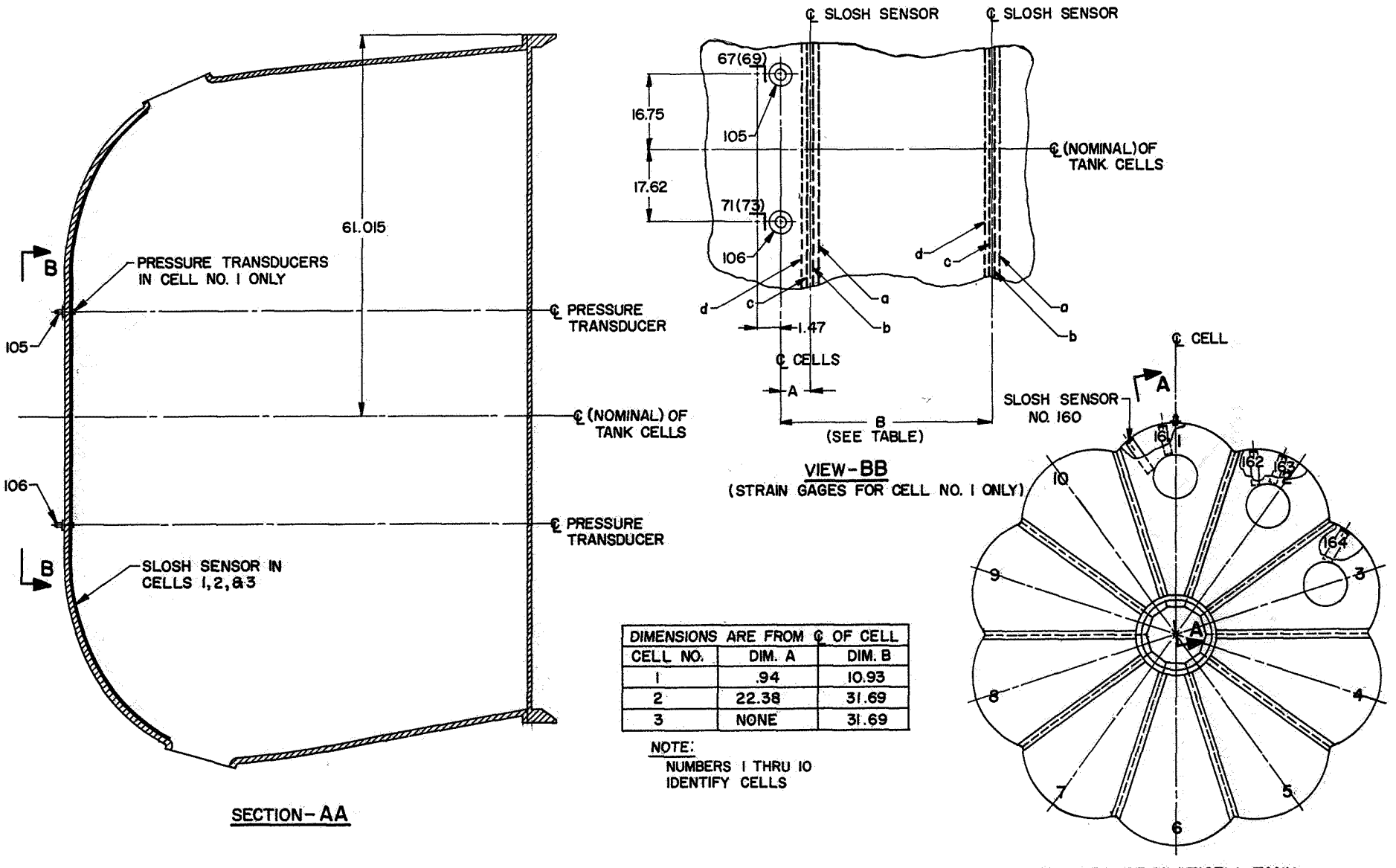


FIGURE 13 CABLE ARRANGEMENT FROM WEB



DIMENSIONS ARE FROM ℄ OF CELL		
CELL NO.	DIM. A	DIM. B
1	.94	10.93
2	22.38	31.69
3	NONE	31.69

NOTE:
NUMBERS 1 THRU 10 IDENTIFY CELLS

FIGURE 14 INSTRUMENTATION DRAWING FOR MULTICELL TANK

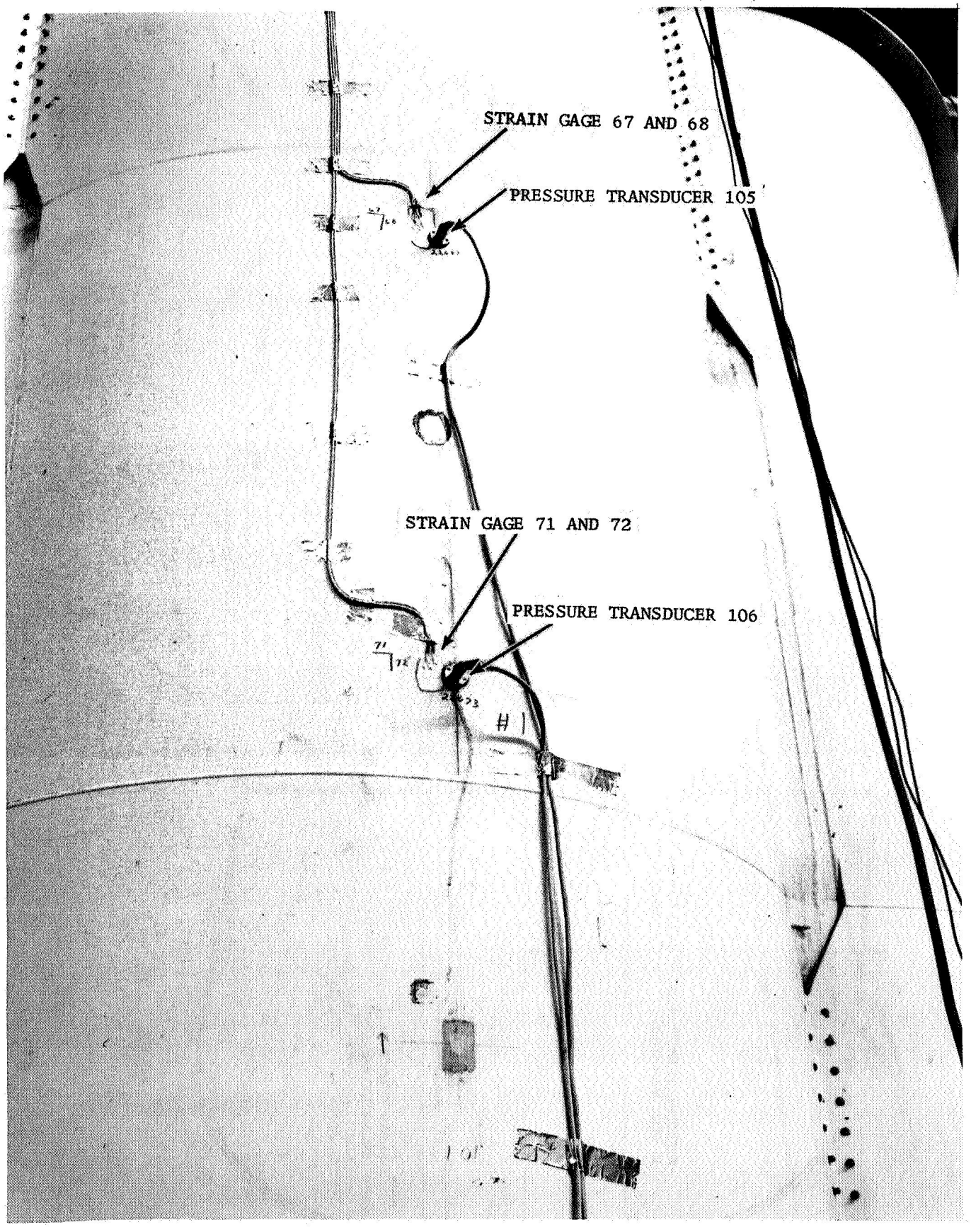


FIGURE 15 CELL 1 EXTERNAL VIEW

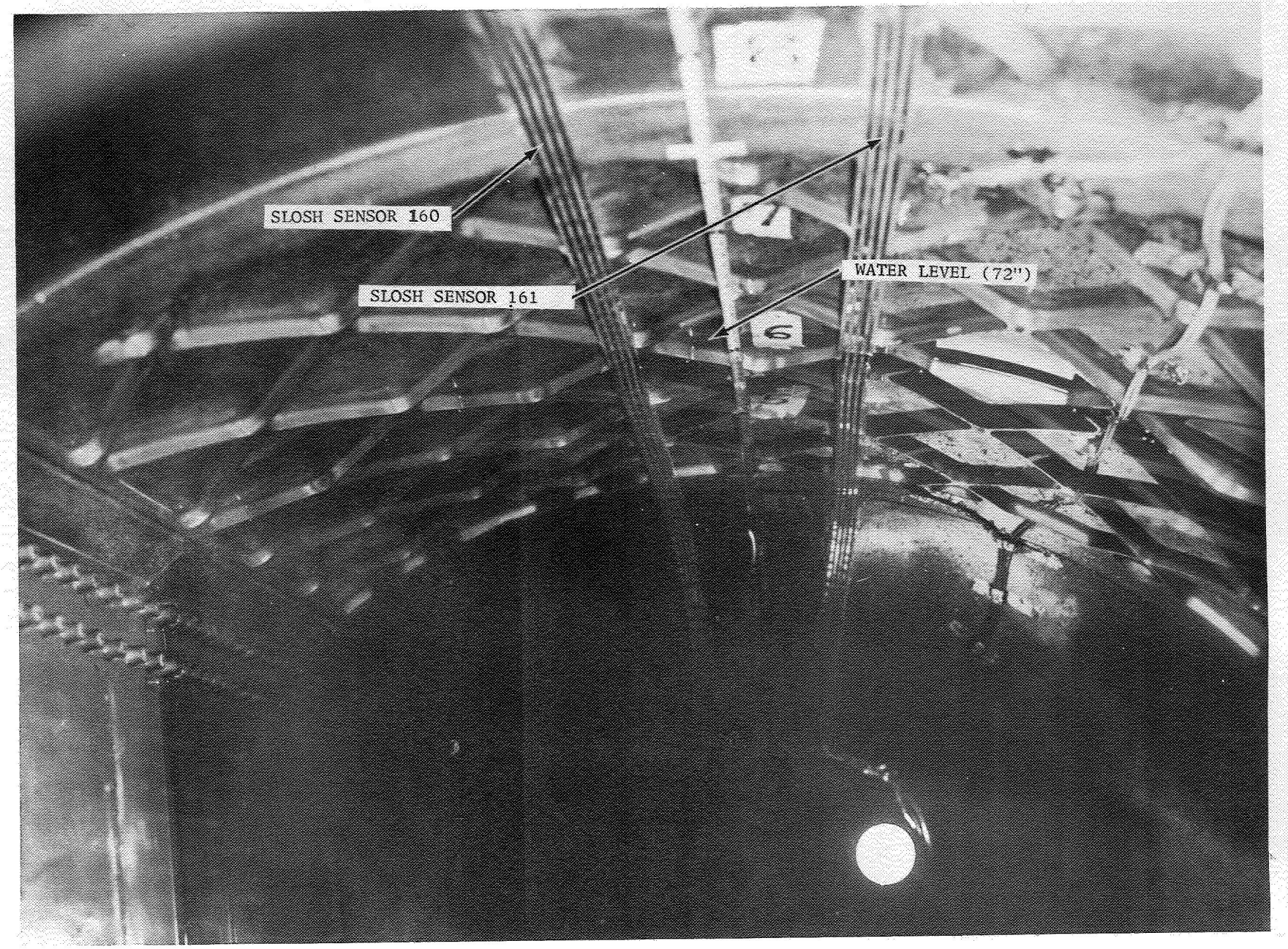


FIGURE 16 CELL 1 VIEW FROM TOP AT 1/2 -FULL LEVEL

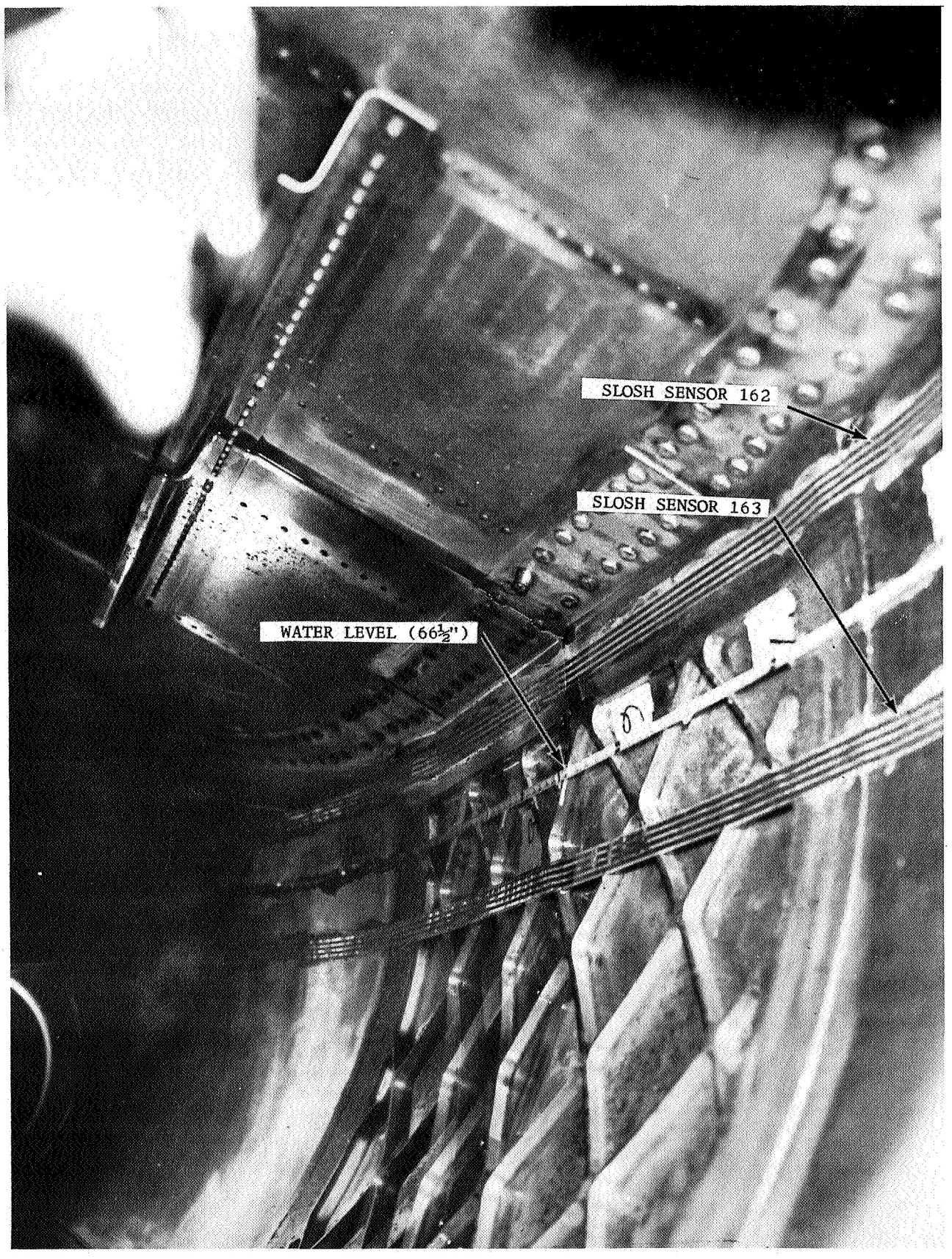


FIGURE 17 CELL 2 VIEW FROM TOP AT 1/2-FULL LEVEL

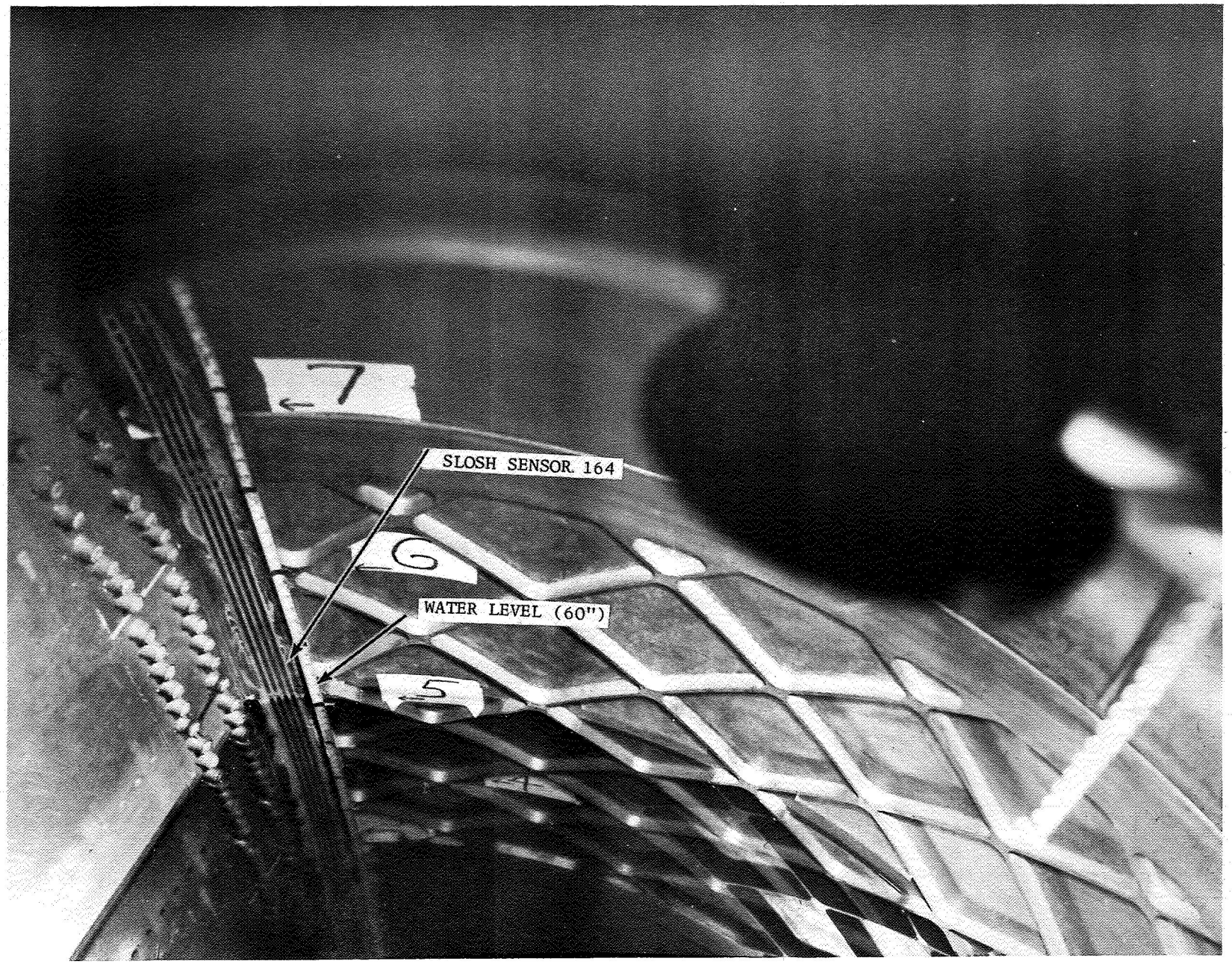
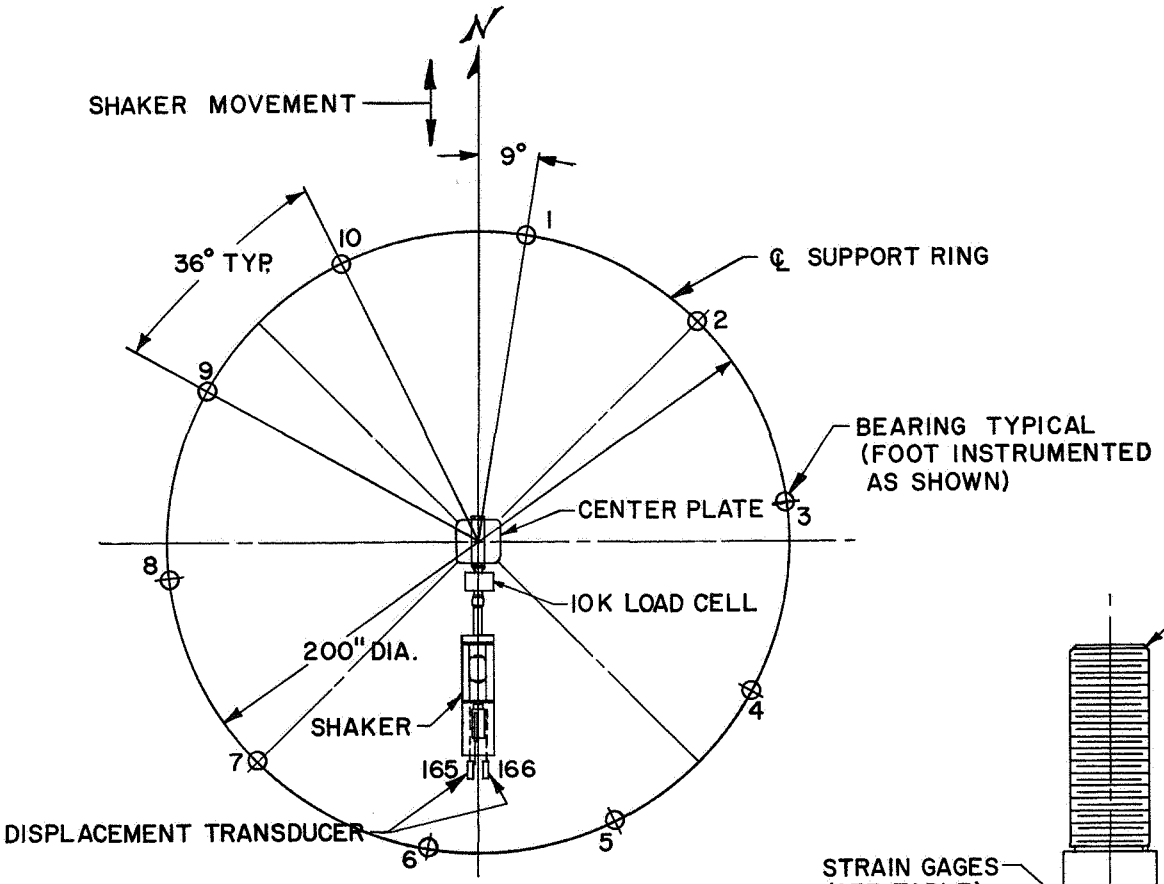


FIGURE 18 CELL 3 VIEW FROM TOP AT 1/2-FULL LEVEL



BEARING NUMBER	STRAIN GAGE NUMBER			
	NEAR SIDE		FAR SIDE	
	HOR.	VERT.	HOR.	VERT.
1	115	116	117	118
2	119	120	121	122
3	123	124	125	126
4	127	128	129	130
5	131	132	133	134
6	135	136	137	138
7	139	140	141	142
8	143	144	145	146
9	147	148	149	150
10	151	152	153	154

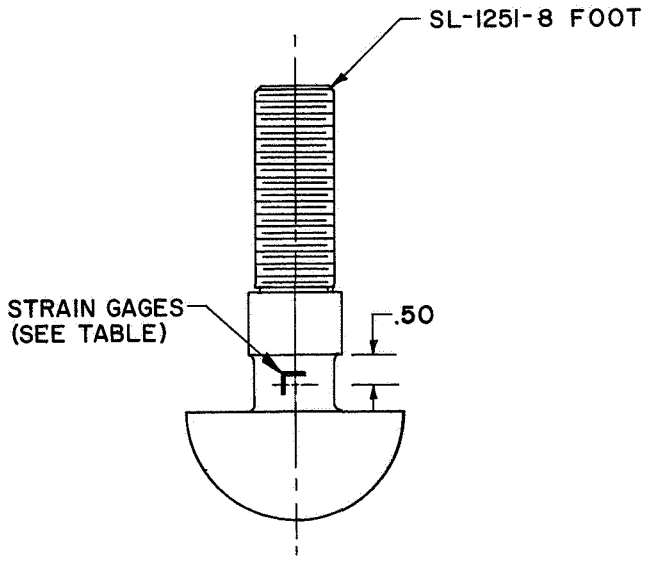


FIGURE 19 SUPPORT RING AND BEARING ARRANGEMENT
TOP VIEW

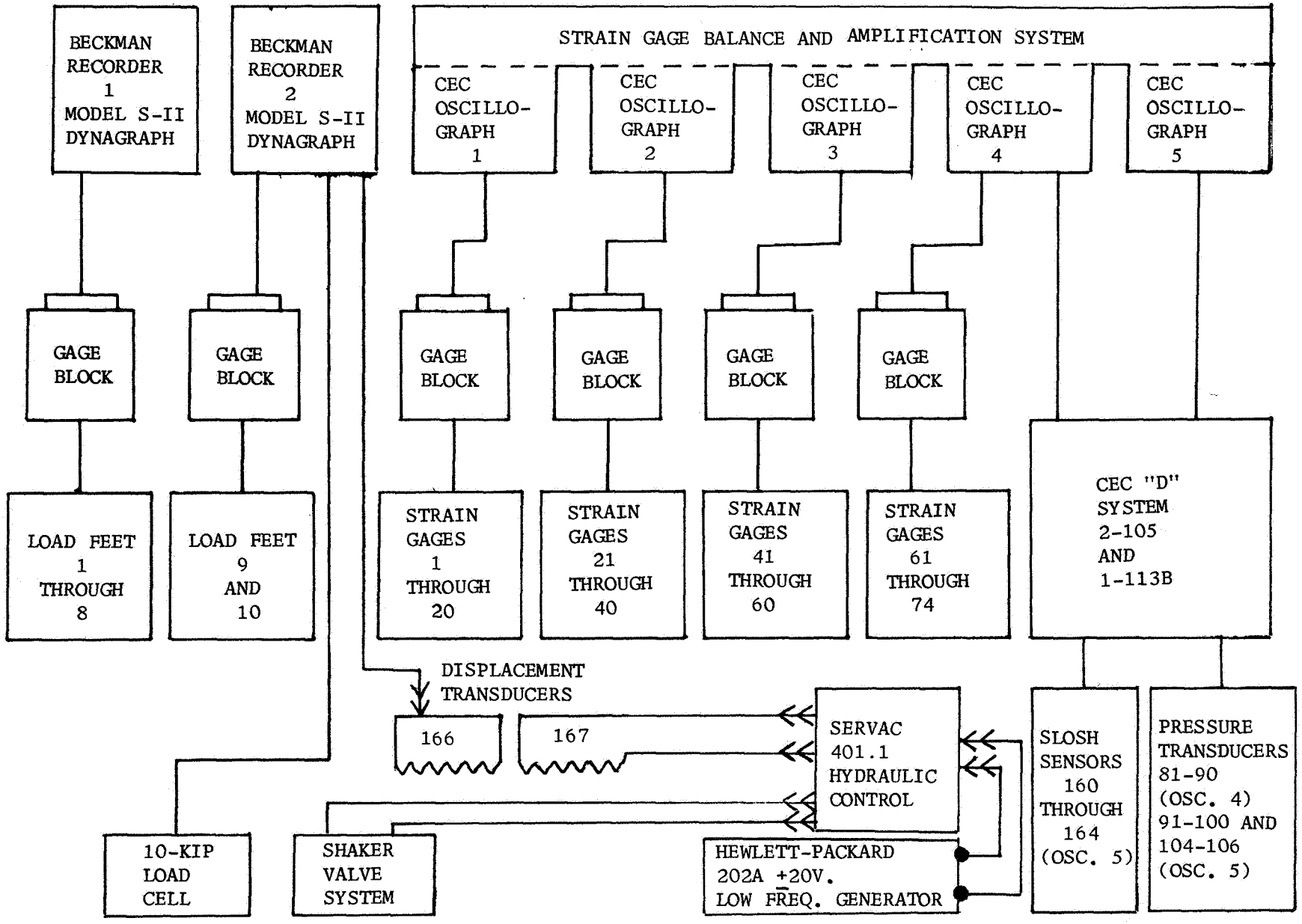


FIGURE 20 INSTRUMENTATION HOOKUP



FIGURE 21 T.V. UNITS AND FREQUENCY GENERATOR

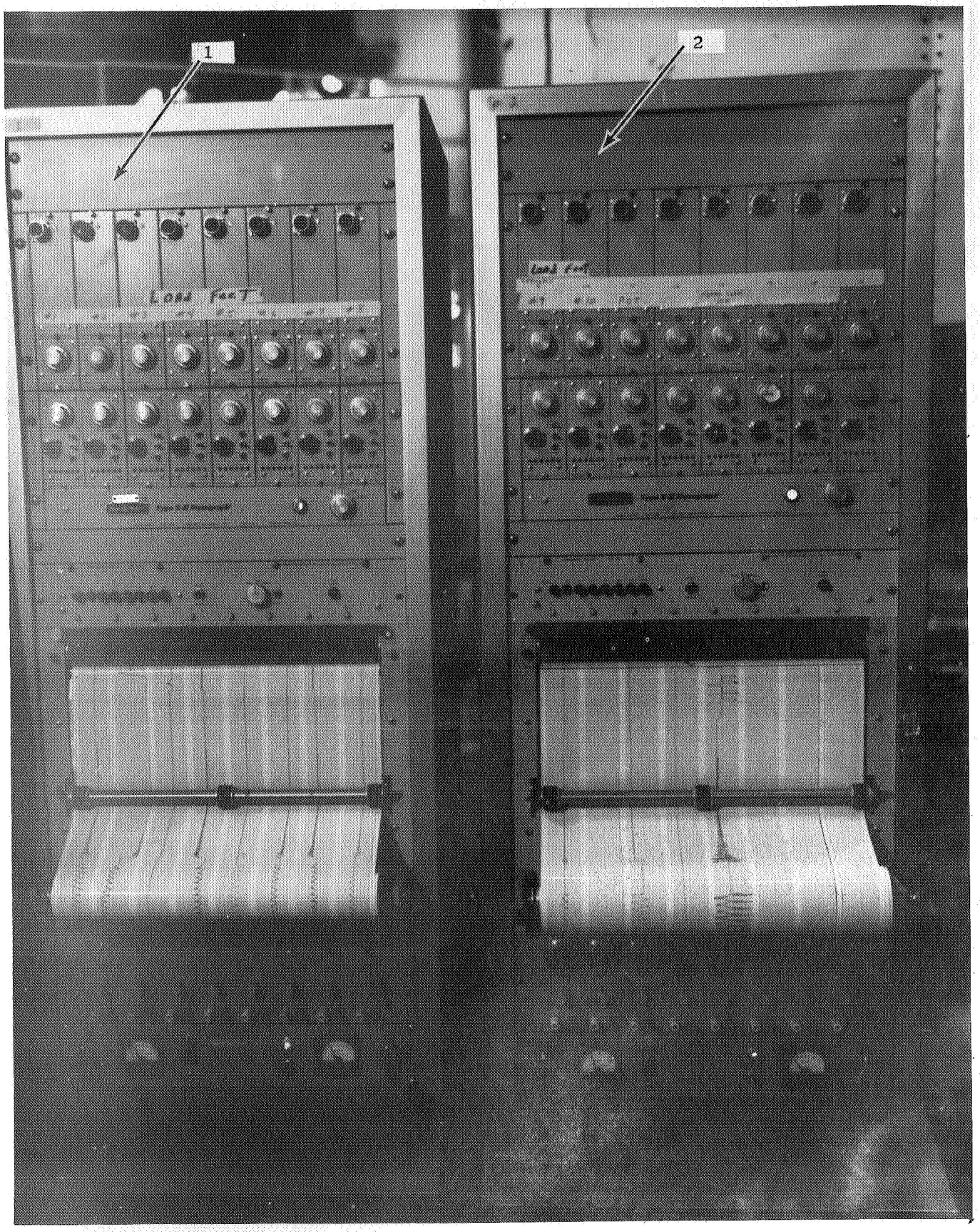


FIGURE 22 BECKMAN RECORDERS 1 AND 2

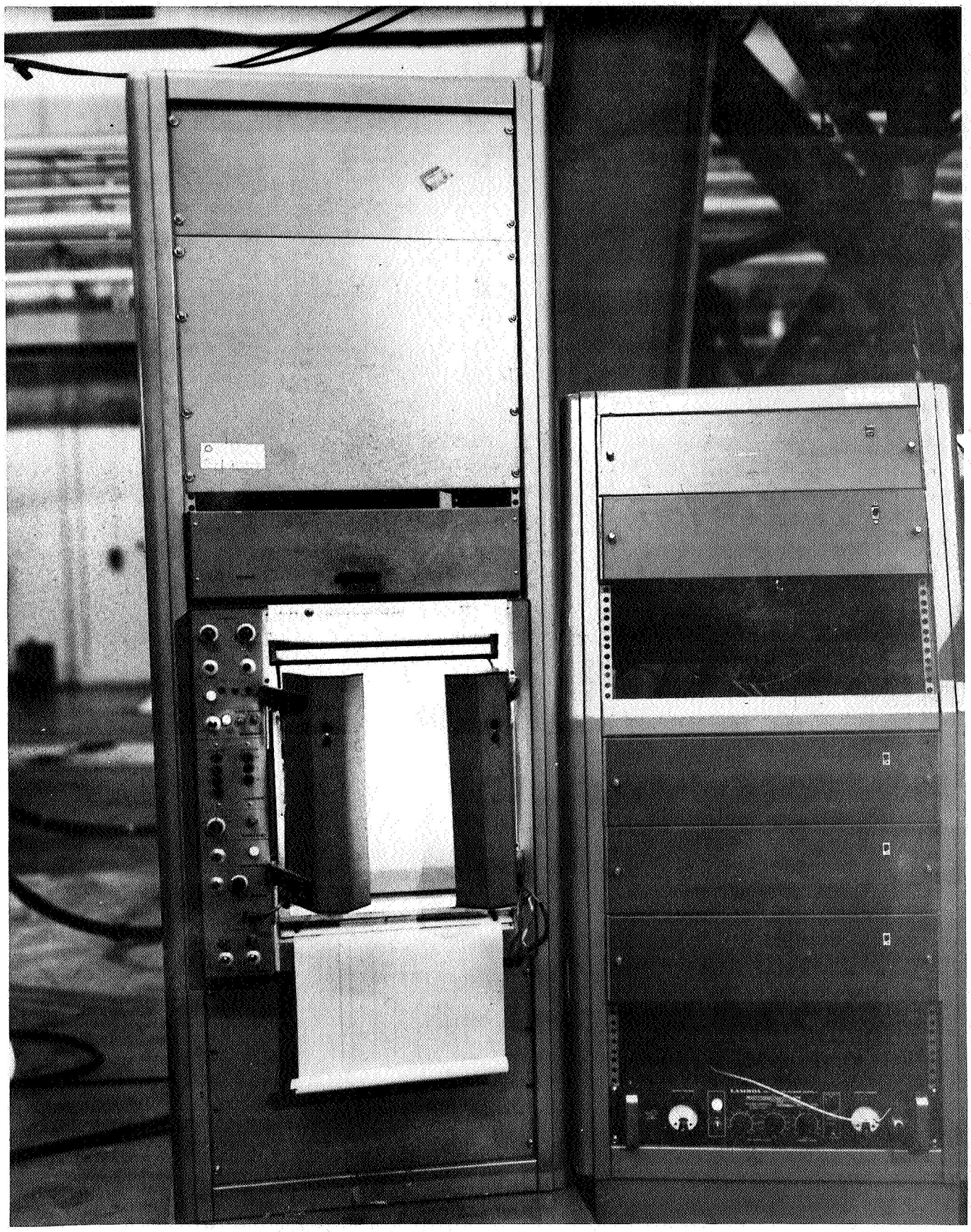


FIGURE 23 CEC OSCILLOGRAPH 2

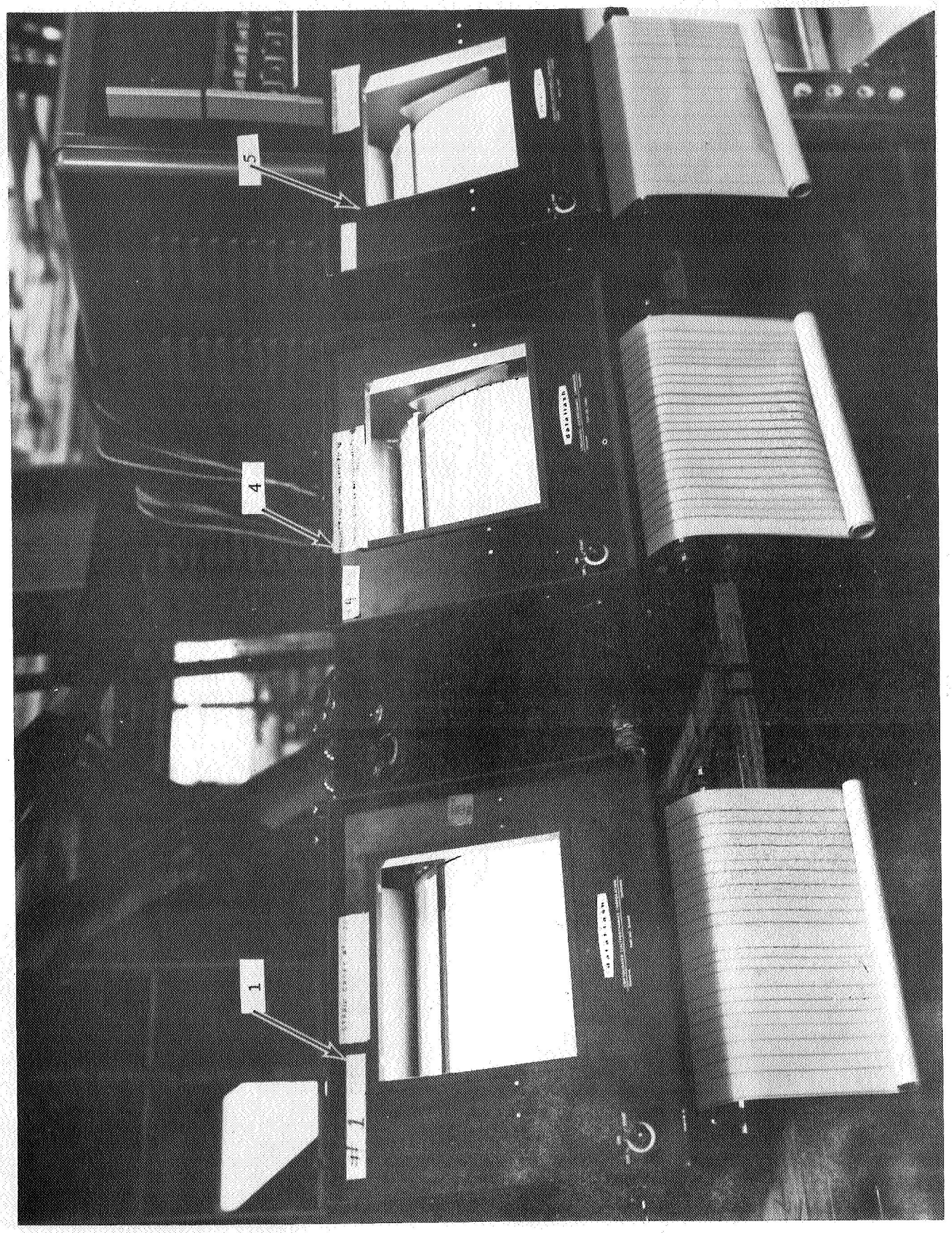


FIGURE 24 CEC OSCILLOGRAPHS 1, 4, AND 5

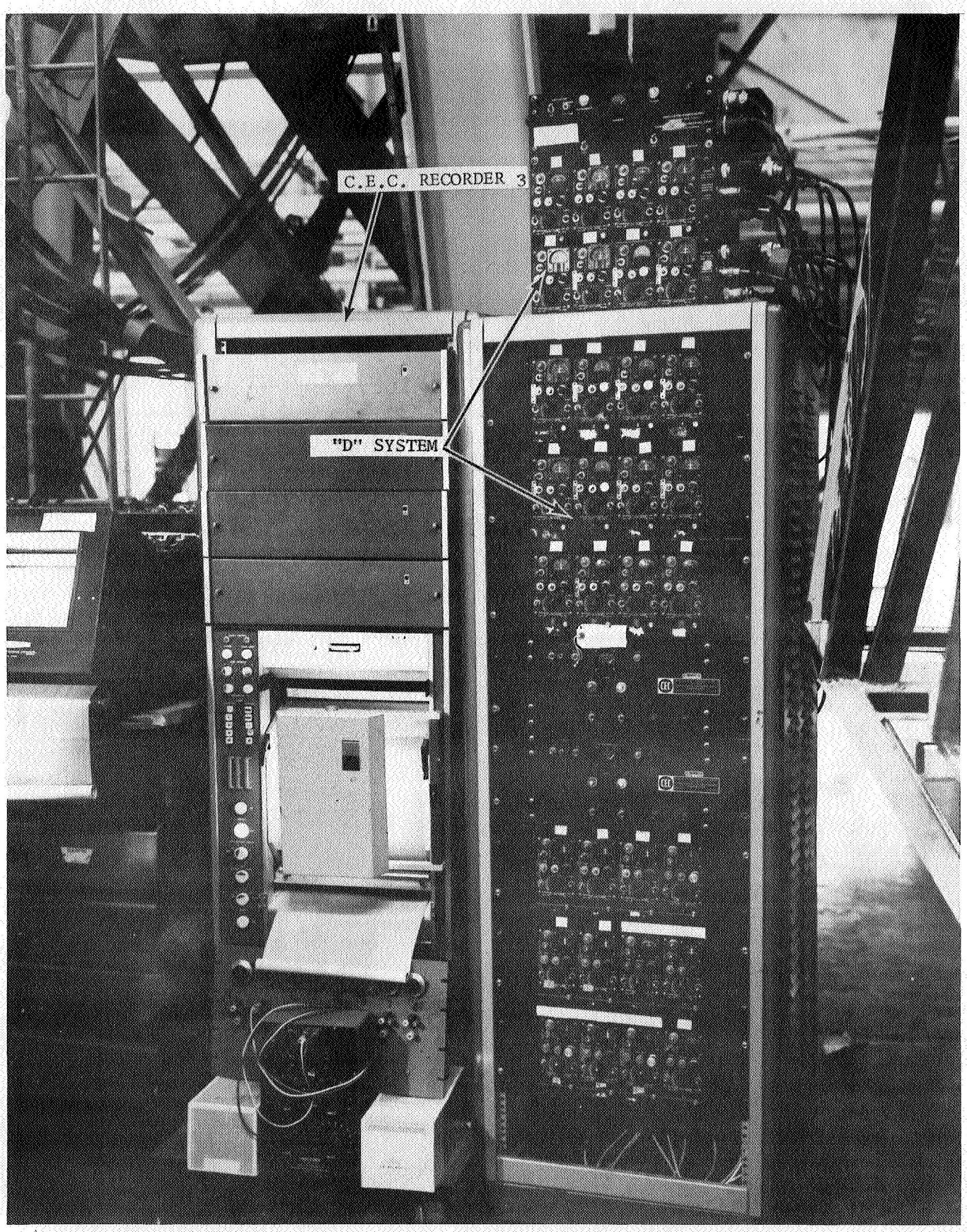
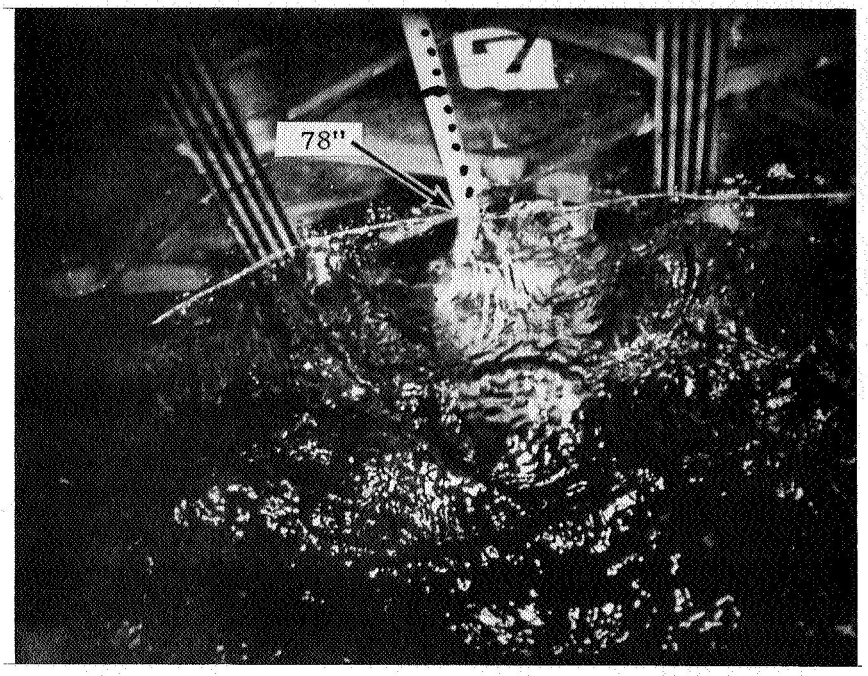


FIGURE 25 CEC OSCILLOGRAPH 3 AND "D" SYSTEM

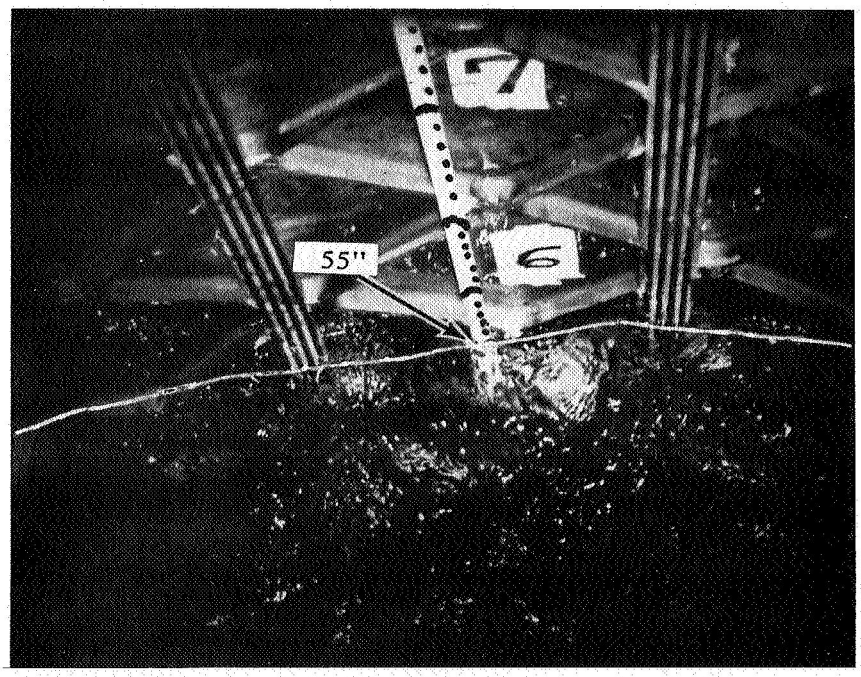


STATIC LEVEL

FIGURE 26 CELL 1 AT 1/2-FULL WATER LEVEL



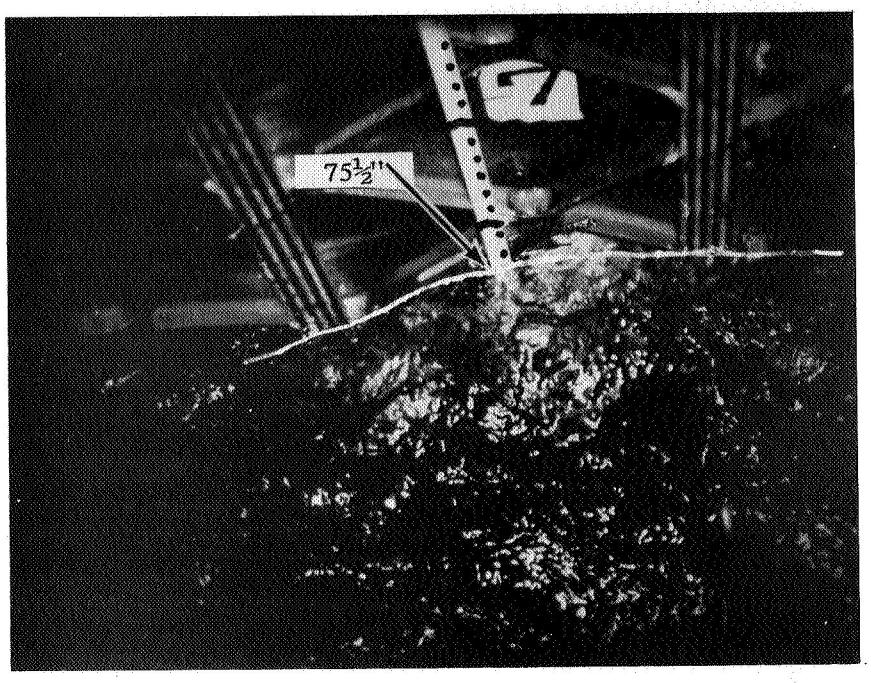
PEAK



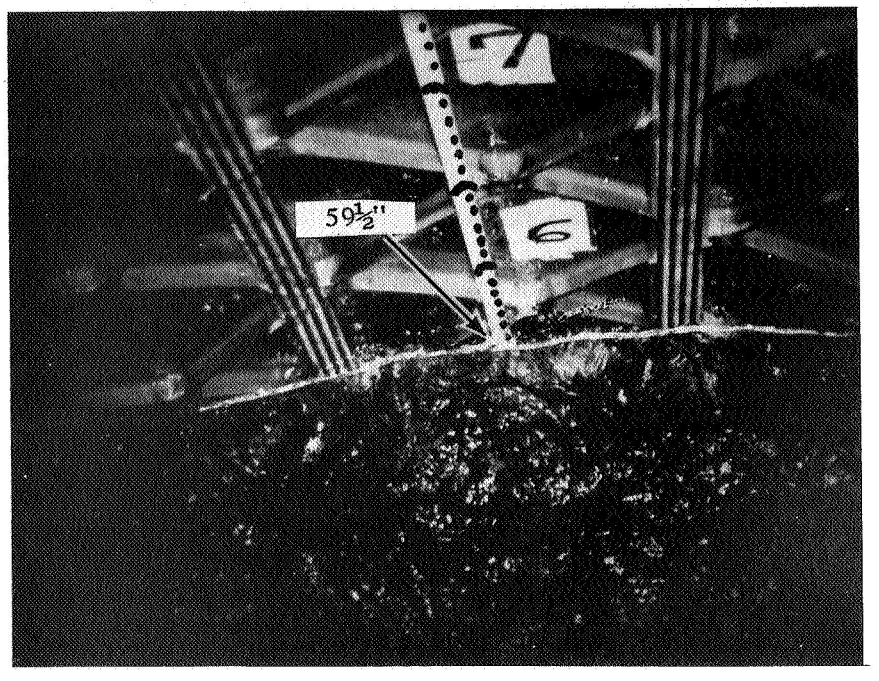
TROUGH

MAXIMUM NON-SPLASH SLOSH CONDITION
½ FULL WATER LEVEL

FIGURE 27 CELL 1 AT RESONANCE



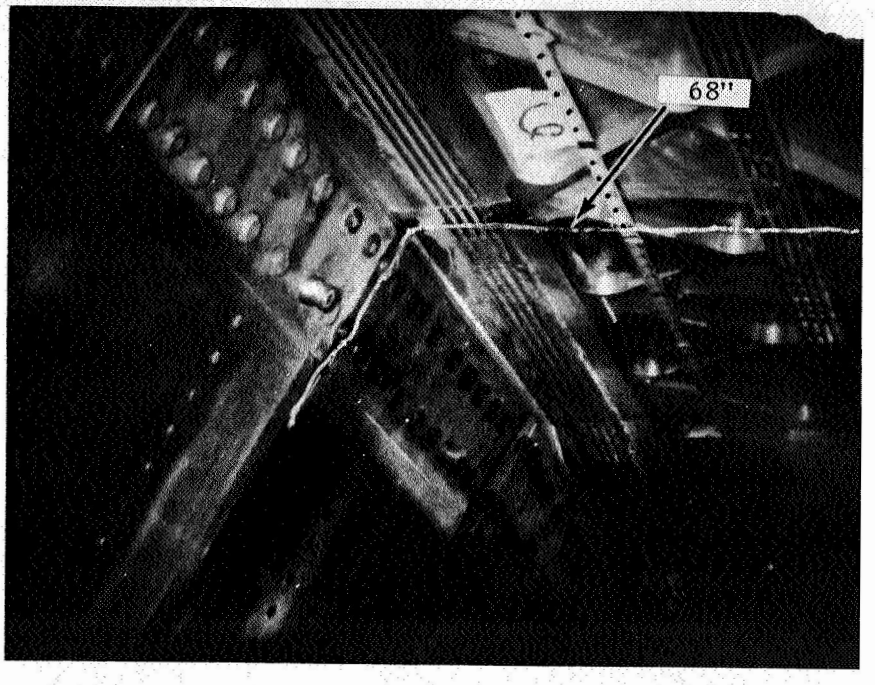
PEAK



TROUGH

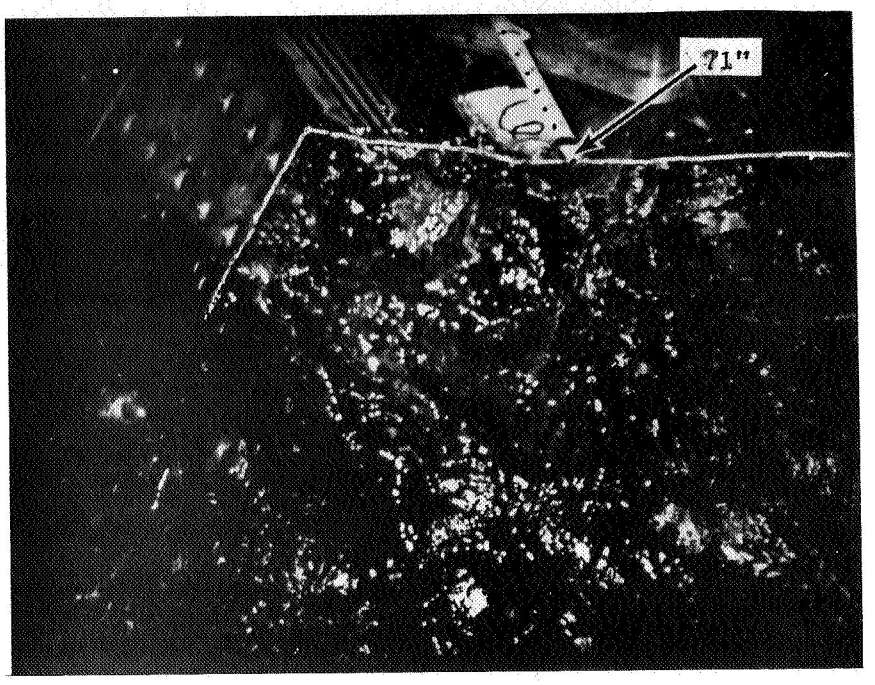
SLOSH WITH SPLASH
½ FULL WATER LEVEL

FIGURE 28 CELL 1 AT RESONANCE

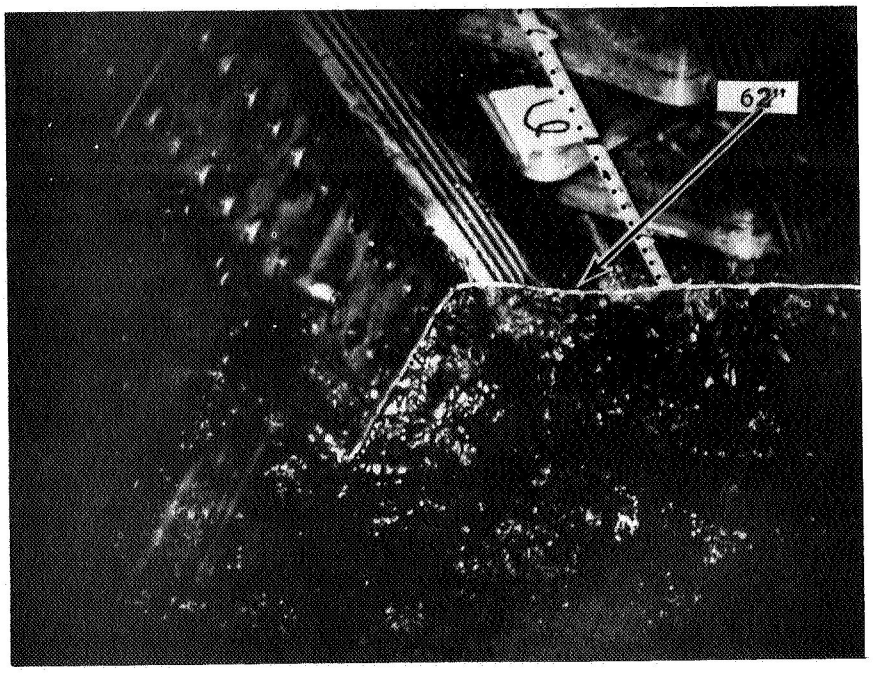


STATIC LEVEL

FIGURE 29 CELL 2 AT 1/2-FULL WATER LEVEL



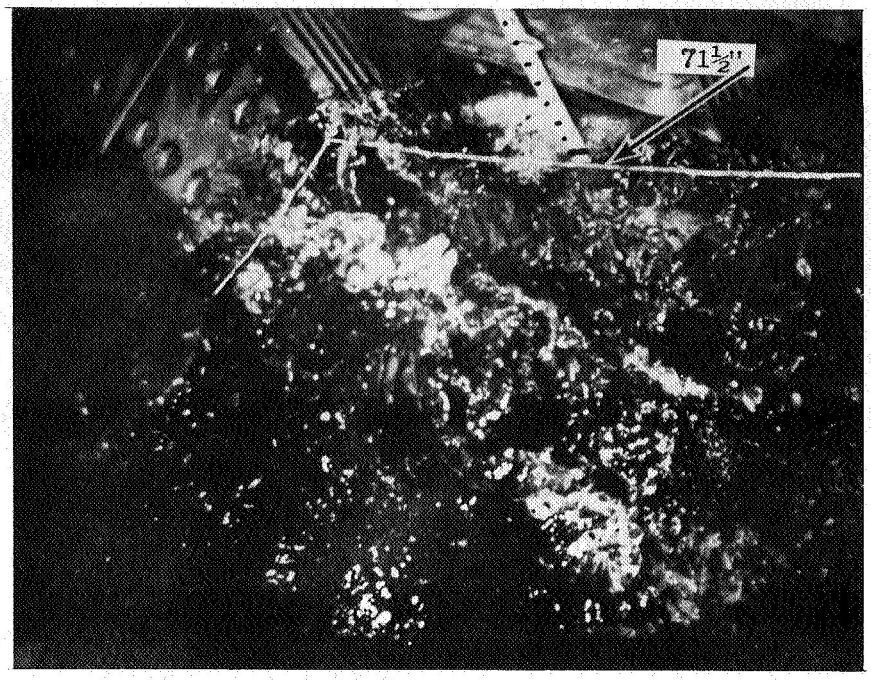
PEAK



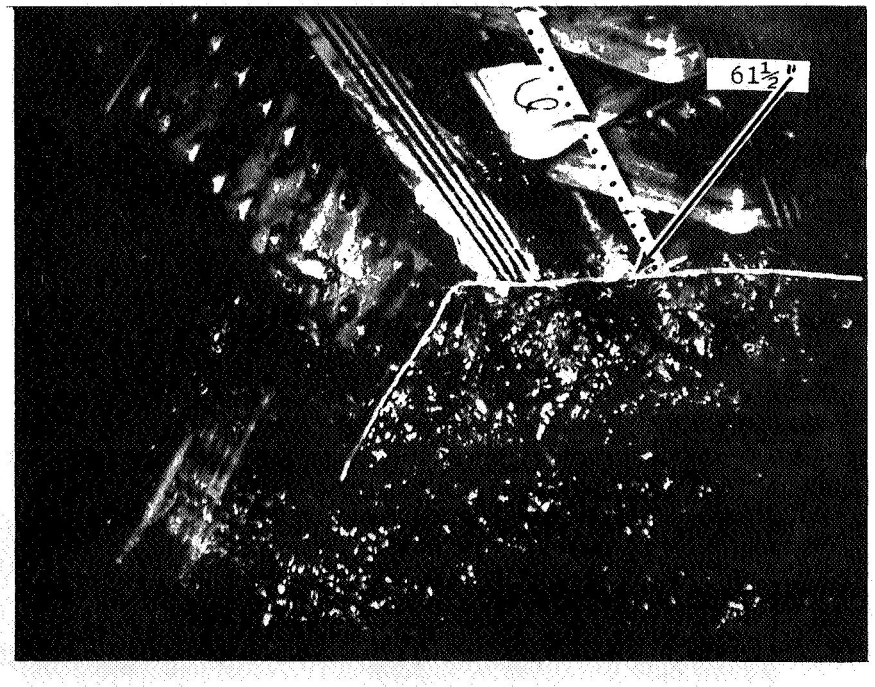
TROUGH

MAXIMUM NON-SPLASH SLOSH CONDITION
½ FULL WATER LEVEL

FIGURE 30 CELL 2 AT RESONANCE



PEAK



TROUGH

SLOSH WITH SPLASH
½ FULL WATER LEVEL

FIGURE 31 CELL 2 AT RESONANCE

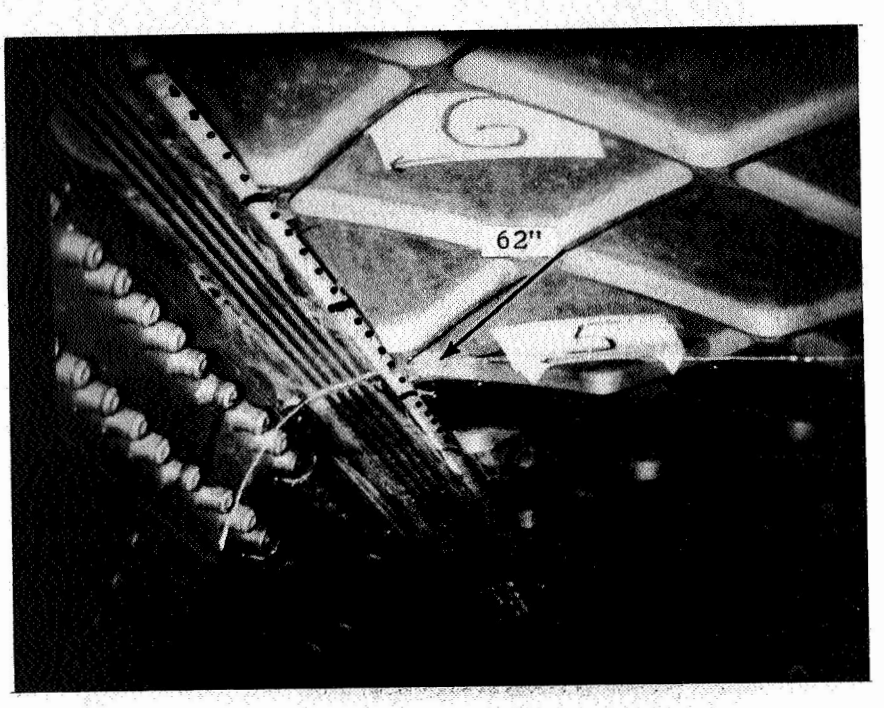
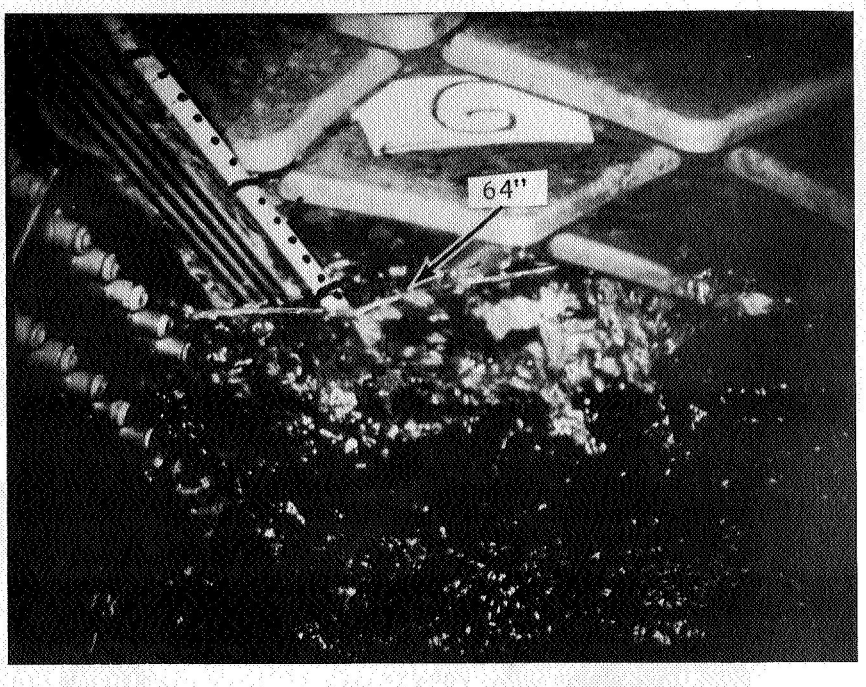
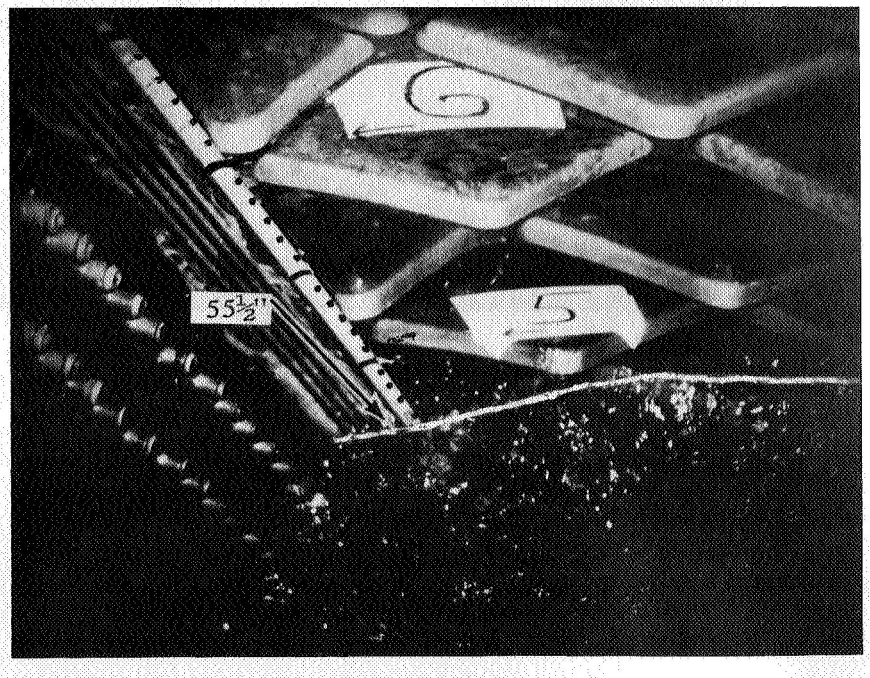


FIGURE 32 CELL 3 AT 1/2-FULL WATER LEVEL



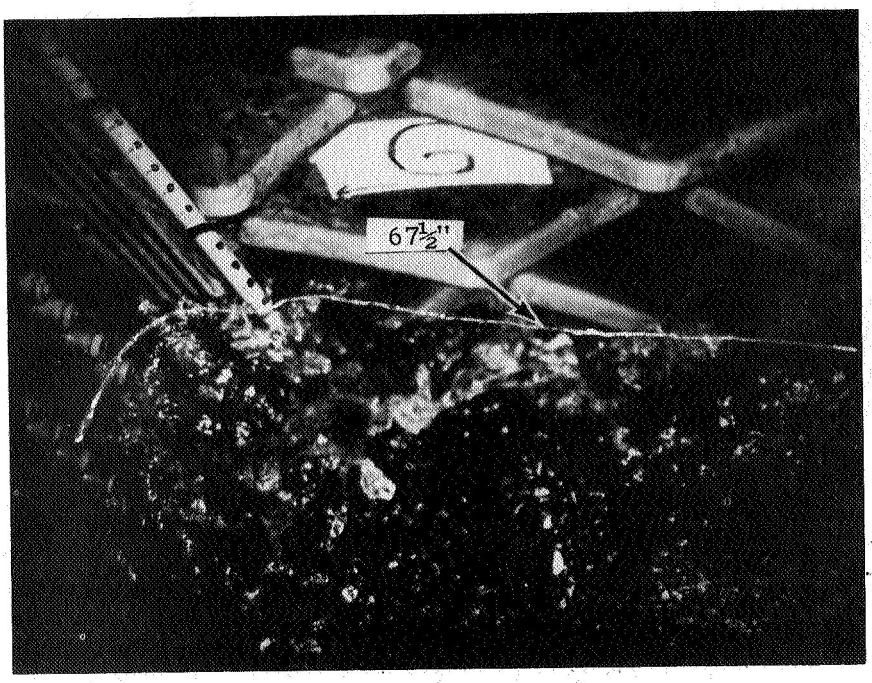
PEAK



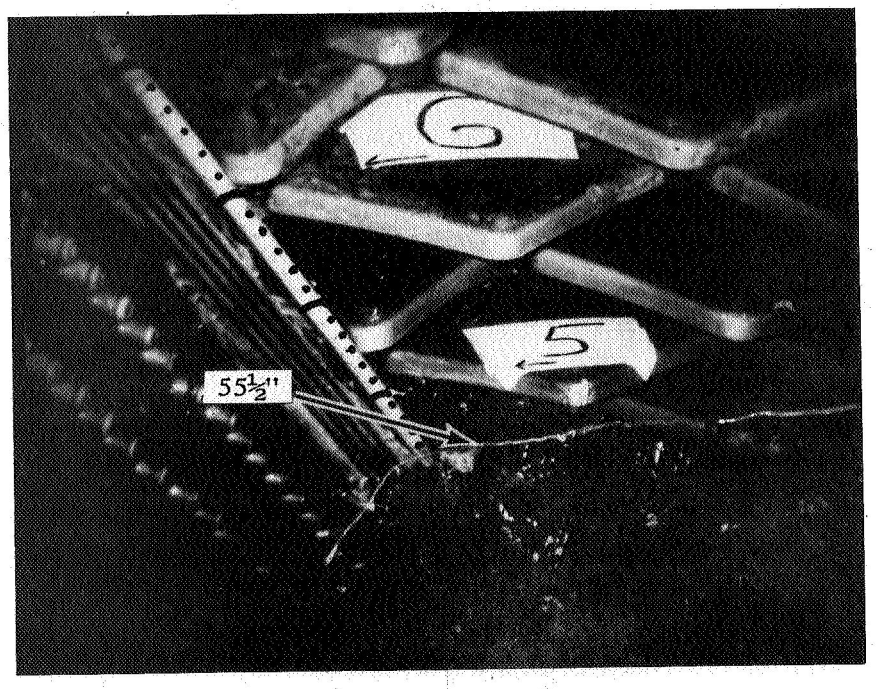
TROUGH

MAXIMUM NON-SPLASH SLOSH CONDITION
½ FULL WATER LEVEL

FIGURE 33 CELL 3 AT RESONANCE



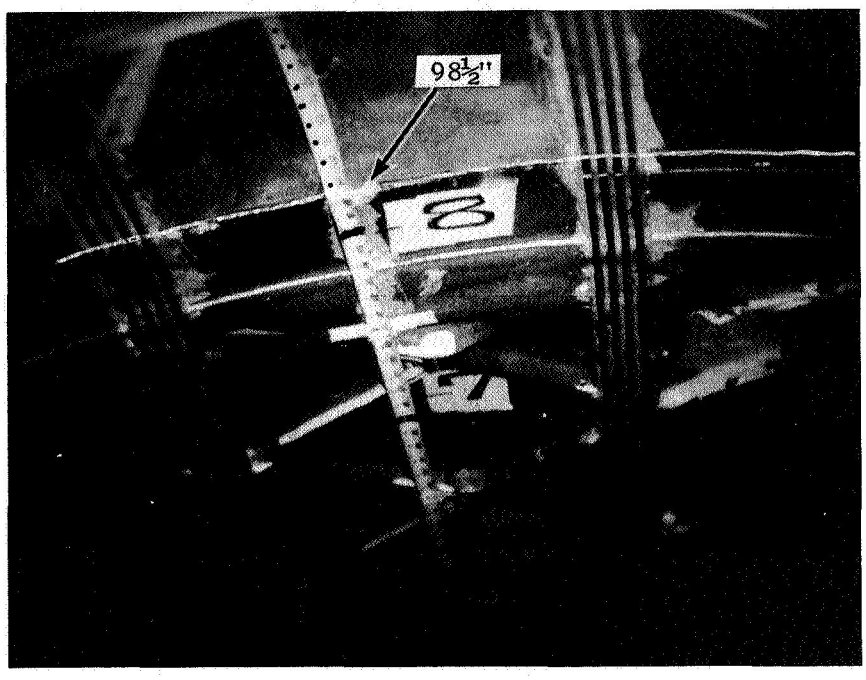
PEAK



TROUGH

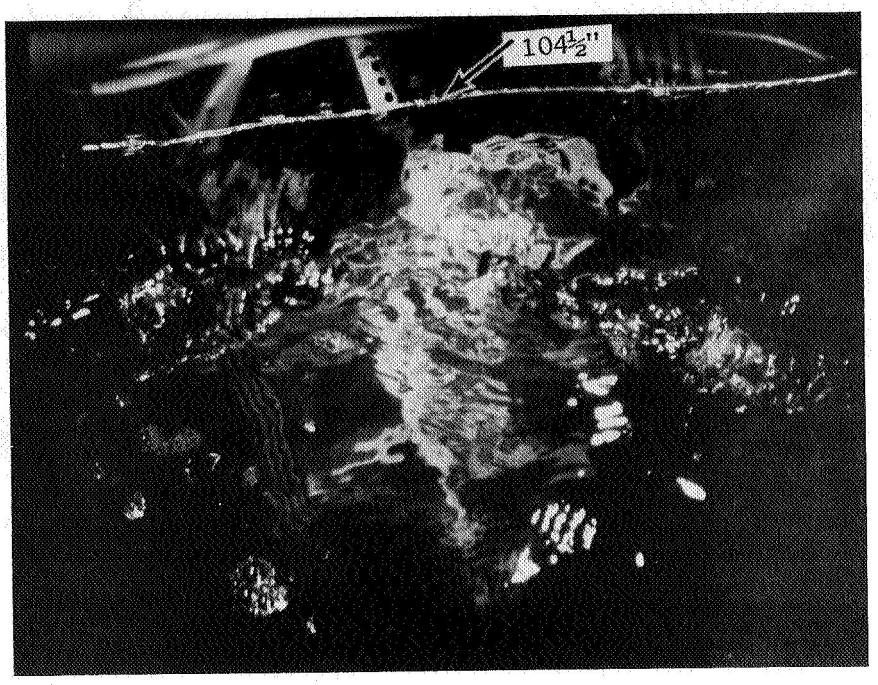
SLOSH WITH SPLASH
½ FULL WATER LEVEL

FIGURE 34 CELL 3 AT RESONANCE

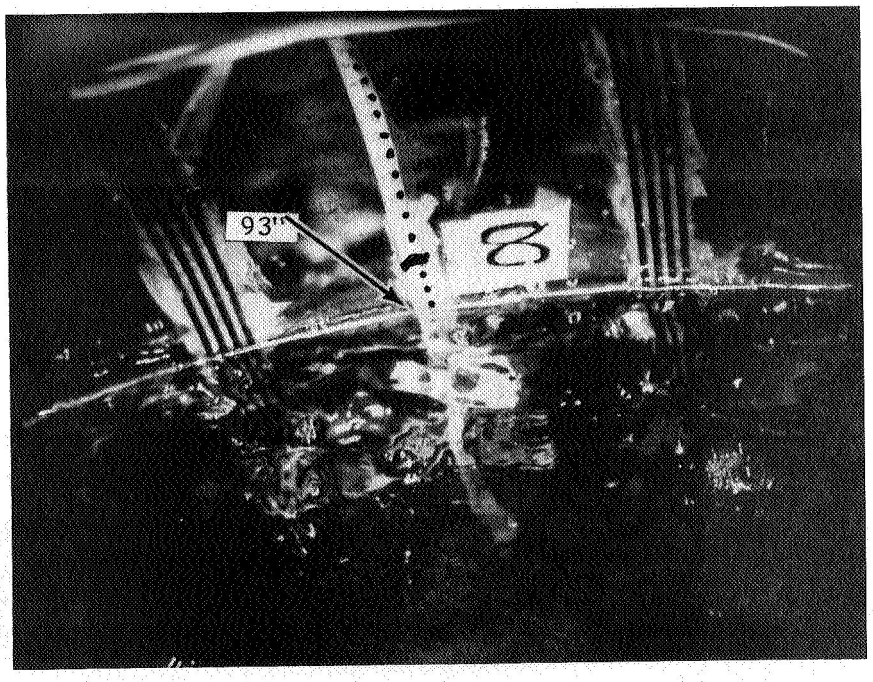


STATIC LEVEL

FIGURE 35 CELL 1 AT 3/4-FULL WATER LEVEL



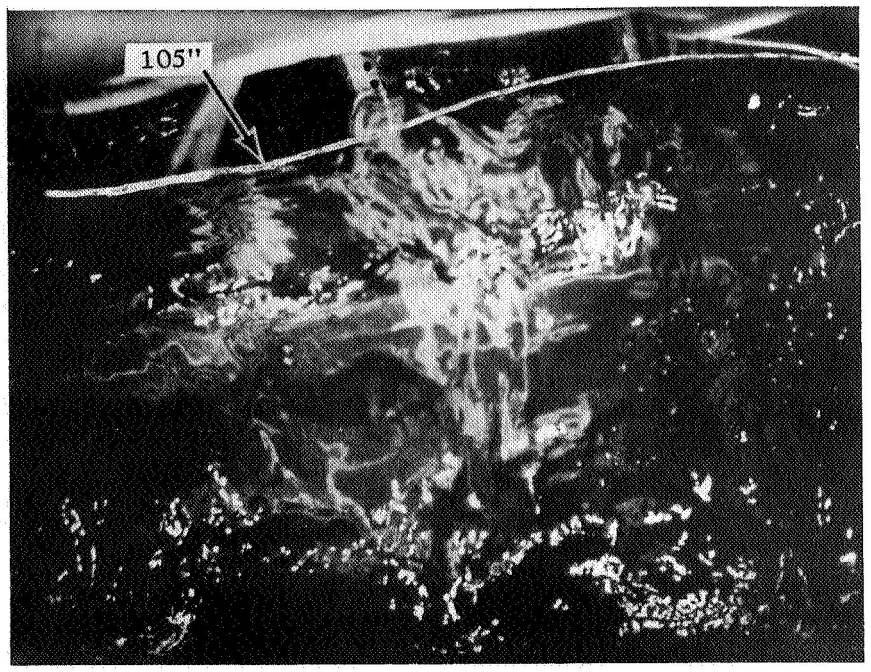
PEAK



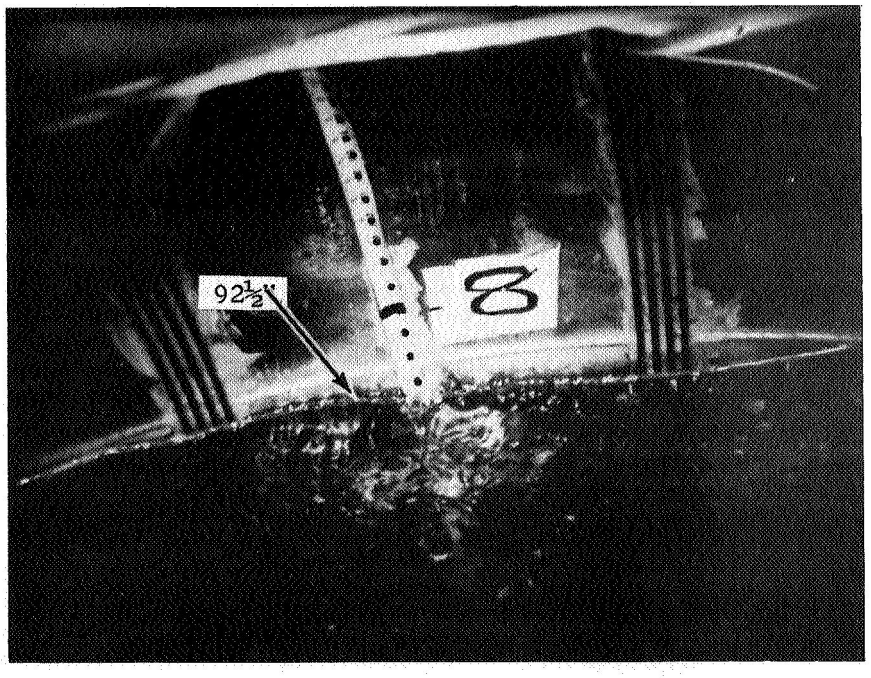
TROUGH

MAXIMUM NON-SPLASH SLOSH CONDITION
3/4 FULL WATER LEVEL

FIGURE 36 CELL 1 AT RESONANCE



PEAK



TROUGH

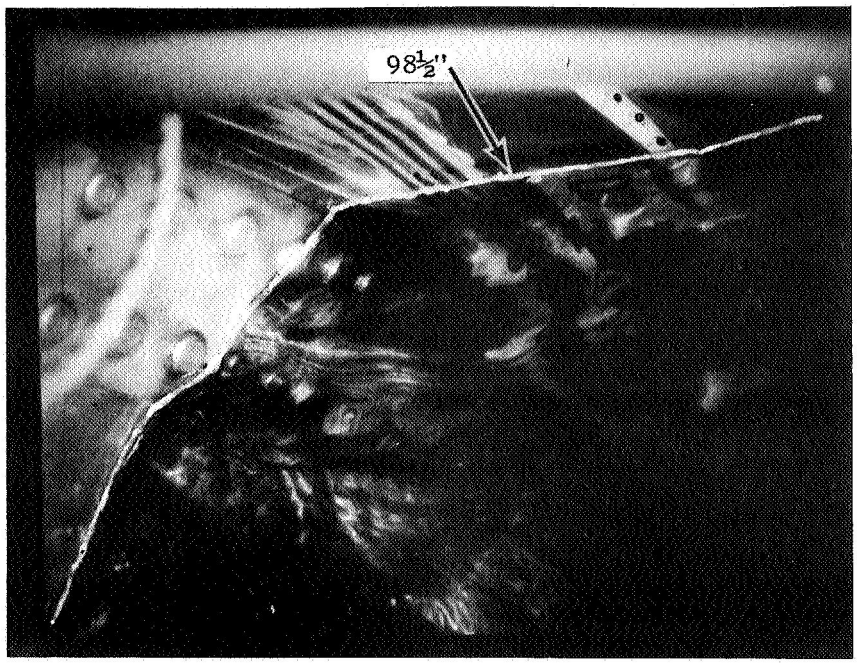
SLOSH WITH SPLASH
3/4 FULL WATER LEVEL

FIGURE 37 CELL 1 AT RESONANCE

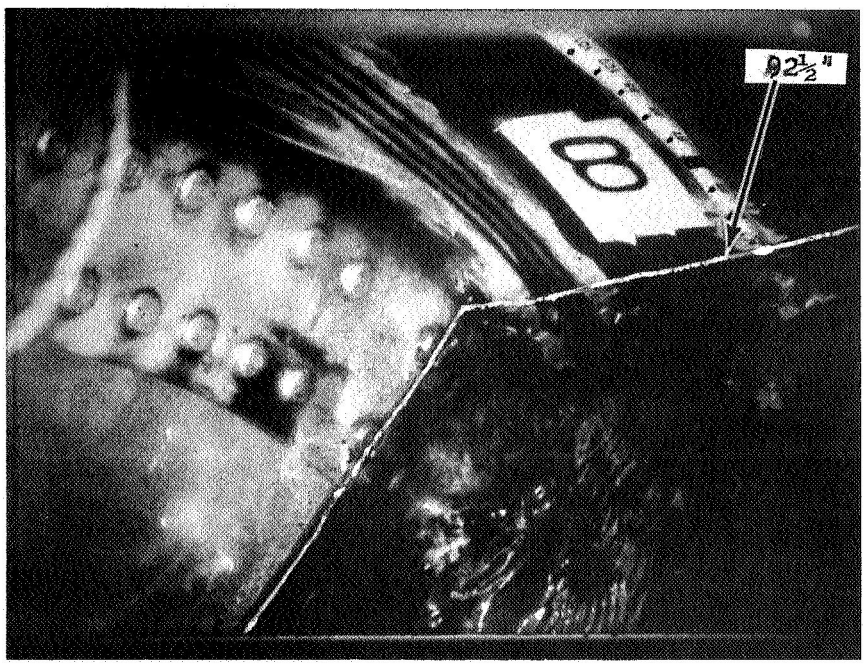


STATIC LEVEL

FIGURE 38 CELL 2 AT 3/4-FULL WATER LEVEL



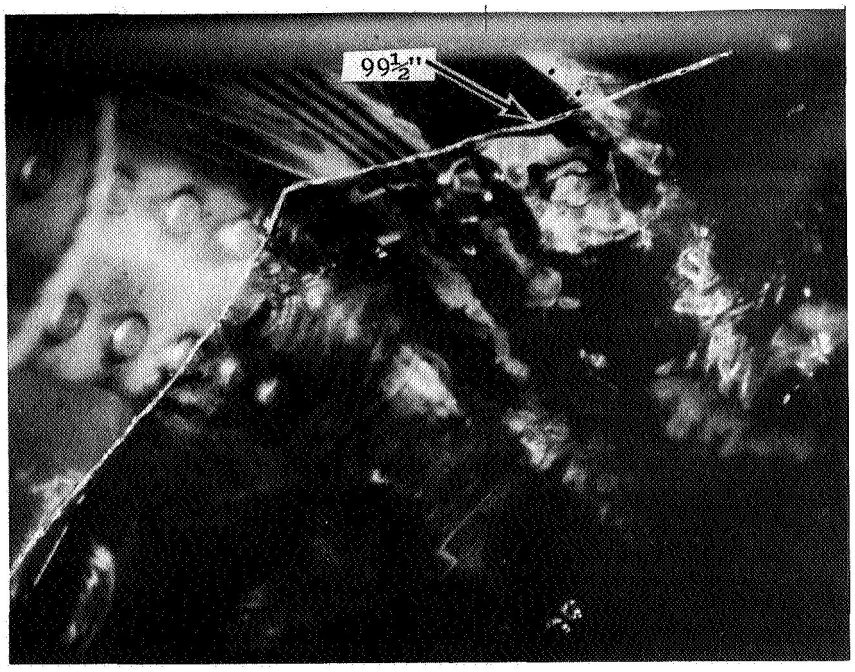
PEAK



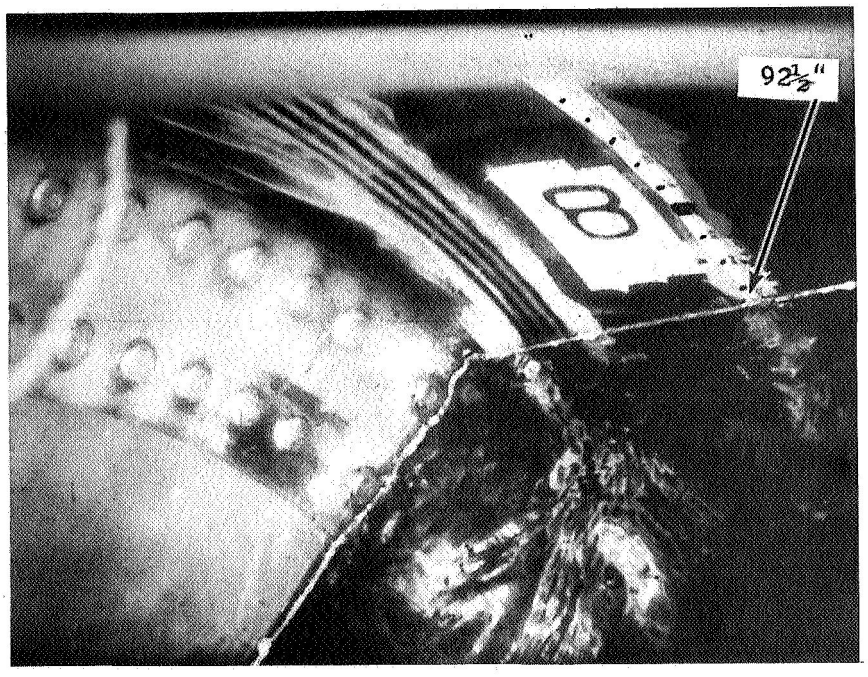
TROUGH

MAXIMUM NON-SPLASH SLOSH CONDITION
3/4 FULL WATER LEVEL

FIGURE 39 CELL 2 AT RESONANCE



PEAK



TROUGH

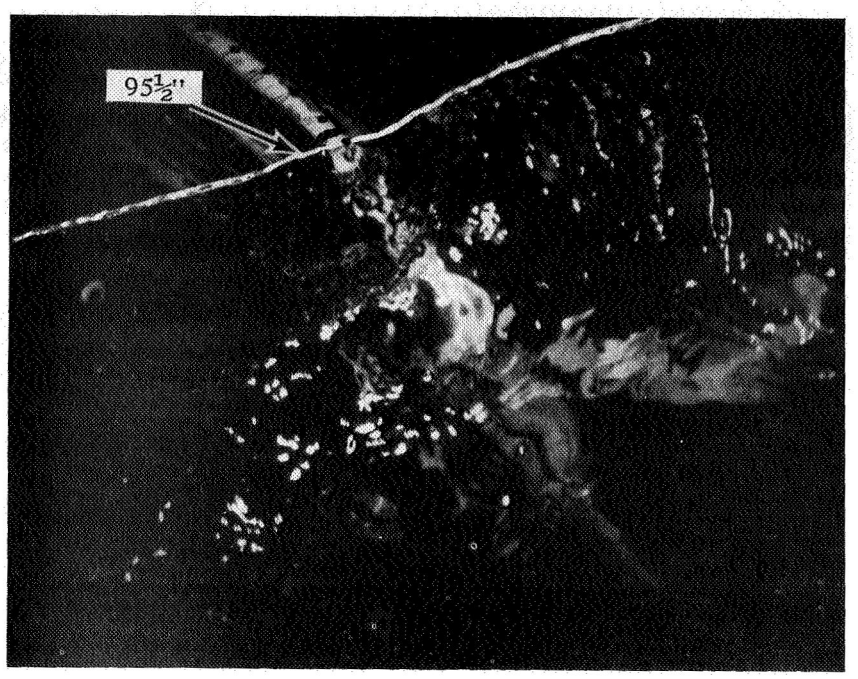
SLOSH WITH SPLASH
3/4 FULL WATER LEVEL

FIGURE 40 CELL 2 AT RESONANCE

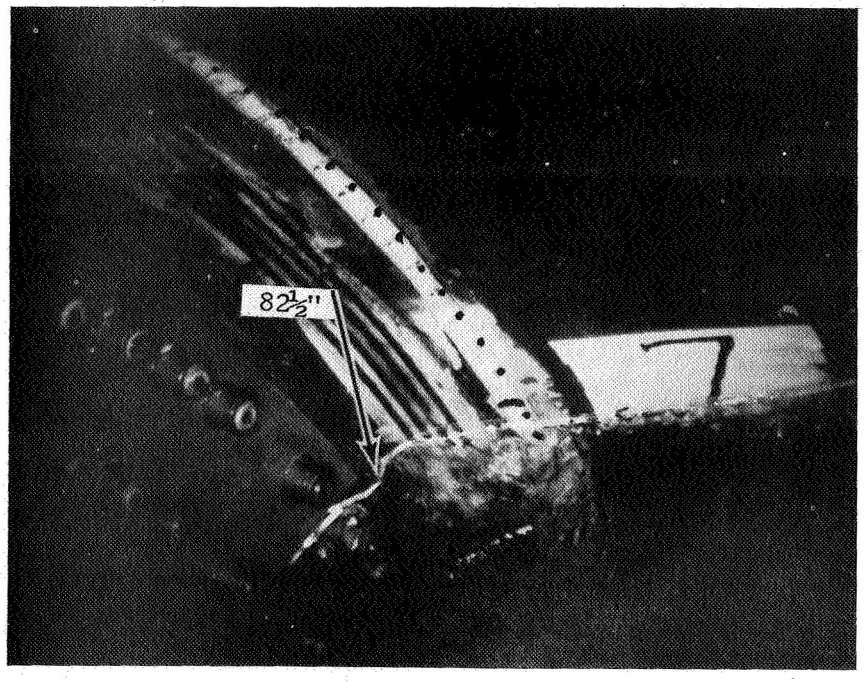


STATIC LEVEL

FIGURE 41 CELL 3 AT 3/4-FULL WATER LEVEL



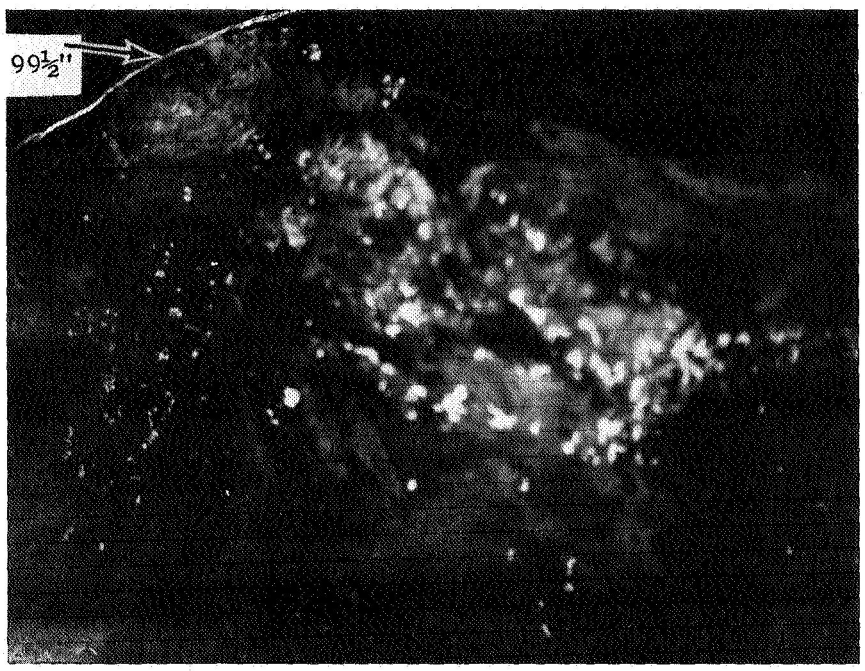
PEAK



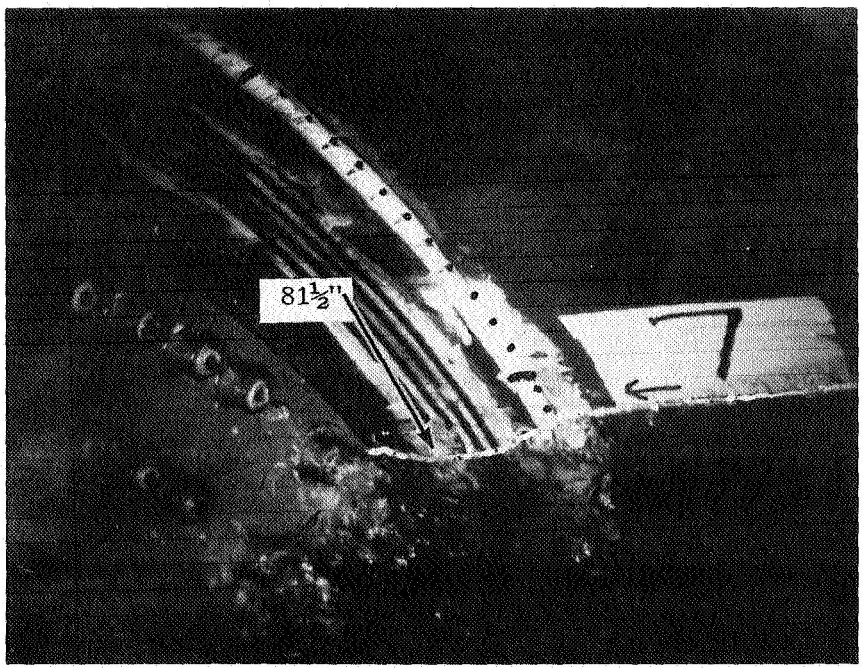
TROUGH

MAXIMUM NON-SPLASH SLOSH CONDITION
3/4 FULL WATER LEVEL

FIGURE 42 CELL 3 AT RESONANCE



PEAK



TROUGH

SLOSH WITH SPLASH
3/4 FULL WATER LEVEL

FIGURE 43 CELL 3 AT RESONANCE

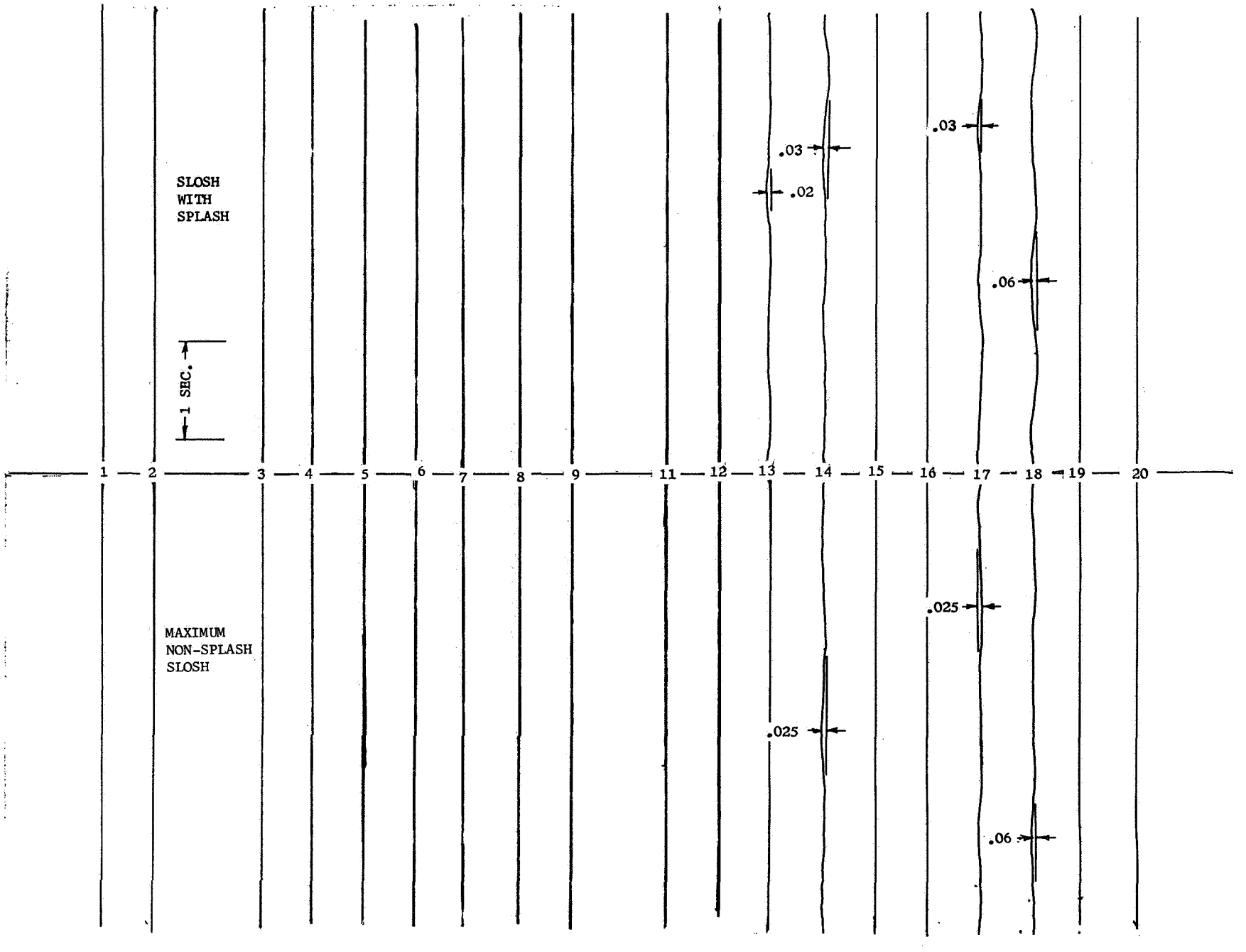


FIGURE 44 CELL 1 AT RESONANCE 1/2 FULL WATER LEVEL

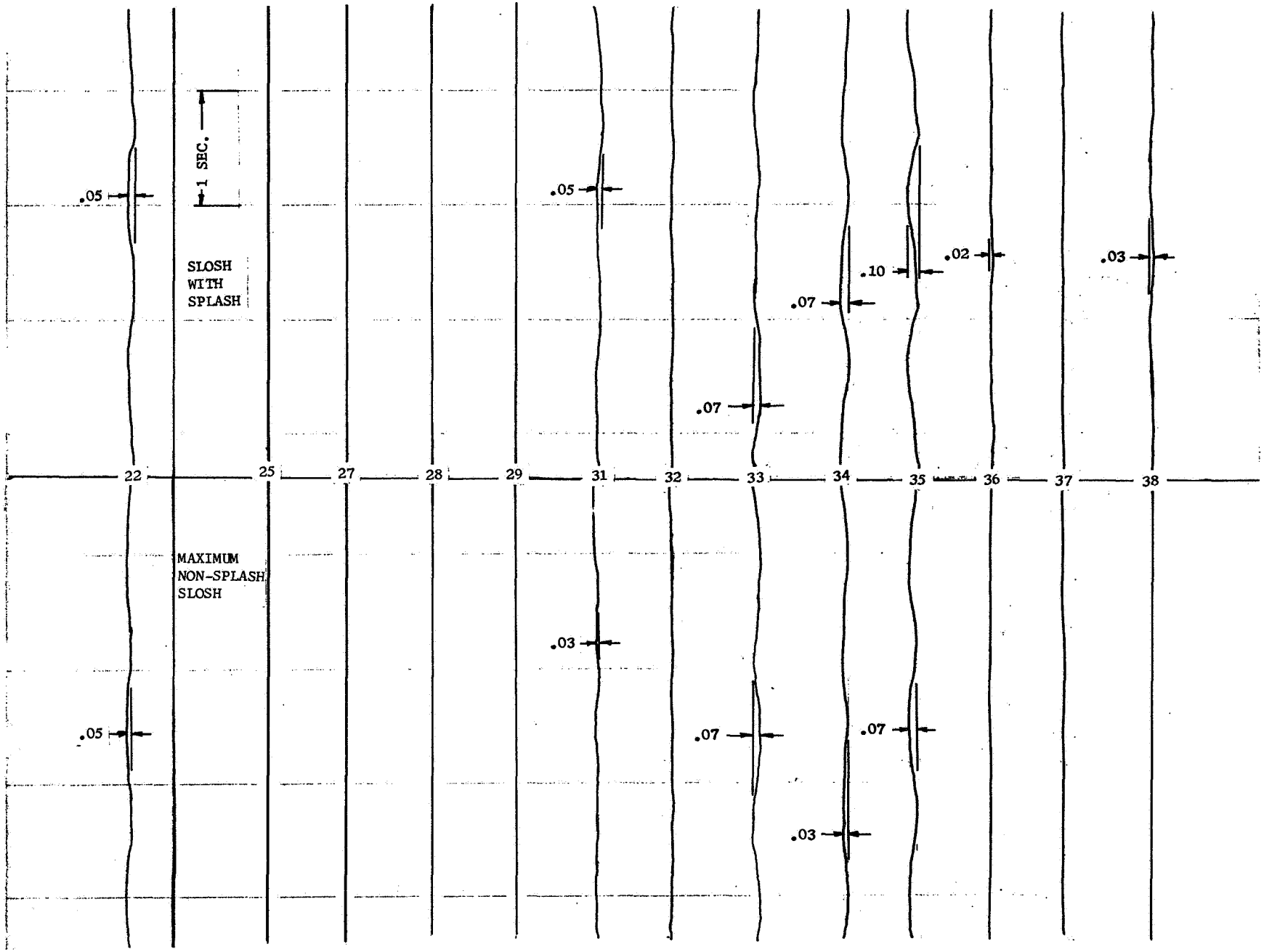


FIGURE 45 CELL 1 AT RESONANCE 1/2 FULL WATER LEVEL

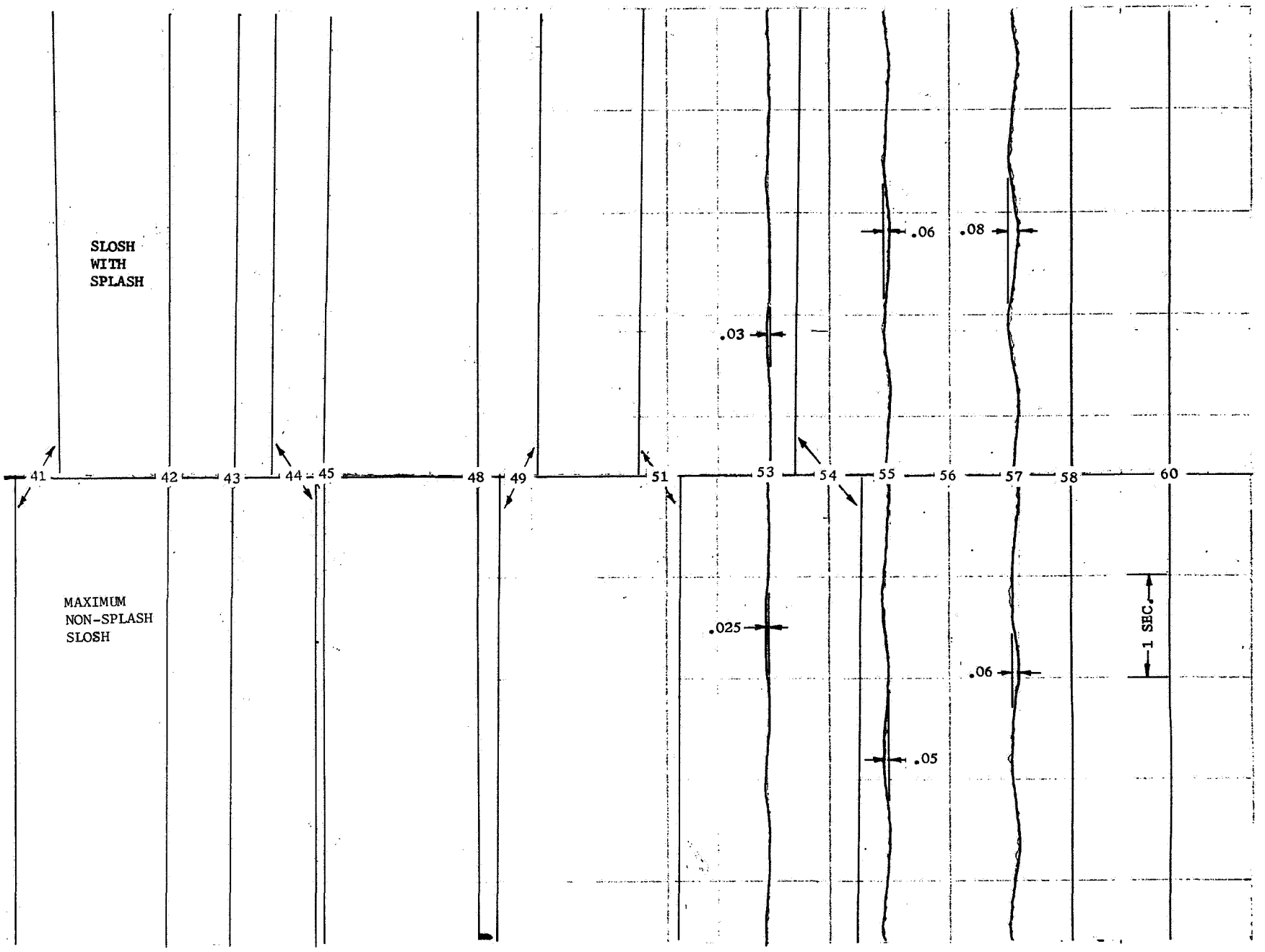


FIGURE 46 CELL 1 AT RESONANCE 1/2 FULL WATER LEVEL

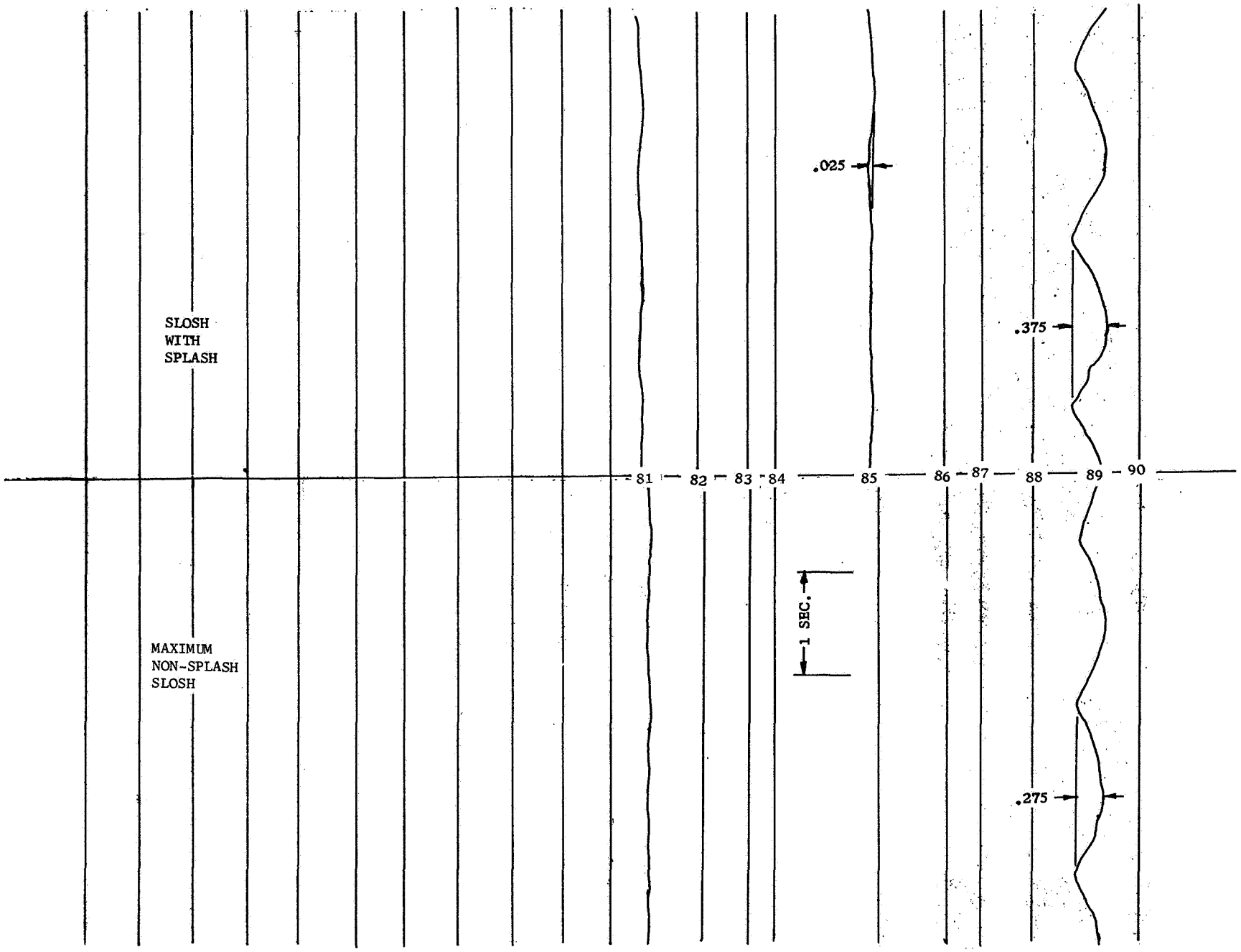


FIGURE 47 CELL 1 AT RESONANCE 1/2 FULL WATER LEVEL

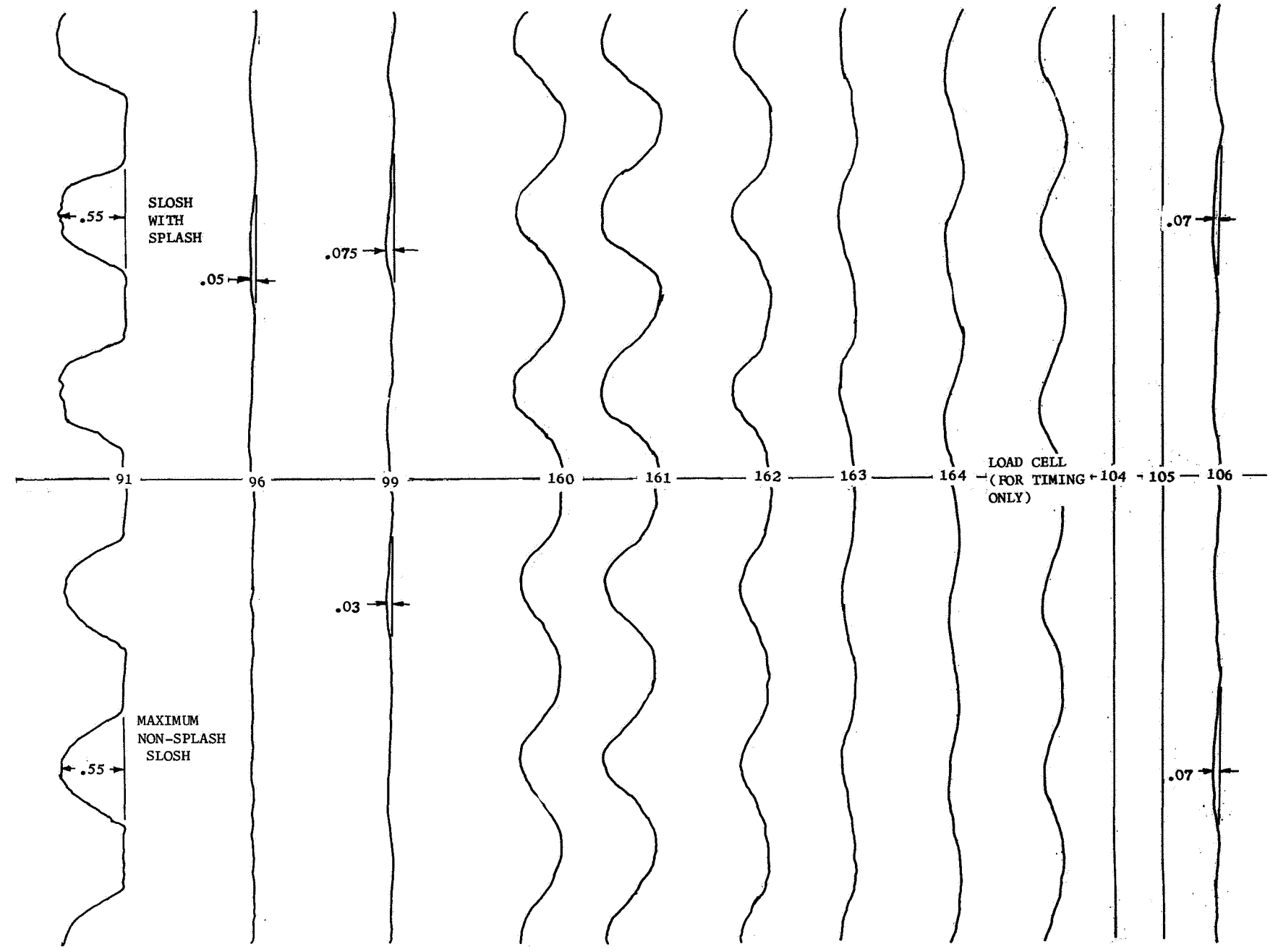


FIGURE 48 CELL 1 AT RESONANCE 1/2 FULL WATER LEVEL

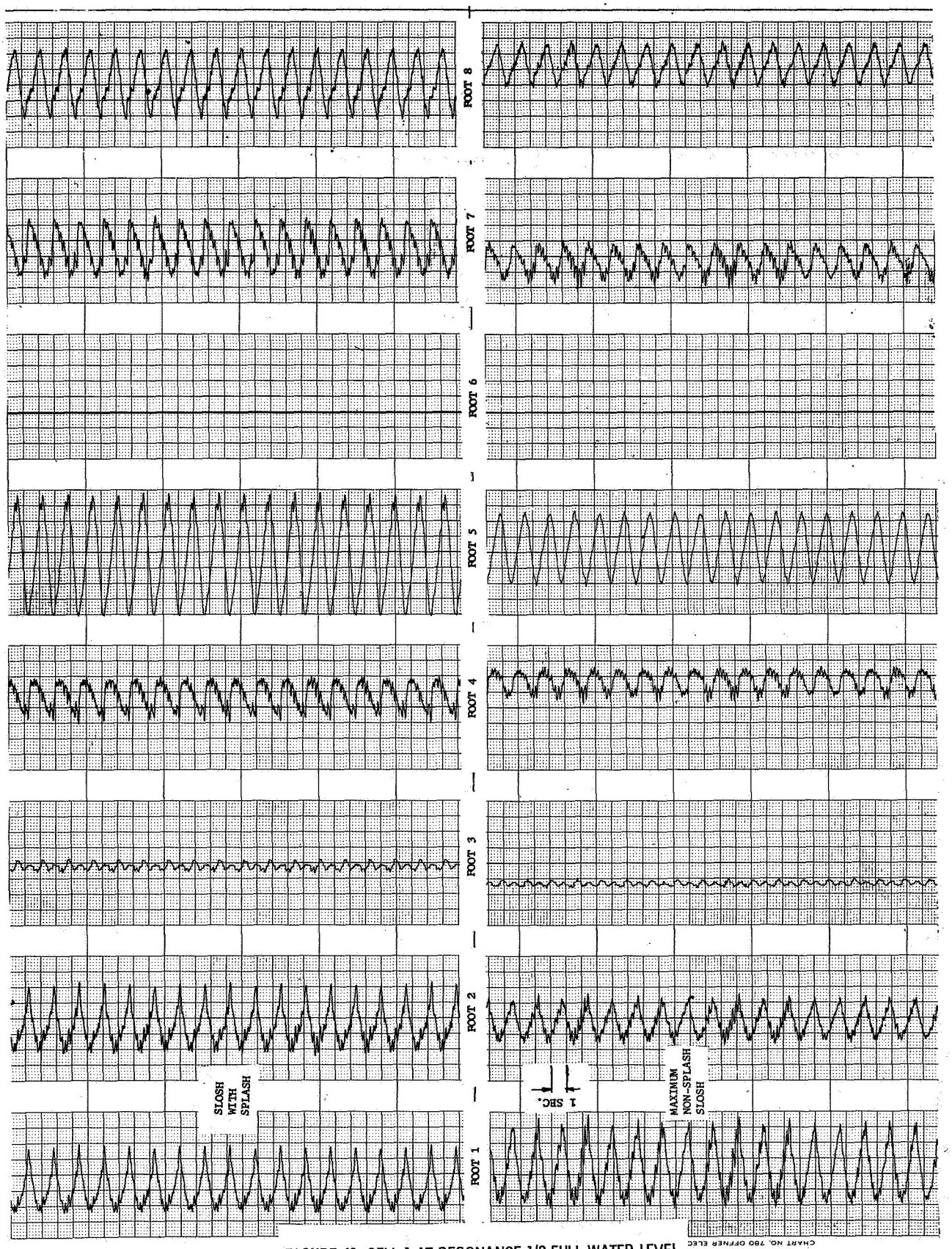


FIGURE 49 CELL 1 AT RESONANCE 1/2 FULL WATER LEVEL

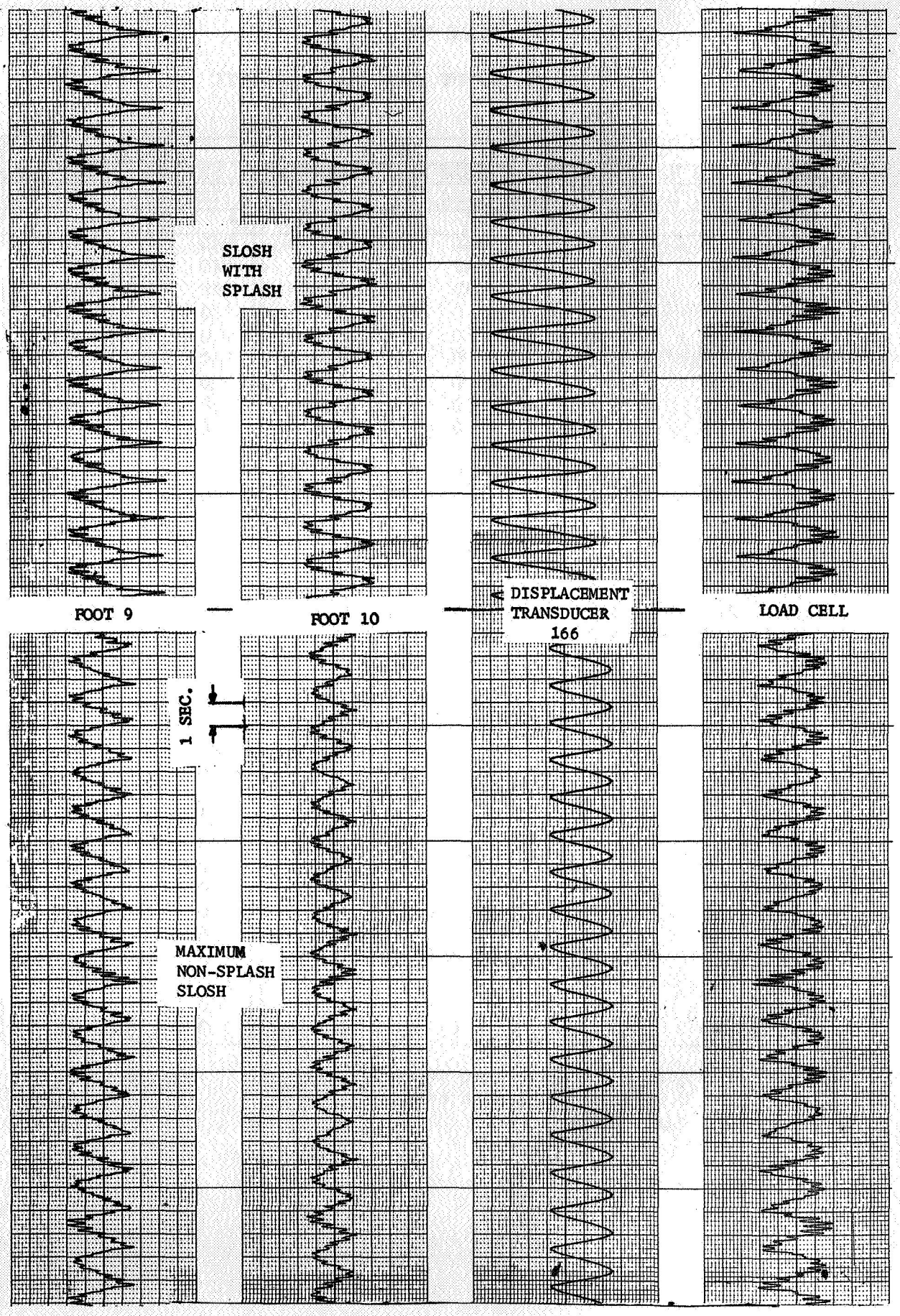


FIGURE 50 CELL 1 AT RESONANCE 1/2 FULL WATER LEVEL

TABLE I

TRANSDUCER OUTPUT WHEN TANK IS ½-FULL

	CELL 1		CELL 2		CELL 3	
R.F.	.613 HZ.	.615 HZ.	.820 HZ.	.815 HZ.	.825 HZ.	.827 HZ.
S.D.	.850 IN.	1.425 IN.	.124 IN.	.239 IN.	.128 IN.	.244 IN.
GAGE	μ - IN.	μ - IN.	μ - IN.	μ - IN.	μ - IN.	μ - IN.
1	BAD	BAD	BAD	BAD	BAD	BAD
2	BAD	BAD	BAD	BAD	BAD	BAD
3	BAD	BAD	BAD	BAD	BAD	BAD
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	BAD	BAD	BAD	BAD	BAD	BAD
12	BAD	BAD	BAD	BAD	BAD	BAD
13	0	160	400	400	320	400
14	280	330	665	780	665	780
15	0	0	800	800	0	0
16	0	0	330	265	0	330
17	210	250	250	210	250	250
18	220	220	180	180	180	145
19	BAD	BAD	BAD	BAD	BAD	BAD
20	0	0	0	0	0	0
21	BAD	BAD	BAD	BAD	BAD	BAD
22	400	400	0	0	0	0
23	BAD	BAD	BAD	BAD	BAD	BAD
24	BAD	BAD	BAD	BAD	BAD	BAD
25	0	0	600	600	600	600
26	BAD	BAD	BAD	BAD	BAD	BAD
27	0	0	0	0	0	0
28	0	0	0	0	0	0
29	0	0	0	0	0	0
30	0	0	0	0	0	0
31	100	165	0	0	0	0
32	0	0	0	0	0	0
33	350	350	0	0	0	0
34	85	200	0	0	0	0
35	200	290	0	0	0	0

SYMBOLS: R.F. = Resonant Frequency
S.D. = Shaker Displacement
μ = Micro

TABLE I

TRANSDUCER OUTPUT WHEN TANK IS ½-FULL

	CELL 1		CELL 2		CELL 3	
R.F.	.613 HZ.	.615 HZ.	.820 HZ.	.815 HZ.	.825 HZ.	.827 HZ.
S.D.	.850 IN.	1.425 IN.	.124 IN.	.239 IN.	.128 IN.	.244 IN.
GAGE	μ - IN.	μ - IN.	μ - IN.	μ - IN.	μ - IN.	μ - IN.
36	0	160	0	0	0	0
37	0	0	0	0	0	0
38	0	90	0	0	0	0
39	BAD	BAD	BAD	BAD	BAD	BAD
40	BAD	BAD	BAD	BAD	BAD	BAD
41	0	0	0	0	0	0
42	0	0	0	0	0	0
43	0	0	0	0	0	0
44	0	0	0	0	0	0
45	0	0	0	0	0	0
46	BAD	BAD	BAD	BAD	BAD	BAD
47	BAD	BAD	BAD	BAD	BAD	BAD
48	0	0	0	0	0	0
49	0	0	0	0	0	0
50	BAD	BAD	BAD	BAD	BAD	BAD
51	0	0	0	0	0	0
52	BAD	BAD	BAD	BAD	BAD	BAD
53	145	170	170	285	170	230
54	0	0	0	0	0	0
55	265	315	210	315	210	265
56	0	0	0	0	0	0
57	345	455	230	285	145	285
58	0	0	0	0	0	0
59	BAD	BAD	BAD	BAD	BAD	BAD
60	BAD	BAD	BAD	BAD	BAD	BAD
61	0	0	0	0	0	0
62	BAD	BAD	BAD	BAD	BAD	BAD
67	0	0	0	0	0	0
68	0	0	0	0	0	0
69	0	0	0	0	0	0
70	0	0	0	0	0	0
71	0	0	0	0	0	0
72	0	0	0	0	0	0
73	0	0	0	0	0	0
74	0	0	0	0	0	0

SYMBOLS: R.F. = Resonant Frequency
S.D. = Shaker Displacement
μ = Micro

TABLE I

TRANSDUCER OUTPUT WHEN TANK IS ½-FULL

	CELL 1		CELL 2		CELL 3	
R.F.	.613 HZ.	.615 HZ.	.820 HZ.	.815 HZ.	.825 HZ.	.827 HZ.
S.D.	.850 IN.	1.425 IN.	.124 IN.	.239 IN.	.128 IN.	.244 IN.
P.T.	P.S.I.	P.S.I.	P.S.I.	P.S.I.	P.S.I.	P.S.I.
81	BAD	BAD	BAD	BAD	BAD	BAD
82	0	0	0	0	0	0
83	0	0	0	0	0	0
84	BAD	BAD	BAD	BAD	BAD	BAD
85	0	.30	0	0	0	0
86	0	0	0	0	0	0
87	BAD	BAD	BAD	BAD	BAD	BAD
88	BAD	BAD	BAD	BAD	BAD	BAD
89	.35	.50	.20	.25	.20	.25
90	BAD	BAD	BAD	BAD	BAD	BAD
91	.35	.35	.03	.05	.03	.08
96	0	.10	0	0	0	0
99	.02	.06	0	0	0	0
100	BAD	BAD	BAD	BAD	BAD	BAD
104	0	0	0	0	0	0
105	0	0	0	0	0	0
106	.35	.35	0	0	0	0
S.S.*	Oscillograph Movement and Corresponding (Peak-to-Trough Slosh Movement) (Inches)					
160	.375(9¼)	.450(15½)	.140(N.A.)	.225(N.A.)	.180(N.A.)	.300(N.A.)
162	.275(N.A.)	.360(N.A.)	.230(10 3/4)	.300(14¼)	.200(N.A.)	.300(N.A.)
164	.080(N.A.)	.140(N.A.)	.580(N.A.)	.625(N.A.)	.560(11)	.650(14)
L.F.	Change in Load While Sloshing (Pounds) (Peak Load-Minimum Load)					
1	1560	2380-2630	560-715	750-935	435-680	620-865
2	910-1210	1520-1670	455-530	530-605	304-450	420-610
3	190	250	60-95	125	95-125	155
4	805-895	1070-1340	585-675	535-715	405-675	585-810
5	1435	2375-2500	310-465	750	280-435	650-710
6	BAD	BAD	BAD	BAD	BAD	BAD
7	690-940	1060-1250	370-560	625-750	435-650	590-745
8	810	1375-1440	250-340	435	185-280	370-465
9	950	1300	375	500	250-600	375-500
10	600	950	350	500	250-450	450-575
L.C.	720	1040	415	400	200-390	280-460

SYMBOLS: R.F. = Resonant Frequency; S.D. = Shaker Displacement; P.T. = Pressure Transducer; S.S. = Slosh Sensor; L.F. = Load Feet; L.C. = Load Cell

*NOTE: The actual slosh movement is not linearly proportional to oscillograph movement.

TABLE II

TRANSDUCER OUTPUT WHEN TANK IS 3/4-FULL

	CELL 1		CELL 2		CELL 3	
R.F.	.634 HZ.	.633 HZ.	.830 HZ.	.830 HZ.	.840 HZ.	.840 HZ.
S.D.	.850 IN.	1.250 IN.	.034 IN.	.067 IN.	.129 HZ.	.222 IN.
GAGE	μ - IN.	μ - IN.	μ - IN.	μ - IN.	μ - IN.	μ - IN.
1	BAD	BAD	BAD	BAD	BAD	BAD
2	BAD	BAD	BAD	BAD	BAD	BAD
3	BAD	BAD	BAD	BAD	BAD	BAD
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	300	350	0	0	0	0
9	240	240	0	0	0	0
10	0	0	0	0	0	0
11	BAD	BAD	BAD	BAD	BAD	BAD
12	BAD	BAD	BAD	BAD	BAD	BAD
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	320	720	0	0	0	240
18	200	275	0	75	75	125
19	BAD	BAD	BAD	BAD	BAD	BAD
20	0	0	0	0	0	0
21	BAD	BAD	BAD	BAD	BAD	BAD
22	0	200	0	0	0	0
23	BAD	BAD	BAD	BAD	BAD	BAD
24	BAD	BAD	BAD	BAD	BAD	BAD
25	0	0	0	0	0	0
26	BAD	BAD	BAD	BAD	BAD	BAD
27	80	180	0	0	0	100
28	0	0	0	0	0	0
29	0	0	0	0	0	0
30	0	0	0	0	0	0
31	135	335	0	0	0	0
32	0	0	0	0	0	0
33	0	150	0	0	0	100
34	55	170	0	0	0	70
35	215	400	0	55	55	145

SYMBOLS: R.F. = Resonant Frequency
S.D. = Shaker Displacement
μ = Micro

TABLE II

TRANSDUCER OUTPUT WHEN TANK IS 3/4-FULL

	CELL 1		CELL 2		CELL 3	
R.F.	.634 HZ.	.633 HZ.	.830 HZ.	.830 HZ.	.840 HZ.	.840 HZ.
S.D.	.850 IN.	1.250 IN.	.034 IN.	.067 IN.	.129 IN.	.222 IN.
GAGE	μ - IN.	μ - IN.	μ - IN.	μ - IN.	μ - IN.	μ - IN.
36	0	0	0	0	0	0
37	0	0	0	0	0	0
38	90	185	0	0	0	90
39	BAD	BAD	BAD	BAD	BAD	BAD
40	BAD	BAD	BAD	BAD	BAD	BAD
41	0	0	0	0	0	0
42	0	0	0	0	0	0
43	0	0	0	0	0	0
44	0	0	0	0	0	0
45	0	0	0	0	0	0
46	BAD	BAD	BAD	BAD	BAD	BAD
47	BAD	BAD	BAD	BAD	BAD	BAD
48	0	0	0	0	0	0
49	0	0	0	0	0	0
50	BAD	BAD	BAD	BAD	BAD	BAD
51	0	0	0	0	0	0
52	BAD	BAD	BAD	BAD	BAD	BAD
53	285	400	0	115	0	230
54	0	0	0	0	0	0
55	420	895	130	210	265	395
56	0	0	0	0	0	0
57	715	1140	230	220	170	400
58	0	0	0	0	0	0
59	BAD	BAD	BAD	BAD	BAD	BAD
60	BAD	BAD	BAD	BAD	BAD	BAD
61	0	0	0	0	0	0
62	BAD	BAD	BAD	BAD	BAD	BAD
67	0	0	0	0	0	0
68	0	0	0	0	0	0
69	0	0	0	0	0	0
70	0	0	0	0	0	0
71	0	0	0	0	0	0
72	0	0	0	0	0	0
73	0	0	0	0	0	0
74	0	0	0	0	0	0

SYMBOLS: R.F.=Resonant Frequency
S.D.=Shaker Displacement
μ =Micro

TABLE II

TRANSDUCER OUTPUT WHEN TANK IS 3/4-FULL

	CELL 1		CELL 2		CELL 3	
R.F.	.634 HZ.	.633 HZ.	.830 HZ.	.830 HZ.	.840 HZ.	.840 HZ.
S.D.	.850 IN.	1.250 IN.	.034 IN.	.067 IN.	.129 IN.	.222 IN.
P.T.	P.S.I.	P.S.I.	P.S.I.	P.S.I.	P.S.I.	P.S.I.
81	BAD	BAD	BAD	BAD	BAD	BAD
82	.35	.50	.30	.40	.60	.90
83	.10	.15	.06	.04	.04	.07
84	BAD	BAD	BAD	BAD	BAD	BAD
85	1.85	5.40	0	.55	.85	2.55
86	0	0	0	0	0	0
87	BAD	BAD	BAD	BAD	BAD	BAD
88	BAD	BAD	BAD	BAD	BAD	BAD
89	.40	.60	.20	.15	.10	.35
90	BAD	BAD	BAD	BAD	BAD	BAD
91	.40	.65	0	0	.08	.10
96	0	0	0	0	0	0
99	0	0	0	0	0	0
100	BAD	BAD	BAD	BAD	BAD	BAD
104	0	0	0	0	0	0
105	.20	.30	0	0	0	0
106	0	0	0	0	0	0
S.S.*	Oscillograph Movement and Corresponding (Peak-to-Trough Slosh Movement) (Inches)					
160	.18 (9)	.20 (13½)	.05 (N.A.)	.06 (N.A.)	.08 (N.A.)	.12 (N.A.)
162	.16 (N.A.)	.20 (N.A.)	.10 (5 3/4)	.11 (6)	.10 (N.A.)	.12 (N.A.)
164	.10 (N.A.)	.15 (N.A.)	.25 (N.A.)	.25 (N.A.)	.28 (9¼)	.35 (15½)
L.F.	Change in Load While Sloshing (Peak Load-Minimum Load) (Pounds)					
1	BAD	BAD	BAD	BAD	BAD	BAD
2	1250	2100-2230	260-330	330-395	330-395	850-985
3	BAD	BAD	BAD	BAD	BAD	BAD
4	895-1160	2500-2860	355-445	355-445	445	1160-1520
5	1485-1545	2380	120-180	240-300	360	715-775
6	BAD	BAD	BAD	BAD	BAD	BAD
7	1310-1690	2250-2500	310-435	375-560	435	1250
8	BAD	BAD	BAD	BAD	BAD	BAD
9	1450	2400	350	350	250-450	1100
10	800	800	150	200-250	250-300	650
L.C.	1000	1680	200-260	220-280	180-260	840

SYMBOLS: R.F. = Resonant Frequency; S.D. = Shaker Displacement; P.T. = Pressure Transducer; S.S. = Slosh Sensor; L.F. = Load Feet; L.C. = Load Cell

*NOTE: The actual slosh movement is not linearly proportional to oscillograph movement.

TABLE III

SLOSH MOVEMENT AND TIMING DATA FROM MOVIES

CELL IN RESONANCE	TOTAL SHAKER MOVEMENT (INCHES)	TROUGH TO PEAK MOVEMENT (INCHES)	TIME PEAK OCCURRED RELATIVE TO THE CELL IN RESONANCE (SECONDS)			TIME TROUGH OCCURRED RELATIVE TO THE CELL IN RESONANCE (SECONDS)			WATER LEVEL
			CELL 1	CELL 2	CELL 3	CELL 1	CELL 2	CELL 3	
1	.850	9¼	0	.127	-.035	0	-.046	-.379	½ FULL
1	1.425	15½	0	-.163	.198	0	-.083	-.103	½ FULL
2	.124	10 3/4	.050	0	-.030	.420	0	-.020	½ FULL
2	.239	14¼	.020	0	-.050	.070	0	-.020	½ FULL
3	.128	11	.230	.010	0	-.020	.100	0	½ FULL
3	.244	14	-.020	.100	0	.060	.040	0	½ FULL
1	.129	9	0	-.190	-.030	0	-.090	-.030	3/4 FULL
1	.235	13½	0	-.020	-.200	0	-.100	-.130	3/4 FULL
2	.034	5 3/4	-.005	0	-.170	-.035	0	-.020	3/4 FULL
2	.067	6	U.A.	0	U.A.	U.A.	0	U.A.	3/4 FULL
3	.850	9¼	-.045	.185	0	.045	.040	0	3/4 FULL
3	1.250	15¼	.020	.070	0	.220	.150	0	3/4 FULL

NOTE: U.A. MEANS "UNAVAILABLE"

TABLE IV

BASIC DIMENSIONAL AND TIMING DATA FROM MOVIES

TANK AT ½-FULL WATER LEVEL

CELL AT RESONANCE	SCALE LEVEL	FRAME TIME - SECONDS		
CELL 1	CELL 1	CELL 1	CELL 2	CELL 3
STATIC LEVEL	73½"			
PEAK LEVEL (a)	77¼"	4.6870	4.8140	4.6520
TROUGH LEVEL (a)	68"	5.7100	5.6640	5.3310
PEAK LEVEL (b)	81½"	1.6930	1.5300	1.8905
TROUGH LEVEL (b)	66"	2.8030	2.7200	2.7000
CELL 2	CELL 2	CELL 2	CELL 1	CELL 3
STATIC LEVEL	67 3/4"			
PEAK LEVEL (a)	73 3/4"	43.6600	43.7100	43.6300
TROUGH LEVEL (a)	63"	44.3600	44.7800	44.3400
PEAK LEVEL (b)	76 3/4"	18.8600	18.8800	18.8100
TROUGH LEVEL (b)	62½"	19.5300	19.6000	19.5100
CELL 3	CELL 3	CELL 3	CELL 1	CELL 2
STATIC LEVEL	62 3/4"			
PEAK LEVEL (a)	68 3/8"	13.7700	14.0000	13.7800
TROUGH LEVEL (a)	57"	14.4000	14.5300	14.5000
PEAK LEVEL (b)	70½"	46.8000	46.7800	46.9000
TROUGH LEVEL (b)	56½"	47.6000	47.6600	47.6400
	TANK AT 3/4-FULL WATER LEVEL			
CELL 1	CELL 1	CELL 1	CELL 2	CELL 3
STATIC LEVEL	99"			
PEAK LEVEL (a)	103½"	6.9100	6.7200	6.8800
TROUGH LEVEL (a)	94½"	8.0400	7.9500	8.0100
PEAK LEVEL (b)	106 3/4"	45.1100	45.0900	44.9100
TROUGH LEVEL (b)	93¼"	46.0200	45.9200	45.8900
CELL 2	CELL 2	CELL 2	CELL 1	CELL 3
STATIC LEVEL	94½"			
PEAK LEVEL (a)	98"	44.4300	44.4250	BAD
TROUGH LEVEL (a)	92¼"	45.0550	45.0200	BAD
PEAK LEVEL (b)	98½"	50.8250	50.6500	BAD
TROUGH LEVEL (b)	92½"	51.4400	51.4200	BAD
CELL 3	CELL 3	CELL 3	CELL 1	CELL 2
STATIC LEVEL	87"			
PEAK LEVEL (a)	92 3/4"	41.0750	41.0300	41.2600
TROUGH LEVEL (a)	83½"	41.7000	41.7200	41.7700
PEAK LEVEL (b)	97¼"	45.0900	45.1350	45.1300
TROUGH LEVEL (b)	82"	45.4600	45.6800	45.6100

NOTES: Data obtained from maximum non-splash slosh conditions are shown on rows designated with an (a). Data from splashing slosh conditions are shown on rows designated with a (b).

TABLE V

OSCILLOGRAPH MOVEMENTS WHEN TANK IS ½-FULL

	CELL 1		CELL 2		CELL 3	
R.F.	.613 HZ.	.615 HZ.	.820 HZ.	.815 HZ.	.825 HZ.	.827 HZ.
S.D.	.850 IN.	1.425 IN.	.124 IN.	.239 HZ.	.128 IN.	.244 IN.
GAGE	INCHES	INCHES	INCHES	INCHES	INCHES	INCHES
1	BAD	BAD	BAD	BAD	BAD	BAD
2	BAD	BAD	BAD	BAD	BAD	BAD
3	BAD	BAD	BAD	BAD	BAD	BAD
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	BAD	BAD	BAD	BAD	BAD	BAD
12	BAD	BAD	BAD	BAD	BAD	BAD
13	0	.020	.050	.050	.040	.050
14	.025	.030	.060	.070	.060	.070
15	0	0	.020	.020	0	0
16	0	0	.025	.020	0	.025
17	.025	.030	.030	.025	.030	.030
18	.060	.060	.050	.050	.050	.040
19	BAD	BAD	BAD	BAD	BAD	BAD
20	0	0	0	0	0	0
21	BAD	BAD	BAD	BAD	BAD	BAD
22	.05	.05	0	0	0	0
23	BAD	BAD	BAD	BAD	BAD	BAD
24	BAD	BAD	BAD	BAD	BAD	BAD
25	0	0	.03	.03	.03	.03
26	BAD	BAD	BAD	BAD	BAD	BAD
27	0	0	0	0	0	0
28	0	0	0	0	0	0
29	0	0	0	0	0	0
30	0	0	0	0	0	0
31	.03	.05	0	0	0	0
32	0	0	0	0	0	0
33	.07	.07	0	0	0	0
34	.03	.07	0	0	0	0
35	.07	.10	0	0	0	0

SYMBOLS: R.F. = Resonant Frequency
S.D. = Shaker Displacement

TABLE V

OSCILLOGRAPH MOVEMENTS WHEN TANK IS ½-FULL

	CELL 1		CELL 2		CELL 3	
R.F.	.613 HZ.	.615 HZ.	.820 HZ.	.815 HZ.	.825 HZ.	.827 HZ.
S.D.	.850 IN.	1.425 IN.	.124 IN.	.239 IN.	.128 IN.	.244 IN.
GAGE	INCHES	INCHES	INCHES	INCHES	INCHES	INCHES
36	0	.020	0	0	0	0
37	0	0	0	0	0	0
38	0	.030	0	0	0	0
39	BAD	BAD	BAD	BAD	BAD	BAD
40	BAD	BAD	BAD	BAD	BAD	BAD
41	0	0	0	0	0	0
42	0	0	0	0	0	0
43	0	0	0	0	0	0
44	0	0	0	0	0	0
45	0	0	0	0	0	0
46	BAD	BAD	BAD	BAD	BAD	BAD
47	BAD	BAD	BAD	BAD	BAD	BAD
48	0	0	0	0	0	0
49	0	0	0	0	0	0
50	BAD	BAD	BAD	BAD	BAD	BAD
51	0	0	0	0	0	0
52	BAD	BAD	BAD	BAD	BAD	BAD
53	.025	.030	.030	.050	.030	.040
54	0	0	0	0	0	0
55	.050	.060	.040	.060	.040	.050
56	0	0	0	0	0	0
57	.060	.080	.040	.050	.025	.050
58	0	0	0	0	0	0
59	BAD	BAD	BAD	BAD	BAD	BAD
60	BAD	BAD	BAD	BAD	BAD	BAD
61	0	0	0	0	0	0
62	BAD	BAD	BAD	BAD	BAD	BAD
67	0	0	0	0	0	0
68	0	0	0	0	0	0
69	0	0	0	0	0	0
70	0	0	0	0	0	0
71	0	0	0	0	0	0
72	0	0	0	0	0	0
73	0	0	0	0	0	0
74	0	0	0	0	0	0

SYMBOLS: R.F. = Resonant Frequency
S.D. = Shaker Displacement

TABLE V

OSCILLOGRAPH MOVEMENTS WHEN TANK IS ½-FULL

	CELL 1		CELL 2		CELL 3	
R.F.	.613 HZ.	.615 HZ.	.820 HZ.	.815 HZ.	.825 HZ.	.827 HZ.
S.D.	.850 IN.	1.425 IN.	.124 IN.	.239 IN.	.128 IN.	.244 IN.
P.T.	INCHES	INCHES	INCHES	INCHES	INCHES	INCHES
81	BAD	BAD	BAD	BAD	BAD	BAD
82	0	0	0	0	0	0
83	0	0	0	0	0	0
84	BAD	BAD	BAD	BAD	BAD	BAD
85	0	.025	0	0	0	0
86	0	0	0	0	0	0
87	BAD	BAD	BAD	BAD	BAD	BAD
88	BAD	BAD	BAD	BAD	BAD	BAD
89	.275	.375	.160	.200	.150	.175
90	BAD	BAD	BAD	BAD	BAD	BAD
91	.550	.550	.050	.075	.050	.120
96	0	.050	0	0	0	0
99	.030	.075	0	0	0	0
100	BAD	BAD	BAD	BAD	BAD	BAD
104	0	0	0	0	0	0
105	0	0	0	0	0	0
106	.07	.07	0	0	0	0
S.S.						
160	.375	.450	.140	.225	.180	.300
162	.275	.360	.230	.300	.200	.300
164	.080	.140	.580	.625	.560	.650
L.F.	MILLI-METERS	MILLI-METERS	MILLI-METERS	MILLI-METERS	MILLI-METERS	MILLI-METERS
1	25	19-21	18-23	12-15	14-22	20-28
2	12-16	20-22	12-14	7-8	8-12	11-16
3	3	4	2-3	2	3-4	5
4	9-10	12-15	13-15	6-8	9-15	13-18
5	23	38-40	10-15	12	9-14	21-23
6	BAD	BAD	BAD	BAD	BAD	BAD
7	11-15	17-20	12-18	10-12	14-21	19-24
8	13	22-23	8-11	7	6-9	12-15
9	19	26	15	10	10-24	15-20
10	12	19	14	10	10-18	18-23
L.C.	18	26	52	20	25-49	14-23
166	17	28.5	31	43	23	44

SYMBOLS: R.F. = Resonant Frequency; S.D. = Shaker Displacement; P.T. = Pressure Transducer; S.S. = Slosh Sensor; L.F. = Load Feet; L.C. = Load Cell

NOTE: A range of values indicates the variation observed in the range of cyclic extremes.

TABLE VI

OSCILLOGRAPH MOVEMENTS WHEN TANK IS 3/4-FULL

	CELL 1		CELL 2		CELL 3	
R.F.	.634 HZ.	.633 HZ.	.830 HZ.	.830 HZ.	.840 HZ.	.840 HZ.
S.D.	.850 IN.	1.250 IN.	.034 IN.	.067 IN.	.129 IN.	.222 IN.
GAGE	INCHES	INCHES	INCHES	INCHES	INCHES	INCHES
1	BAD	BAD	BAD	BAD	BAD	BAD
2	BAD	BAD	BAD	BAD	BAD	BAD
3	BAD	BAD	BAD	BAD	BAD	BAD
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	.030	.035	0	0	0	0
9	.030	.030	0	0	0	0
10	0	0	0	0	0	0
11	BAD	BAD	BAD	BAD	BAD	BAD
12	BAD	BAD	BAD	BAD	BAD	BAD
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	.040	.090	0	0	0	.030
18	.055	.075	0	.020	.020	.035
19	BAD	BAD	BAD	BAD	BAD	BAD
20	0	0	0	0	0	0
21	BAD	BAD	BAD	BAD	BAD	BAD
22	0	.025	0	0	0	0
23	BAD	BAD	BAD	BAD	BAD	BAD
24	BAD	BAD	BAD	BAD	BAD	BAD
25	0	0	0	0	0	0
26	BAD	BAD	BAD	BAD	BAD	BAD
27	.020	.045	0	0	0	.025
28	0	0	0	0	0	0
29	0	0	0	0	0	0
30	0	0	0	0	0	0
31	.040	.100	0	0	0	0
32	0	0	0	0	0	0
33	0	.030	0	0	0	.020
34	.020	.060	0	0	0	.025
35	.075	.140	0	.020	.020	.050

SYMBOLS: R.F. = Resonant Frequency
S.D. = Shaker Displacement

TABLE VI

OSCILLOGRAPH MOVEMENTS WHEN TANK IS 3/4-FULL

	CELL 1		CELL 2		CELL 3	
R.F.	.634 HZ.	.633 HZ.	.830 HZ.	.830 HZ.	.840 HZ.	.840 HZ.
S.D.	.850 IN.	1.250 IN.	.034 IN.	.067 IN.	.129 IN.	.222 IN.
GAGE	INCHES	INCHES	INCHES	INCHES	INCHES	INCHES
36	0	0	0	0	0	0
37	0	0	0	0	0	0
38	.030	.060	0	0	0	.030
39	BAD	BAD	BAD	BAD	BAD	BAD
40	BAD	BAD	BAD	BAD	BAD	BAD
41	0	0	0	0	0	0
42	0	0	0	0	0	0
43	0	0	0	0	0	0
44	0	0	0	0	0	0
45	0	0	0	0	0	0
46	BAD	BAD	BAD	BAD	BAD	BAD
47	BAD	BAD	BAD	BAD	BAD	BAD
48	0	0	0	0	0	0
49	0	0	0	0	0	0
50	BAD	BAD	BAD	BAD	BAD	BAD
51	0	0	0	0	0	0
52	BAD	BAD	BAD	BAD	BAD	BAD
53	.050	.070	0	.020	0	.040
54	0	0	0	0	0	0
55	.080	.170	.025	.040	.050	.075
56	0	0	0	0	0	0
57	.125	.200	.040	.040	.030	.070
58	0	0	0	0	0	0
59	BAD	BAD	BAD	BAD	BAD	BAD
60	BAD	BAD	BAD	BAD	BAD	BAD
61	0	0	0	0	0	0
62	BAD	BAD	BAD	BAD	BAD	BAD
67	0	0	0	0	0	0
68	0	0	0	0	0	0
69	0	0	0	0	0	0
70	0	0	0	0	0	0
71	0	0	0	0	0	0
72	0	0	0	0	0	0
73	0	0	0	0	0	0
74	0	0	0	0	0	0

SYMBOLS: R.F. = Resonant Frequency
S.D. = Shaker Displacement

TABLE VI

OSCILLOGRAPH MOVEMENTS WHEN TANK IS 3/4-FULL

	CELL 1		CELL 2		CELL 3	
R.F.	.634 HZ.	.633 HZ.	.830 HZ.	.830 HZ.	.840 HZ.	.840 IN.
S.D.	.850 IN.	1.250 IN.	.034 IN.	.067 IN.	.129 IN.	.228 IN.
P.T.	INCHES	INCHES	INCHES	INCHES	INCHES	INCHES
81	BAD	BAD	BAD	BAD	BAD	BAD
82	.060	.080	.050	.070	.100	.150
83	.380	.500	.200	.140	.150	.220
84	BAD	BAD	BAD	BAD	BAD	BAD
85	.160	.470	0	.050	.075	.220
86	0	0	0	0	0	0
87	BAD	BAD	BAD	BAD	BAD	BAD
88	BAD	BAD	BAD	BAD	BAD	BAD
89	.290	.470	.150	.120	.090	.250
90	BAD	BAD	BAD	BAD	BAD	BAD
91	.660	1.000	0	0	.120	.150
96	0	0	0	0	0	0
99	0	0	0	0	0	0
100	BAD	BAD	BAD	BAD	BAD	BAD
104	0	0	0	0	0	0
105	.050	.070	0	0	0	0
106	0	0	0	0	0	0
S.S.						
160	.180	.20	.05	.06	.08	.12
162	.160	.20	.10	.11	.10	.12
164	.100	.15	.15	.25	.28	.35
L.F.	MILLI-METERS	MILLI-METERS	MILLI-METERS	MILLI-METERS	MILLI-METERS	MILLI-METERS
1	BAD	BAD	BAD	BAD	BAD	BAD
2	19	16-17	4-5	5-6	5-6	13-15
3	BAD	BAD	BAD	BAD	BAD	BAD
4	10-13	14-16	4-5	4-5	5	13-17
5	25-26	20	2-3	4-5	6	12-13
6	BAD	BAD	BAD	BAD	BAD	BAD
7	21-27	18-20	5-7	6-9	7	20
8	BAD	BAD	BAD	BAD	BAD	BAD
9	29	24	7	7	5-9	22
10	16	12	3	4-5	5-6	13
L.C.	25	21	10-13	11-14	9-13	42
166	17	25	6	12	23	40

SYMBOLS: R.F. = Resonant Frequency
S.D. = Shaker Displacement
P.T. = Pressure Transducer
S.S. = Slosh Sensor
L.F. = Load Feet
L.C. = Load Cell

NOTE: A range of values indicates the variation observed in the range of cyclic extremes

TABLE VII

CALIBRATION FOR OSCILLOGRAPH MOVEMENT

2K MICRO-INCH INPUT							
GAGE	OSCILLOGRAPH MOVEMENT INCHES	GAGE	OSCILLOGRAPH MOVEMENT INCHES	GAGE	OSCILLOGRAPH MOVEMENT INCHES	P.T.	PSI PER INCH OF CHART MOVEMENT
1	BAD	25	.10	49	.32	81	BAD
2	BAD	26	BAD	50	BAD	82	6.06
3	BAD	27	.50	51	.36	83	.30
4	.15	28	.10	52	BAD	84	BAD
5	.15	29	.02	53	.35	85	11.5
6	.06	30	.02	54	.35	86	22.4
7	.10	31	.60	55	.38	87	BAD
8	.22	32	.70	56	.35	88	BAD
9	.25	33	.40	57	.35	89	1.30
10	.25	34	.70	58	.26	90	BAD
11	BAD	35	.70	59	BAD	91	.625
12	BAD	36	.25	60	BAD	96	2.00
13	.25	37	.12	61	.02	99	.80
14	.18	38	.65	62	BAD	100	BAD
15	.05	39	BAD	67	.40	104	4.00
16	.15	40	BAD	68	.15	105	4.00
17	.25	41	.30	69	.30	106	4.70
18	.55	42	.03	70	.20		
19	BAD	43	.30	71	.38		
20	.05	44	.03	72	.15		
21	BAD	45	.05	73	.16		
22	.25	46	BAD	74	.30		
23	BAD	47	BAD				
24	BAD	48	.35				

	POUNDS PER MM. FOR TABLE V						POUNDS FOR MM. FOR TABLE VI					
	CELL 1		CELL 2		CELL 3		CELL 1		CELL 2		CELL 3	
L.F.	COL. 1	COL. 2	COL. 1	COL. 2	COL. 1	COL. 2	COL. 1	COL. 2	COL. 1	COL. 2	COL. 1	COL. 2
1	62.5	125.0	31.0	62.5	31.0	31.0	BAD	BAD	BAD	BAD	BAD	BAD
2	75.8	75.8	38.0	75.8	38.0	38.0	65.6	131.2	65.6	65.6	65.6	65.6
3	62.5	62.5	31.0	62.5	31.0	31.0	BAD	BAD	BAD	BAD	BAD	BAD
4	89.5	89.5	45.0	89.5	45.0	45.0	89.3	178.6	89.3	89.3	89.3	89.3
5	62.5	62.5	31.0	62.5	31.0	31.0	59.5	119.0	59.5	59.5	59.5	59.5
6	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD	BAD
7	62.5	62.5	31.0	62.5	31.0	31.0	62.5	125.0	62.5	62.5	62.5	62.5
8	62.5	62.5	31.0	62.5	31.0	31.0	BAD	BAD	BAD	BAD	BAD	BAD
9	50.0	50.0	25.0	50.0	25.0	25.0	50.0	100.0	50.0	50.0	50.0	50.0
10	50.0	50.0	25.0	50.0	25.0	25.0	50.0	100.0	50.0	50.0	50.0	50.0
L.C.	40.0	40.0	8.0	20.0	8.0	20.0	40.0	80.0	20.0	20.0	20.0	20.0

INCHES OF SHAKER MOVEMENT PER MM. CHART MOVEMENT

	FOR TABLE V						FOR TABLE VI					
	CELL 1		CELL 2		CELL 3		CELL 1		CELL 2		CELL 3	
	COL. 1	COL. 2	COL. 1	COL. 2	COL. 1	COL. 2	COL. 1	COL. 2	COL. 1	COL. 2	COL. 1	COL. 2
166	.050	.050	.004	.00556	.00556	.00556	.050	.050	.00556	.00556	.00556	.00556

TABLE VIII

DATA REDUCTION EXAMPLES

1. Determine change in strain at gage 57 when cell 1 is in resonance and the slosh condition is maximum slosh height without splash and the tank is 1/2 full.

Step 1 - Refer to Table V, Cell 1, column 1 and for gage 57 read .060 inches which is the oscillograph trace movement during slosh.

Step 2 - Refer to Table VII for strain gage calibration for gage 57 and read .35 inches for 2K micro-inches per inch.

Step 3 - Compute strain for gage 57.
$.060 \text{ inches} \times \frac{2000 \text{ micro-inches}}{.35 \text{ inches}} = 340$ micro-inches which agrees with the value shown in column 1 of Table I.

2. Determine change in pressure for pressure transducer 91 when cell 3 is in resonance at slosh-with-splash conditions, and the tank is 1/2 full.

Step 1 - Refer to Table V, page 72, cell 3, second column and read .120 inches oscillograph movement for gage 91.

Step 2 - Refer to Table VII and read .625 psi per inch of chart movement.

Step 3 - Compute P.S.I. for gage 91.
$.120 \text{ inches} \times .625 \frac{\text{psi}}{\text{inch of chart movement}} = .08$ P.S.I. which agrees with Table I.

3. Determine change in load on load foot 7 when cell 2 is in resonance for maximum non-splash slosh condition and tank is 1/2 full.

Step 1 - Refer to Table V, Page 72 and for L.F.7 read 12-18 millimeters. This indicates that the range varied from 12 to 18 millimeters during the test.

Step 2 - Refer to Table VII under heading "Pounds Per Min. for Table V." In column 1 for cell 2 read 31 pounds per mm. for L.F.7.

Step 3 - Compute pounds for L.F.7.
$(12\text{-}18)\text{mm} \times 31 \frac{\text{pounds}}{\text{mm.}} = 370 - 560$ pounds which agrees with Table I.

4. Determine amplitude of shaker movement when cell 1 is in resonance, the maximum non-splash slosh condition prevails, and the tank is 1/2 full.

Step 1 - From Table V, 1st Column, Read 17 mm inch oscillograph movement for transducer 166.

Step 2 - From Table VII, Under "Inches .F Shaker Movement per Millimeter Chart Movement," read .050 for transducer 166.

TABLE VIII (CONTINUED):

Step 3 - Compute shaker displacement.
17 mm. x .050 $\frac{\text{inch}}{\text{mm}}$ = .85 inches which agrees with the value recorded for S.D. on Tables I and V.

November 29, 1968

DISTRIBUTION

R-AS-DIR	Mr. Williams
R-AERO-DIR	Mr. Geissler
R-ASTR-DIR	Dr. Haeusserman
R-EO-DIR	Mr. Johnson
R-ME-DIR	Mr. Kuers
R-ME-DIR	Mr. Wuenscher
R-QUAL-DIR	Dr. Stuhlinger
R-TO-DIR	Mr. Richard
R-TEST-DIR	Mr. Heimburg
R-P&VE-DIR	Dr. Lucas
R-P&VE-DIR	Mr. Hellebrand
R-P&VE-DIR	Mr. Palaoro
R-P&VE-A	Mr. Goerner
R-P&VE-M	Mr. Kingsbury
R-P&VE-ME	Mr. McKannan
R-P&VE-MC	Mr. Nunnelley
R-P&VE-MM	Mr. Cataldo
R-P&VE-MN	Mr. Curry
R-P&VE-RT	Miss Scott
R-P&VE-S	Mr. Kroll
R-P&VE-S	Mr. Sterett
R-P&VE-SA	Mr. Verble
R-P&VE-V	Mr. Aberg
R-P&VE-X	Mr. Brooksbank
R-ME-M	Mr. Orr
MS-H	Mr. Akens
MS-IP	Mr. Ziak
MS-T	Mr. Wiggins
F&D-CH	Mr. Dykes
MS-IL	(6)
R-P&VE-BSVD-S4	McCandless (10)

Scientific and Technical Inf. Facility (25)
P. O. Box 33
College Park, Maryland 20740