THE EFFECT OF VARIOUS SLOPES OF BREAKWATER FACES ON THE AMPLITUDE OF THE REFLECTED WAVE

A Thesis Prepared in the
Department of Civil Engineering
California Institute of Technology

May 1947

by

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Candidates for the Degree

Master of Science in Engineering

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Letter of Transmittal

California Institute of Technology
Pasadena, California

May 1947

Department of Civil Engineering
California Institute of Technology
Pasadena,California

Dear Sirs:

We, the undersigned, herewith submit our repoxt in completion of the thesis requirement for the Degree of Master of Science in Civil Engineering in June 1947.

We trust that this work meets with your approval.

Respectfully submitted,

Charles M. Duke

Charles M. Duke

Myron E. Page, Jr.

Myron E. Page, Jr.

Chapter I

Introduction

Purpose of the Report

This investigation was undertaken to determine the variations in amplitude of the reflected wave when the initial wave is subjected to the effects of various slopes of breakwater faces. The investigation was conducted as a one inch to forty foot model study the results of which may be of some value in further development of techniques and procedures at the California Institute of Technology's Hydraulics Model Laboratory and which may prove of some practical significance in the selection of breakwater slopes where the amplitude of the reflected waves is a major problem.

Outline of the Investigation

The investigation included the determination of the amplitudes of the reflected waves at various distances from the reflecting surface for different angles of the reflecting surface and variations in amplitude and length of the initial waves.

In the initial tests, the following conditions were investigated: -

1. Angles of Reflecting Surface with horizontal

   (a) 90°
   (b) 60°
   (c) 45°
   (d) 30°
   (e) 20°
   (f) 10°

2. Amplitudes of Initial Waves

   (a) 30 feet (3/4" at model scale)
   (b) 15 feet (3/8" at model scale)

3. Lengths of Initial Waves

   (a) 2400 feet (60" at model scale)
   (b) 1600 feet (40" at model scale)
   (c) 800 feet (20" at model scale)
   (d) 538 feet (13.5" at model scale)

In the second tests, the following conditions were investigated: -

1. Angles of Reflecting Surface with horizontal

   (a) 90°
   (b) 60°
   (c) 45°
   (d) 30°
   (e) 20°
   (f) 10°

2. Amplitudes of the Initial Waves

   (a) 10 feet (1/4" at model scale)
   (b) 5 feet (1/8" at model scale)

3. Lengths of Initial Waves

   (a) 2150 feet (53.8" at model scale)
   (b) 1075 feet (26.9" at model scale)
   (c) 538 feet (13.5" at model scale)

Acknowledgments

With the facilities of the Hydraulics Model Laboratory of the California Institute of Technology at our disposal and the assistance of the staff, the primary limiting factor on this investigation was the time available for the work. The authors are greatly indebted to Dr. W. O. Wagner for his assistance in outlining the problem and general procedures and to the various personnel of the Hydraulics Laboratory staff for their cooperation and assistance.

The counsel of Mr. Taggart Aston, Consulting Engineer, Los Angeles, California, with respect to breakwater designs is hereby acknowledged.

Chapter II

Experimental Equipment

Hydraulics Laboratory Facilities

The facilities of the Hydraulics Laboratory of the California Institute of Technology used in making this investigation included practically all phases of the installation and equipment available at the Harbor Model Laboratory in Azusa, California. The major items utilized included the model basin proper, the wave machines, the wave dampers, the oscillograph equipment and necessary appurtenances, and such materials as were required to complete the layouts described later. A general description of these facilities follows: -

1. Model Basin -- The model basin was a water tight enclosure approximately 121 feet by 128 feet by 2 feet deep in which a model harbor had been constructed. The maximum space available for installing the equipment for this investigation was an area 70 feet long by 20 feet wide. A general idea of this model basin can be obtained from the photographs accompanying this report.

2. Wave Machine -- The wave machine was of the latest type developed by the California Institute of Technology. It consisted of a unit, 20 feet in length, which

operated on an alternate compression - suction cycle, the intensity and rate of change of the cycle being controlled to establish the desired wave characteristics. A photograph illustrating this wave machine is included in the report.

3. Wave Dampers -- The wave dampers consisted of adjustable frames on which were mounted metal sheets covered with a mixture of asphaltic paint and coarse sand. These dampers could be adjusted as to height and angle with the horizontal. The accompanying photographs illustrate this equipment.

4. Oscillograph -- A seventeen channel oscillograph was used to measure variations in the height of the waves through variable resistances created by changes in the depth to which 2 1/2 inch submergence elements were immersed in the water. The submergence elements consisted primarily of two wires each 2 1/2 inches long mounted so that they were insulated on the lower ends and with connections for leads to the oscillograph on the upper ends. The variations in resistance created by the change in depth of immersion of each element actuated a galvanometer in the oscillograph. A light beam trained on the galvanometer mirror sensitized a photographic strip producing a chronological record of the wave heights. Sample illustrations of these records are included as Appendix "B" of this report.

Fabricated Equipment

The special equipment which had to be fabricated for this investigation included a vertical wall section, an adjustable angle wall section of considerable rigidity and stability and supports for the submergence elements. A general description of these pieces of equipment follows: -

1. Vertical Wall Section -- The vertical wall section was fabricated from three sections of the material used in the construction of the wall for the larger basin. This required bolting these sections together and anchor-bolting this wall in position on the concrete floor of the basin. Several of the photographs illustrate this vertical wall in place for the experiment.

2. Adjustable Angle Wall Section -- This wall section had to be considerably larger than the vertical wall to provide for sufficient height and depth above and below the water surface at the smaller angles. It was constructed by bolting together six sections of the previously mentioned wall material and then bracing this with bolted lengths of one inch angle iron. The face of this wall was then covered by sheets of galvinized iron so as to present a smooth reflecting surface. The resulting dimensions of this wall was 4 feet wide by 18 feet long. Variations in

the angle of the wall were obtained by resting it against or on the vertical wall and supporting the lower end of the wall at the proper depth to result in the desired angle. Several of the photographs illustrate this wall resting on the aforementioned vertical wall.

3. Supports for the Submergence Elements -- The supports for the submergence elements were fabricated of wooden extensions to some very light I - beams so that they would extend across the 20 foot span. The ends of these supports were then placed on the wave dampers at the sides and the submergence elements secured to the center of the supports by means of clamps.

Chapter III

Experimental Layout and Procedure

Experimental Layout

Initial Tests - The layout of the equipment for the initial tests is indicated on the schematic diagram included as Appendix "A" of this report.

Second Tests - The modified layout of the equipment for the second tests was essentially the same as the initial layout except that the wave dampers on the sides were placed in a vertical position instead of sloping at approximately five degrees.

Experimental Procedure

Initial Tests - With the equipment set up as indicated in the previous section, the experimental data was obtained as follows: - Prior to the recording of any results, submergence element #5 was calibrated with the oscillograph so as to obtain correct indications of the wave amplitudes. This was accomplished by varying the depth of immersion of the element in a beaker of water and adjusting the oscillograph to give the correct readings. The tests were then conducted by setting the initial reflecting wall angle at 90°, generating a 30 foot high wave (crest to trough) of 535 foot length by the wave machine, taking a record of the initial wave after the "shock" wave had passed element #5 and finally taking a record of the reflected wave pattern after equilibrium conditions had been reached. This procedure was repeated for each of the other three wave lengths, without changing the setting on the amplitude-generating motor. The amplitude of the initial wave was then changed to 15 feet and the same procedure followed as in the case of the 30 foot wave. After the initial wave patterns for both amplitudes at the four wave lengths had once been obtained, tests were made to obtain the records of the reflected wave pattern after equilibrium conditions had been reached in each of the cases listed in Chapter I.

Second Tests - As indicated in the Chapters on the Reduction of Data and Discussion of Results which follow, the large inconsistencies in the results of the initial tests necessitated modifying the previously described procedure to eliminate the interference created by the sloping side dampers, to insure that the submergence elements were located at the positions of maximum oscillation of the reflected waves, and to adjust the setting on the amplitude motor for each wave length in order to obtain a constant amplitude of the initial wave.

With the equipment set up as indicated previously, with the exception of adjusting the oscillograph to magnify the readings by two because of the small amplitudes, the experimental data was obtained as follows: - The submergence elements were calibrated in the same manner as those for the initial tests. The tests were then conducted by setting the initial reflecting wall angle at 10° and generating a 5 foot wave of 2150 foot wave length by the wave machine. Visual observations were made on the oscillograph of the amplitude of the initial waves. Oscillograph records were taken of the initial wave after the "shock" wave had passed element #5, and of the reflected wave pattern prior to the return of the reflected wave to element #6. The positions of the submergence elements were then adjusted so as to be at points of maximum oscillation of the reflected waves after equilibrium conditions had been reached, and then an oscillograph record of the reflected wave pattern at equilibrium conditions was taken. This procedure was repeated for this amplitude at each of the other two wave lengths. The amplitude of the initial wave was then changed to 10 feet and the same procedure followed as in the case of the 5 foot wave. After the initial wave patterns for both amplitudes at the three wave lengths had once been obtained, tests were conducted for each of the other cases as outlined above with the exception that the records of the initial wave patterns were omitted. Special emphasis was placed on the visual observation of the initial wave amplitude on the oscillograph screen and on the adjusting of the position of the elements under steady state wave conditions in an effort to improve upon the erratic results obtained from the previously described initial tests. In addition to making the measurements indicated above, visual observations were made of the wave patterns produced and comments noted of the special characteristics of the individual tests to facilitate the interpretation of the results.

Chapter IV

Reduction of Data

Initial Tests - As mentioned previously, a recording was made of the initial wave on element #5 for all eight combinations of amplitude and wave length of the 90° setting of the reflecting surface. Measurements of the amplitudes on the oscillograph tape indicated, however, that the settings for wave length and amplitudes were interdependent and therefore one setting on the amplitude motor would not result in a constant amplitude for the four different wave lengths. The exact amplitude of the initial wave could be measured, however, and was used as a standard in each case for computing the percentage amplification. Measurements were made on the oscillograph tape of the amplitudes under equilibrium conditions and tabulated. Using the standard measurement for each wave length, the percentage amplification at each element was computed and recorded.

Second Tests - Inasmuch as the amplitude settings were adjusted to give approximately a constant and desired amplitude for the different wave lengths, the standard amplitude for each wave length in the second tests was nearly the same. For each wave length, however, the actual measurement of the initial wave amplitude from the oscillograph tape was used as 100%. By readjusting the settings at each angle of the reflecting surface exactly to those recorded as 100%, no additional measurements on the initial wave pattern were required. Measurements were made on the oscillograph tape of the amplitudes at each element under each of the equilibrium conditions and tabulated. Percentage amplification at each element under each of the equilibrium conditions was computed and recorded. Tables I and II, included as Appendix "C" of this report, indicate these measurements and percentages.

Curves indicating percentage amplification versus distance from the reflecting surface for the following conditions are included in Chapter V:

1. All wave lengths and amplitudes for 10° reflecting surface
2. All wave lengths and amplitudes for 20° reflecting surface
3. All wave lengths and amplitudes for 30° reflecting surface
4. All wave lengths and amplitudes for 45° reflecting surface
5. All wave lengths and amplitudes for 60° reflecting surface
6. All wave lengths and amplitudes for 90° reflecting surface
7. The loci of maximum amplitudes for each reflecting angle
8. The average maximum amplitudes considering both the 5 and 10 foot waves.

The recordings made on the oscillograph of the reflected wave pattern prior to the establishment of equilibrium conditions could not be utilized in the analysis because the submergence elements were not located at points of maximum oscillation of the standing wave patterns.

As stated previously, sample illustrations of the oscillograph tape records are included in Appendix "B" of this report.

In a few of the tests equilibrium conditions were not developed. This was indicated by the very erratic results recorded by the oscillograph and in these cases the results were discarded.

Chapter V

Discussion of Results

Sources of Error in Initial Tests

The results obtained in the initial tests were definitely erratic. A study of the operating conditions indicated the following sources of error:

1. In practically each run standing waves developed under equilibrium conditions. The position of each submergence element was adjusted only to keep the distance between it and the reflecting wall constant for all conditions, which may or may not have been at the point of maximum oscillation of the standing wave. As a result the percentages obtained were exceedingly inconsistent and in no way could the maximum oscillation at the element be definitely determined from the data obtained.

2. The side dampers were inclined at an angle of about 5° to the horizontal. This resulted in a curved wave pattern striking the reflecting surface and introducing side reflections during otherwise equilibrium conditions.

3. The wave machine had a wave damper parallel to the reflecting surface which in itself acted as a 5° reflecting slope back towards the test wall. As a result the percentages would be expected to be larger in the area of elements

#5 and #6 than those obtained with no effect of secondary reflection.

4. Inasmuch as the setting on the amplitude motor was maintained constant over the entire range of different wave lengths, the mutual interdependency of the amplitude and wave length motors precluded a direct comparison of results. The desired amplitude was obtained for only the wave length for which the amplitude had been originally adjusted.

5. The amplitudes chosen for the test were too large (3/8" and 3/4" model scale). In several instances the standing waves topped and dropped below the submergence element.

6. The assumption was made that the initial wave did not damp out to any appreciable degree in traveling from the wave machine to the reflecting surface. That this was in error was proved by attempting to test a very small wave length. This wave was completely damped before reaching the wall. The effect of this decrease in amplitude is apparent - the 100% initial wave reading for the elements actually decreases from #6 to #1, resulting in a corresponding increase in the percentages computed for the reflected waves by using the 100% reading of element #6.

Correction of Initial Errors in Second Tests

In the conduct of the second tests, every effort was made to remedy the deficiencies encountered in the initial tests. Using the paragraph numbers of the section immediately preceding, the extent of amelioration follows:

1. An attempt was made to adjust the position of each element during equilibrium to the point of maximum oscillation. This necessitated an adjustment of not over a quarter wave length from the set position, but was exceedingly difficult to accomplish. The actual wave height of 1/8 inch is difficult to detect with the naked eye from directly above, and in some cases the results indicate that the peak point apparently was not too successfully located.

2. The side dampers were changed to a vertical position and the wave patterns straightened out to run parallel in all cases. Visual observations indicated that the side reflections were eliminated to a satisfactory degree.

3. An attempt was made to eliminate the effect of secondary reflections from the wave machine by recording on the oscillograph the wave pattern at the instant the primary reflection returned to element #6. This was unsuccessful because of the relative position of the elements with regard to the standing wave pattern developed. Notice can only be taken of the effect of this secondary reflection in our experiment; viz., an increase in the observed

amplifications over those with no such reflection, such increase being greatest at the wave machine and diminishing toward the reflecting wall.

4. On the first wall angle tested, 10°, the magnitude of the initial wave amplitude was adjusted to that desired as closely as visual observation on the oscillograph screen would permit. Thus for the 5 foot waves, three different settings were obtained for the three wave lengths which approximated the 5 foot amplitude. The exact amplitude was of course taken from the oscillograph record of each initial wave.

5. The amplitudes chosen were 5 and 10 feet. The magnifying control of the oscillograph was changed to double the amplitude, to create larger curves and facilitate ease of actual measurements of the amplitudes. In all cases, these smaller amplitudes stayed within the range of the oscillograph elements.

6. Due to the greater velocity of the shallow water wave than that of the deep water wave, which it precedes, it was impossible to record the 100% amplitude at each element. Notice was taken of the fact that the basic amplitude was not the same for all elements (basic amplitude decreasing from #6 to #1) and that our procedure in using one initial amplitude to compute percentage of the initial amplitude introduces small errors. The correct percentage would therefore be slightly larger than those plotted, such increases

being greatest at element #1 and decreasing to zero at element #6.

Effect of Various Slopes of Reflecting Surface on the Amplitude of the Reflected Wave.

The curves indicating percentage amplification versus distance from the reflecting surface for the various initial wave lengths and amplitudes and the different angles of the reflecting surface are included as figures 1 to 3 of Appendix "D" of this report.

An examination of these curves indicates that the maximum reflections occurred as shown in the following tabulation:

Initial Amplitude (feet)	Reflecting Slope (degrees)	Maximum % of Initial Amplitude (%)	Distance of Maximum Amplitude from Wall (feet)
10	10	142	7200
10	20	316	7200
10	30	328	2400
10	45	450	2400
10	60	290	2400
10	90	321	7200
5	10	166	16800*
5	20	220	2400
5	30	291	2400
5	45	239	2400
5	60	315	2400
5	90	261	2400

*Approximately same amplitude at 7200 feet.

From the referenced curves and the above tabulation it is apparent that the amplitude of the reflected wave is smallest for the 10 degree wall angle and increases in both the 10 and 5 foot wave series thru the 30 degree wall angle. The maximum effect is reached in the $30^{\circ} - 60^{\circ}$ wall angle range and drops off slightly for the 90 degree wall angle.

Giving equal weight to the results of both tests, the plot of the average maximum amplitudes for each of the reflecting wall angles illustrates the previously described trend. This diagram is included as figure 4 in Appendix "D" of this report.

With the exception of the maximum amplitude recorded in the case of the 5 foot wave reflecting on the 10 degree wall, the maximum amplitudes occurred at the first two stations from the wall. Since the amplitude at station two in the exception cited above is approximately the same as the maximum at station four, it appears that the maximum amplitudes, as would be expected, occur at the stations relatively near to the reflecting surface, the waves damping out at greater distances.

Effect of Distance from and Slope of Reflecting Surface on the Maximum Amplitudes of Waves.

The diagram indicating the loci of maximum reflected amplitudes at the various distances from the reflecting surface is included as figure 5 in Appendix "D" of this report. This diagram also indicates the positions of maximum amplitudes to be at the stations nearest the reflecting surface. It further indicates a trend of diminishing maximum amplitudes as the distance from the reflecting surface increases. Another trend can be noted in that the rate of decrease in the maximum amplitudes is greatest at the intermediate stations for the reflecting surfaces giving the greatest amplitudes at the stations near the reflecting wall. This trend coupled with the indication that at the more distant stations there is a general decay of the reflected wave illustrates the expected tendency for the reflected wave to disappear gradually as the distance from the reflecting surface increases.

Effect on Results of Assumption of a Constant Initial Wave Amplitude for All Distances from the Reflecting Surface

As pointed out in the first two sections of this Chapter, the assumption that the magnitude of the initial wave amplitude was constant was in error. The effect of this assumption on the results of these tests is as previously stated. That is, the percentages of the initial amplitudes for the stations nearest the reflecting surface are not as high as they would be if the actual initial amplitudes at each station were used as the basis of computations. If it had been possible to record the initial wave amplitudes at all stations and use these recorded values as the basis of computations, the effect on the resulting diagrams would be to rotate them clockwise about the values indicated at element $\#6$, thus increasing their percentage amplitudes near the reflecting surface.

Effect on Results of Secondary Reflections from the Wave Machine

As stated previously, an unsuccessful attempt was made to eliminate the effect of the secondary reflections from the wave damper at the wave machine. The effect of these reflections on the results is to increase the amplitudes at all stations, the increase being greatest at the stations nearest the wave machine and diminishing toward the reflecting wall.

Chapter VI

Summary of Conclusions

1. The amplitude of a reflected wave is smallest for low angle reflecting surfaces. This amplitude increases rapidly as the angle of the reflecting surface increases up to approximately 45° and thereafter remains approximately constant as the angle of the reflecting surface increases from 45° to 90°. In other words, whenever wave disturbances outside a breakwater are of importance, the face of the breakwater should be kept as flat as possible to decrease the magnitude of the disturbance.

2. As was to be expected, the maximum amplitudes of the reflected wave occurred at positions relatively near to the reflecting wall, i.e., disturbances caused by reflections are greatest near the breakwater.

3. High amplitudes of reflected waves persist for great distances from the reflecting surface.

Chapter VII

Suggestions for Future Work

As indicated in the last two sections of Chapter V, the results of these tests were influenced by the assumption of a constant initial wave amplitude at all distances from the wave machine and by the effect of secondary reflections from the wave machine damper.

To eliminate the effect of the assumption of a constant initial wave, further investigations should include a series of preliminary tests, prior to the installation of the reflecting surface, to determine the actual amplitude of the initial wave at all stations being investigated.

To eliminate the effect of the secondary reflections from the wave machine damper, future work should be conducted in a basin large enough to obviate the return of the primary reflected wave to the vicinity of the wave machine. As an alternate procedure, in the event a larger basin is not available, it is suggested that the procedure outlined for the second tests in this report be modified to make the record of the reflected wave pattern prior to the return of the reflected wave to element #6 after the equilibrium tests. By doing this, the adjusted positions of the submergence elements will probably be more nearly at the positions of maximum oscillation of the wave.

To facilitate the interpretation of the data in future experiments, additional submergence elements should be used so as to give more definite indications of the trends of the results.

References

Townsend, C. McD., "Hydraulic Principles Governing River and Harbor Construction.

Cunningham, Brysson, "Harbour Engineering" and "The Harbour Engineer's Reference Book".

Gaillard, D.D., "Wave Action in Relation to Engineering Structures".

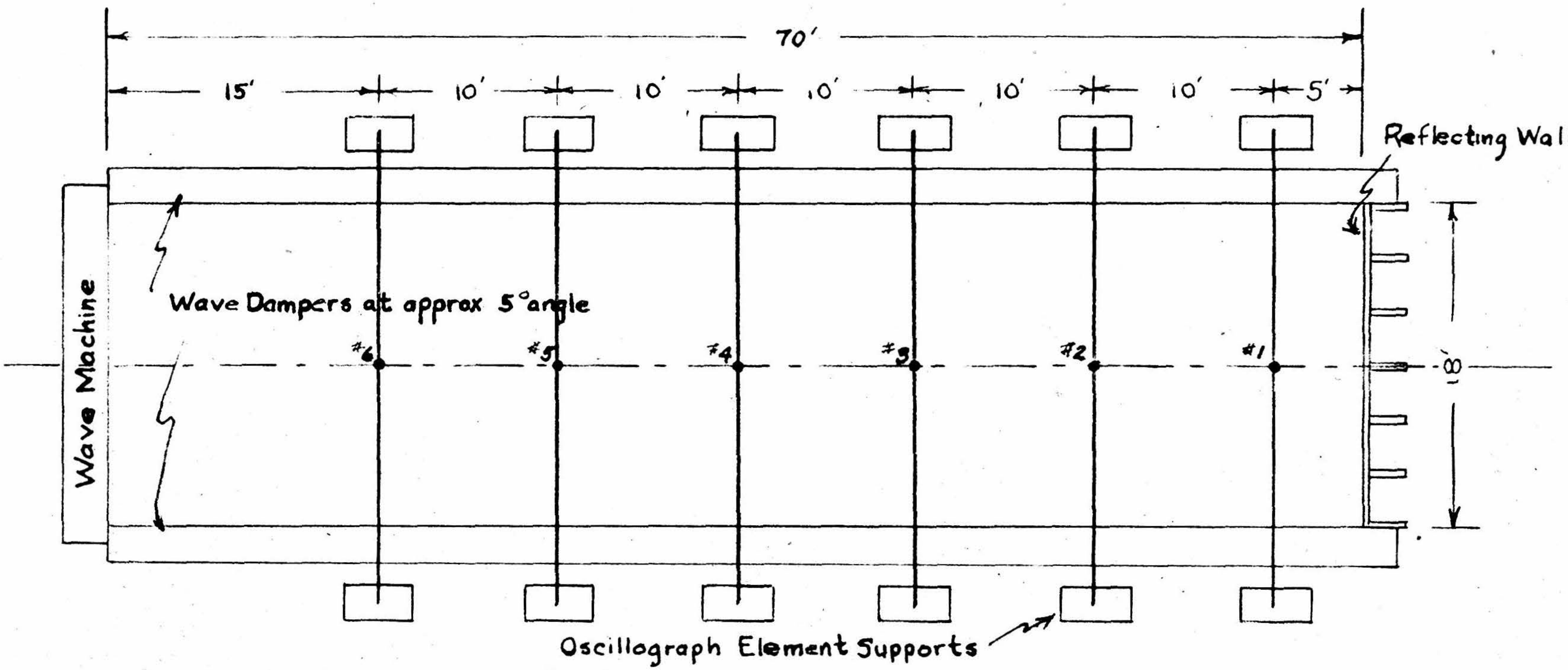
Rouse, Hunter, "Fluid Mechanics for Hydraulic Engineers".

Albertazzi, A. and Cagli, E. Coen "Report on Breakwaters in Tideless Seas"

Fletcher, Robert, "The Proper Profile for Resisting Wave Action" ASCE Transactions 1896

APPENDIX "A"

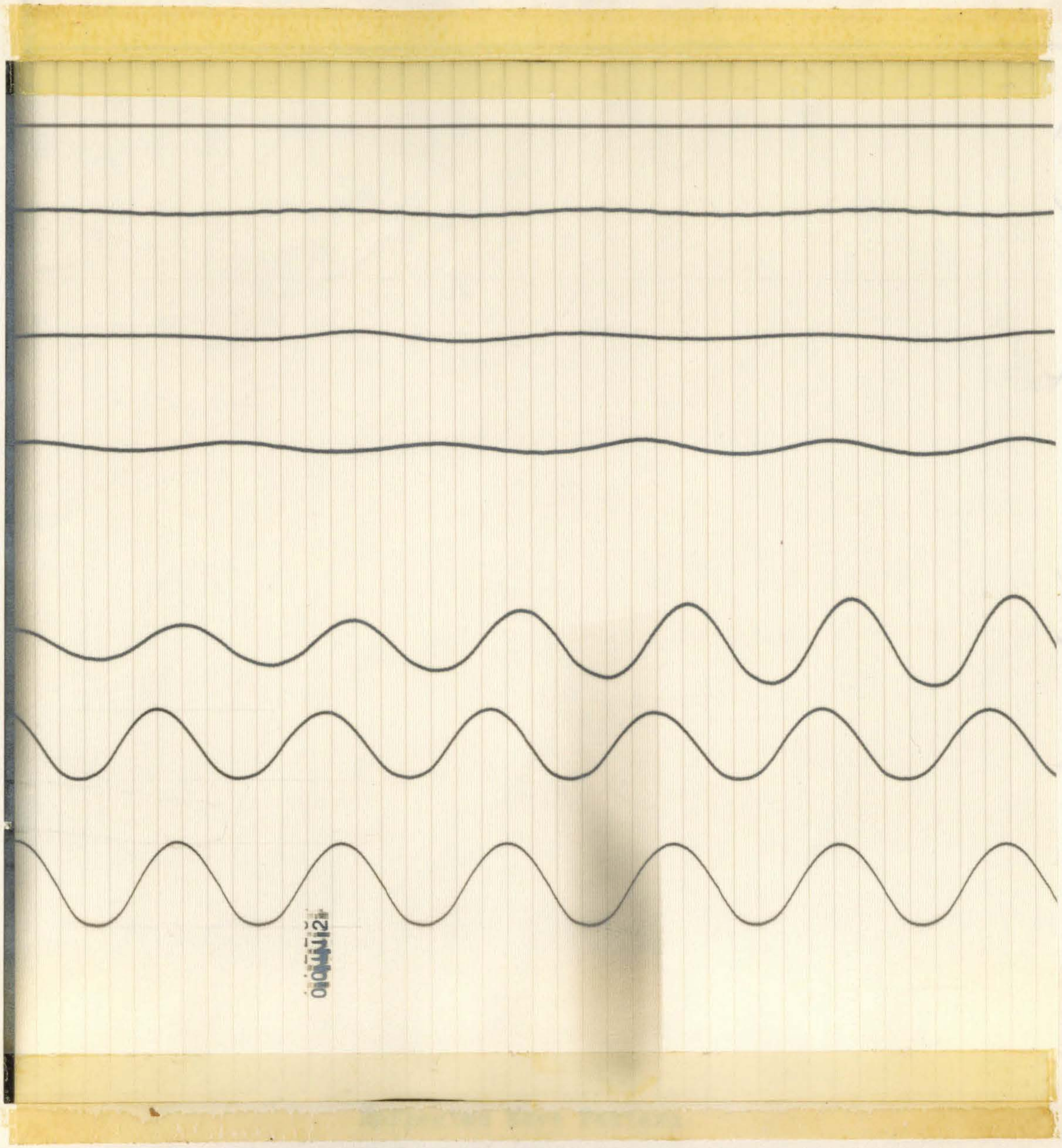
EQUIPMENT LAYOUT



EQUIPMENT LAYOUT, INITIAL TESTS

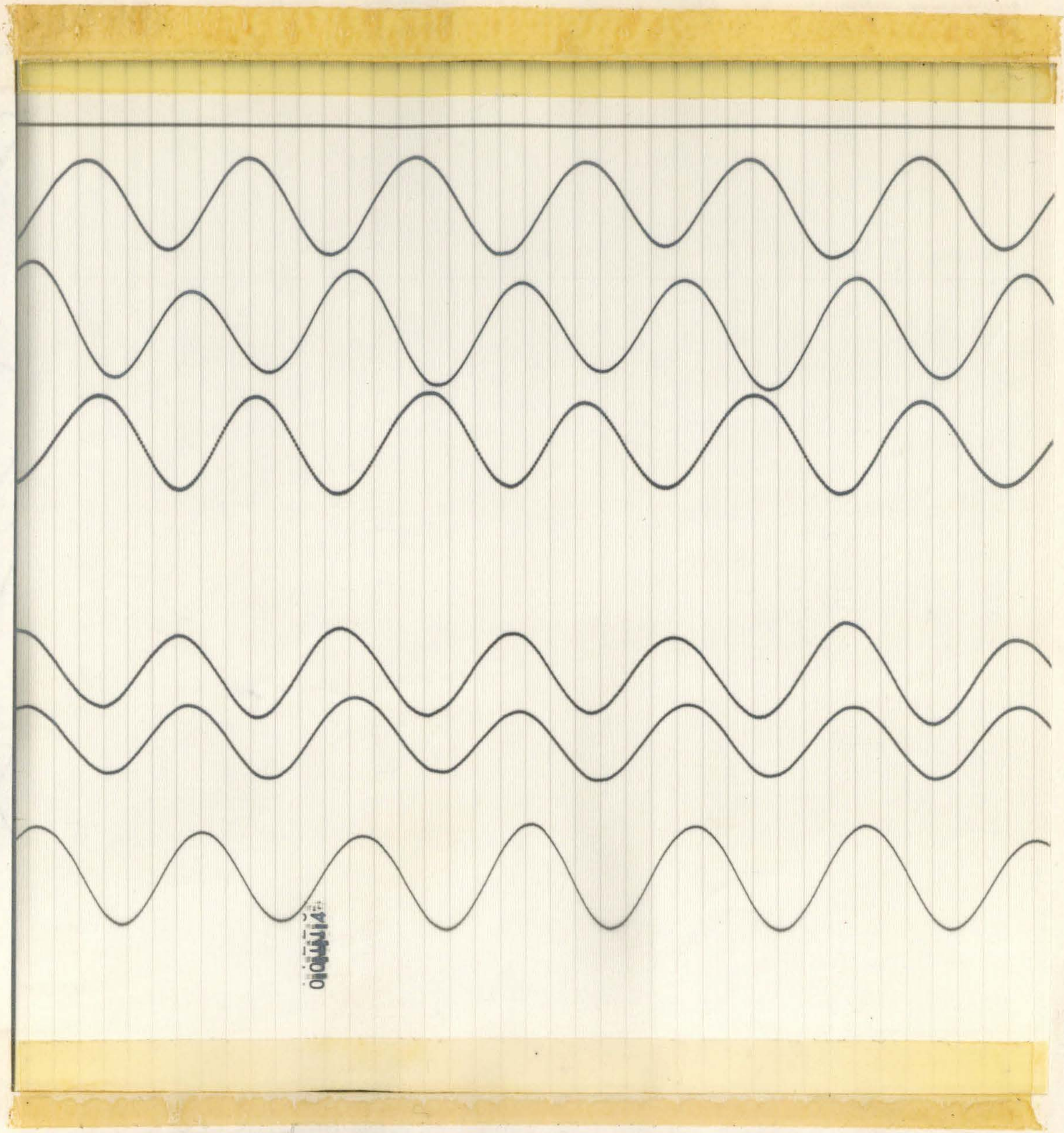
APPENDEX "B"

SAMPLES OF OSCILLOGRAPH RECORDS



Initial Wave Pattern

10' Amplitude 1075' Wave Length

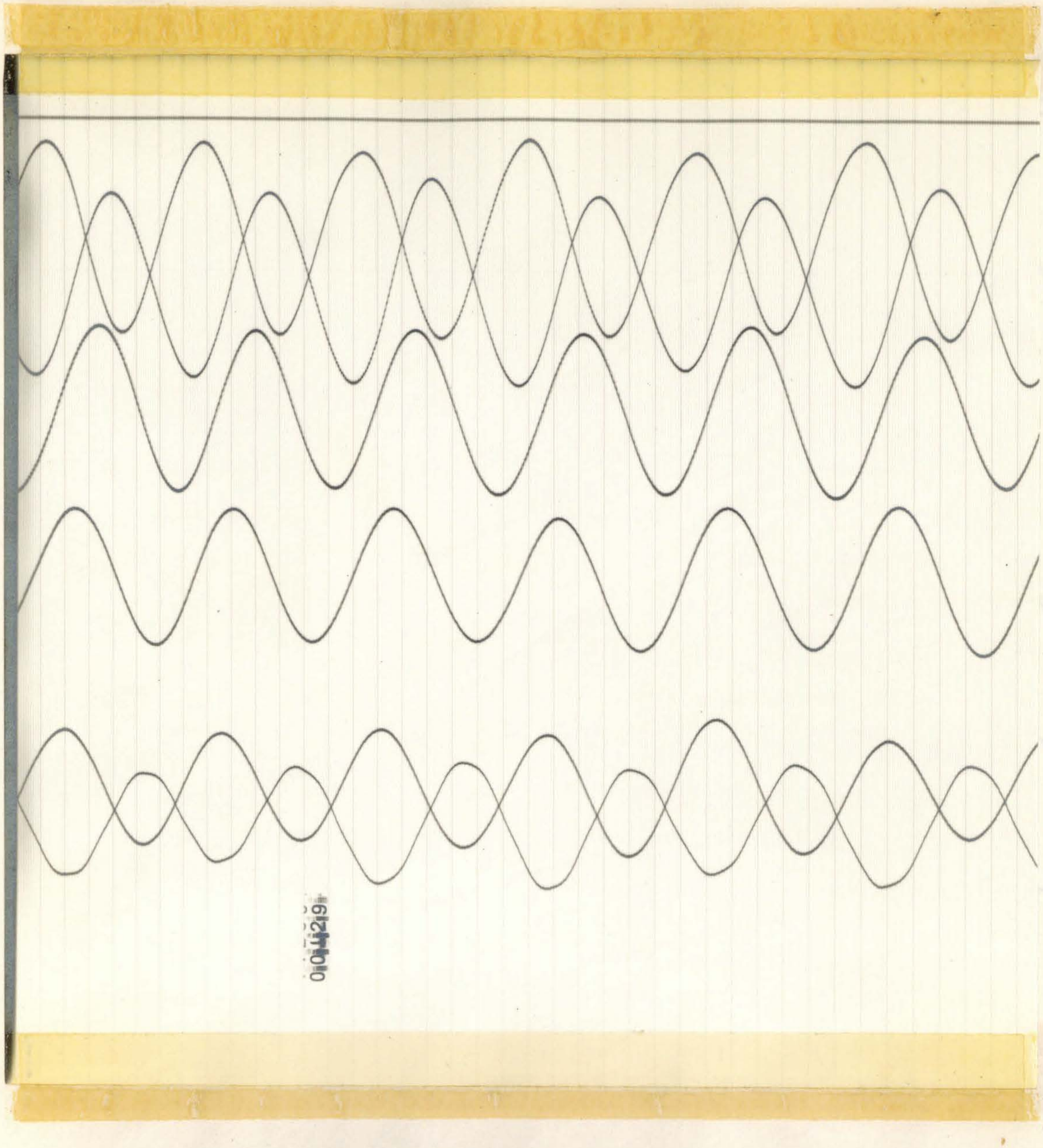


Reflected Wave Pattern

for

10° Reflecting Surface

Initial Wave 10' Amplitude 1075' Wave Length

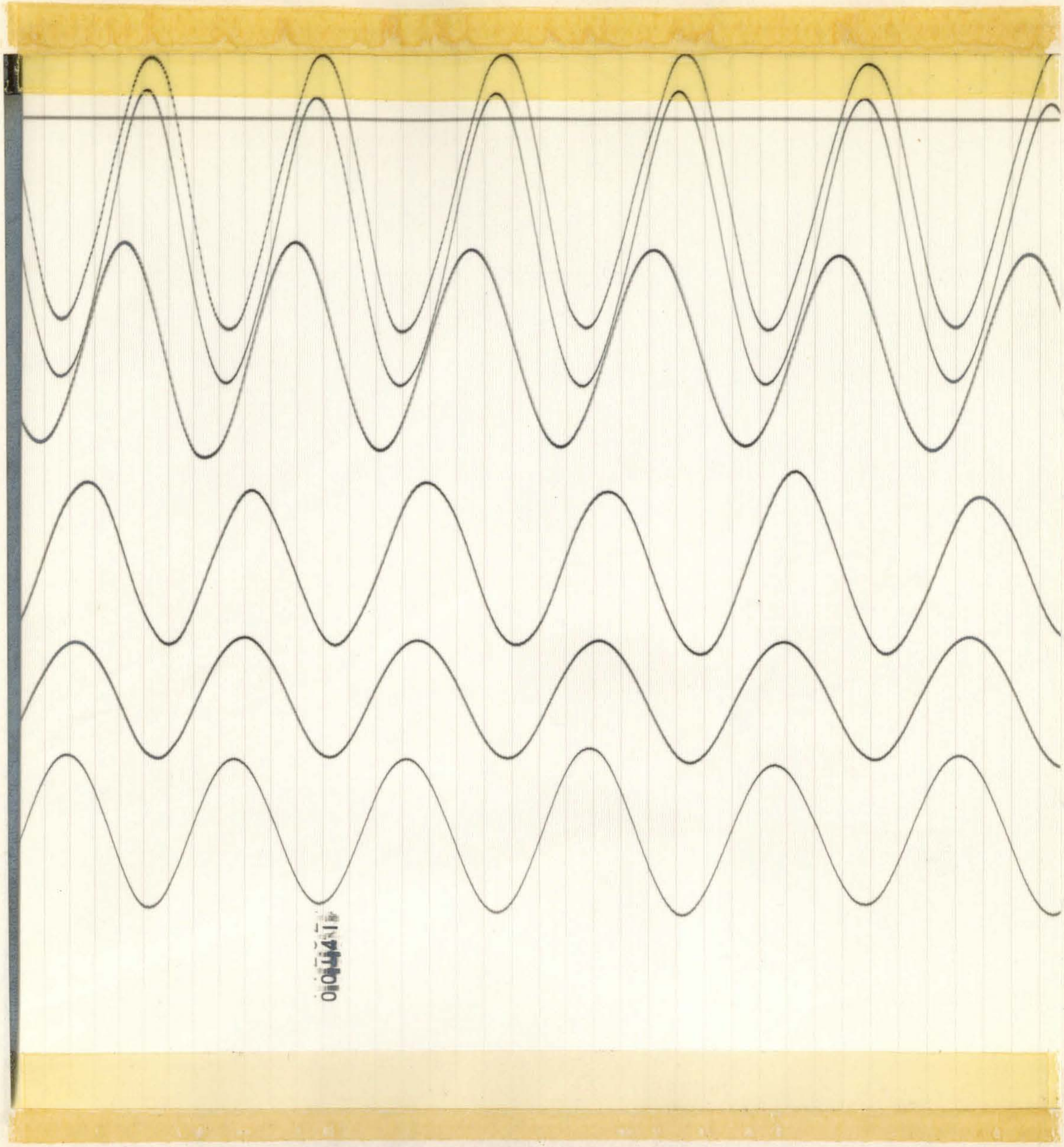


Reflected Wave Pattern

for

20° Reflecting Surface

Initial Wave 10' Amplitude 1075' Wave Length

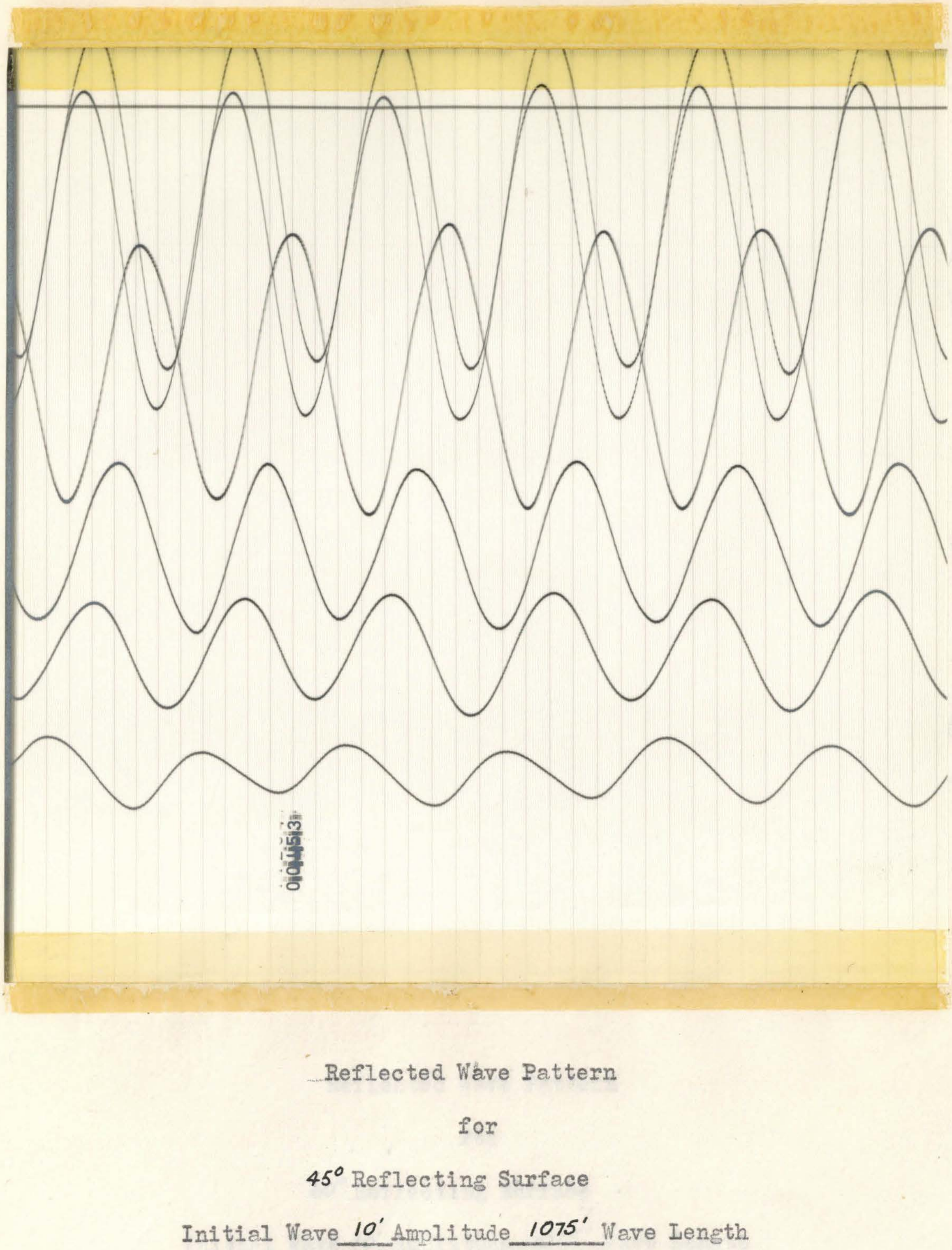


Reflected Wave Pattern

for

30° Reflecting Surface

Initial Wave 10' Amplitude 1075' Wave Length

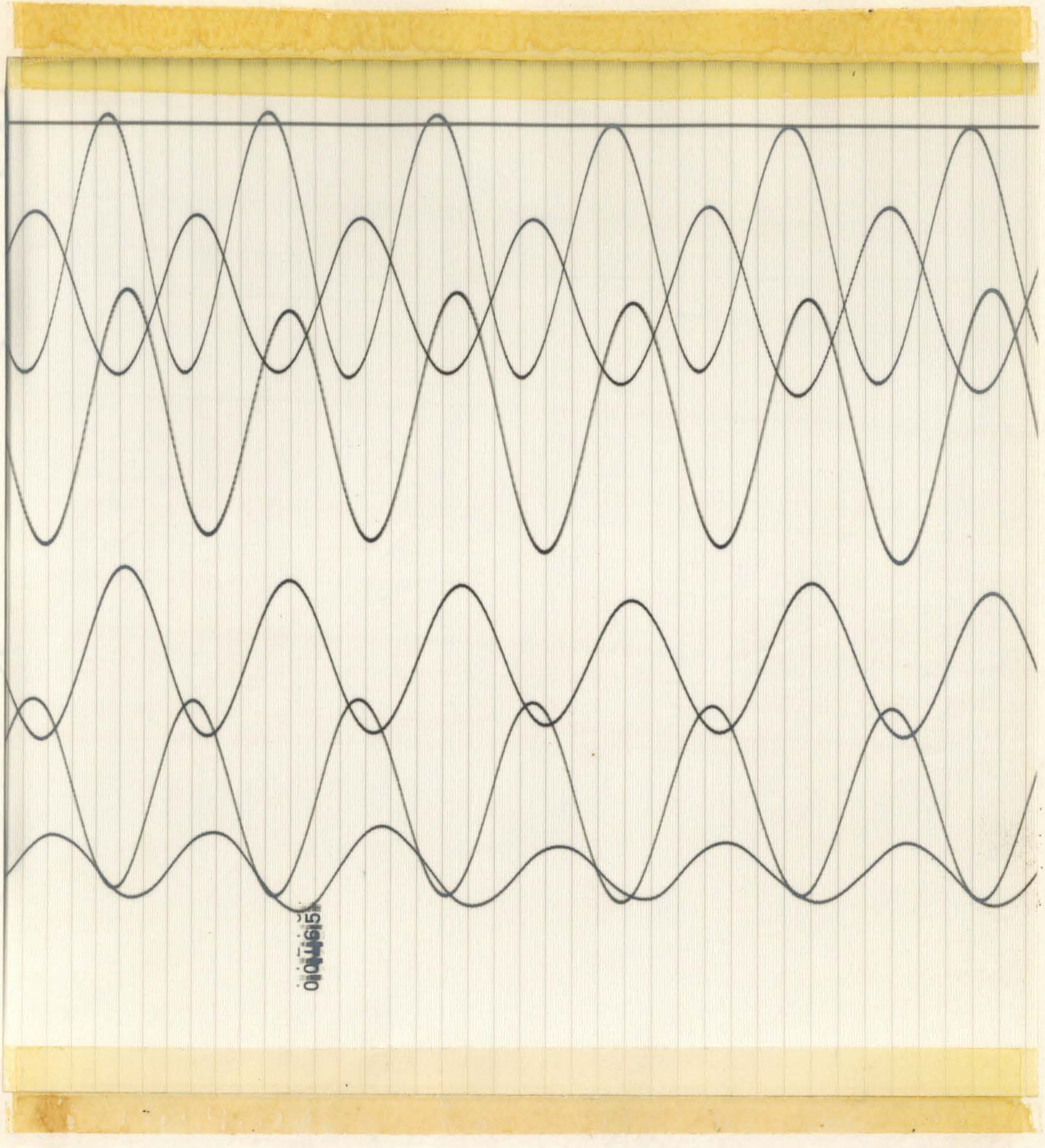


Reflected Wave Pattern

for

45° Reflecting Surface

Initial Wave 10' Amplitude 1075' Wave Length

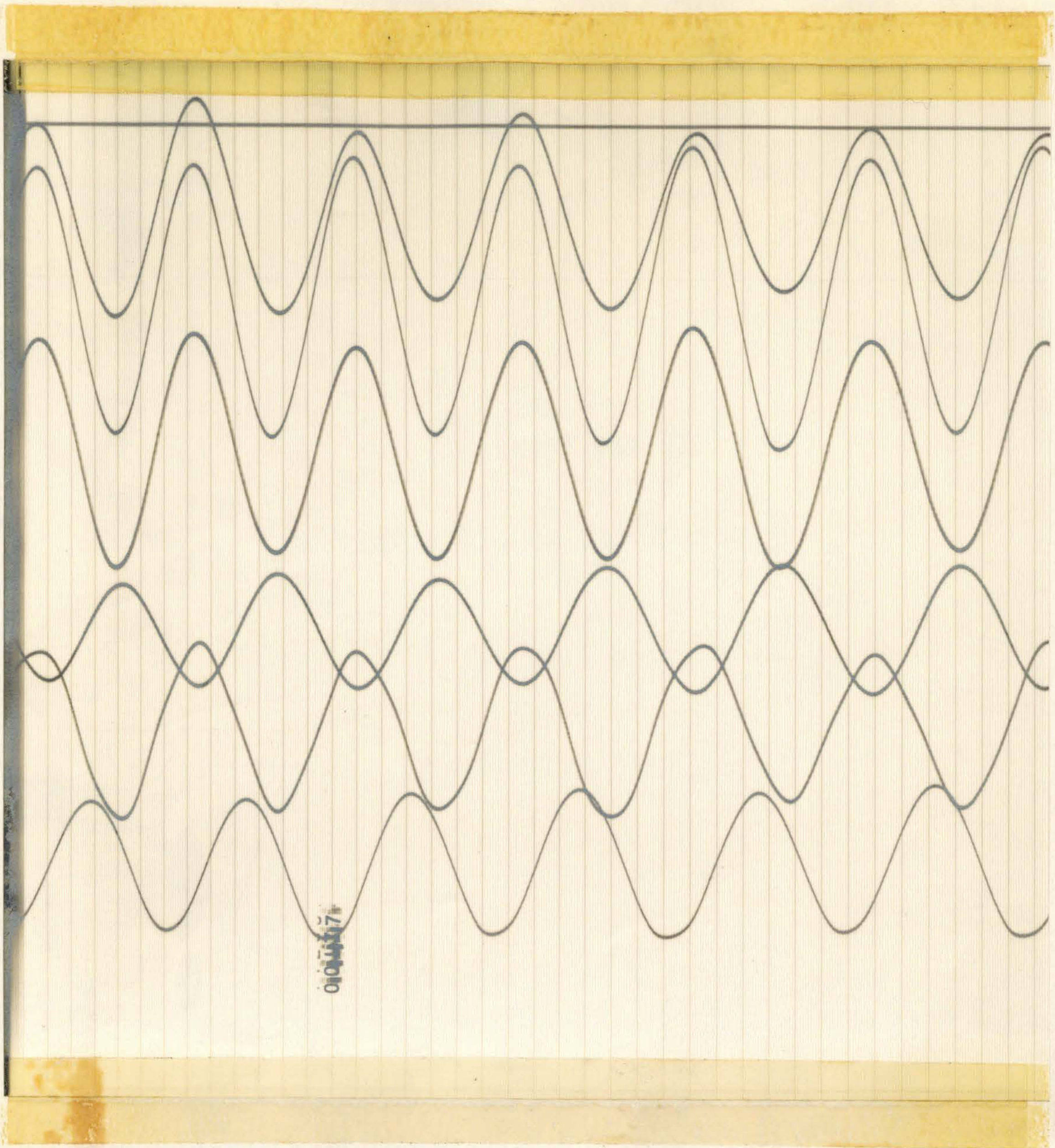


Reflected Wave Pattern

for

60° Reflecting Surface

Initial Wave 10' Amplitude 1075' Wave Length



Reflected Wave Pattern

for

90° Reflecting Surface

Initial Wave 10' Amplitude 1075' Wave Length

APPENDIX "C"

TABULATION OF MEASUREMENTS

Wall Angle	Run No.	Wave Length	Initial Wave	Wave Measurements (actual) inches — Element Number 1	2	3	4	5	6	Percentages of Initial Wave — Element Number 1	2	3	4	5	6
10°	102	2150	.30	.38	.48	.43	.50	.38	.40	127	160	143	166	127	133
	104	1075	.23	.31	.30	.37	.28	.32	.22	91	130	161	122	139	96
	107	538	.28	.32	.24	.28	.31	.30	.30	79	86	100	111	107	107
20°	121	2150	.30	.66	.38	.62	.48	.44	.40	220	127	207	160	147	133
	123	1075	.23	.39	.39	.36	.35	.27	.33	170	169	155	152	117	143
	125	538	.28	.37	.27	.32	.24	.34	.30	132	97	114	86	122	107
30°	133	2150	.30	.78	.72	.68	.72	.61	.52	260	240	228	240	204	173
	135	1075	.23	.67	.34	.58	.36	.28	.35	291	148	262	157	122	152
	137	538	.28	.36	.30	.35	.32	.25	.23	129	107	125	114	89	82
45°	145	2150	.30	.54	.49	.46	.44	.30	.34	180	163	153	146	107	113
	147	1075	.23	.55	.49	.35	.40	.30	.40	239	214	152	173	130	173
	149	538	.28	.23	.39	.29	.30	.39	.37	82	139	104	107	139	132
60°	157	2150	.30	.77	.67	.66	.62	.48	.55	267	223	220	207	160	183
	159	1075	.23	.65	.62	.57	.38	.30	.60	283	270	248	165	130	217
	161	538	.28	.88	.70	.22	.44	.32	.33	315	250	79	157	114	118
90°	169	2150	.30	.70	.52	.68	.52	.46	.32	233	174	194	174	153	107
	171	1075	.23	.60	.68	.54	.46	.38	.50	261	252	235	200	165	217
	173	538	.28	.44	.28	.40	.30	.22	.33	157	100	143	107	79	118

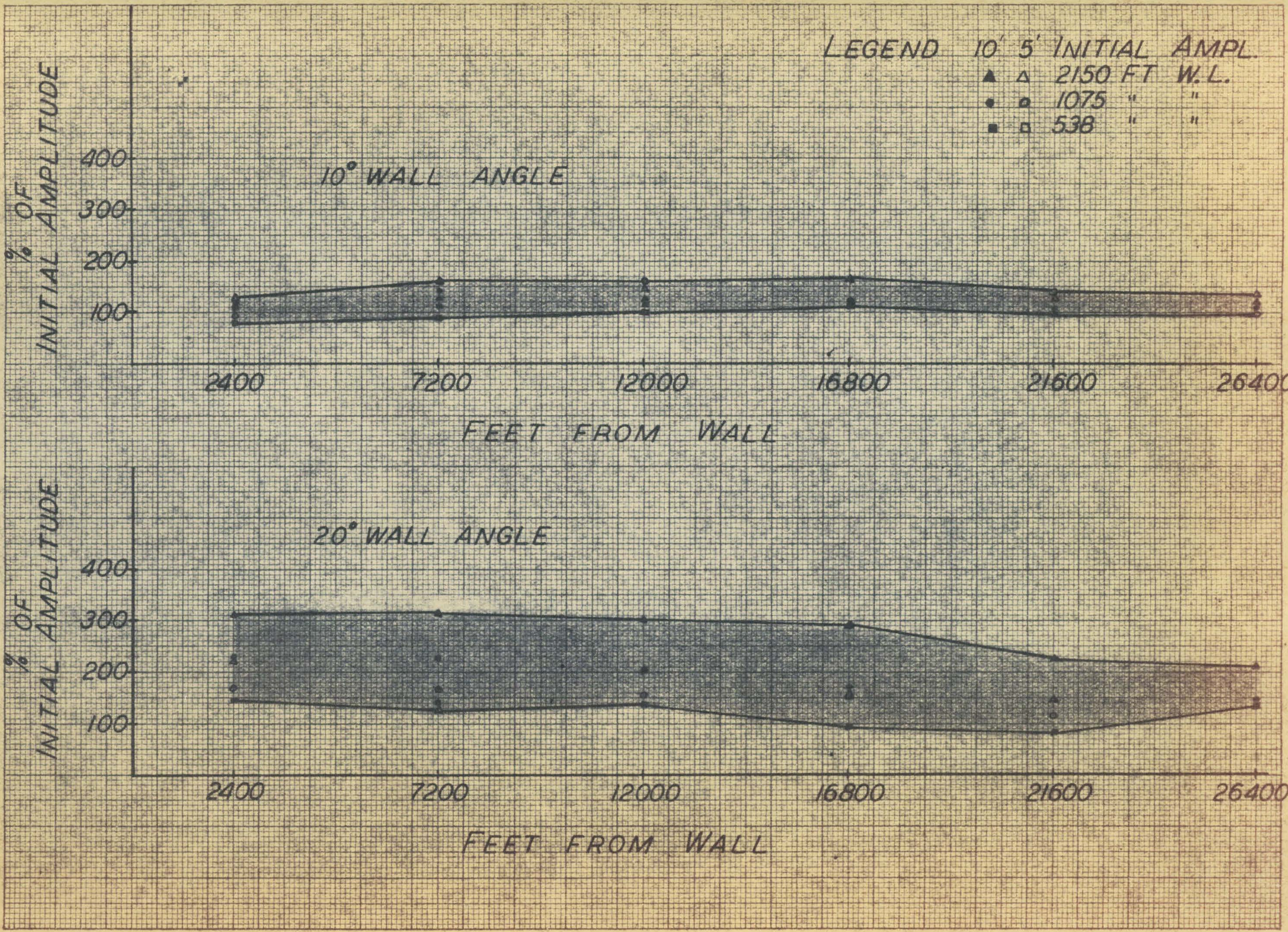
TABLE I MEASUREMENTS FOR 5 FOOT WAVE

				Wave Measurements (actual) inches						Percentages of Initial Wave					
Wall Angle	Run No.	Wave Length	Initial Wave	Element Number						Element Number					
				1	2	3	4	5	6	1	2	3	4	5	6
10°	111	2150	.62	.72	.80	.78	.76	.67	.76	116	129	126	122	108	123
	114	1075	.48	.58	.68	.57	.59	.48	.58	121	142	119	123	100	121
	117	538	.49	.53	.55	.55	.54	.50	.57	108	112	112	110	102	116
20°	127	2150	.62	1.93	1.96	1.87	1.80	1.40	1.32	312	316	302	290	226	212
	129	1075	.48	1.10	1.10	.97	.88	.71	.70	229	229	202	173	148	146
	131	538	.49	.72	.68	.68	.47	.40	.66	147	140	139	96	82	135
30°	139	2150	.62	1.60	1.82	1.70	1.18	.73	1.22	258	294	274	191	118	197
	141	1075	.48	1.57	1.54	1.18	1.10	.74	.82	328	320	246	229	154	171
	143	538	.49	.60	.58	.52	.58	.47	.40	123	118	106	118	96	82
45°	161	2150	.62	1.90	1.85	1.75	1.36	.90	1.20	320	300	282	219	145	194
	153	1075	.48	2.16	2.12	1.68	1.08	.76	.67	450	442	350	225	158	140
	155	538	.49	.79	.88	.86	.66	.38	.64	161	180	175	135	78	131
60°	163	2150	.62	1.80	1.56	.79	1.32	.68	.68	290	252	128	213	110	110
	166	1076	.48	1.35	1.14	1.58	.92	1.05	.36	281	238	329	192	219	75
	167	538	.49	.44	.50	.58	.73	.38	.70	90	102	118	149	78	143
90°	175	2150	.62	1.40	1.00	1.13	.58	.58	.67	226	162	182	94	94	108
	177	1076	.48	1.15	1.54	1.38	.94	.76	.84	240	321	288	196	158	175
	179	538	.49	.64	.74	.61	.99	.83	.52	131	151	125	202	169	106

TABLE II MEASUREMENTS FOR 10 FOOT WAVE

APPENDIX "D"

DIAGRAMS OF RESULTS



LEGEND 10' 5' INITIAL AMPL.
▲ △ 2150 FT W.L.
● ○ 1075 " "
■ □ 538 " "
10° WALL ANGLE
% OF INITIAL AMPLITUDE
400
300
200
100
2400
7200
12000
16800
21600
26400
FEET FROM WALL
20° WALL ANGLE
% OF INITIAL AMPLITUDE
400
300
200
100
2400
7200
12000
16800
21600
26400
FEET FROM WALL

FIG. i

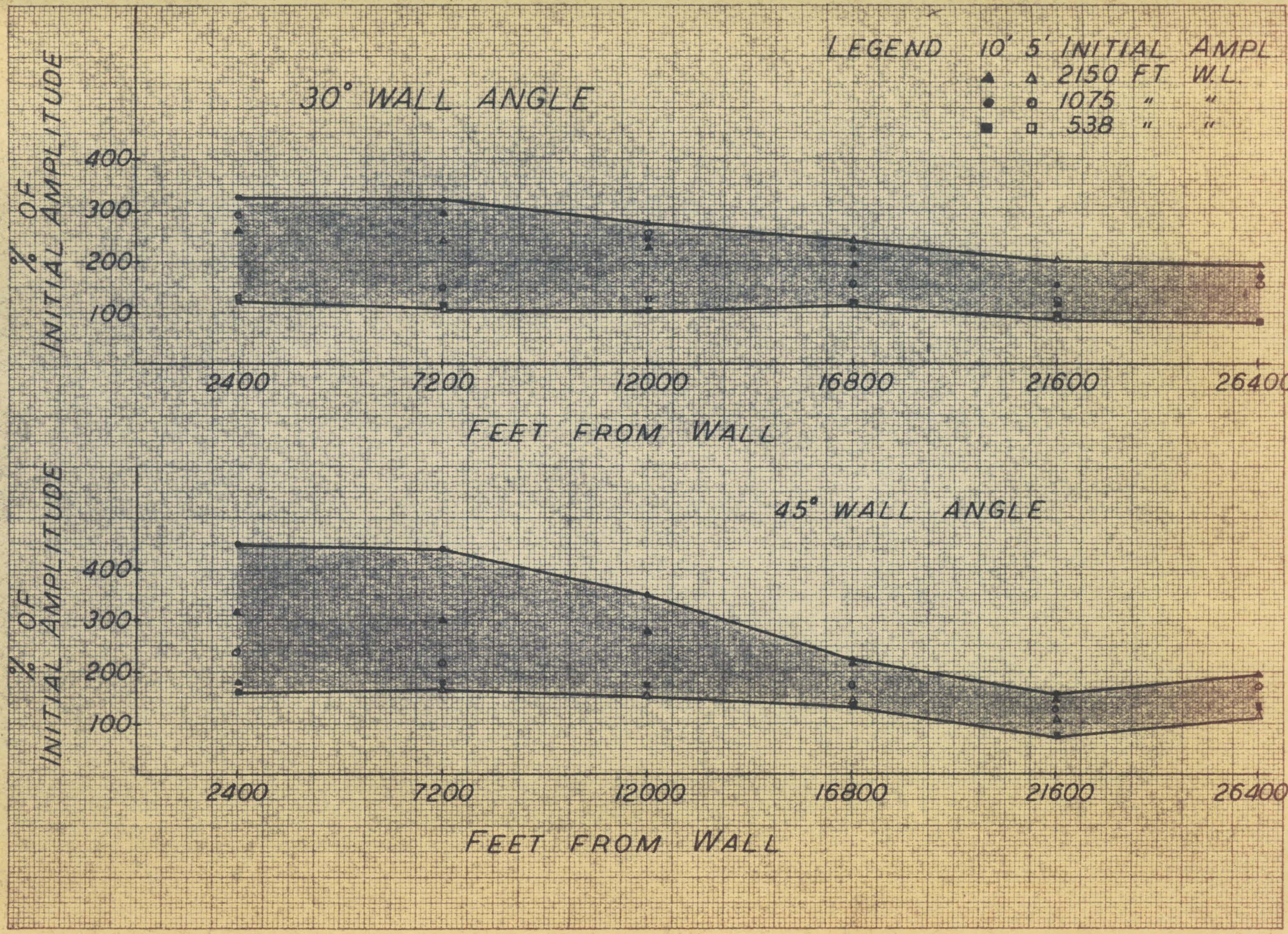

LEGEND 10' 5' INITIAL AMPL
2150 FT W.L.
1075 " "
538 " "
30° WALL ANGLE
% OF INITIAL AMPLITUDE
400
300
200
100
2400
7200
12000
16800
21600
26400
FEET FROM WALL
45° WALL ANGLE
% OF INITIAL AMPLITUDE
400
300
200
100
2400
7200
12000
16800
21600
26400
FEET FROM WALL

FIG. 2

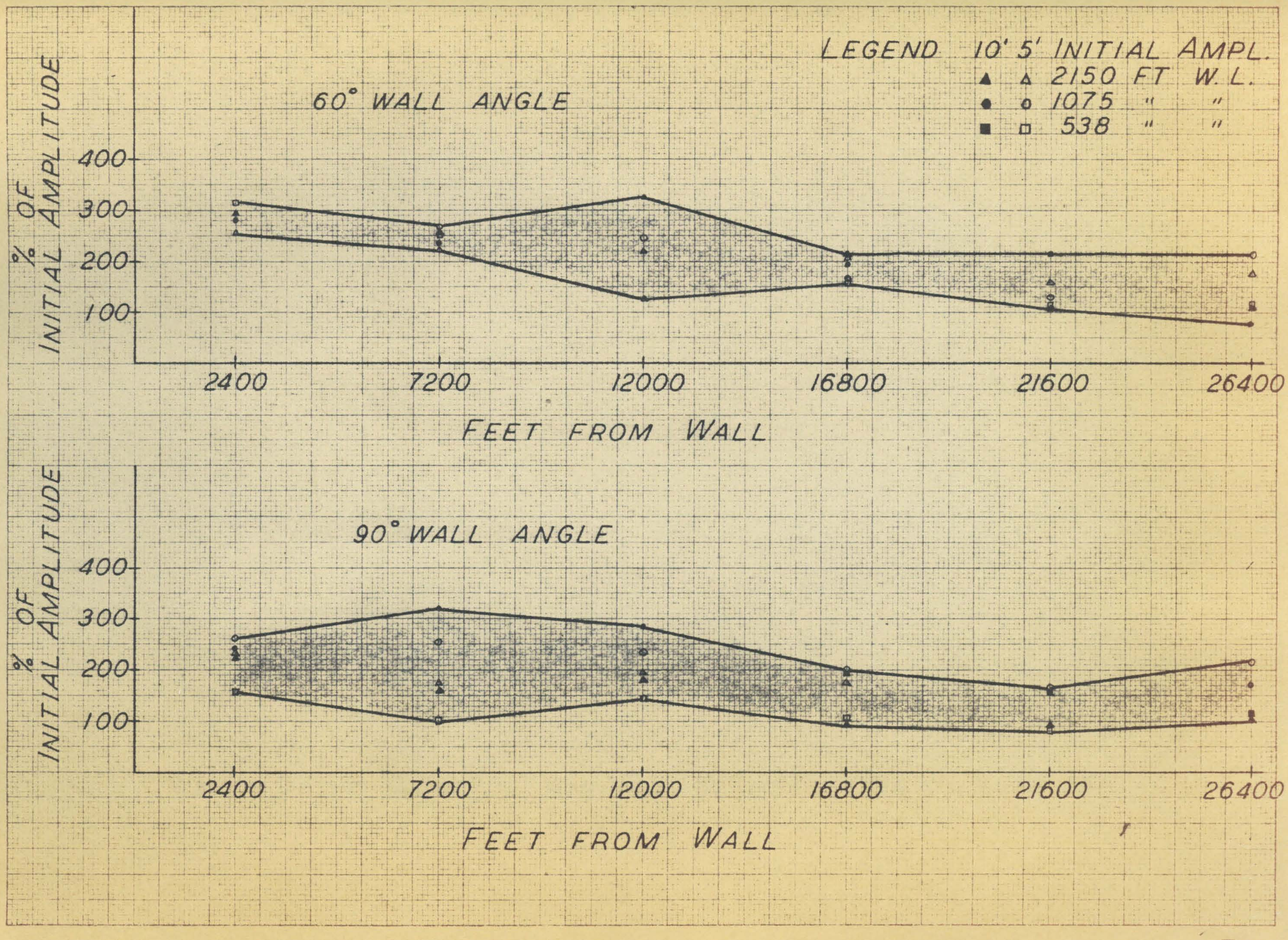
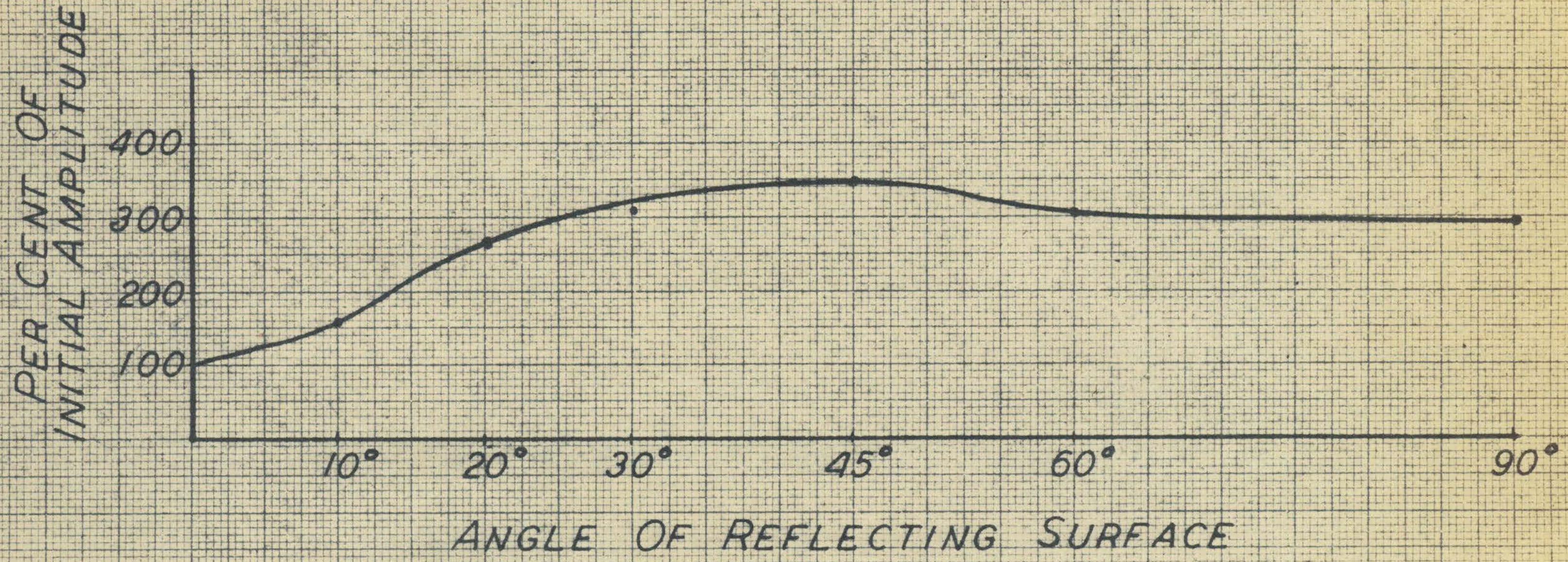
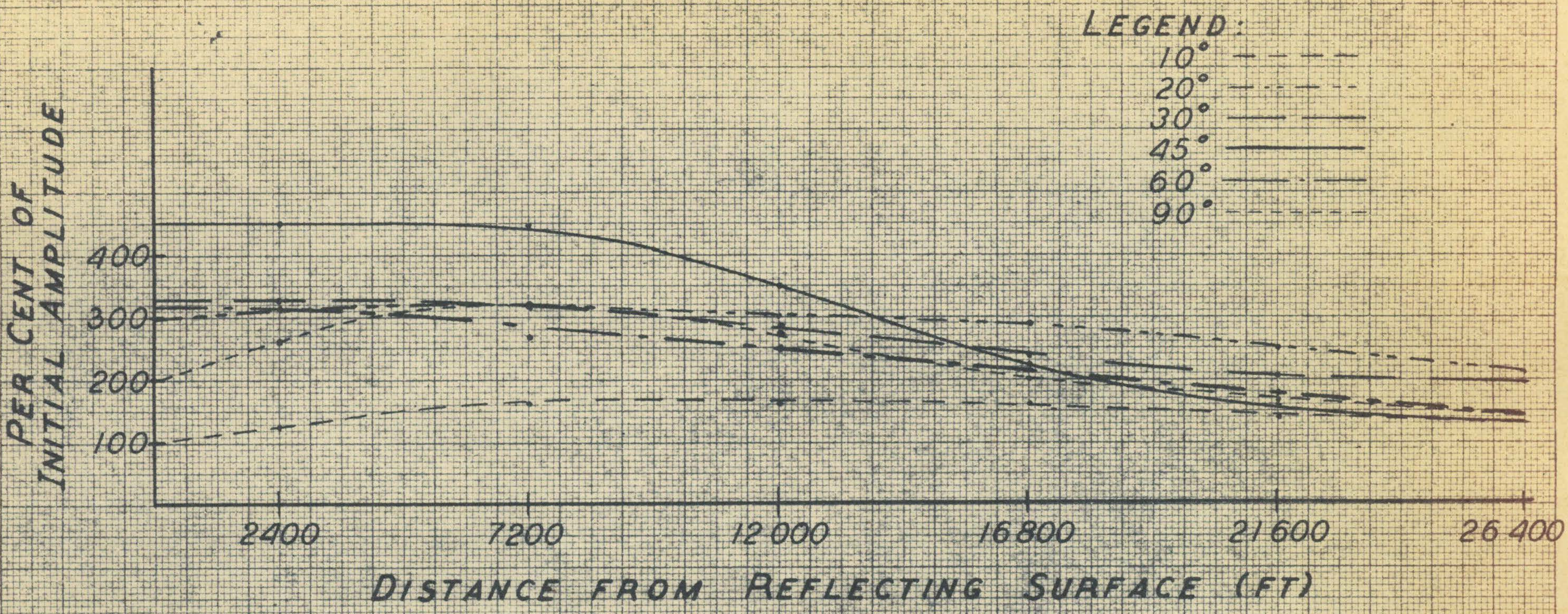

LEGEND 10' 5' INITIAL AMPL.
2150 FT W. L.
1075 " "
538 " "
60° WALL ANGLE
% OF INITIAL AMPLITUDE
400
300
200
100
2400
7200
12000
16800
21600
26400
FEET FROM WALL
90° WALL ANGLE
% OF INITIAL AMPLITUDE
400
300
200
100
2400
7200
12000
16800
21600
26400
FEET FROM WALL

FIG. 3



AVERAGE MAXIMUM AMPLITUDE, CONSIDERING BOTH 5' AND 10' WAVES, FOR VARIOUS ANGLES OF REFLECTING SURFACE

FIG. 4



MAXIMUM WAVE AMPLITUDE FOR VARIOUS ANGLES OF REFLECTING SURFACE

FIG. 5

APPENDIX "E"

PHOTOGRAPHS

LIST OF PHOTOGRAPHS

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