PRELIMINARY REPORT ON WAVE PUMP THE PALMAS DEL MAR MARINA

ORKUSTOFNUN STRAUMFRÆÐISTÖÐ
NEA HYDRAULIC LABORATORY
REYKJAVÍK ICELAND

NEA Hydraulic Laboratory
Reykjavik Iceland

PRELIMINARY REPORT ON WAVE PUMP THE PALMAS DEL MAR MARINA

BY

Gísli Viggósson, Principal Investigator

AND

Bjorn Erlendsson, Laboratory Engineer

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I. INTRODUCTION.

This preliminary report presents the results of tests on wave pump for flushing of the Palmas Del Mar Marina, Puerto Rico.

The work was executed under agreement of January 23rd 1973 as a continuation of previous study for the Palmas Del Mar Company by the NEA Hydraulic Laboratory in Reykjavik. The tests were performed jointly by NEA Hydraulic Laboratory (SFS) and the Icelandic Harbour Authority (IHA).

Principal investigator was Res. Eng. Gisli Viggosson, IHR and the tests were performed by Lab. Eng. Björn Erlendsson and the NEA's Laboratory staff.

Dr. P. Bruun who supervised the test for Palmas Del Mar Company visited the laboratory on Nov. 28th-29th, Dec. 27th 1974 and Febr. 4th 1975

2. SCOPE OF TEST ON WAVE PUMP

The scope of the test is to investigate efficiency and operation of the wave pump under a varity of wave conditions and layout of entrance funnel. The map of locations of the wave pump in the Palmas Del Mar Marina is shown on sheet no. 1, and the schematic flushing channel is shown on sheet no. 2.
The main application of the wave pump is for pollution control, e.g. on sea coasts where tidal currents are weak while wave action is present most of the time as in the case for the Palmas Del Mar Marina.

The wave pump utilize the momentum of shallow water waves which develop over a shallow bottom or on a slope and is used to create currents.

To improve the effectiveness of the wave pump so that even smaller waves may become effective wave heights are beef ed up by concentration of wave energy in the discharge channel.

The general description of the theory and function of the wave pump is given in Appendix , paper by Prof. P. Bruun and Res. Eng. G. Viggosson "THE WAVE PUMP, APPLICATION IN POLLUTION CONTROL, published in Proceedings of the Second International Conference on Port and Ocean Engineering under Arctic Conditions. August 1973. Iceland.

3. SUMMARY AND CONCLUSION

The test on the wave pump can be divided in to the following subjects:

a. Optimalization test of several layout of funnel and ramp position for given wave condition.
- Wave heights and discharge flow were measured.

b. Test with variating direction of incident wave.
- Wave heights and discharge flow were measured.

c. Test on uprush by storm waves at bridge, at MSL.
- Visual observation of uprush at bridge by varying ramp position.

d. Test on storm tides and uprush at bridge at three foot above MSL.
- Visual observation of uprush at bridge by varying ramp position.

e. Test on wave action at inner entrance of discharge channel.
- Wave heights measured in channel and marina for varying ramp position.

f. Preliminary test on the influence on flow by wind and waves

- wind velocity and wind generating currents as well as combined flow by winds and waves were measured.

The main conclusion of the tests can be summarized as follows:

a. The most effective layout of the funnel is training wall 50 m and entrance width 30 m.
The discharged flow is given in table I, which shows that 1 ft waves give ab. 3 m^3/sec but 2 ft waves give 5 to 8 m^3/sec, depending on wave period and ramp position.

b. When the incident waves deviate about ten degrees from the centerline the discharge flow decreases less than ten per cent but fifteen degrees deviation however reduces the flow about twenty to thirty per cent.

c. When the discharge channel is closed by the ramp under storm wave condition uprush occur on the bridge. No uprush occur when the opening between the top elevation of the ramp and the bridge beam is about 2 ft.

d. During storm tide condition with water level 3 ft above M.S.L. heavy uprush occur at the bridge although wave screen of 2 ft was used and the ramp was kept horizontal.

e. With 2 ft waves in the discharge channel the area of waves higher than 0.5 ft in the marina is observed within 1 m from the entrance. But when the top elevation of the ramp is at M.S.L. the area of waves higher than 0.5 ft in the marina is observed within 4 m from entrance.

f. The wind current generation did not success in the model. The main reason is expected to be the limited fetch and incorrect loope system. These tests, however, were though just as preliminary.

The results of the tests show that the wind velocity of 5 knots do not generate any current in the model. Wind of 20 knots generate flow of 0.4 m^3/s. When wind and waves were run simultaneously the flow was almost the sum of the wind current flow and the wave current flow when generated separately.

4. MODEL SCALE AND HYDRAULIC CIMILITUDE

The model scale used in the present study is 1:20. According to Froude's Modelling Law the following scale factors apply:

Geometrical scale			1:20
Velocity scale	$1:(20)^{1/2}$	=	1:4,47
Time scale	$1:(20)^{1/2}$	=	1:4,47
Area scale	$1:20^2$	=	1:400
Volume scale	$1:20^3$	=	1:8000
Discharge scale	$1:20^{2,5}$	=	1:1789

The scale 1:40 was used on the tests on wave action at the inner entrance of the wave pump channel.

5. MODEL CONSTRUCTION AND EXPERIMENTAL TECHNIQUES

The model layout is shown on sheet no. 1. A concrete wall, 15 cm above the bottom was built around the model area. The bottom of the model was made of sand with a 2 centimetre thick concrete layer to the final elevation. All absorbing slopes were made of gravel with stones approx. 2 cm in diameter, and some absorbing madrasses were laid on top of the gravel. The discharge channel was made of concrete bricks, 15 cm above the bottom. In front of the wave generator there was a slope of 1:15. All lines and measurepoints were painted on the bottom. The ramp was made of waterproof plywood, with two devices on either side to adjust the ramp in exact position. The funnel was made of waterproof plywood in several sizes. At the outlet of the discharge channel there was an absorbing rubble mound with the slope of 1:2 and a few absorbing nets.

To simulate the same energy losses per unit area in the proper model scale the bottom in the funnel was with rough concrete surface, -(rough, not finished to imitate a ripple floor), but the training walls and the discharge channel - the surface was of concrete, finished, smooth.

In the model the wave generator produces a regular wave. The practice accepted for comparison of irregular waves in the prototype with regular wave in the laboratory is to set the significant wave height and period in the prototype equal to the regular wave in the model.

The waves were produced by a pneumatic wave generator. The wave period is adjusted with thyristor adjustments and checked with a stop watch. Wave heights were measured with 6 resistance meters, one in fixed point (X) (reference point) the five others for comparison ($Y_{1,2,3,4,5}$), sheet no. 3.

All measurements were calculated and printed out with a computer, i.e. average X and average Y, standard deviation, variance and the comparison between the X meter and one of the five Y meters.

A strip chart recorder was used to observe the form of the waves.

The incident wave was measured in the reference point marked X on the layout, and the waves measured for comparison were measured in the five points marked $Y_{1,2,3,4,5}$.

The current meter is of OTT-type, with an accuracy of 1.5%.

6. TEST ON THE INFLUENCE ON FLOW BY WAVES

6.1 Introduction

More than 61 tests were run where wave conditions and discharge flow was measured.
The test results are summarized in two ways; in table I to III and sheet no. 4 to 6. Several typical print out from the wave height analyser are given in sheet no. 9 to 18.

As mentioned under section 2 the scope of the test is to investigate the efficiency and operation of the wave pump under a variety of wave conditions and layout of entrance funnel.

6.2 Layout of funnel

Four layout of funnel were tested. Most of the tests were performed with an entrance width of 30 m. The length of the training wall was 50 m, 60 m and 70 m. Also entrance width of 40 m and 50 m training wall were tested.

When the width of the entrance of the funnel is 40 m, the crest of the waves does not turn peripendicular on the training walls because of too large incident angle of the wave direction and the training wall. The waves reflect from the wall causing peripendicular surge at the wave direction. This does not happen for entrance width of 30 m.

The evaluation of the effectiveness of the various length of training wall with 30 m entrance width are given in the following table (with the ramp horizontal):

WAVE HEIGHT	WAVE PERIOD	L = 50 m W = 30 m		L = 60 m W = 30 m		L = 70 m W = 30 m	
FT	SEC	TEST No	Q m^3/s	TEST No	Q m^3/s	TEST No	Q m^3/s
1	4	35	3,0	38	3,1		
1	6	41	3,1	44	2,7		
1	8	76	3,3				
1	10	47	2,8	50	3,2		
2	6	1	6,2	13	4,2	15	5,2
2	8	17	8,0	5	7,5	19	7,2
2	10			58	6,5	9	4,3
3	10	57	5,5				

From the table above it can be concluded that the 50 m long training wall is most favourable with regard to discharge flow.

6.3 Influence of the ramp and length of the ramp

Most of the tests were run with ramp of 9,12 m length. In accordance with letter by Prof. P. Bruun dated Dec. 12th the length of the ramp was decreased to 6,0 m.

The slope of the ramp is given in degrees horizontally. The following slopes were run (the slope angle is also compared with the top elevation of the ramp relatively to M.S.L.).

Top elevation of the ramp	Length of ramp 9,12 m	Length of ramp 6,0 m
M.S.L.	Slope/degrees	Slope/degrees
- 2,5 ft	4,7°	7,2°
0,0 ft	9,4°	14,5°
+ 1,5 ft	12,0°	

The tests' results do not show any significant differences between discharge flow and length of the ramp, for various slopes of the ramp.

The ramp does not increase the discharge flow for higher waves but controls the discharge and the wave height in the discharge channel. The wave height 10 m inside the ramp section is plotted on sheet no. 4 to 6 where the influence of the ramp position is demonstrated on the wave height in the discharge channel. The ramp, however, increases the discharge flow for lowest waves.

6.4 Test with varying direction of incident waves

Most of the time the wave enters the entrance of the funnel with a propagation direction along the center line. It is assumed that the wave direction does not deviate from the center line more than 10 degrees.

To evaluate the influence on the varying direction of incident waves six tests were run with the center line varying from the wave direction.- Test no. 59 to 61 and 62 to 64 in Table I.

When the incident waves deviate about ten degrees from the center line the discharge flow decreases less than ten per cent. When the incident waves deviate about fifteen degrees from the center line the discharge flow reduces about twenty to thirty per cent.

7. TEST ON STORM WAVES CONDITION

7.1 Test on uprush by storm waves at the bridge

Test on storm wave conditions was run at M.S.L. with breaking waves offshore and wave period of 10 sec. The waves break just in front of the wave generator, producing secondary waves at the funnel entrance. Under such wave condition the discharged flow was measured about 5 to 6 m^3/sec.

These tests were run with the bridge to evaluate the uprush on the bridge. The bridge was located just behind the ramp section so the edge of the ramp in the highest position reach the bridge beam and closes the discharged channel.

The main dimension of the bridge is as follows:

Width of bridge:	8 m
Height of bridge floor	8 ft above M.S.L.
Height of bright beam	6 ft above M.S.L.
Height of wave screen	10 ft above M.S.L.

When the discharge channel is closed by the ramp, uprush on the bridge was observed. When the ramp was horizontal no uprush was observed. This was also the case without the wave screen.

Under such storm condition the ramp can control the wave height in the channel and also the discharge flow.

7.2 Test on storm tides and uprush at the bridge

Test on storm tide condition was run at water level 3 ft above M.S.L. with breaking waves offshore and wave period of 10 sec. These tests were also run with the bridge to evulate the uprushes on the bridge. Under such wave condition the waves run over the training walls in the inner part of the funnel disregarding the position of the ramp.
When the ramp was kept in the highest position and closing the discharge channel heavy uprushes were observed at the bridge, although the wave screen was used.

Photo no. 2 demonstrates the heavy uprushes when the discharge channel is closed.
Photo no. 1 demonstrates the reduction in uprushes when the ramp is horizontal. This wave condition will be clearly demonstrated in the movie.

8. TEST ON WAVE ACTION AT INNER ENTRANCE OF DISCHARGE CHANNEL

These tests were carried out in model scale 1:40, sheet no. 7. The scope of these tests was to investigate how the wave height reduces in the inner harbour, when the wave propagates into the marina with the vertical drop in depth of 5 ft from the channel to the marina.

The tests were performed by wave period of 8 sec and wave height of 2 ft in the channel behind the ramp section.

Three tests were run with three positions of the ramp: 0°, 7,2° and 14,5°. The results of the tests are shown schematic on sheet no. 8 where the area of waves higher than 0.5 ft is shown for each test.

9. PRELIMINARY TESTS ON THE INFLUENCE ON FLOW BY WINDS AND WAVES

9.1 Introduction

The normal case will be that wind and wave currents occur simultaneously. The wind does not generate wind waves only but also surface currents and pile up the M.S.L. at the funnel entrance higher than at the harbour entrance due to lower depth. The wind will also lower the M.S.L. in the marina at the end of the discharge channel due to wind shear stress in the inner harbour.

From the previous test on wave action in the outer harbour it was recognized that the waves caused current out of the entrance to the inner harbour due to the form of the coast and the small rubble mound at the north side of the entrance.

All the factors mentioned above will increase the influence of the wind to cause currents through the harbour.

The local wind is in normal case 5 to 20 knots. Experience has shown that the surface currents are about three per cent of the wind in 10 m height.
The pile up by the wind at the entrance of the funnel is at the range of one centimeter.

This report does not include theoretical calculation of the influence on the flow by the wind in the discharge channel.

In order to run the model tests the wind current as well as the wave current model laws must be published. As these model laws are not the same, one is faced by the situation of having to produce the correct wind current model first and then produce the wave and wind model.
It is however assumed that the waves do not alter the basic wind current model law.

The theory for calculation of the wind scale factor used in this preliminary test refers to two papers:-
"Modelling of Wind Driven Currents in a Laboratory", University of Florida, Coastal Eng. Dept. Gainesville; and by Gervitsen, F.: Surface Wind Stress over Water as related to Wave Action", De Ingenieur Bouw-en Water bouw Kunde, 1963.

The model wind scale factor is given by

$$\zeta\mu = \left(\frac{1}{\zeta \cdot \zeta_{c_s}} \frac{1}{(1+2\ h/d)}\right)^{1/2}$$

where

ζ = model scale 1:20

ζ_{c_s} = ratio between friction shear stress in prototype and model estimated to 1,3.

h = depth of water in model = 7,5 cm

d = height of wind funnel above water = 50 cm

The above equation gives

$$\zeta\mu = \frac{1}{5,8}$$

From this follows that the wind velocity in the model was in the range 0,4 to 1,7 m/sec.

9.2 Model construction of wind-tunnel and experimental technique

The wind-tunnel, see photo no. 3 was made of wood and waterproof plywood. The tunnel was covering the model from the wave generator to the ramp section. The roof of the tunnel was 0,5 m above the water level. To obtain the right wind profile an air distributor was used. The air-blower was of centrifugal type with a capacity of 30.000 m^3/h. The experimental techniques and measurements were carried out in the same manner as in the model without the wind-tunnel with an addition of three aero-meters which were located 3 meters from the inlet of the air-stream. They were 1 m apart and 0,2 meters below the roof.

9.3 Wind current generation results of model test

The wind current generation in the model did not succeed. The main reason is expected to be due to limited fetch and incorrect loop-system. The tests were, however, just preliminary.

In the following table the test results are given.

Current generation	Wind velocity	Wave height	Wave period	Discharge flow
	knots	ft	sec	m^3/sec
Wind only	5			0.0
	20			0.4
	31			2.2
Wave only		1	6	3.1
		2	8	8.0
Wind and waves	20	1	6	3.4
	30	1	6	3.9
	20	2	8	8.4
	30	2	8	9.0

The results of the tests show that wind velocity of 5 knots do not generate any current in the model. Wind velocity of 20 knots generates 0.4 m^3/sec in the discharge channel. When wind and waves were run simultaneously the flow is almost the sum of the wind current flow and the wave current flow when generated separately.

TABLE I

RESULT OF MODEL TEST

TRAINING WALL 50 M AND FUNNEL ENTRANCE 30 M

TEST No	Wave PERIOD ft	WAVE HEIGHT sec	RAMP LENGTH m	RAMP SLOPE degree	Q m^3/sec	REMARKS
35	4	1		0°	3.0	
36	4	1	9.12	4.7°	3.7°	
37	4	1	"	9.4°	3.0	
41	6	1		0°	3.1	
42	6	1	9.12	4.7°	3.3	
43	6	1	"	9.4°	2.5	
65	6	1	6.0	7.2°	3.2	
66	6	1	"	14.0°	3.3	
76	8	1	0°	3.3		
69	8	1	6.0	7.2°	3.2	
70	8	1	"	14.0°	3.1	?
47	10	1		0°	2.8	
48	10	1	9.12	4.7°	2.8	
49	10	1	"	9.4°	1.6	
1	6	2		0°	6.2	
2	6	2	9.12	4.7°	6.4	
3	6	2	"	9.4°	4.8	
4	6	2	"	12.0°	2.3	
67	6	2	6.0	7.2°	5.1	
68	6	2	"	14.0°	4.1	
17	8	2		0°	8.0	
18	8	2	9.12	9.4°	4.5	
71	8	2	6.0	7.2°	7.4	
72	8	2	"	14.0°	5.0	
57	10	3		0°	5.5	

TABLE II

RESULT OF MODEL TESTS TRAINING WALL 50 M

AND FUNNEL ENTRANCE 30 M

TEST No	T sec	H ft	RAMP LENGTH m	RAMP SCOPE degree	Q m^3/s	REMARKS
59	6	2		0°	6,2	5° } Varying
60	6	2		0°		10° } direction
61	6	2		0°	4.8	15° } of
						} incident
62	8	2		0°	7.2	5° } wave
63	8	2		0°	7.3	10° } in relation to
64	8	2		0°	5.7	15° } the center line
33	6	2		0°	5.1	Rough sand
34	6	2	9.12	9.4°	3.1	Bottom in funnel
29	6	2		0°	4.8	Resistance in
30	8	2		0°	6.7	return flow
27	6	2		0°	6.5	Funnel entrance
28	6	2	9.12	9.4°	3.7	40 m

TABLE II

RESULTS OF MODEL TEST

TRAINING WALL 60 M AND FUNNEL ENTRANCE 30 M

TEST No	T sec	H ft	RAMP LENGTH m	RAMP SCOPE degree	Q m^3/s	REMARKS
38	4	1		0°	3.1	
39	4	1	9.12	4.7°	3.9	
40	4	1	"	9.4°	1.4	
44	6	1		0°	2.7	
45	6	1	9.12	4.7°	3.0	
46	6	1	"	9.4°	2.9	
50	10	1		0°	3.2	
51	10	1	9.12	4.7°	2.8	
52	10	1	"	9.4°	2.2	
13	6	2		0°	4.2	
14	6	2	9.12	9.4°	3.6	
5	8	2		0°	7.5	
6	8	2	9.12	4.7°	7.5	
7	8	2	"	9.4°	6.4	
8	8	2		12.0°	5.2	
58	10	2				

TABLE III

RESULT OF MODEL TEST

TRAINING WALL 70 M AND FUNNEL ENTRANCE 30 M

TEST	T	H	RAMP LENGTH	RAMP SCOPE	Q	REMARKS
No	sec	ft	m	degree	m^3/s	
15	6	2		0°	5.2	
16	6	2	9.12	9.4°	3.7	
19	8	2		0°	7.2	
20	8	2	9.12	9.4°	4.5	
9	10	2		0°	4.3	
10	10	2	9.12	4.7°	3.9	
11	10	2		9.4°	2.8	
12	10	2		12.0°	1.6	

WAVE PUMP

TABLE IV

TEST No. 17

Wave period	8 sec	prototype
Wave height	2 FT	"
Length of funnel	50 M.	"
Width "	30 "	"
Height of ramp	0 DEGREES	"
Discharge in channel	8.0 m^3/sec	"
Wind	m/ "	"

1	2	3	4	5
315• x	305• x	284• x	336• x	315• x
292• y	275• y	260• y	281• y	146• y
308• x	315• x	302• x	300• x	296• x
300• y	264• y	330• y	319• y	150• y
312• x	310• x	309• x	306• x	283• x
288• y	273• y	321• y	315• y	162• y
314• x	323• x	293• x	269• x	290• x
293• y	251• y	334• y	313• y	173• y
319• x	340• x	274• x	272• x	300• x
308• y	267• y	323• y	272• y	162• y
312• x	326• x	248• x	258• x	329• x
330• y	279• y	270• y	302• y	175• y
318• x	286• x	270• x	261• x	315• x
309• y	291• y	262• y	298• y	184• y
317• x	268• x	294• x	276• x	314• x
291• y	286• y	281• y	273• y	161• y
319• x	280• x	302• x	296• x	321• x
276• y	253• y	316• y	323• y	148• y
337• x	295• x	269• x	305• x	334• x
302• y	250• y	302• y	325• y	157• y
317•10MX	304•80MX	284•50MX	288•90MX	309•70MX
298•90MY 1	268•90MY 2	299•90MY 3	302•10MY 4	161•80MY 5
V	V	V	V	V
61•43 x	507•73 x	363•17 x	556•32 x	283•12 x
216•77 y	210•54 y	843•43 y	416•32 y	155•07 y
−3•88 xy	−74•58 xy	313•50 xy	79•46 xy	−5•96 xy
SD	SD	SD	SD	SD
7•84 x	22•53 x	19•06 x	23•59 x	16•83 x
14•72 y	14•51 y	29•04 y	20•40 y	12•45 y
1•97 xy	8•64 xy	17•71 xy	8•91 xy	2•44 xy
298•9 ÷	268•9 ÷	299•9 ÷	302•1 ÷	161•8 ÷
317•1=	304•8=	284•5=	288•9=	309•7=
0•94 *	0•88 *	1•05 *	1•05 *	0•52 *

WAVE PUMP

TABLE V

TEST No. 31

Wave period	6 sec		prototype
Wave height	1 FT		"
Length of funnel	50 M		"
Width "	30	"	"
Height of ramp	0	DEGREES	"
Discharge in channel	3.0	m^3/sec	"
Wind		m/ "	"

150• x	159• x	150• x	149• x	155• x
109• y	174• y	131• y	181• y	200• y
144• x	156• x	150• x	148• x	152• x
111• y	170• y	126• y	178• y	190• y
145• x	157• x	161• x	149• x	159• x
112• y	161• y	121• y	131• y	177• y
153• x	182• x	165• x	148• x	165• x
114• y	170• y	115• y	179• y	174• y
152• x	156• x	167• x	150• x	162• x
114• y	157• y	113• y	176• y	186• y
155• x	161• x	163• x	152• x	143• x
116• y	160• y	113• y	186• y	225• y
156• x	161• x	158• x	151• x	136• x
114• y	161• y	118• y	189• y	231• y
160• x	158• x	156• x	145• x	134• x
109• y	168• y	134• y	177• y	212• y
161• x	157• x	151• x	144• x	145• x
109• y	168• y	144• y	171• y	175• y
153• x	159• x	149• x	144• x	158• x
112• y	163• y	149• y	165• y	162• y
153•00 Mx	160•60 Mx	157•00 Mx	148•00 Mx	151•40 Mx
112•00 My 1	165•70 My 2	126•40 My 3	178•30 My 4	193•30 My 5
V	V	V	V	V
31•78 x	59•82 x	46•22 x	8•00 x	111•50 x
6•22 y	30•46 y	165•38 y	47•34 y	544•68 y
−1•22 xy	10•42 xy	−73•22 xy	16•67 xy	−172•02 xy
SD	SD	SD	SD	SD
5•64 x	7•73 x	6•80 x	2•83 x	10•56 x
2•49 y	5•52 y	12•86 y	6•88 y	23•34 y
1•11 xy	3•23 xy	8•56 xy	4•08 xy	13•12 xy
112• ÷	165•7 ÷	126•4 ÷	178•3 ÷	193•3 ÷
153•=	160•6=	157•=	148•=	151•4=
0•73 *	1•03 *	0•81 *	1•20 *	1•28 *

WAVE PUMP

TABLE VI

TEST No. 47

Wave period	10 sec	prototype
Wave height	1 FT	"
Length of funnel	50 M	"
Width "	30 "	"
Height of ramp	0 DEGREES	"
Discharge in channel	2,8 m^3/sec	"
Wind	m/ "	"

140• x	163• x	152• x	139• x	147• x
164• y	128• y	126• y	203• y	166• y
148• x	153• x	167• x	136• x	150• x
160• y	132• y	125• y	194• y	170• y
151• x	149• x	156• x	134• x	157• x
159• y	146• y	125• y	182• y	178• y
149• x	156• x	151• x	134• x	163• x
162• y	145• y	113• y	182• y	184• y
157• x	160• x	146• x	136• x	156• x
155• y	130• y	105• y	197• y	194• y
163• x	153• x	153• x	149• x	154• x
138• y	133• y	123• y	205• y	192• y
169• x	147• x	152• x	154• x	154• x
159• y	139• y	123• y	216• y	205• y
161• x	152• x	149• x	163• x	153• x
159• y	141• y	129• y	227• y	195• y
169• x	161• x	141• x	168• x	157• x
157• y	134• y	129• y	211• y	166• y
165• x	167• x	136• x	169• x	165• x
144• y	115• y	118• y	187• y	156• y
157•20MX	156•10MX	150•30MX	148•20MX	155•60MX
155•70MY 1	134•30MY 2	121•60MY 3	200•40MY 4	180•60MY
V	V	V	V	V
97•07 x	41•66 x	70•68 x	207•07 x	29•38 x
68•01 y	84•01 y	57•60 y	222•27 y	252•71 y
-42•38 xy	-46•14 xy	14•24 xy	115•24 xy	-14•96 xy
SD	SD	SD	SD	SD
9•85 x	6•45 x	8•41 x	14•39 x	5•42 x
8•25 y	9•17 y	7•59 y	14•91 y	15•90 y
6•51 xy	6•79 xy	3•77 xy	10•74 xy	3•87 xy
155•7 ÷	134•3 ÷	121•6 ÷	200•4 ÷	180•6 ÷
157•2=	156•1=	150•3=	148•2=	155•6=
0•99 *	0•86 *	0•81 *	1•35 *	1•16 *

WAVE PUMP

TABLE VII

TEST No. 57

Wave period	10 sec	prototype
Wave height	3 FT	"
Length of funnel	50 M	"
Width "	30 "	"
Height of ramp	0 DEGREES	"
Discharge in channel	5.5 m^3/sec	"
Wind	m/ "	"

399. x	465. x	478. x	409. x	463. x
473. y	347. y	368. y	393. y	249. y
420. x	418. x	378. x	458. x	414. x
377. y	333. y	463. y	298. y	235. y
455. x	405. x	386. x	455. x	409. x
385. y	352. y	453. y	341. y	273. y
436. x	509. x	377. x	491. x	488. x
337. y	426. y	441. y	325. y	324. y
537. x	532. x	402. x	497. x	487. x
382. y	394. y	352. y	320. y	283. y
439. x	478. x	478. x	529. x	491. x
415. y	445. y	349. y	316. y	302. y
438. x	490. x	515. x	411. x	543. x
360. y	359. y	310. y	308. y	310. y
494. x	478. x	477. x	345. x	519. x
357. y	371. y	354. y	363. y	301. y
533. x	460. x	528. x	503. x	498. x
429. y	405. y	494. y	411. y	290. y
526. x	385. x	475. x	550. x	511. x
395. y	370. y	356. y	441. y	294. y
467.70MX	462.00MX	449.40MX	464.80MX	482.30MX
391.00MY 1	380.20MY 2	394.00MY 3	351.60MY 4	286.10MY 5
V	V	V	V	V
2558.23 x	2170.22 x	3348.93 x	3896.18 x	1849.12 x
1567.33 y	1318.40 y	3890.67 y	2358.27 y	747.66 y
-194.33 xy	859.44 xy	-1315.22 xy	558.24 xy	865.74 xy
SD	SD	SD	SD	SD
50.58 x	46.59 x	57.87 x	62.42 x	43.00 x
39.59 y	36.31 y	62.38 y	48.56 y	27.34 y
13.94 xy	29.32 xy	36.27 xy	23.63 xy	29.42 xy
391. ÷	380.2 ÷	394. ÷	351.6 ÷	286.1 ÷
467.7=	462.=	449.4=	464.8=	482.3=
0.84 *	0.82 *	0.88 *	0.76 *	0.59 *

WAVE PUMP

TABLE VIII

TEST No. 64

Wave period	8	sec	prototype
Wave height	2 FT		"
Length of funnel	50 M		"
Width "	30	"	"
Height of ramp	0 DEGREES		"
Discharge in channel	5.7	m^3/sec	"
Wind		m/ "	"

1	2	3	4	5
297. x	301. x	308. x	320. x	301. x
220. y	286. y	210. y	345. y	306. y
298. x	298. x	324. x	320. x	298. x
234. y	282. y	218. y	354. y	279. y
323. x	297. x	321. x	320. x	304. x
199. y	286. y	246. y	362. y	323. y
318. x	291. x	321. x	305. x	305. x
197. y	292. y	213. y	366. y	368. y
298. x	291. x	312. x	308. x	291. x
221. y	293. y	185. y	361. y	308. y
302. x	286. x	308. x	314. x	298. x
226. y	284. y	212. y	330. y	354. y
276. x	290. x	279. x	323. x	296. x
262. y	282. y	199. y	362. y	309. y
272. x	290. x	306. x	315. x	296. x
265. y	282. y	203. y	409. y	303. y
309. x	288. x	303. x	329. x	315. x
206. y	272. y	199. y	382. y	324. y
295. x	286. x	301. x	329. x	318. x
207. y	273. y	183. y	399. y	298. y
293.80MX	291.80MX	308.30MX	318.30MX	302.20MX
223.70MY1	283.20MY2	206.80MY3	367.00MY4	317.80MY5
V	V	V	V	V
258.40 x	26.62 x	169.79 x	63.57 x	73.73 x
580.01 y	47.07 y	323.96 y	569.11 y	713.73 y
-355.51 xy	13.27 xy	124.62 xy	56.33 xy	23.16 xy
SD	SD	SD	SD	SD
16.07 x	5.16 x	13.03 x	7.97 x	8.59 x
24.08 y	6.86 y	18.00 y	23.86 y	26.72 y
13.86 xy	3.64 xy	11.16 xy	7.51 xy	4.81 xy
223.7 ÷	283.2 ÷	206.8 ÷	367. ÷	317.8 ÷
298.3 =	291.8 =	308.3 =	318.3 =	302.2 =
0.75 *	0.97 *	0.67 *	1.15 *	1.05 *

WAVE PUMP

TABLE IX

TEST No. 71

Wave period	8 sec	prototype
Wave height	2 FT	"
Length of funnel	50 M	"
Width "	30 "	"
Height of ramp	7.2 DEGREES	"
Discharge in channel	7.4 m^3/sec	"
Wind	m/ "	"

324. x	308. x	244. x	243. x	312. x
340. y	467. y	381. y	366. y	254. y
309. x	298. x	245. x	239. x	315. x
323. y	472. y	364. y	350. y	266. y
315. x	299. x	250. x	225. x	297. x
307. y	469. y	375. y	355. y	280. y
304. x	289. x	270. x	222. x	304. x
288. y	457. y	367. y	367. y	279. y
307. x	302. x	256. x	226. x	301. x
283. y	460. y	368. y	379. y	298. y
323. x	295. x	259. x	225. x	304. x
293. y	466. y	379. y	391. y	317. y
334. x	282. x	232. x	228. x	308. x
295. y	468. y	370. y	370. y	307. y
335. x	294. x	245. x	235. x	317. x
295. y	462. y	369. y	342. y	283. y
329. x	295. x	259. x	236. x	299. x
319. y	464. y	345. y	355. y	261. y
325. x	307. x	263. x	226. x	309. x
286. y	469. y	359. y	373. y	280. y
320.50MX	296.90MX	252.30MX	230.50MX	306.60MX
302.90MY 1	465.40MY 2	367.70MY 3	364.80MY 4	282.50MY
V	V	V	V	V
124.50 x	61.88 x	124.90 x	50.94 x	45.60 x
353.66 y	21.38 y	107.79 y	213.29 y	400.28 y
22.83 xy	8.93 xy	-37.46 xy	-54.44 xy	-26.56 xy
SD	SD	SD	SD	SD
11.16 x	7.87 x	11.18 x	7.14 x	6.75 x
18.81 y	4.62 y	10.38 y	14.60 y	20.01 y
4.78 xy	2.99 xy	6.12 xy	7.38 xy	5.15 xy
302.9 ÷	465.4 ÷	367.7 ÷	364.8 ÷	282.5 ÷
320.5=	296.9=	252.3=	230.5=	306.6=
0.95 *	1.57 *	1.46 *	1.58 *	0.92 *

WAVE PUMP

TABLE X

TEST No. 72

Wave period	8	sec	prototype
Wave height	2	FT	"
Length of funnel	50	M	"
Width "	30	"	"
Height of ramp	14.5	DEGREES	"
Discharge in channel	5.0	m^3/sec	"
Wind		m/ "	"

282• X	338• X	236• X	253• X	324• X
360• y	383• y	267• y	241• y	231• y
295• X	324• X	303• X	256• X	320• X
376• y	363• y	293• y	250• y	227• y
307• X	246• X	305• X	261• X	328• X
377• y	363• y	271• y	236• y	211• y
313• X	338• X	315• X	277• X	303• X
370• y	386• y	283• y	268• y	191• y
316• X	316• X	327• X	303• X	295• X
364• y	381• y	271• y	293• y	213• y
325• X	301• X	340• X	286• X	288• X
367• y	398• y	276• y	274• y	211•
299• X	303• X	304• X	283• X	270• X
360• y	386• y	268• y	273• y	215•
304• X	300• X	301• X	290• X	277• X
381• y	386• y	250• y	246• y	245•
344• X	323• X	252• X	282• X	291•
376• y	383• y	249• y	227• y	229•
274• X	326• X	298• X	295• X	320•
313• y	388• y	282• y	248• y	215•
305•90MX	311•50MX	298•10MX	278•60MX	302•20M
364•40MY 1	381•70MY 2	271•00MY 3	255•60MY 4	218•80M
V	V	V	V	V
414•32 X	725•39 X	996•99 X	284•27 X	427•29
380•27 y	118•23 y	191•56 y	421•16 y	218•18
239•82 xy	109•50 xy	189•22 xy	179•93 xy	-58•18
SD	SD	SD	SD	SD
20•35 X	26•93 X	31•58 X	16•86 X	20•67
19•50 y	10•87 y	13•84 y	20•52 y	14•77
15•49 xy	10•46 xy	13•76 xy	13•41 xy	7•63
364•4 ÷	381•7 ÷	271• ÷	255•6 ÷	218•8
305•9=	311•7=	298•1=	278•6=	302•2=
1•19 *	1•22 *	0•91 *	0•92 *	0•72

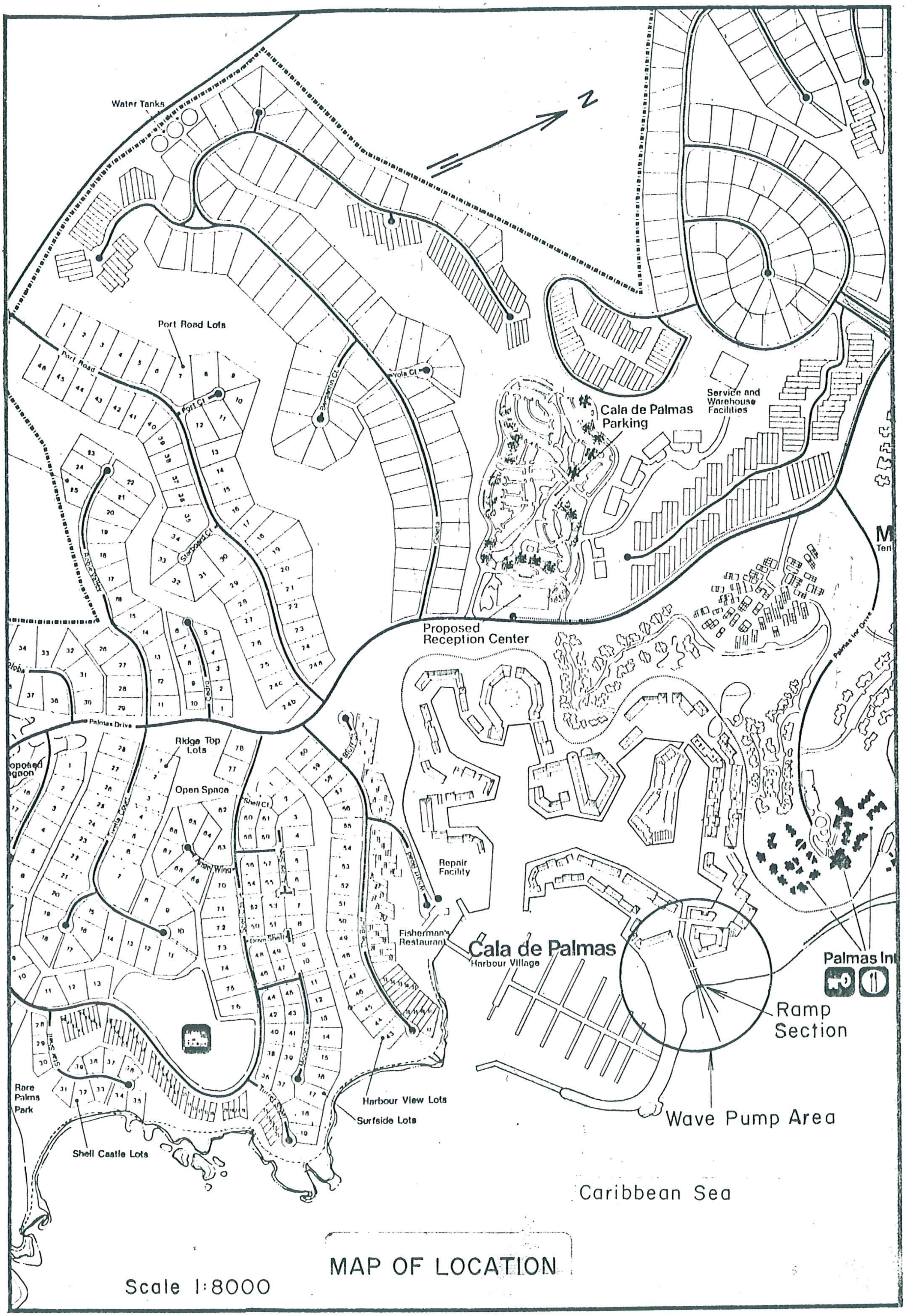
WAVE PUMP

TEST No. 76 — TABLE XI

Wave period	8	sec	prototype
Wave height	1	FT	"
Length of funnel	50	M	"
Width "	30	"	"
Height of ramp	0	DEGREES	"
Discharge in channel	3.3	m^3/sec	"
Wind		m/ "	"

1	2	3	4	5
166• x	150• x	150• x	156• x	150• x
120• y	101• y	165• y	237• y	188• y
163• x	151• x	151• x	156• x	150• x
120• y	101• y	163• y	235• y	190• y
162• x	149• x	150• x	158• x	155• x
120• y	98• y	164• y	234• y	196• y
162• x	153• x	156• x	153• x	148• x
122• y	100• y	155• y	228• y	196• y
155• x	160• x	154• x	152• x	152• x
123• y	103• y	154• y	233• y	200• y
154• x	165• x	151• x	149• x	149• x
136• y	104• y	158• y	234• y	197• y
149• x	162• x	157• x	148• x	149• x
124• y	103• y	155• y	233• y	199• y
154• x	161• x	159• x	151• x	149• x
122• y	102• y	156• y	236• y	199• y
161• x	159• x	158• x	151• x	150• x
123• y	101• y	158• y	238• y	196• y
166• x	158• x	160• x	155• x	145• x
121• y	101• y	158• y	248• y	197• y
159•20.000MX	156•80.000MX	154•60.000MX	152•90.000MX	149•70.000MX
123•10.000MY 1	101•40.000MY 2	158•60.000MY 3	235•60.000MY 4	195•80.000MY 5
V	V	V	V	V
33•51111 x	31•51111 x	15•15556 x	10•76667 x	6•67778 x
22•54444 y	2•93333 y	16•04444 y	26•48889 y	15•06667 y
-14•35556 xy	8•03889 xy	-10•62222 xy	3•95556 xy	-0•51111 xy
SD	SD	SD	SD	SD
5•78888 x	5•61348 x	3•89301 x	3•28126 x	2•58414 x
4•74810 y	1•71270 y	4•00555 y	5•14674 y	3•88158 y
3•78887 xy	2•84410 xy	3•25918 xy	1•98886 xy	0•71492 xy
123•1 ÷	101•4 ÷	158•6 ÷	235•6 ÷	195•8 ÷
159•2=	156•8=	154•6=	152•9=	149•7=
0•77324 *	0•64668 *	1•02587 *	1•54088 *	1•30795 *

SHEET NO. 1

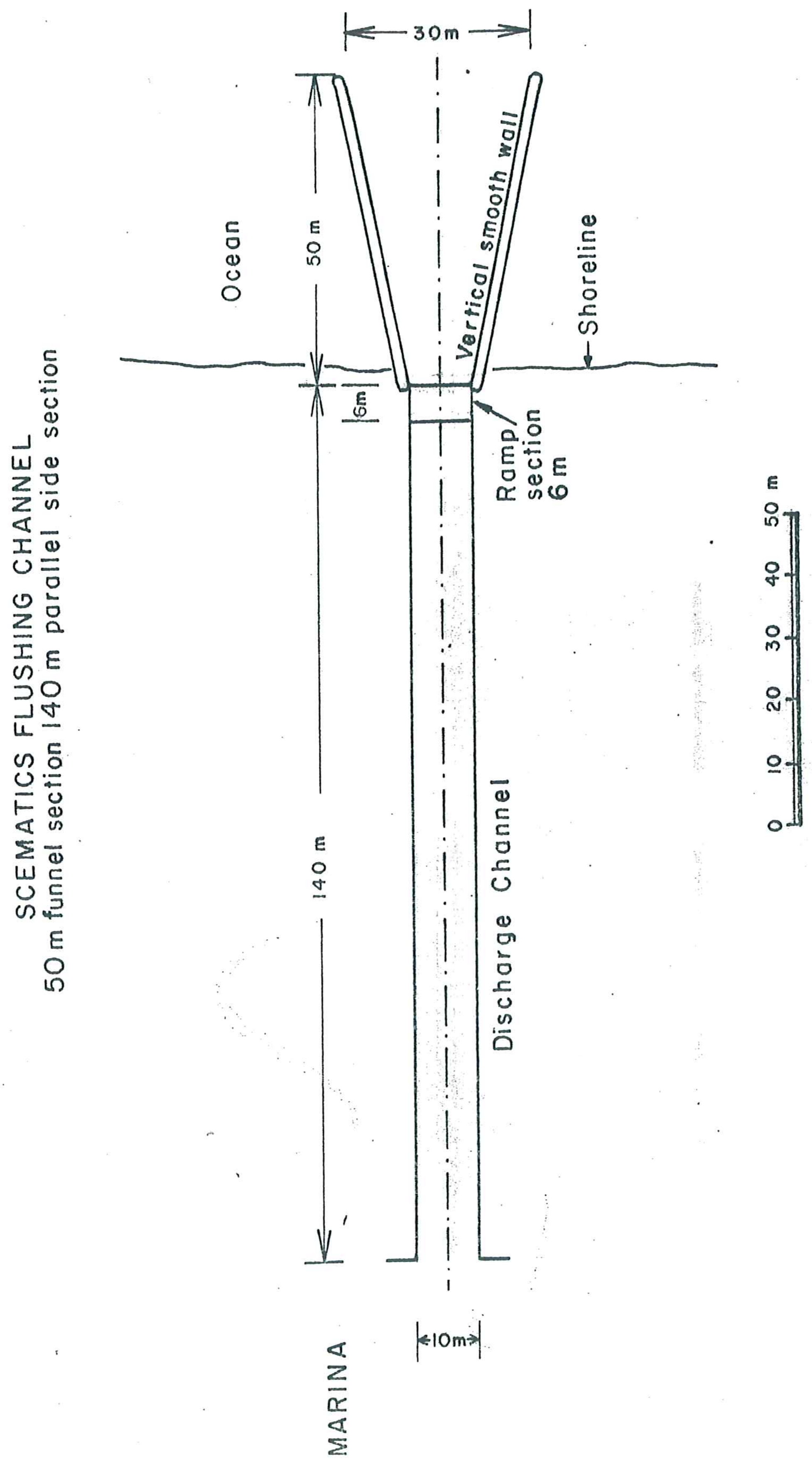


MAP OF LOCATION

Scale 1:8000

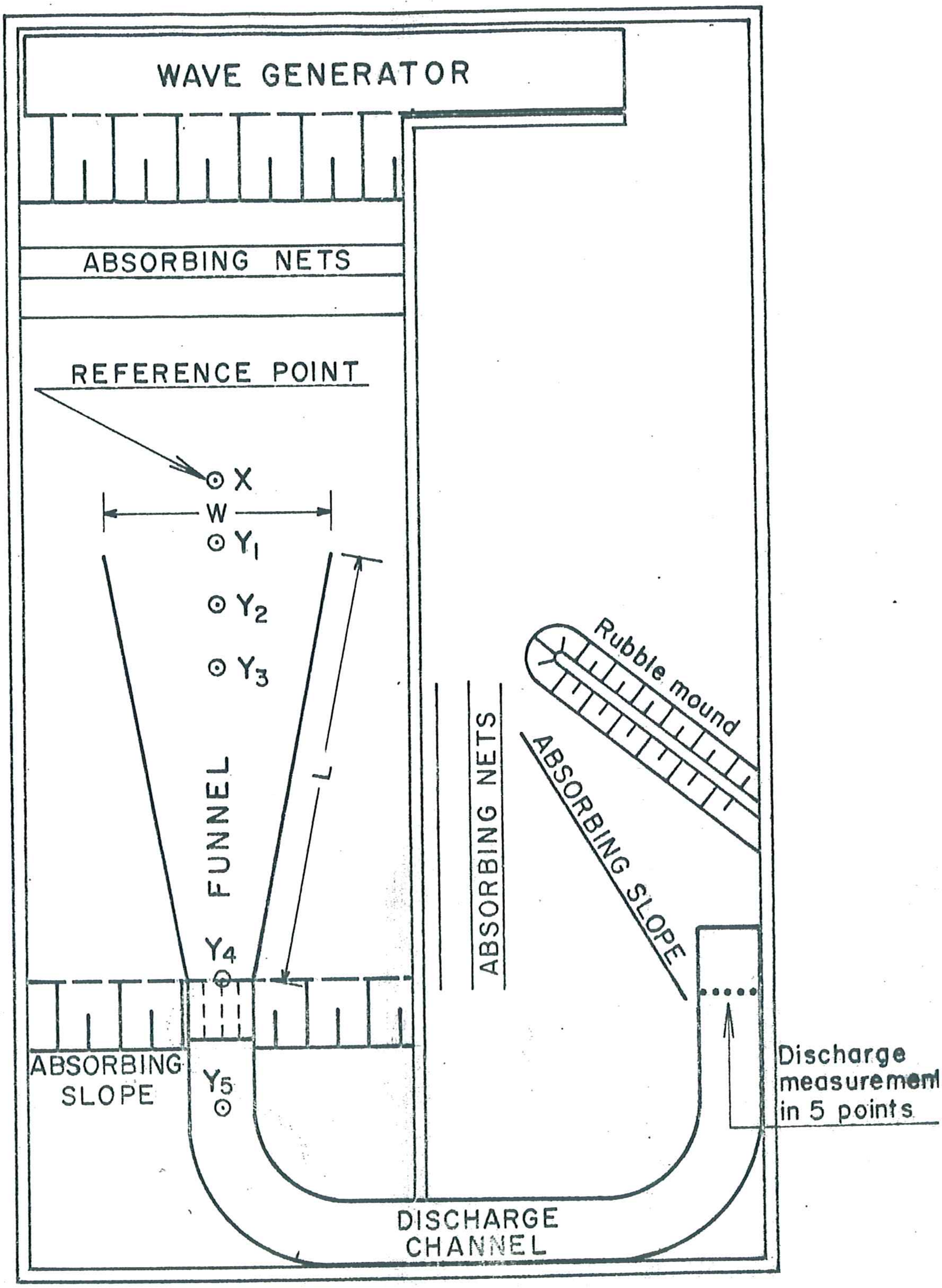
NEA HYDRAULIC LABORATORY	11.1 '75 B.E/H.O
REYKJAVIK ICELAND	Tnr. 42
PALMAS DEL MAR MARINA, PUERTO RICO	ORS-4
WAVE PUMP. SCALE 1:1000	Fnr. 12419

SHEET NO. 2



NEA HYDRAULIC LABORATORY	13.2'75 GV/BE/HO
REYKJAVIK, ICELAND	Tnr. 44
PALMAS DEL MAR MARINA, PUERTO RICO	ORS-4
WAVE PUMP LAYOUT OF MODEL STUDY, SCALE 1:20	Fnr. 12453

SHEET NO. 3

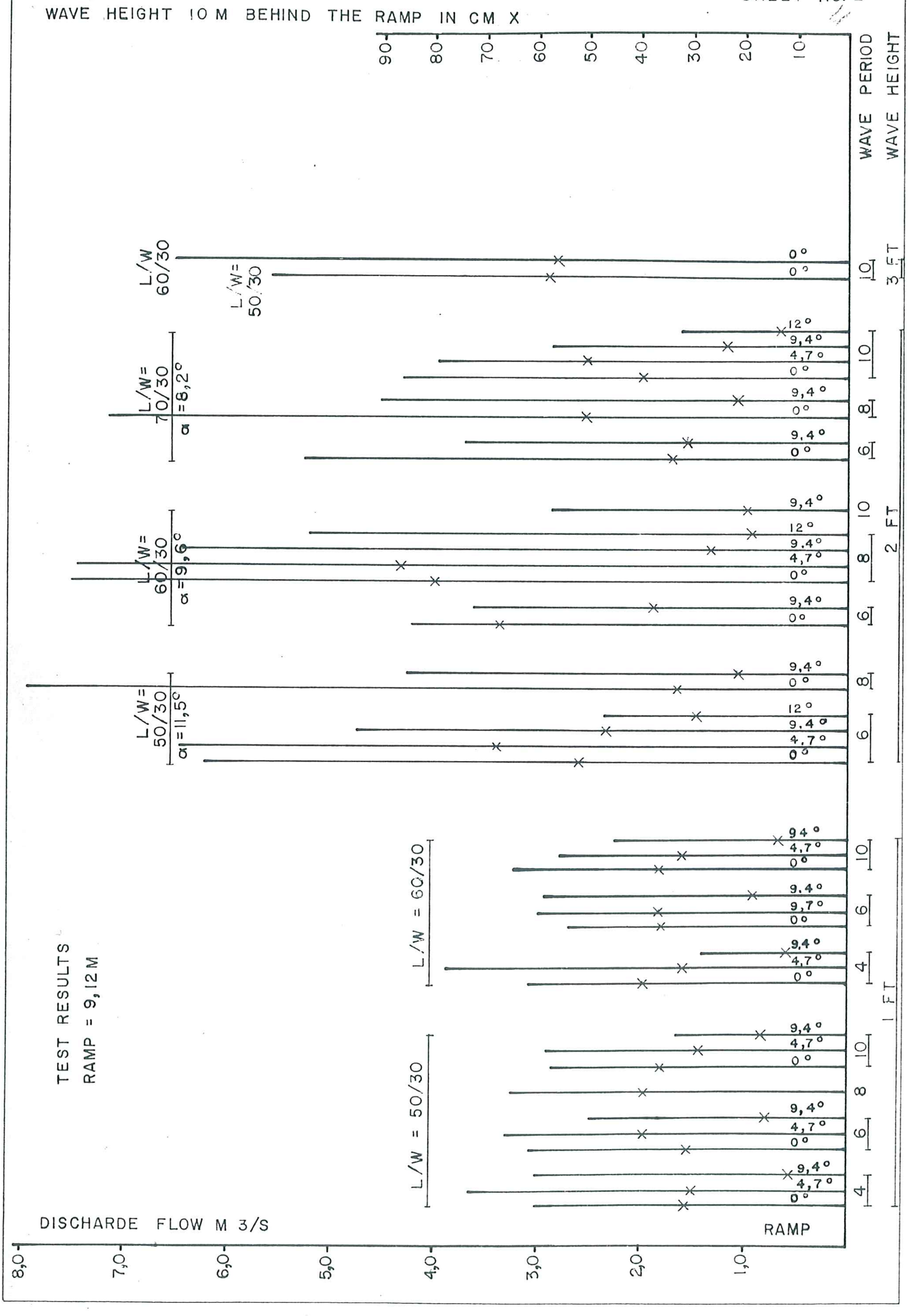


W = WIDTH, L = LENGTH, Y_2 = MEASURE POINT

DWG-MODEL, SCALE 1:50

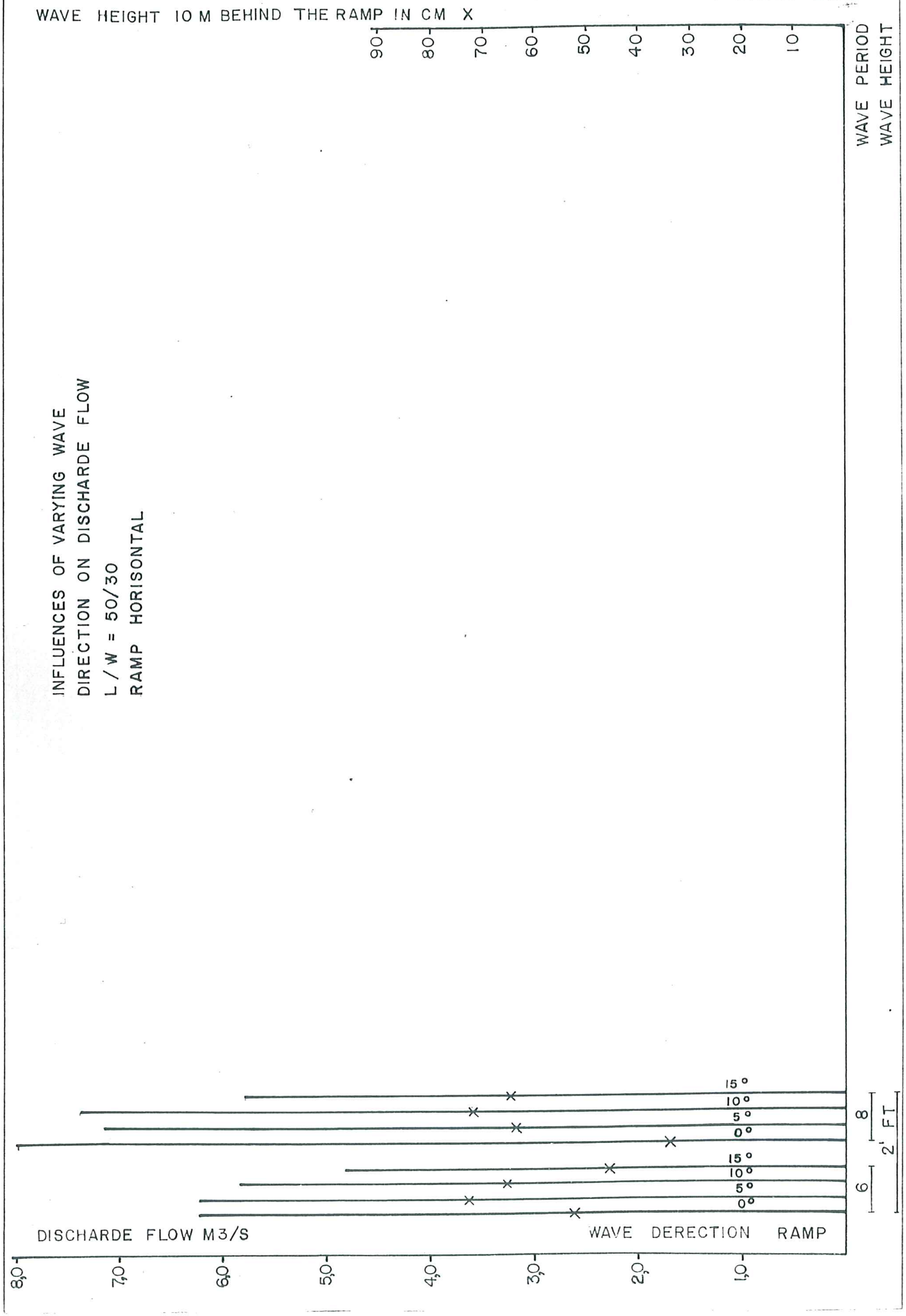
NEA HYDRAULIC LABORATORY	14.2 '75 GV/HJ
REYKJAVIK, ICELAND	TNR. 46
PALMAS DEL MAR MARINA, PUERTO RICO	ORS. 4
TEST ON WAVE PUMP	FNR. 12457

SHEET NO. 2



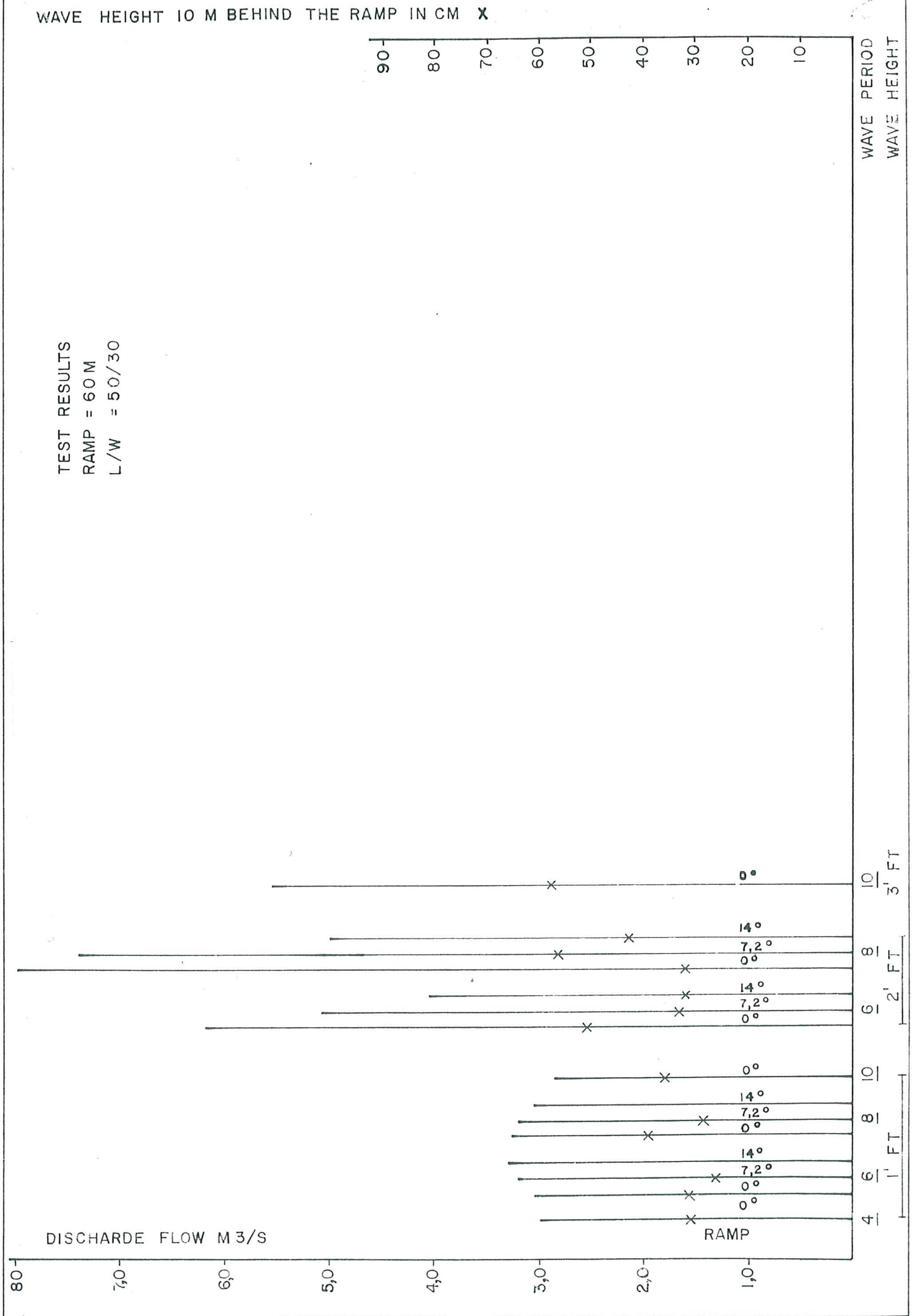
NEA HYDRAULIC LABORATORY	14.2 '75 GV/HJ
REYKJAVIK, ICELAND	TNR. 47
PALMAS DEL MAR MARINA, PUERTO RICO	ORS. 4
TEST ON WAVE PUMP	FNR. 12458

SHEET NO. 3



NEA HYDRAULIC LABORATORY	14.2 '75 GV/HJ
REYKJAVIK, ICELAND	TNR. 48
PALMAS DEL MAR MARINA, PUERTO RICO	ORS. 4
TEST ON WAVE PUMP	FNR. 12459

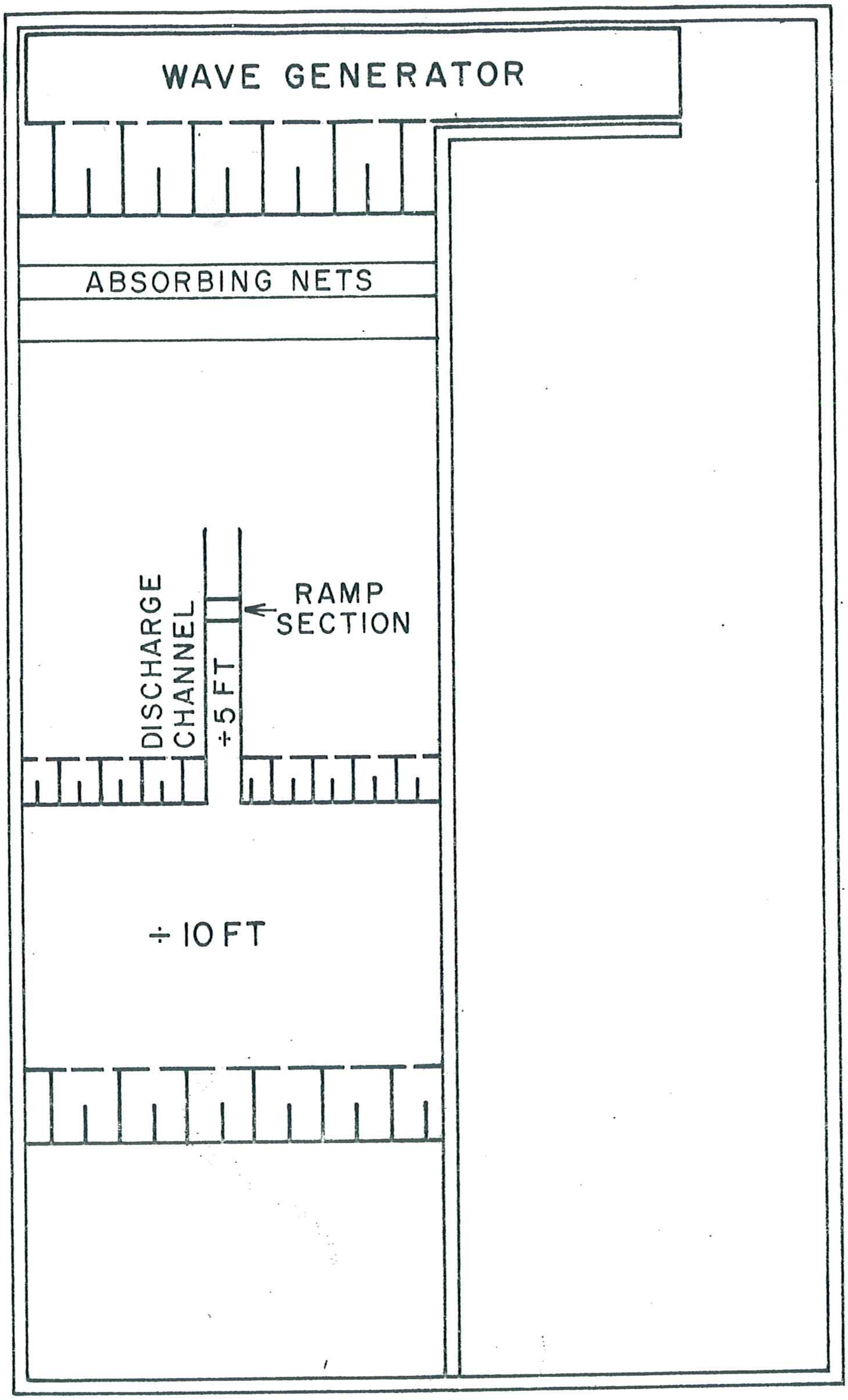
SHEET NO. 4



NEA HYDRAULIC LABORATORY	13.2 '75 GV/BE/HO
REYKJAVÍK, ICELAND	Tnr. 43
PALMAS DEL MAR MARINA, PUERTO RICO	ORS-4
WAVE PUMP, LAYOUT OF MODEL STUDY, SCALE 1:40	Fnr. 12452

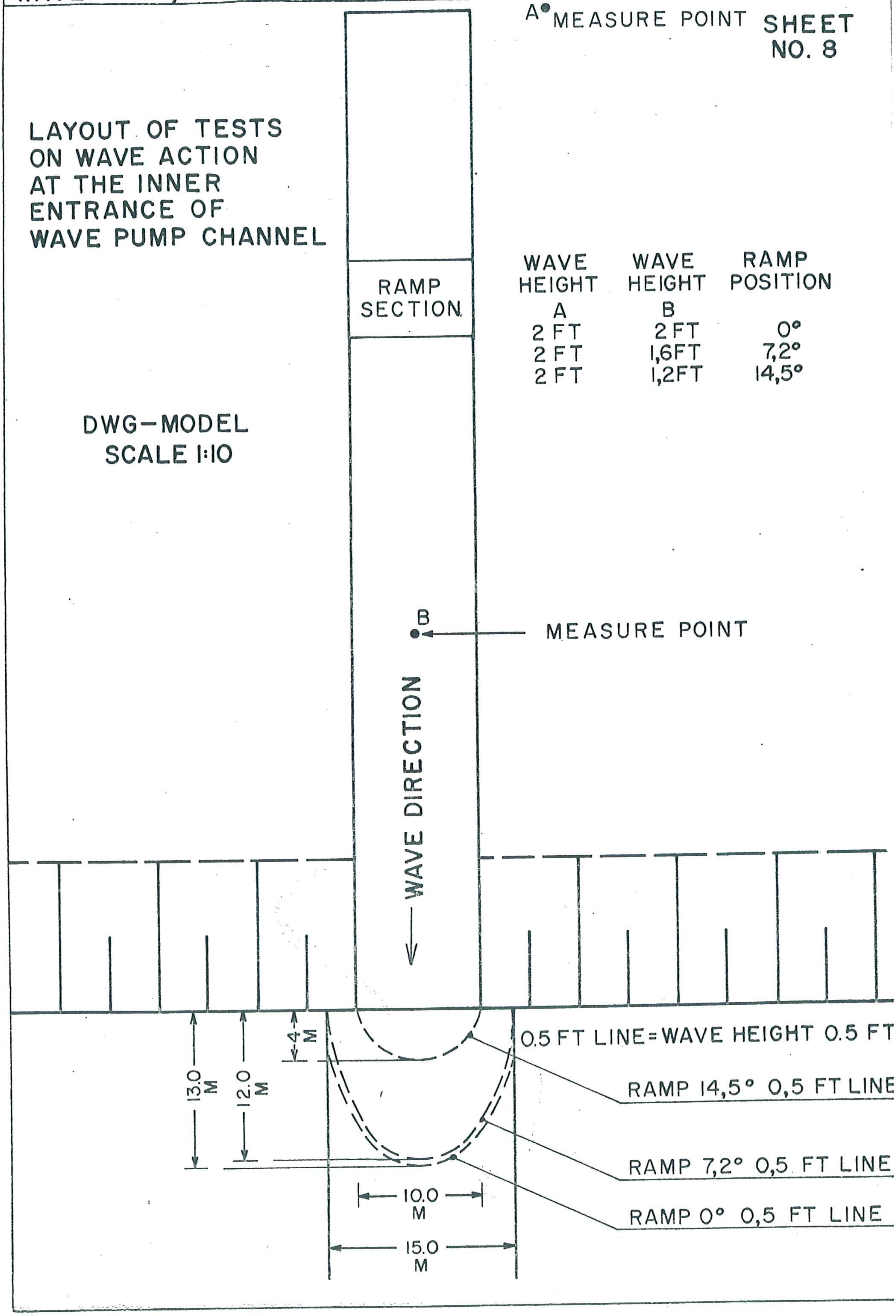
TEST ON WAVE ACTION AT THE INNER ENTRANCE OF WAVE PUMP CHANNEL

SHEET NO. 7



DWG-MODEL. SCALE 1:50

NEA HYDRAULIC LABORATORY	13.2 '75 GV/BE/H
REYKJAVIK, ICELAND	Tnr. 45
PALMAS DEL MAR MARINA, PUERTO RICO	ORS-4
WAVE PUMP, MODEL STUDY, SCALE 1:40	Fnr. 12454



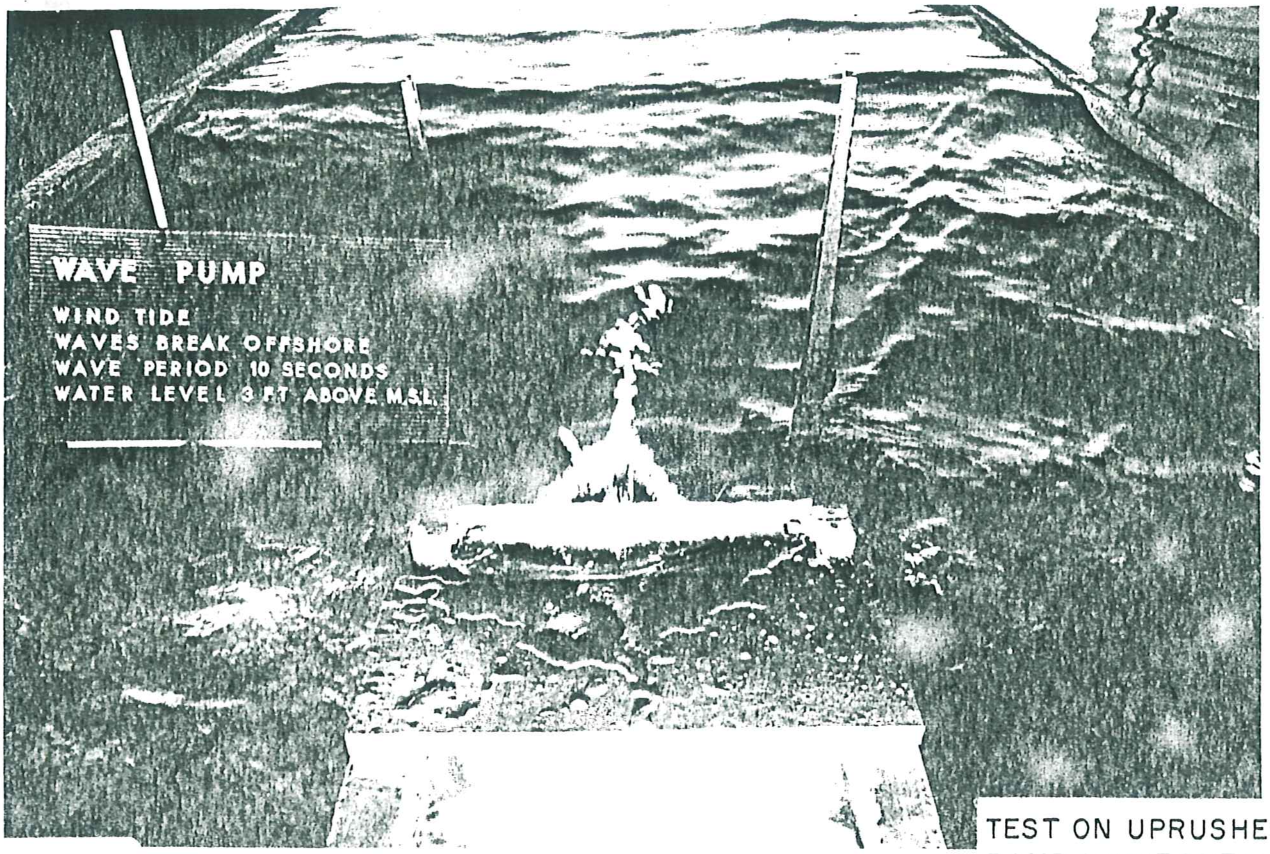


PHOTO 1

TEST ON UPRUSHES
RAMP HORIZONTAL

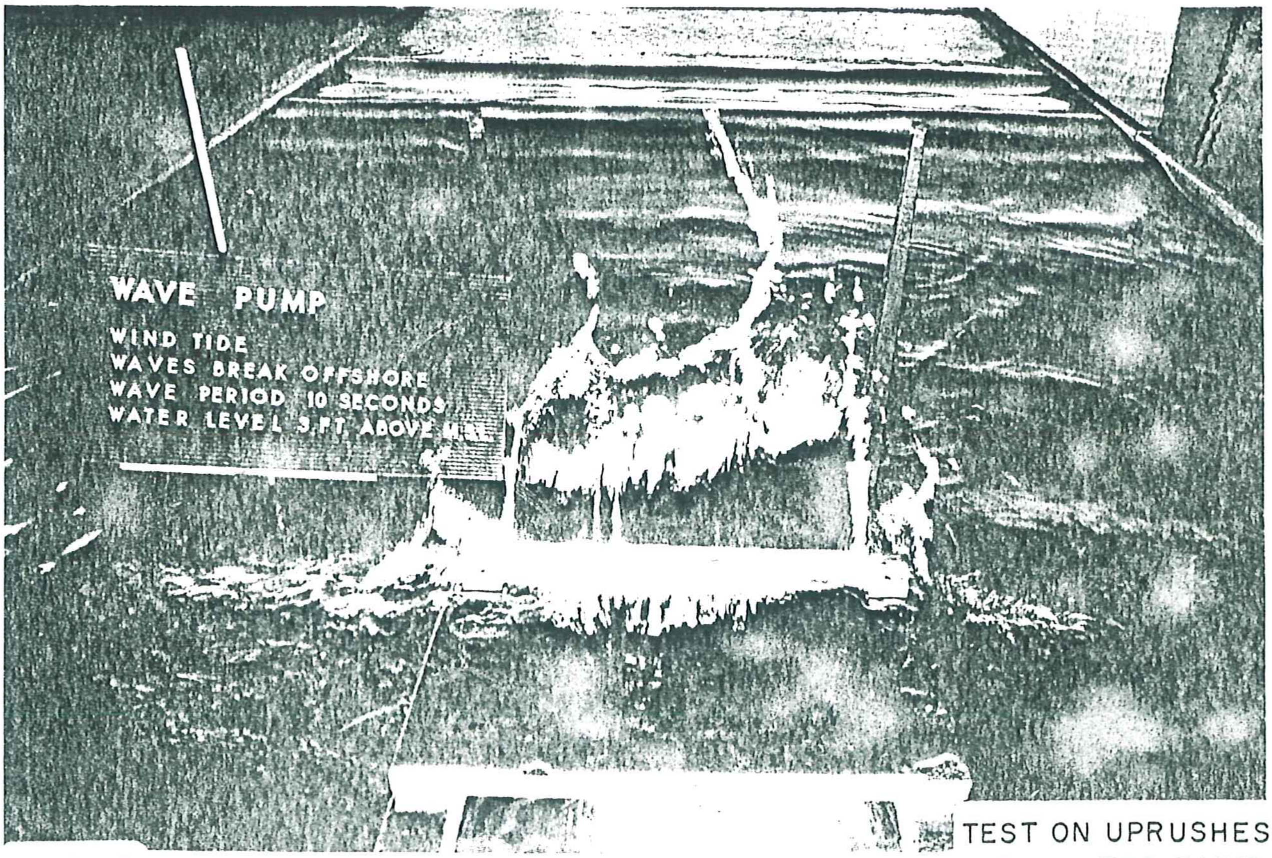


PHOTO 2

TEST ON UPRUSHES
RAMP IN TOP POSITION

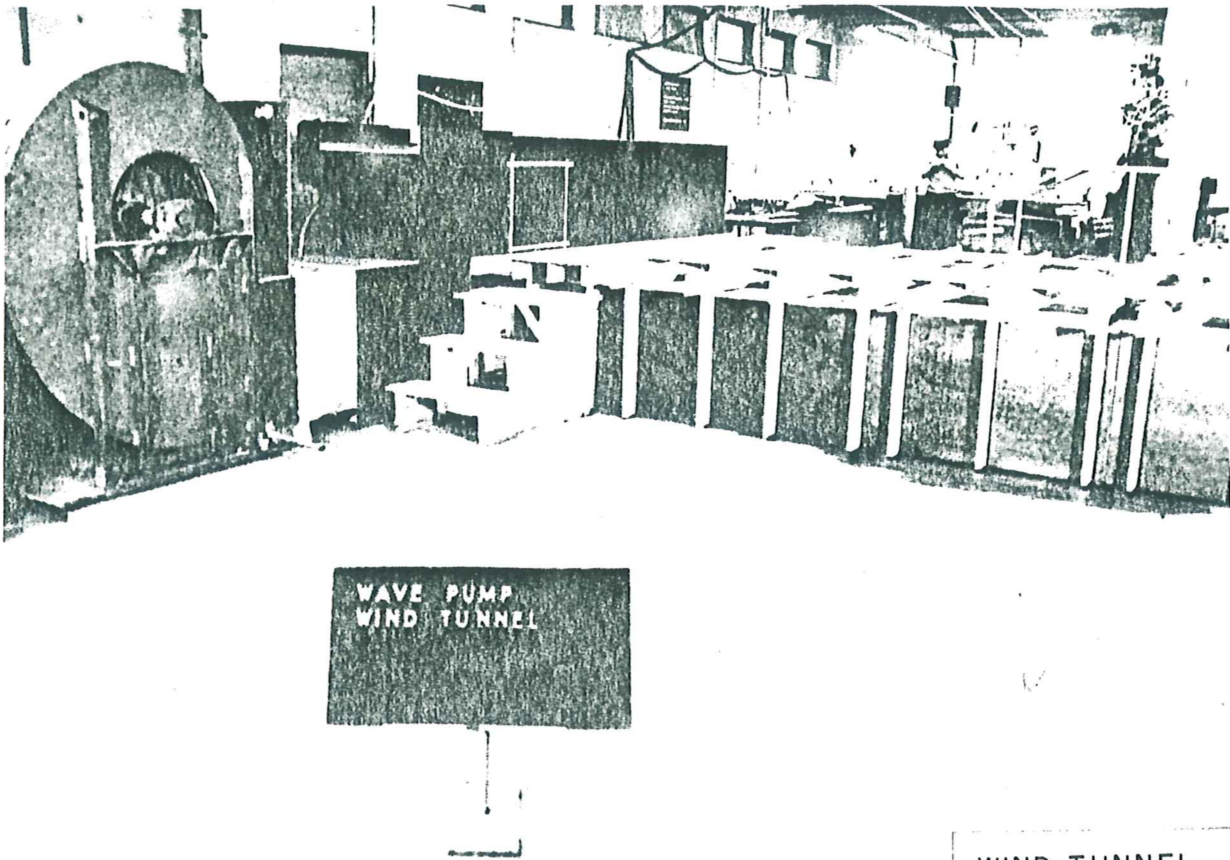
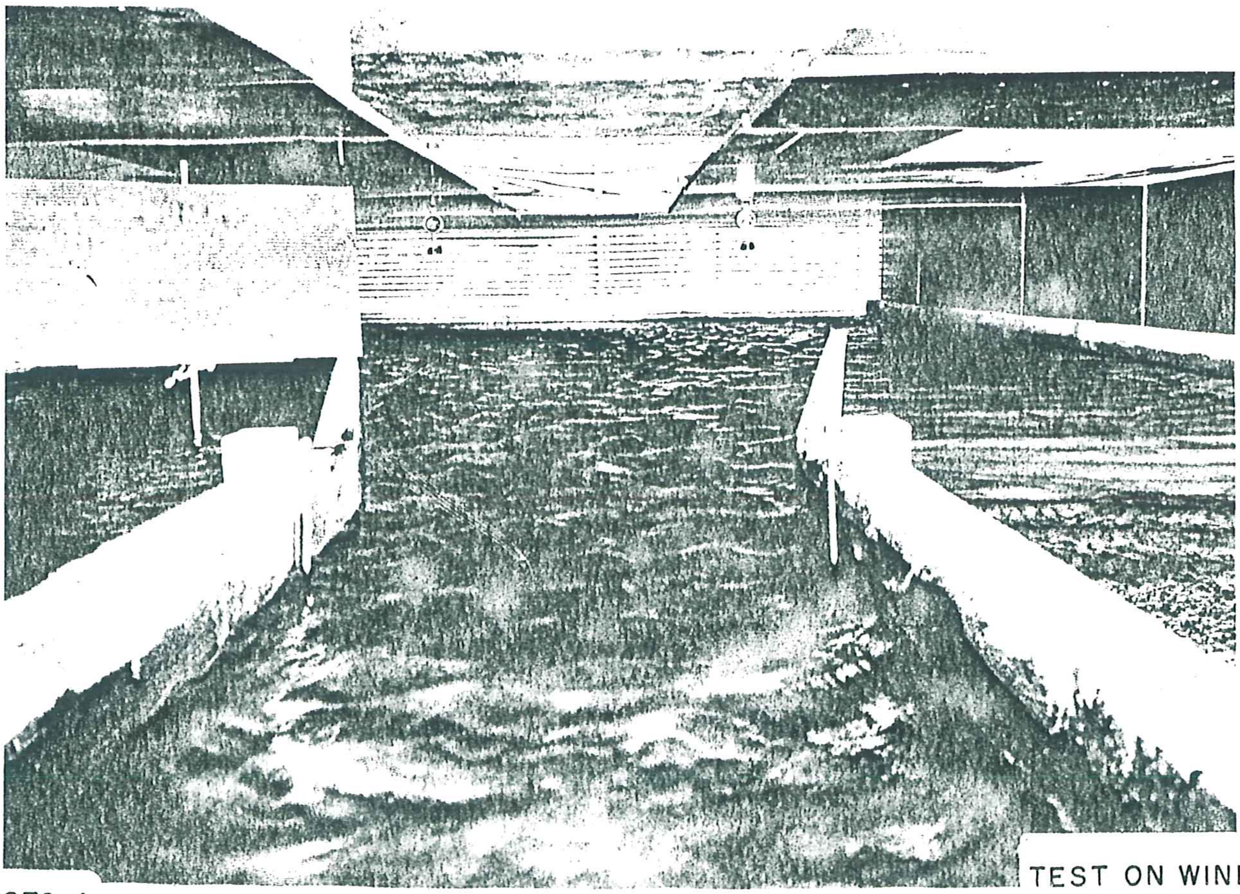


PHOTO 3

WIND TUNNEL
ARRANGEMENTS



TEST ON WIND

PHOTO 4

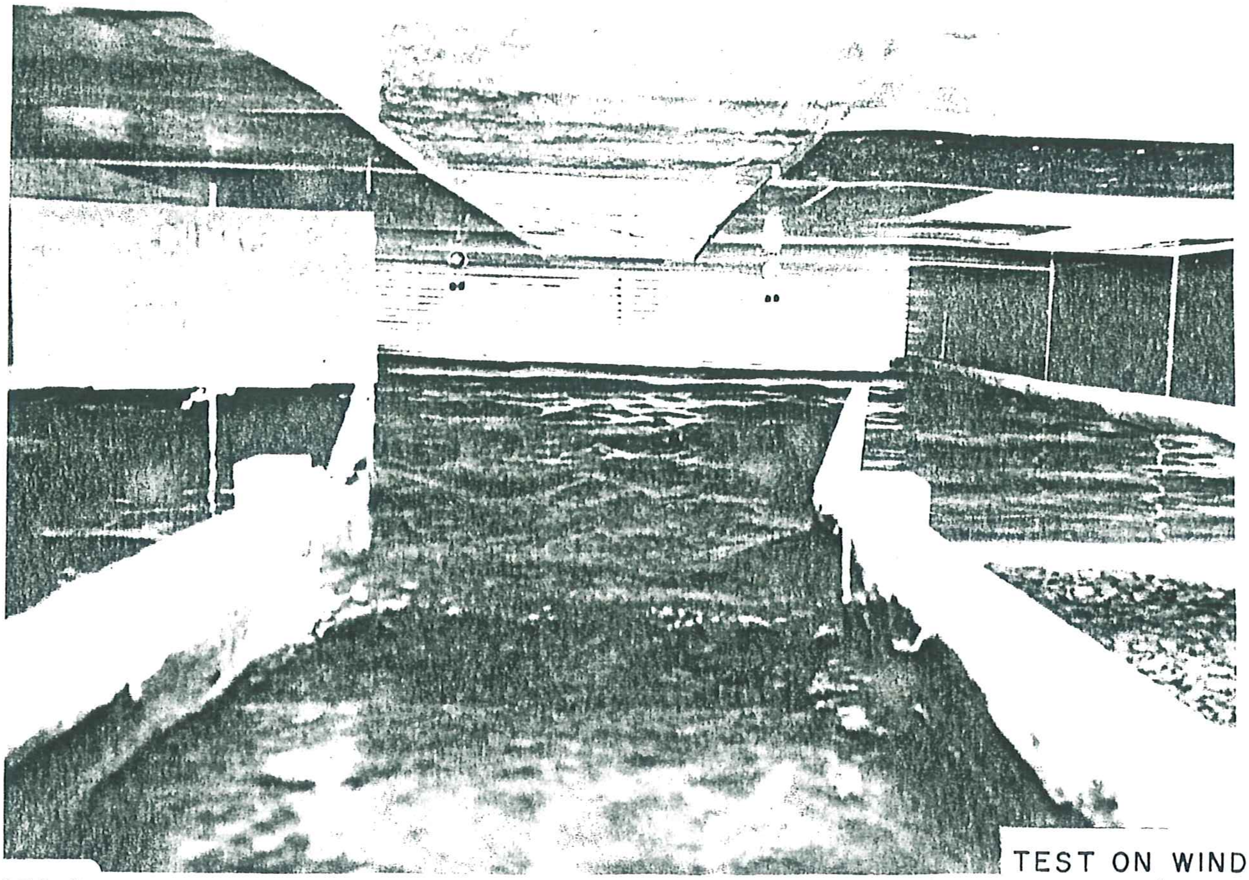


PHOTO 5

TEST ON WIND AND WAVES