REPORT

WAVE PUMP MODEL STUDY

PALMAS DEL MAR MARINA PUERTO RICO

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REPORT

WAVE PUMP MODEL STUDY

PALMAS DEL MAR MARINA PUERTO RICO

The Palmas del Mar Company

San Juan, Puerto Rico

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L I S T O F C O N T E N T S

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I. INTRODUCTION

This report presents the results of tests on the socalled wave pump to be used 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 and the Icelandic Harbour Authority (IHA).

Principal investigator was Res. Eng. Gisli Viggosson, IHA. 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-28th 1974, Feb. 5-6th and March 12th-13th 1975.

NEA Hydraulic Laboratory

Principal Investigator | Director of Laboratory

GISLI VIGGÓSSON | Jónas Elíasson

2. SCOPE OF TEST ON WAVE PUMP

The location of the wave pump in the Palmas Del Mar Marina is shown on Sheet no. 1. A schematics of the 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 of the Palmas Del Mar Marina.

The wave pump is used to create currents. It utilizes the momentum of shallow water waves which develop over a shallow bottom or on a slope. The scope of the test was to investigate the efficiency and the operation of the wave pump under a variety of wave conditions and layouts of the entrance funnel.

To improve the efficiency of the wave pump so that even smaller waves may become effective wave heights are beefed 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 1, 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 tests on the wave pump include the following:

a. Optimization test of several layouts of entrance funnel and slope of ramp for given wave conditions.

- Wave heights and discharge flow were measured.

b. Tests with varying direction of incident waves.

- Wave heights and discharge flow were measured.

c. Test on uprush by storm waves at the bridge, for MSL.

- Visual observation of uprush at bridge by varying slopes of ramp.

d. Tests on storm tides and uprush at bridge at water level. three foot above MSL.

- Visual observation of uprush at bridge for varying slopes of ramp.

e. Tests on wave action at the inner entrance of the discharge channel.

- Wave heights measured in channel and marina for varying slopes of ramp.

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

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

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

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

b. When the incident waves deviate about ten degrees from the centerline the discharge decreases less than ten per cent. 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 occurs at the bridge. No uprush occurs however, 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 occurs at the bridge although a 2 ft high screen was used and the ramp was kept horizontal.

e. With 2 ft input waves in the discharge channel waves higher than 0.5 ft were observed as far as 13 m from the entrance. When the top of the ramp was at M.S.L. waves higher than 0.5 ft occurred as far as 4 m from the entrance.

f. Wind current tests are of preliminary nature.

The result of the tests show that wind velocity of 5 knots does not generate any measurable current in the model. Wind of 20 knots generated a flow of 0.4 m^3/s. When wind and waves were run simultaneously the flow was almost the total of the wind current flow and the wave current flow as generated separately.

4. MODEL SCALE AND HYDRAULIC SIMILITUDE

The model scale used in the present study was 1:20. According to Froude´s Model 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

Scale of 1:40 was used on the tests on wave action at the inner entrance of the wave 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 up to the final bottom elevation. All absorbing slopes were made of gravel with stones approx. 2 cm in diameter, and some absorbing mattresses were laid on top of the gravel. The discharge channel was made of concrete brick, 15 cm above the bottom. In front of the wave generator there was slope of 1:15. The ramp was made of waterproof plywood, with two devices on either side to adjust the ramp in exact position. The entrance funnel was made of waterproof plywood.

To simulate the prototype energy losses in the model the bottom in the funnel had a rough concrete surface, - ("rough" means "not finished" to imitate a rippled floor). The training walls and the discharge channel had smooth concrete faces.

The waves were produced by a pneumatic wave generator. The wave period was adjusted by means of a thyristor and checked with a stop watch. Wave heights were measured with 6 resistance meters. The location of the six meters is shown on Sheet no. 3.
All measurements were calculated and printed out with a computer, i.e. the average X and the average Y, corresponding standard deviations, variance and the ratio between the average wave height at the X- and each of the five Y meters. See Tables IV to XI. Table IV gives detailed explanation.
A strip chart recorder was used to check the shape of the waves. The current meter is of OTT-type, with an accuracy of 5%.

6. TEST ON THE INFLUENCE OF WAVES ON FLOW

6.1 Introduction

As mentioned in chapter 2 the scope of the tests was to investigate the efficiency and operation of the wave pump under a variety of wave conditions and layout of entrance funnel.

More than 61 tests were run where wave conditions and discharge flow were measured. The results of the tests are shown in Tables I to III and Sheets 4 to 6. Several typical print outs from the wave height analyser are given in Tables IV to XI.

6.2 Layout of funnel

Four layouts of the 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. Entrance width of the 40 m and 50 m training walls were also tested.

When the width of the entrance of the funnel is 40 m the crests of the waves do not turn perpendicular to the training walls because of a too large angle of incidence between the direction of wave propagation and the training wall. The waves reflect from the wall causing transversal surge in the entrance. This does not occur when entrance width is 30 m.

The effectiveness of the funnel for various lengths of the training wall with 30 m entrance width is given in the following table (the ramp is 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 may be concluded that the 50 m long training wall is most favourable with regard to discharge.

6.3 The Influence of the ramp and the length of the ramp

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

The slope of the ramp is given in degrees from horizontal level. Tests were run on the following slopes:

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°	

These tests do not reveal any significant differences between discharge and length of the ramp, for various slopes of the ramp.

The purpose of ramp is not to increase the discharge for higher waves, but instead to control the discharge and the wave height in the discharge channel. The wave height at 10 m distance from the ramp section is plotted on Sheets no. 4 to 6 where the influence of the slope of the ramp on the wave height in the discharge channel is demonstrated. The ramp, however, increases the discharge for the lowest waves.

6.4 Test with varying direction of the incident waves

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

To evaluate the influence of the varying directions of the incident waves six tests were run with the center line of the entrance funnel deviating from the wave direction: Tests no. 59 to 61 and 62 to 64 in Table I.

When the direction of wave propagation deviates about ten degrees from the center line the discharge decreases less than ten per cent. When the incident waves deviate about fifteen degrees from the center line the discharge reduces about twenty to thirty per cent.

7. TEST ON STORM WAVES CONDITIONS

7.1 Test on uprush by storm waves at the bridge

Tests on storm wave conditions were run at M.S.L. with waves breaking offshore. Wave period was 10 sec. The waves broke in front of the wave generator, producing secondary waves at the funnel entrance. Under such wave conditions the discharge was measured about 5 to 6 m^3/sec.

Tests were run to evaluate the uprush at the bridge, which is located just behind the ramp section so that the edge of the ramp in its highest position reaches the bridge beam and closes the discharge channel.

The main dimensions of the bridge are as follows:

Width of bridge	8 m
Height of bridge floor	8 ft above M.S.L.
Height of bridge 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 is considerable. When the ramp is horizontal no uprush occurs.

Under such storm condition the ramp is able to control the wave height in the channel as well as the discharge.

7.2 Tests on storm tides and uprush at the bridge

Tests on storm tides were run at water level, 3 ft above M.S.L. with waves breaking offshore at wave period 10 sec. These tests included uprushes at the bridge. Under such wave condition the waves ran over the training walls in the inner part of the funnel regardless of the position of the ramp.

When the ramp was kept in the highest position closing the discharge channel heavy uprushes were observed at the bridge, even with a 2 ft high wave screen.

Photo no. 8 demonstrates the heavy uprushes with the discharge channel closed.
Photo no. 7 shows the reduction of uprushes with the ramp horizontal. This wave condition is demonstrated in the movie belonging to this report.

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

These tests were carried out in scale 1:40, see Sheet no. 7. The aim of the tests was to investigate how the wave height is reduced in the inner harbour, as waves propagate into the marina with a vertical drop in depth of 5 ft when the channel enters the marina.

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

Three tests were run with three position of the ramp slope: 0°, 7.2° and 14.5°. The results of the tests are shown schematically on Sheet no. 8 where the area in the marina bases with higher than 0.5 ft is shown for each test.

9. PRELIMINARY TESTS ON THE INFLUENCE OF WIND AND WAVES ON FLOW

9.1 Introduction

The normal case is that winds and waves occur simultaneously. The wind not only generates wind waves but also surface currents and piles up water at the entrance of the funnel higher than at the harbour entrance due to lower depth at the funnel. The wind also lowers the M.S.L. in the marina at the end of the discharge channel due to wind shear stresses in the inner harbour basin.

These factors will increase the influence of the wind to cause currents through the harbour.

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

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

In order to run the model tests the wind current as well as the wave current model laws must be recognized. As these model laws differ, one is faced with 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 no alter the basic wind current model law.

The theory for calculation of the wind scale factor used in these preliminary tests refers to two papers:- "Modelling of Wind Driven Currents in a Laboratory", University of Florida, Coastal Eng. Dept. Gainesville; 1970 and "Surface Wind Stress over Water as related to Wave Action", by F. Gerritsen, De Ingenieur Bouw-en Water bouw Kunde, 1963.

The model wind scale factor is given by

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

where

ζ = model scale 1:20

ζ_{c_s} = ratio between friction shear stresses in the prototype and in the 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 should be in the range of 0,4 to 1,7 m/sec.

9.2 Construction of the wind-tunnel and the experimental technique

The wind-tunnel (photo no. 10) was made of wood and marine plywood. The tunnel covered 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 blower was of centrifugal type with a capacity of

30.000 m^3/h. The experimental techniques were the same and measurements were carried out in the same manner as in the model without the wind-tunnel. Three aero-meters located 3 meters from the inlet of the air-stream were added. They were 1 m apart and 0,2 meters below the roof.

9.3 Results of tests on wind current generation

The wind current generation in the model was not satisfactory. The main reason undoubtedly was the limited tunnel length and incorrect loop-system. The tests, however, were of preliminary nature only.

The following table gives the results:

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 a wind velocity of 5 knots does not generate any current in the model. A 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 total of the wind current flow and the wave current flow as generated separately.

TABLE I

RESULT OF MODEL TEST

TRAINING WALL 50 M AND FUNNEL ENTRANCE 30 m

TEST No	WAVE PERIOD	WAVE HEIGHT	RAMP LENGTH	RAMP SLOPE	Q m^3/sec	REMARKS
	sec	ft	m	degree		
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	

continue /

TABLE I

RESULT OF MODEL TESTS TRAINING WALL 50 M
AND FUNNEL ENTRANCE 30 M

TEST	T	H	RAMP LENGTH	RAMP SCOPE	Q	REMARKS
No	sec	ft	m	degree	m^3/s	
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	T	H	RAMP LENGTH	RAMP SCOPE	Q	REMARKS
No.	sec	ft	m	degree	m^3/s	
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	

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TABLE IV

OUTPUT PRINTING FROM THE COMPUTER

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/ "	"

Measure point	Y^1	Y^2	Y^3	Y^4	Y^5
1	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	279. 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
2	317.10MX	304.80MX	284.50MX	288.90MX	309.70MX
3	298.90MY 1	268.90MY 2	299.90MY 3	302.10MY 4	161.80MY 5
	V	V	V	V	V
4	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
5	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
6	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 *

1. Output printing of ten X waves respectively Y waves.
2. Mean wave height in point X (ex. 317.10 = 31.7 mm)
3. " " " " " Y (ex. 298.90 = 29.9 mm)
4. Variance (ex. Vx = 61.43 = 6.14 mm^2)
5. Standard deviation (ex. SDx = 7.84 = 0.78 mm)
6. The ratio between the mean wave height in X respectively Y

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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/ "	"

1	2	3	4	5
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	185• 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
163• 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	163• 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	152• y
153•00Mx	160•60Mx	157•00Mx	148•00Mx	151•40Mx
112•00My 1	165•70My 2	126•40My 3	178•30My 4	193•30My 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
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•83 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•31 *	1•20 *	1•28 *

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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/ "	"

1	2	3	4	5
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 5
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	236• y	246• y	362• y	329• 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•70MY 1	283•20MY 2	206•80MY 3	367•00MY 4	317•80MY 5
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 5
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/ "	"

1		2		3		4		5	
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	308•	X
370•	Y	386•	Y	283•	Y	268•	Y	191•	Y
316•	X	316•	X	327•	X	303•	X	296•	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•	Y
299•	X	303•	X	304•	X	283•	X	270•	X
360•	Y	386•	Y	268•	Y	273•	Y	215•	Y
304•	X	300•	X	301•	X	290•	X	277•	X
381•	Y	386•	Y	250•	Y	246•	Y	245•	Y
344•	X	323•	X	252•	X	282•	X	291•	X
376•	Y	383•	Y	249•	Y	227•	Y	229•	Y
274•	X	326•	X	298•	X	295•	X	320•	X
313•	Y	388•	Y	282•	Y	248•	Y	215•	Y
305•90	MX	311•50	MX	298•10	MX	278•60	MX	302•20	MX
364•40	MY 1	381•70	MY 2	271•00	MY 3	255•60	MY 4	218•80	MY 5
V		V		V		V		V	
414•32	X	725•39	X	996•99	X	284•27	X	427•29	X
380•27	Y	118•23	Y	191•56	Y	421•16	Y	218•18	Y
239•82	XY	109•50	XY	189•22	XY	179•93	XY	−58•18	XY
SD		SD		SD		SD		SD	
20•35	X	26•93	X	31•58	X	16•86	X	20•67	X
19•50	Y	10•87	Y	13•84	Y	20•52	Y	14•77	Y
15•49	XY	10•46	XY	13•76	XY	13•41	XY	7•63	XY
364•4 ÷ 305•9=		381•7 ÷ 311•7=		271• ÷ 298•1=		255•6 ÷ 278•6=		218•8 ÷ 302•2=	
1•19	*	1•22	*	0•91	*	0•92	*	0•72	*

WAVE PUMP

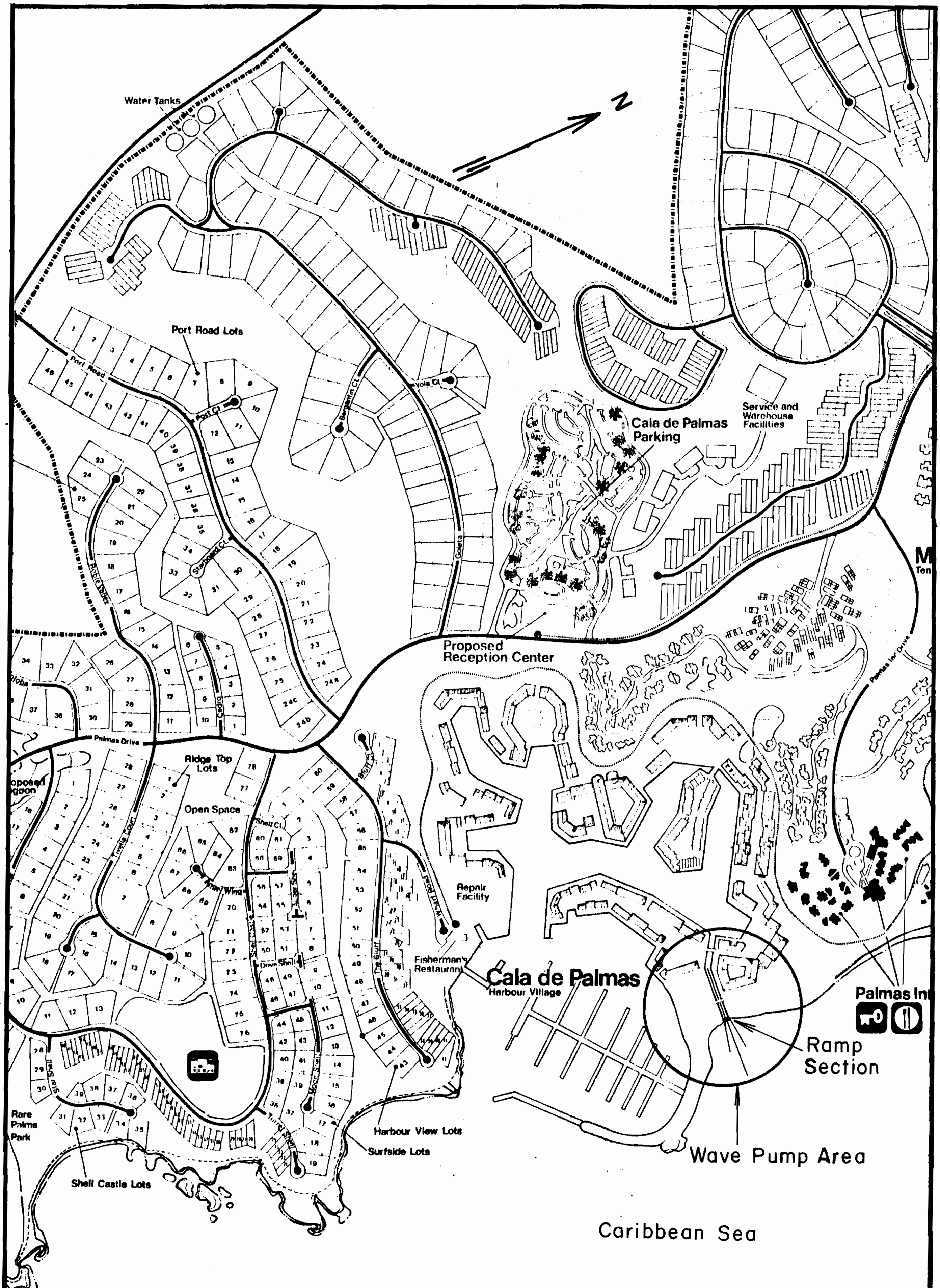
TEST No. 76

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•73888 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

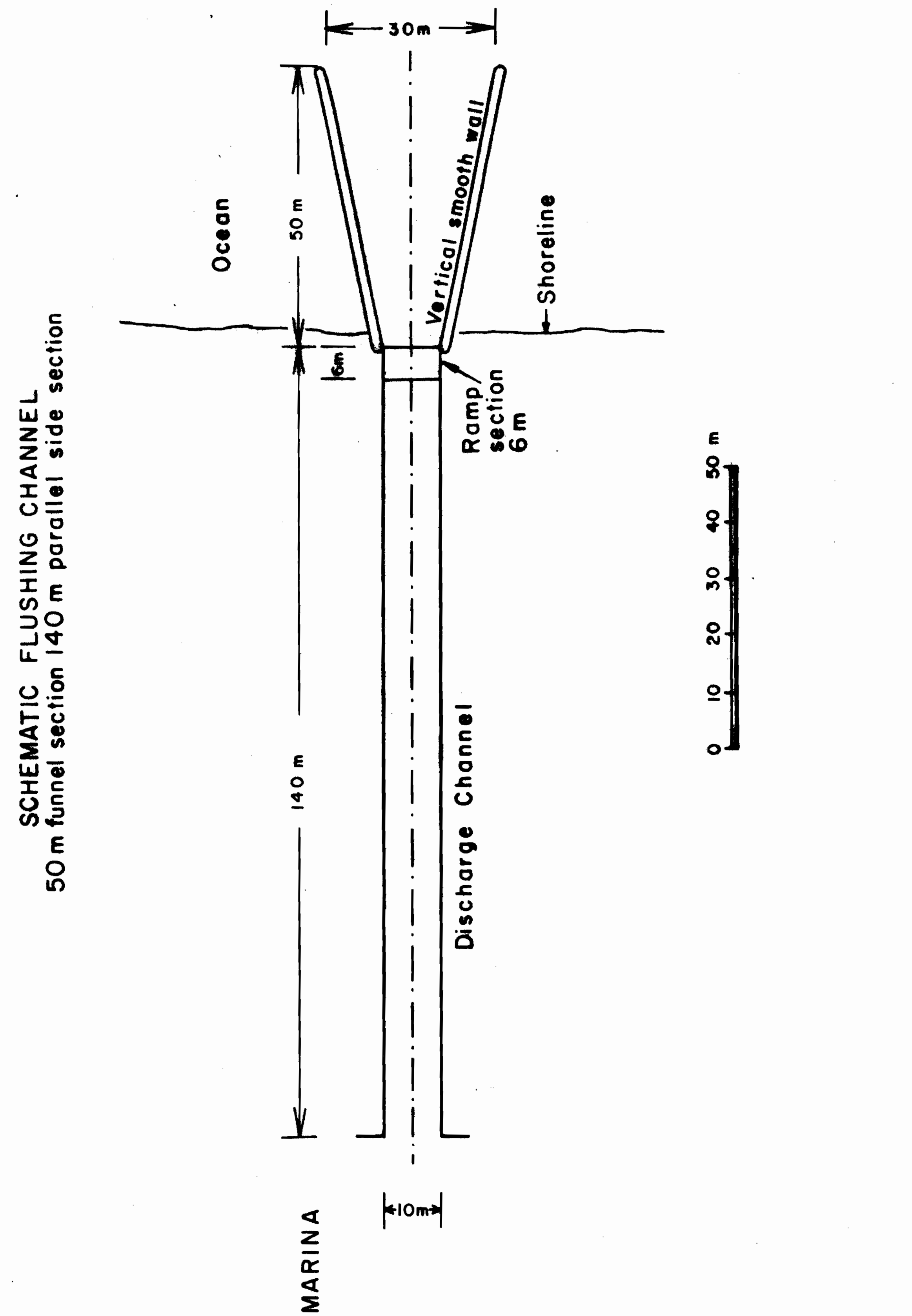


MAP OF LOCATION

Scale 1:8000

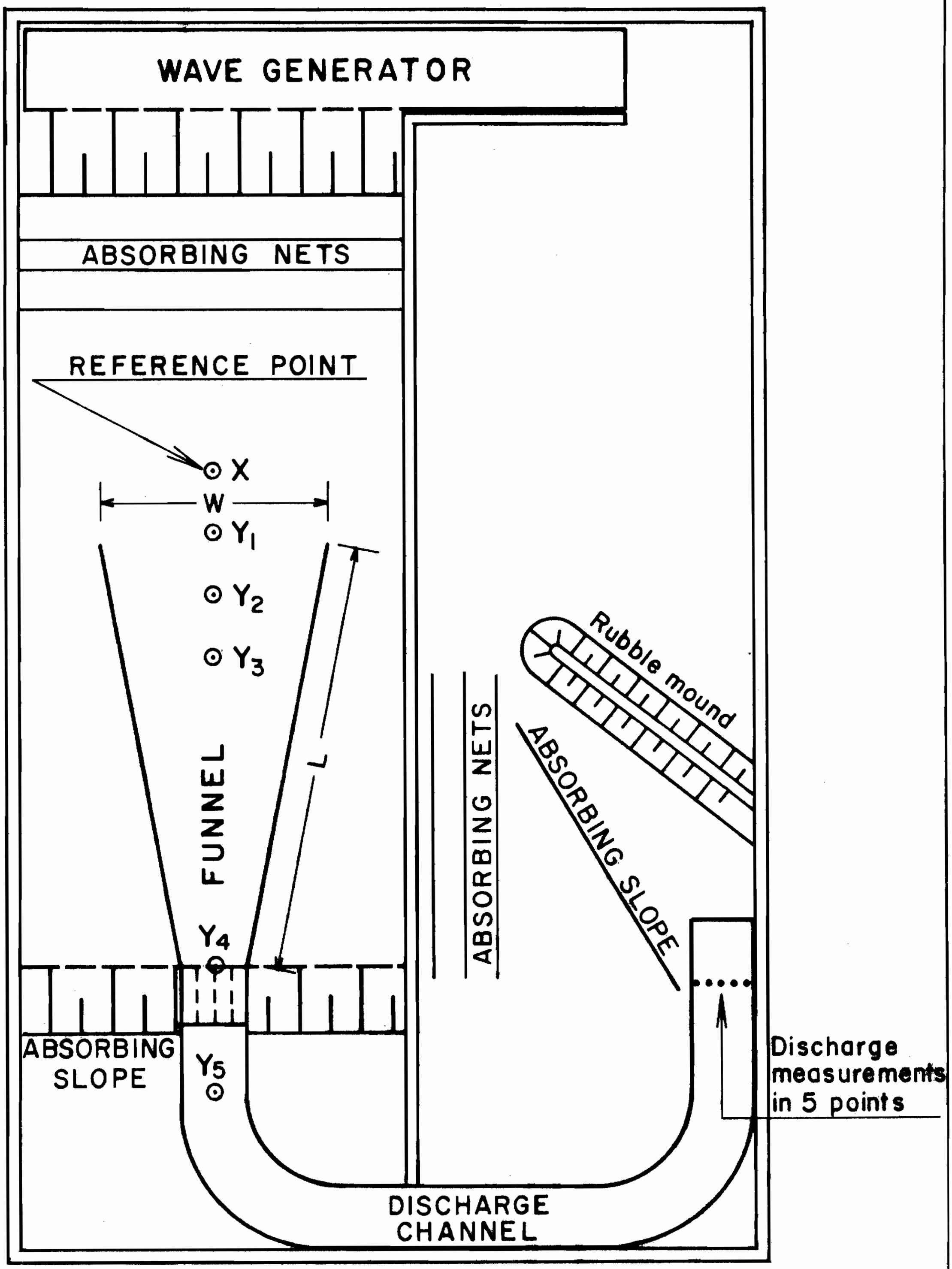
NEA HYDRAULIC LABORATORY	11.1 '75 B.E/H.O
REYKJAVIK ICELAND	Tnr. 42
PALMAS DEL MAR MARINA, PUERTO RICO	ORS-4
WAVE PUMP. SCALE 1:1000	Fnr. 12419

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

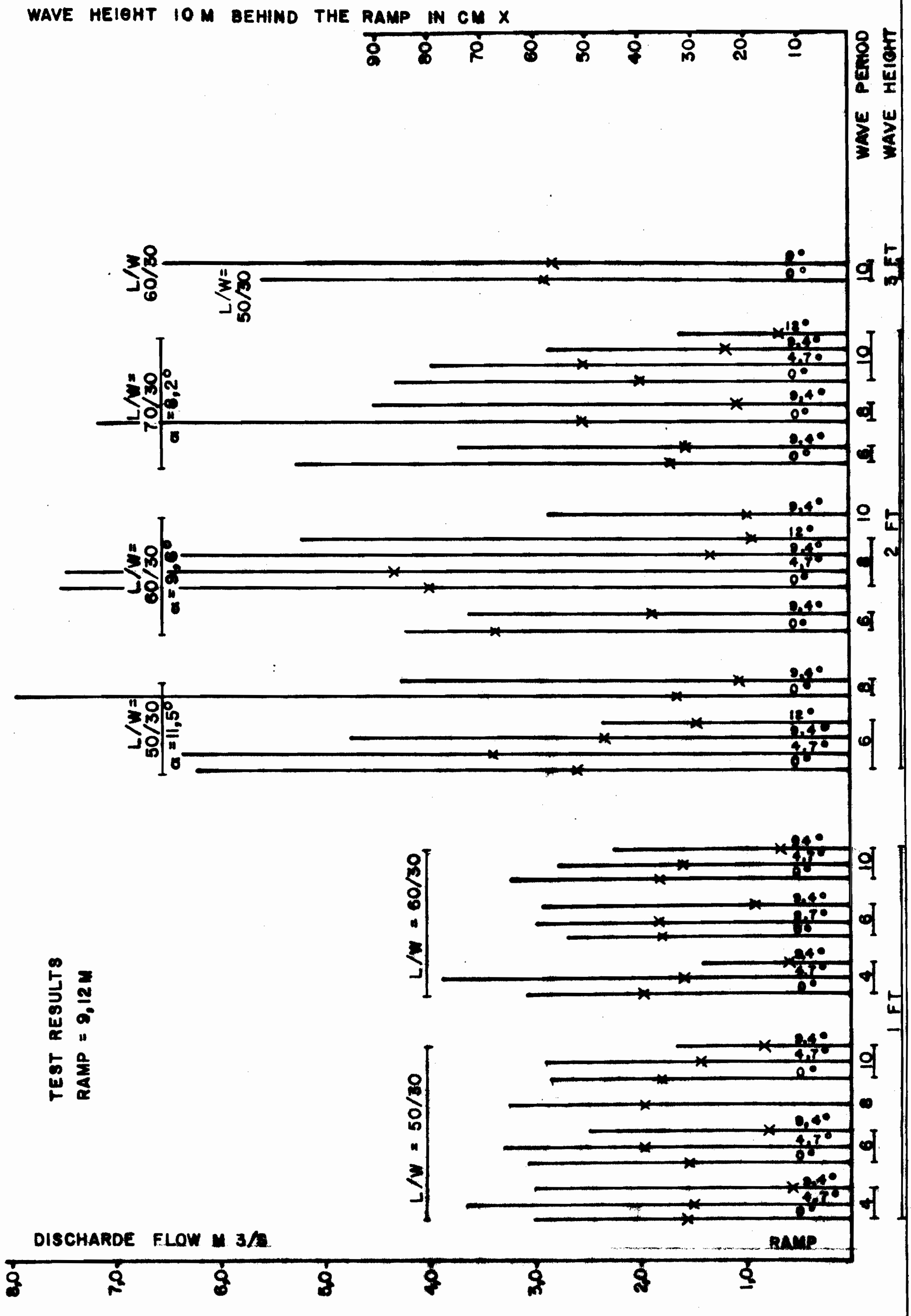


W = WIDTH, L = LENGTH, Y_2 = MEASURE POINT

DWG-MODEL, SCALE 1:50

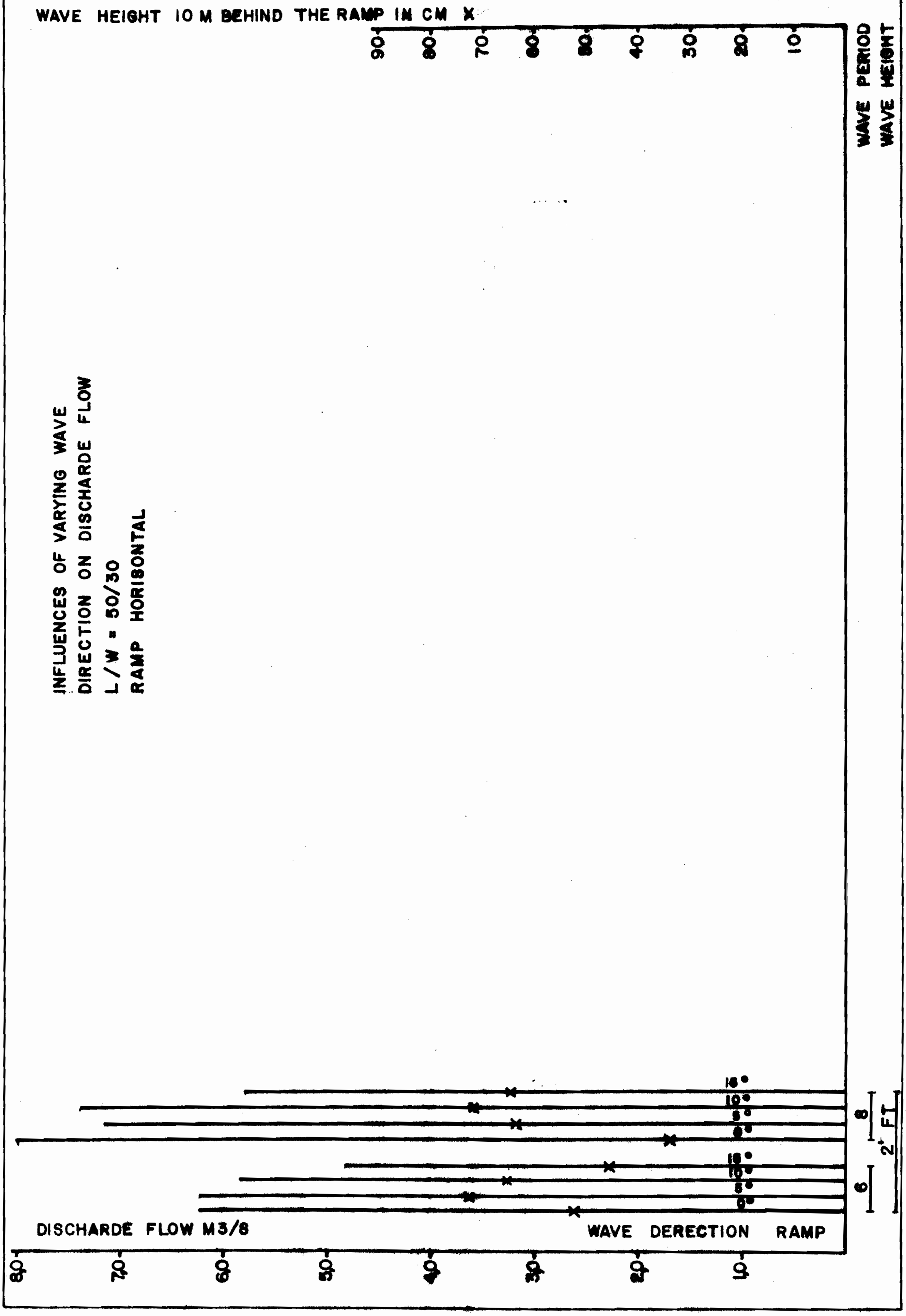
NEA HYDRAULIC LABORATORY	14.2 '75 GV/HJ
REYKJAVIK, ICELAND	TNR. 46
PALMAS DEL MAR MARINA, PUERTO RICO	ORS. 4
TEST ON WAVE PUMP	FNR. 12457

SHEET NO. 4



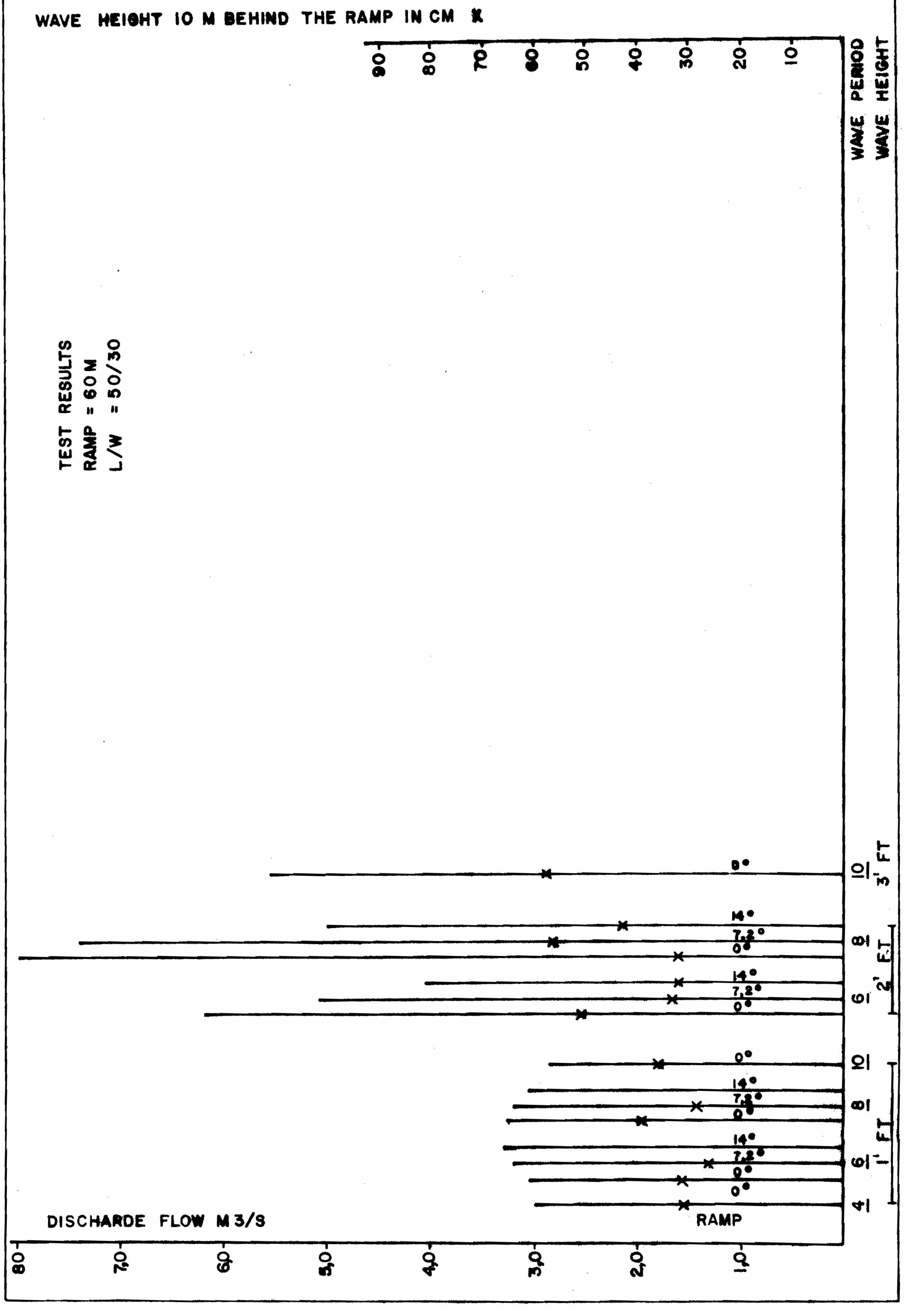
NEA HYDRAULIC LABORATORY	14.2 '75 GV/HJ
REYKJAVIK, ICELAND	TNR. 47
PALMAS DEL MAR MARINA, PUERTO RICO	ORS. 4
TEST ON WAVE PUMP	FNR. 12458

SHEET NO. 5



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

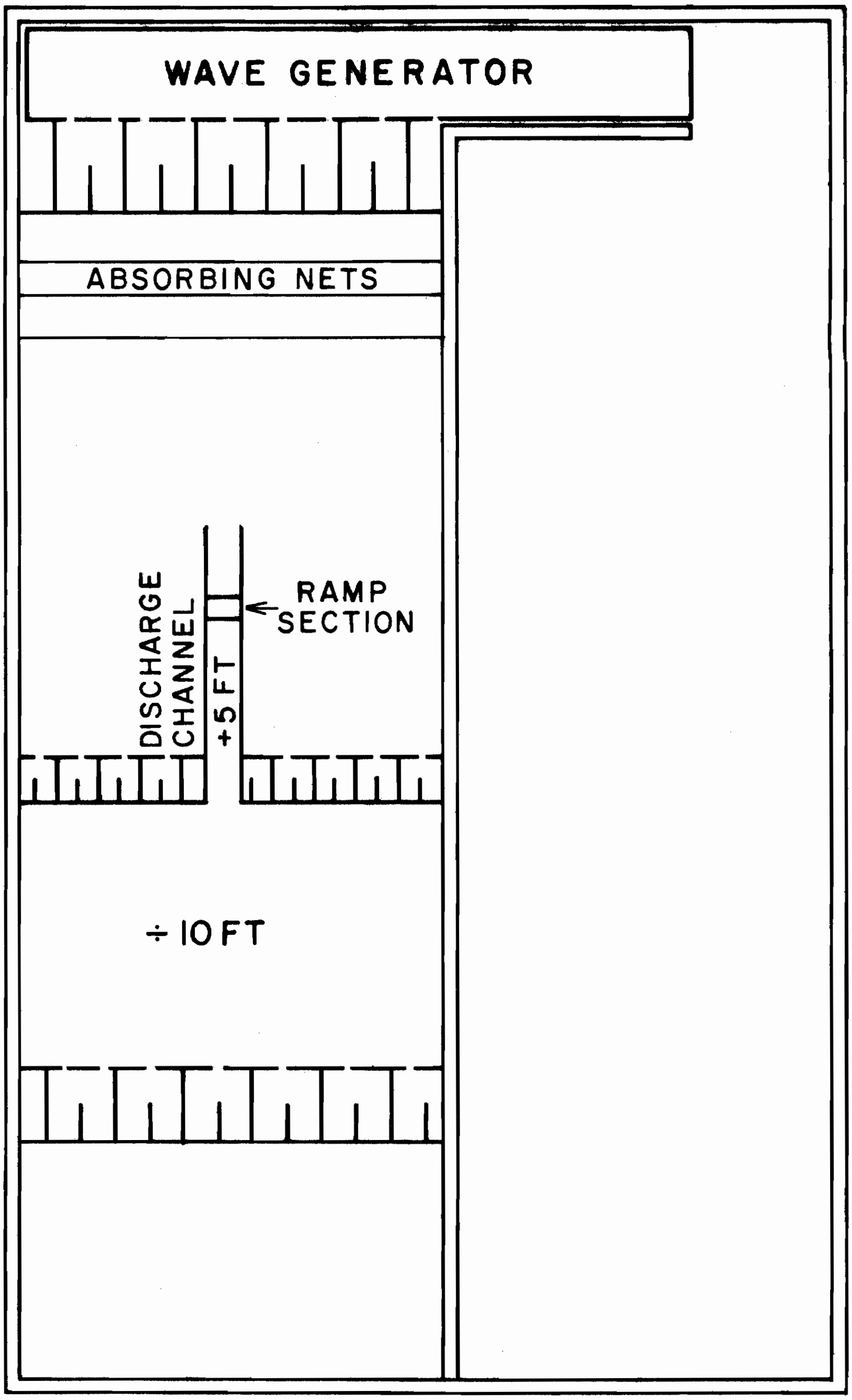
SHEET NO. 6



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

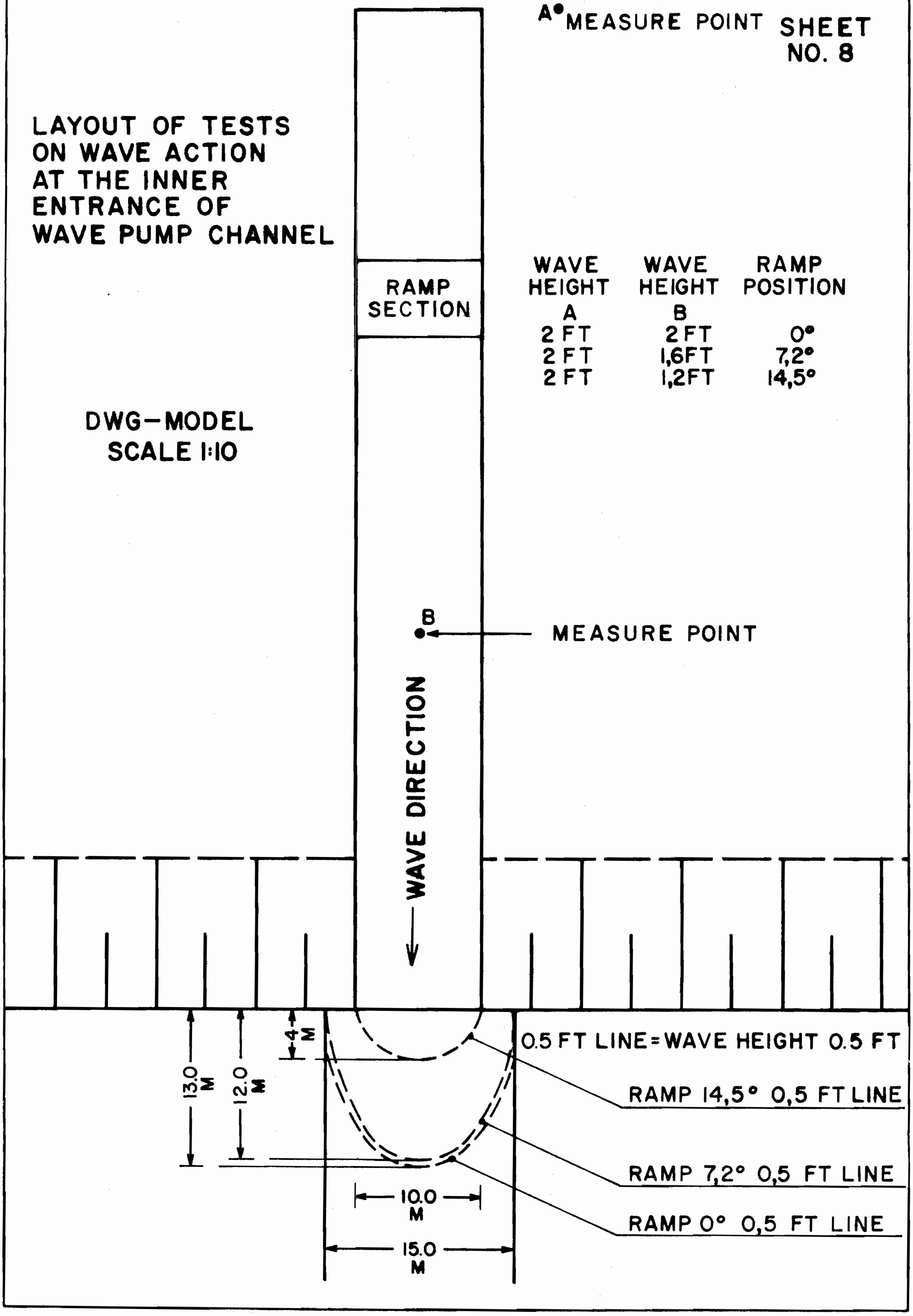
NEA HYDRAULIC LABORATORY	13.2 '75 GV/BE/H
REYKJAVIK, ICELAND	Tnr. 45
PALMAS DEL MAR MARINA, PUERTO RICO	ORS-4
WAVE PUMP, MODEL STUDY, SCALE 1:40	Fnr. 12454

SHEET NO. 8

LAYOUT OF TESTS ON WAVE ACTION AT THE INNER ENTRANCE OF WAVE PUMP CHANNEL

DWG-MODEL
SCALE 1:10

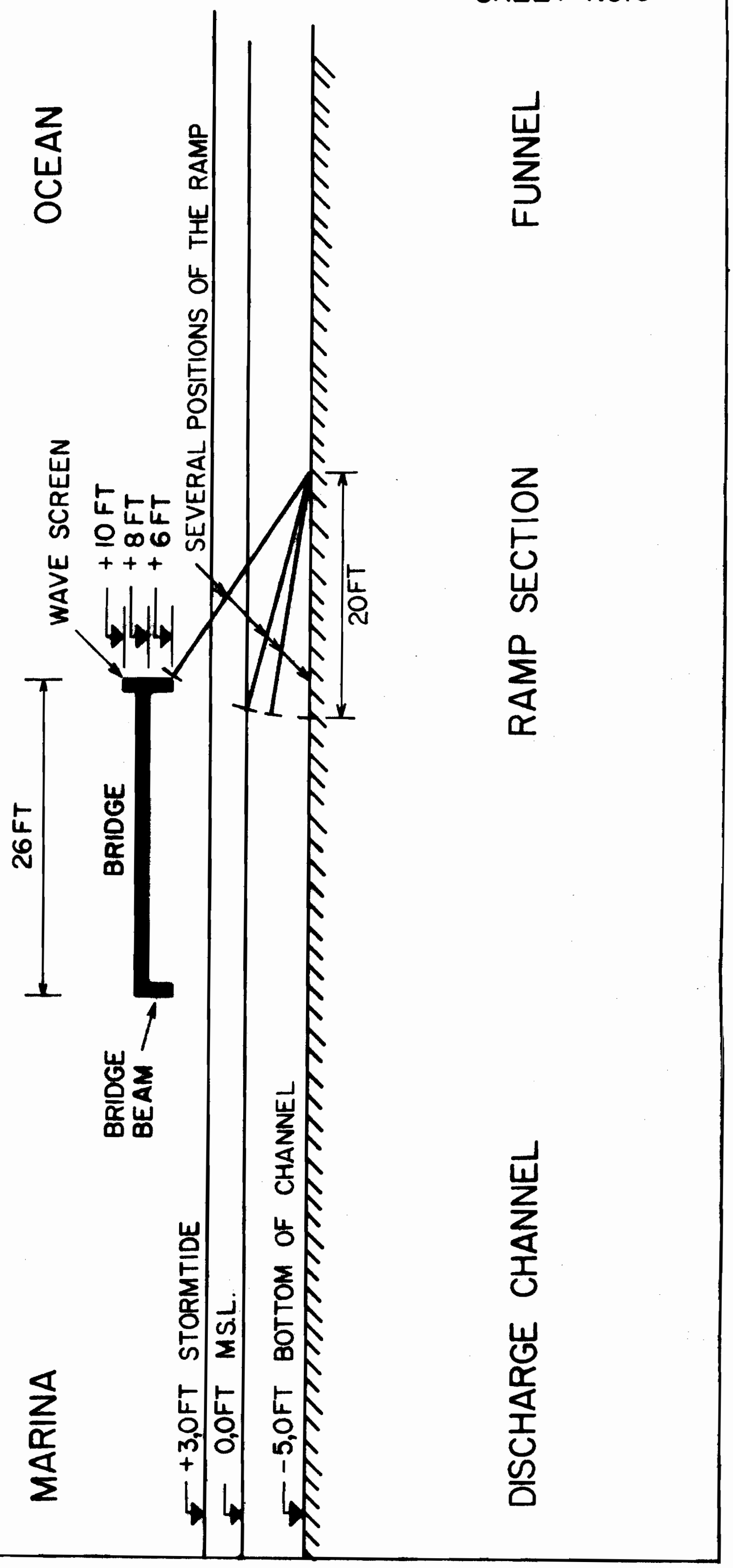
WAVE HEIGHT A	WAVE HEIGHT B	RAMP POSITION
2 FT	2 FT	0°
2 FT	1,6FT	7,2°
2 FT	1,2FT	14,5°



NEA HYDRAULIC LABORATORY	22/4'75 BE/AV
REYKJAVIK ICELAND	Tnr.
PALMAS DEL MAR MARINA, PUERTO RICO	ORS-4
WAVE PUMP, MODEL STUDY, SCALE 1:20	Fnr. 12730

SHEET NO.9

SCHEMATIC CROSS SECTION OF THE BRIDGE AND THE RAMP



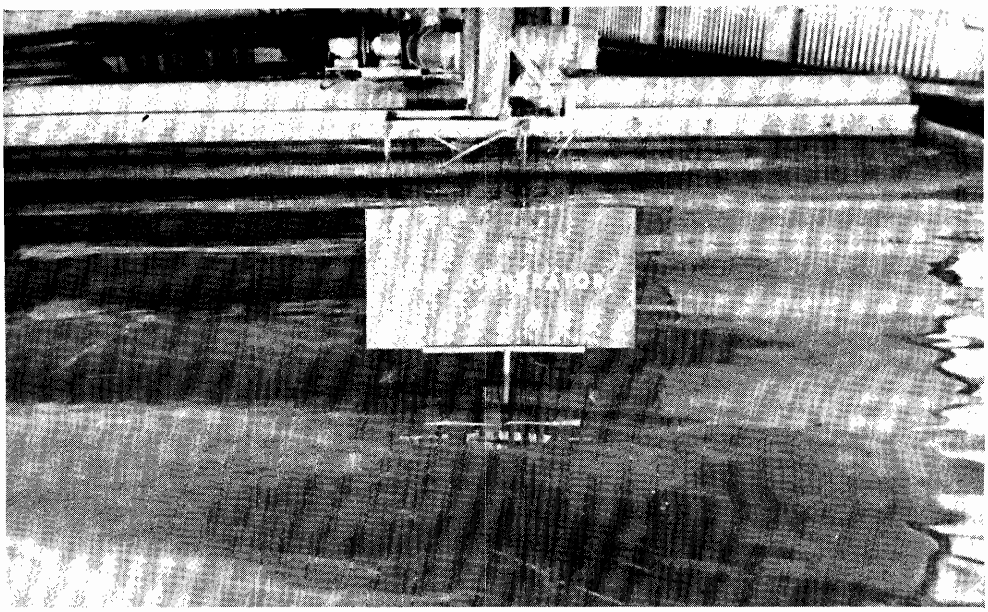


Photo 1 Wave generator

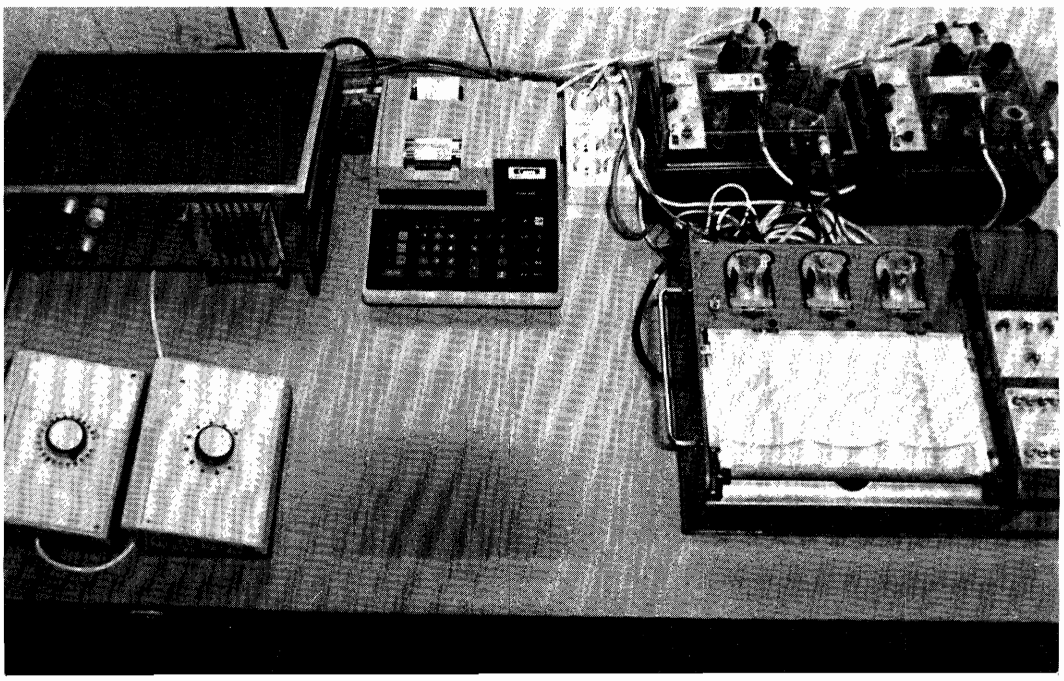


Photo 2 The equipment used for wave measurements and wave calculations

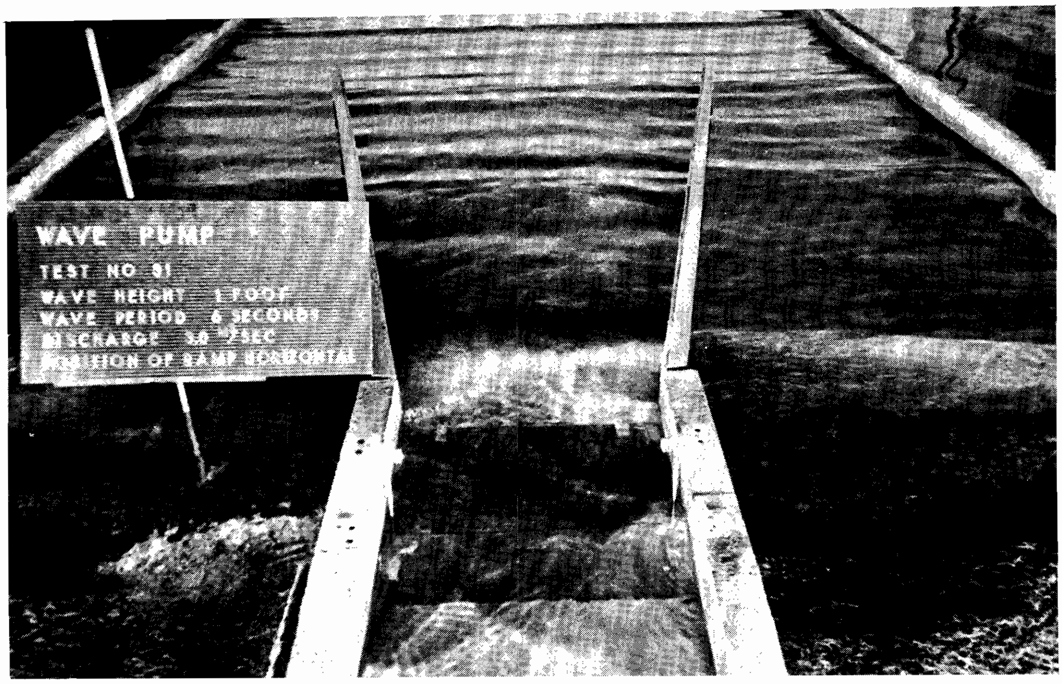


Photo 3 Test no 31, wave height 1 ft, wave period 6 sec, discharge 3,0 m^3/sec, position of ramp horizontal

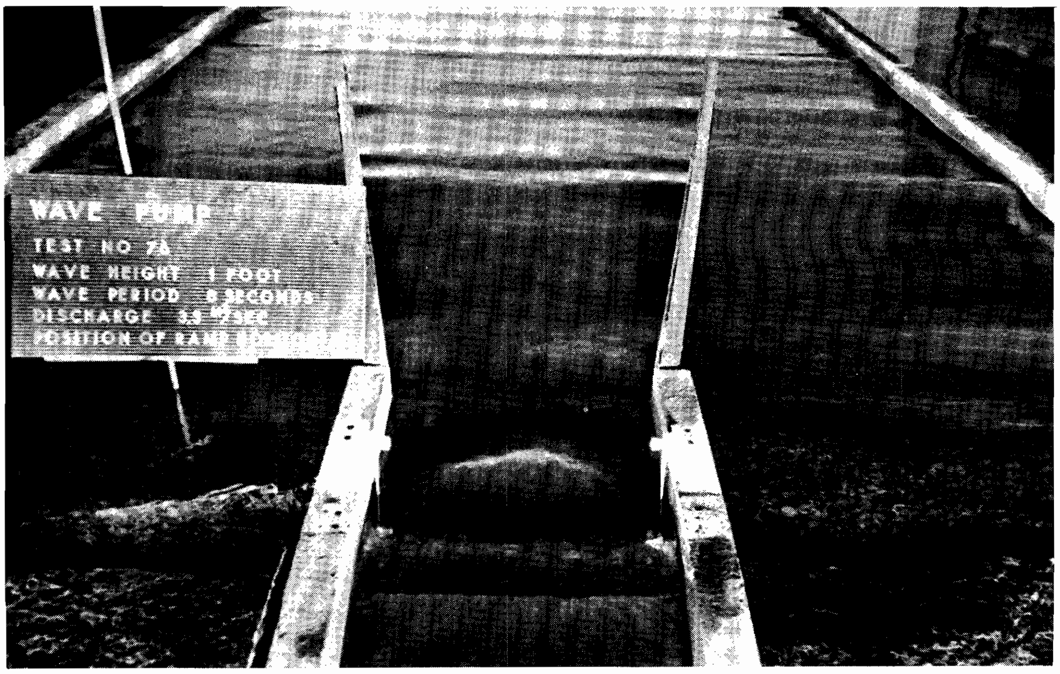


Photo 4 Test no 76, wave height 1 ft, wave period 8 sec, discharge 3,3 m^3/sec, position of ramp horizontal

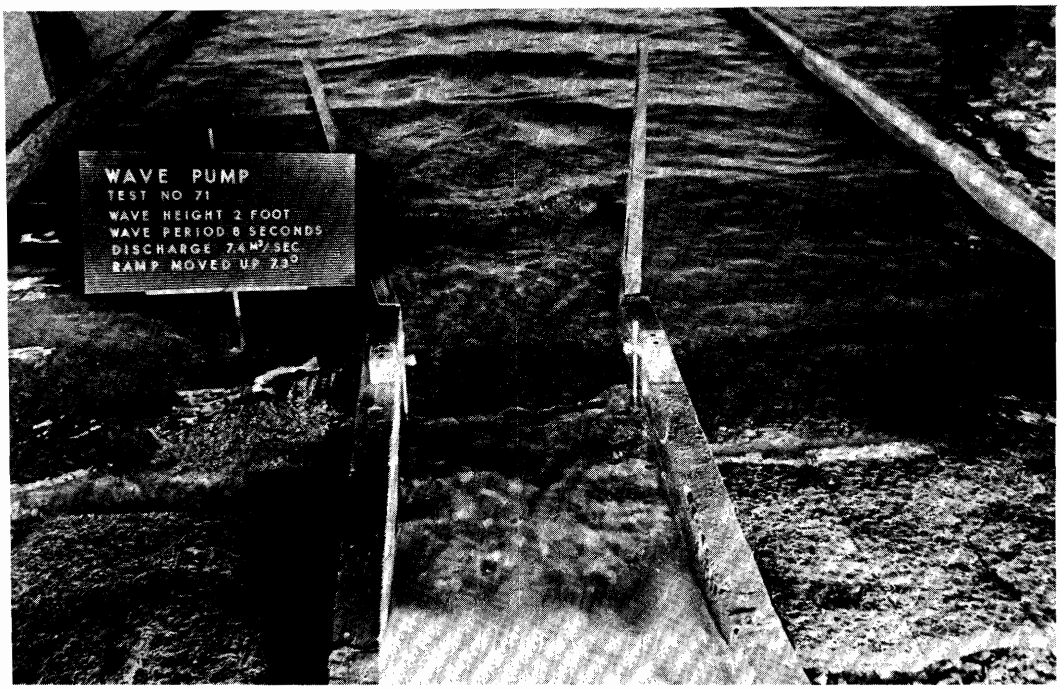


Photo 5 Test no 71, wave height 2 ft, wave period 8 sec, discharge 7,4 m^3/sec, ramp moved up 7,3 degrees

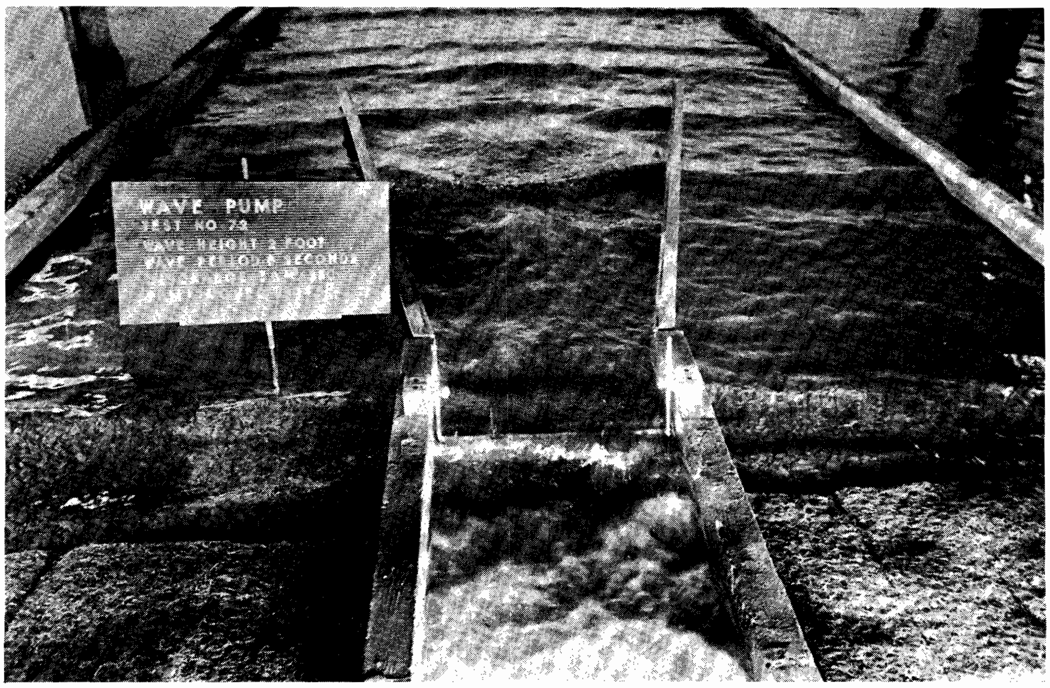


Photo 6 Test no 72, wave height 2 ft, wave period 8 sec, discharge 5,0 m^3/sec, ramp moved up 14,5 degrees

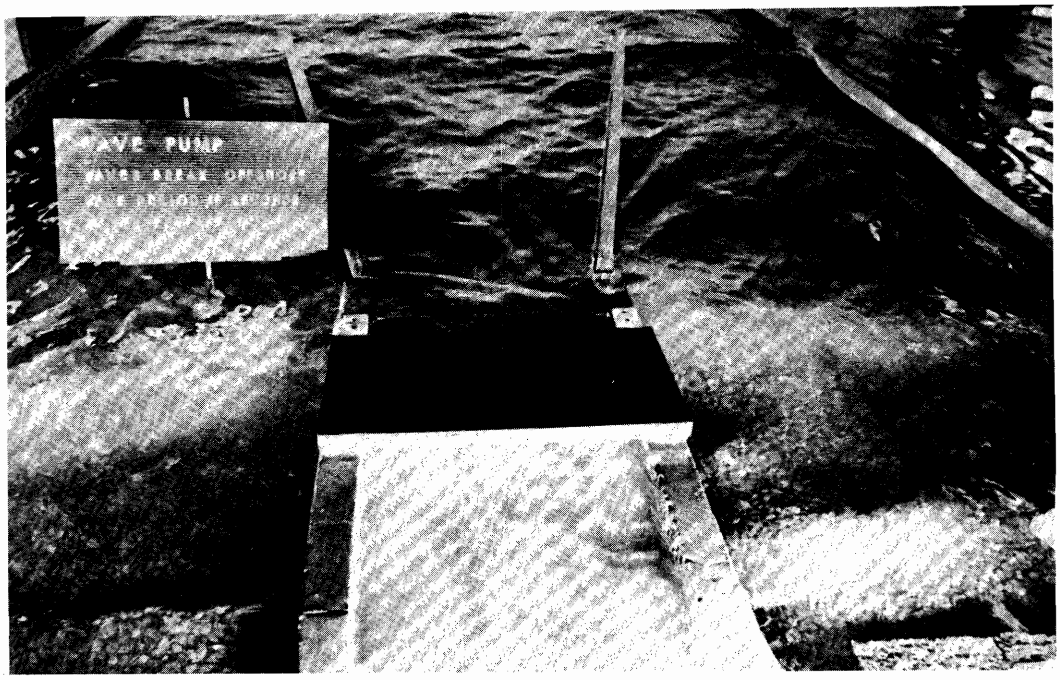


Photo 7 Waves break offshore, wave period 10 sec, water level 3 ft M.S.L., ramp horizontal, without wavescreen

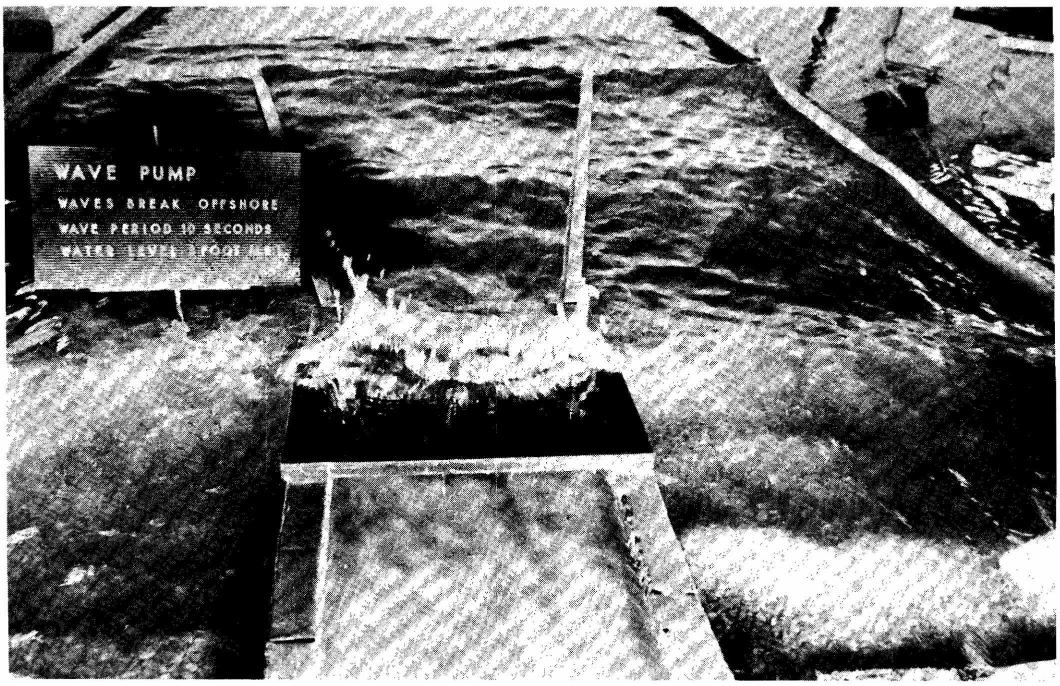


Photo 8 Waves break offshore, wave period 10 sec, water level 3 ft M.S.L., discharge channel closed by the ramp, without wavescreen

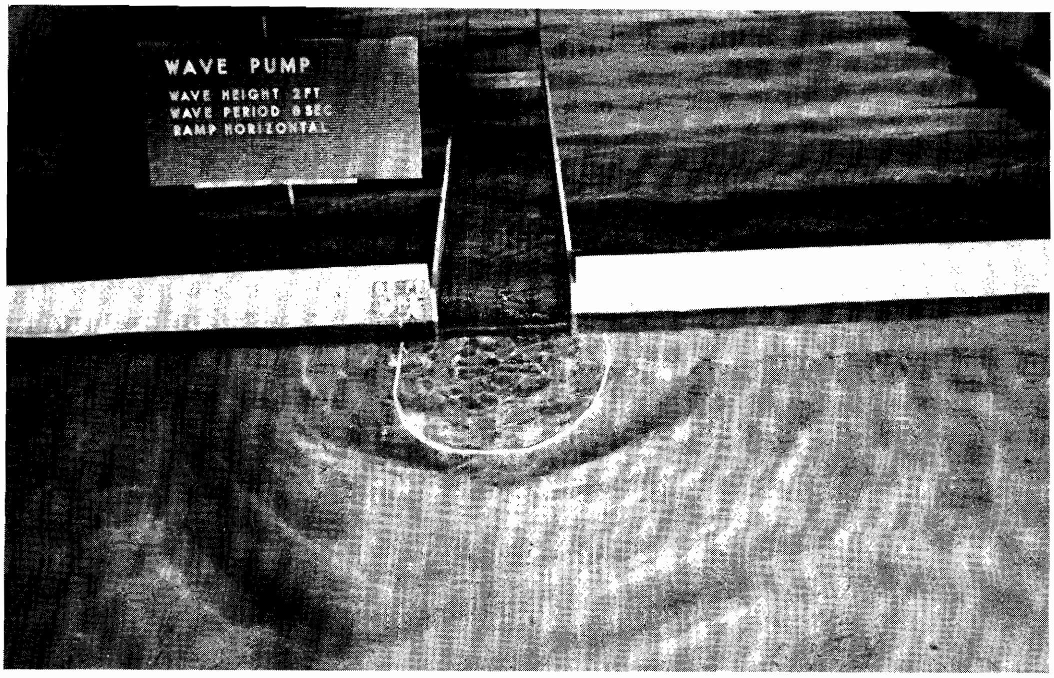


Photo 9 Wave penetration to the inner marina. Model scale 1:40, wave height 2 ft, wave period 8 sec, ramp horizontal. Inside the white circle the wave height is higher than 0.5 ft

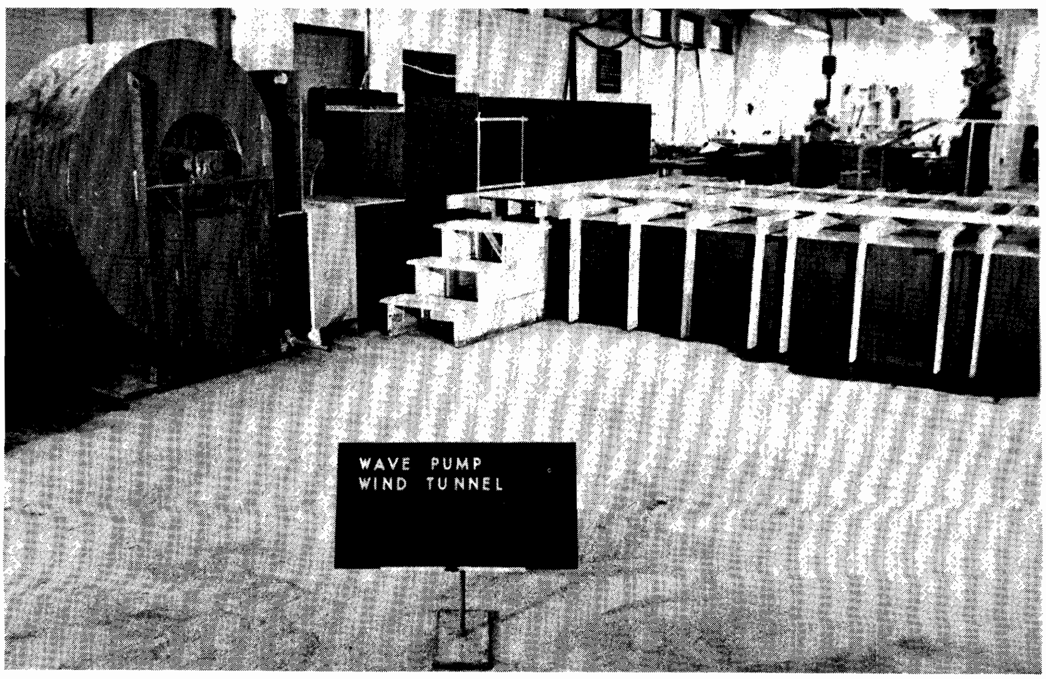


Photo 10 Wind tunnel arrangements

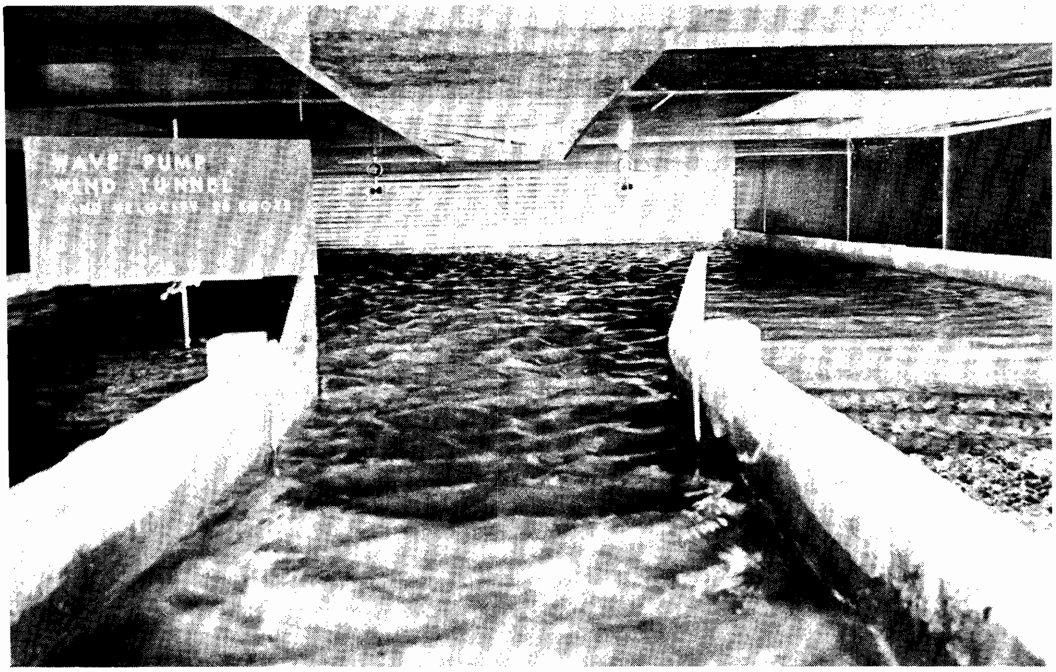


Photo 11 Wind tunnel, wind velocity 20 knots

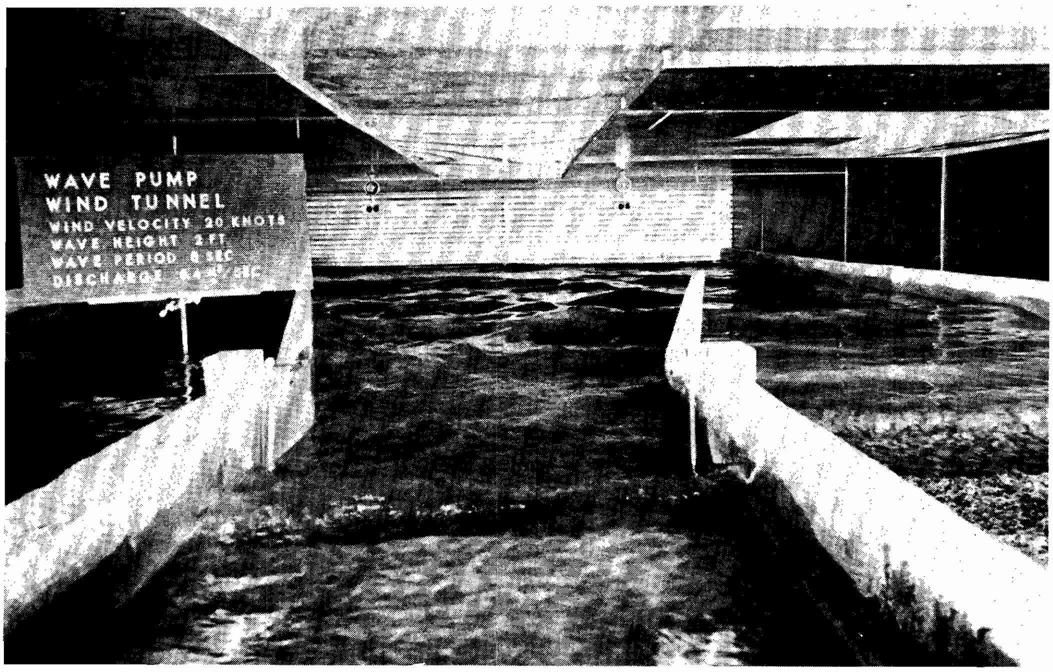


Photo 12 Wind tunnel, wind velocity 20 knots, wave height 2 ft, wave period 8 sec, discharge 8,4 m^3/sec.