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THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING
DEPARTMENT OF CIVIL ENGINEERING

Model Study of Gordon Park Harbor, Cleveland, Ohio

E. F. BRATER

Technical Report No. ~~8~~ 9

The University of Michigan Lake Hydraulics Laboratory

Under Contract With:

City of Cleveland
Department of Port Control

Administered by: *December 1960*

THE UNIVERSITY OF MICHIGAN RESEARCH INSTITUTE • ANN ARBOR

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MODEL STUDY
OF
GORDON PARK HARBOR, CLEVELAND, OHIO

By

E. F. Brater
Professor of Hydraulic Engineering

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SYNOPSIS

The purpose of this model study was to determine methods of reducing wave action in Gordon Park Harbor at Cleveland, Ohio. The waves, which are generated by wind, enter the harbor from Lake Erie. Various methods of keeping the waves out of the harbor or of dispersing or dissipating the wave energy were tested and the most satisfactory solutions are presented in this report.

INTRODUCTION

This study was undertaken as the result of a contract, dated September 25, 1959, between the City of Cleveland, Department of Port Control, and The University of Michigan. The purpose of the study was to find the most economical methods of reducing wave motion in the mooring area. This wave motion is caused by wind-generated waves which enter the harbor from Lake Erie. A scale model of the harbor was constructed. Preliminary tests indicated that the objectionable wave conditions observed in nature could be correctly reproduced in the model.[1] Approximately 100 combinations of devices for improving the harbor showed sufficient promise to warrant a complete test, whereas many other devices were discarded after preliminary tests. The most effective methods are described in detail in this report.

The model study was conducted in The University of Michigan Lake Hydraulics Laboratory[2] under the direction of the author. The testing work was carried out by the following research assistants: Mr. D. N. Contractor, Mr. P. N. Otter, and Mr. K. I. Beitinjaneh. Mr. Bertram Herzog, Instructor in the Department of Engineering Mechanics, was in charge of instrumentation.

PROTOTYPE CONDITIONS

Gordon Park Harbor is located at the northeasterly end of Cleveland Harbor, Cleveland, Ohio. The position of Cleveland on the south shore of Lake Erie, as well as the location of the Gordon Park Harbor within the larger harbor, are shown in Fig. 1.

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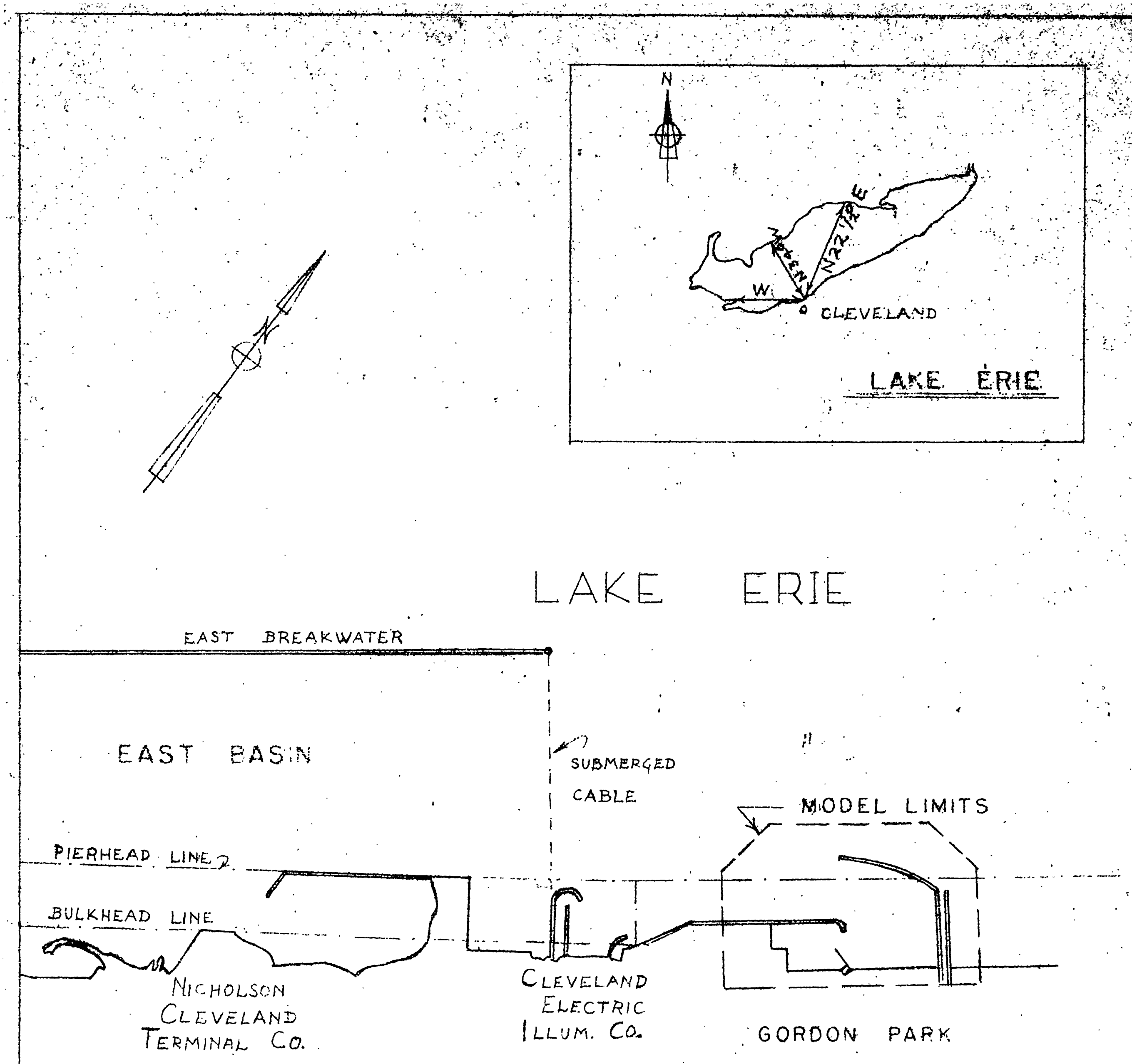
[1] Mr. Harry N. Hobart and Mr. Emil A. Bartunek of the Cleveland Department of Port Control visited the laboratory and observed the tests at this stage of the testing program.

[2] This laboratory is a facility of the Department of Civil Engineering.



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GORDON PARK HARBOR

CLEVELAND, OHIO

Fig. 1

1000 0 3000 Ft.

Waves that enter the harbor are generated in Lake Erie by winds in the sector from west to N 22-1/2°E. Three wind directions in this sector, W, N 34°E and N 22-1/2°E, were selected as the "principal" ones to be reproduced in the model studies. Deep-water wave heights were determined for these three directions from curves[3] which relate deep-water wave height and wave period to fetch length, wind velocity, and wind duration. The fetches for the principal directions are shown in Fig. 1 and in Table I, column 2. Two wind velocities were selected and the resulting wave periods and deep-water wave heights are shown in Table I, columns 5 and 6, respectively. The selected wind velocities are shown in column 3 and the wind durations required to produce these wave heights are listed in column 4. The wave heights and wave periods produced by the 30-mph wind were designated as the "principal" wave characteristics in conducting the tests. This wind velocity was considered to be typical of a major storm. The prototype conditions, reproduced in all preliminary tests and in the majority of the final model tests, consisted of the principal wave characteristics for the three principal wind directions as described above. However, because other wave characteristics will occur in nature, supplementary tests were made for smaller and larger wave periods and for smaller wave heights. Furthermore, in addition to tests for the principal wind directions, tests were conducted for two other intermediate directions. Thus, a wide range of prototype conditions was reproduced in the testing program.

TABLE I

WAVE CHARACTERISTICS

1	2	3	4	5	6	7	8
					Wave Height		Change in
Wind Direction	Fetch	Wind Velocity	Wind Duration	Wave Period	Deep Water	Wave Gage No.1	Wave Direction at Wave Machine
	Miles	mph	Hours	Secs	Feet	Feet	Degrees
West	55	30	6.05	6.62	7.08	5.68	15.9
West		12	10.20	4.08	2.07	1.87	3.0
N 34°W	55	30	6.05	6.62	7.08	6.50	0
N 34°W		12	10.20	4.08	2.07	1.96	0
N 22.5°E	84	30	8.45	7.23	8.48	6.28	22.5
N 22.5°E		12	13.92	4.52	2.31	1.975	5.5

[3] Bretschneider, C. L., "Revisions in Wave Forecasting: Deep and Shallow Water," Proc. 6th Conf. on Coastal Eng., Council on Wave Res., 1958.

THE MODEL

The model was constructed, to a scale ratio of 1:50, in a wave tank having the dimensions of 95 by 50 ft. The area reproduced extends about 2500 ft along the shore and about 1500 feet perpendicular to it. The model limits are shown in Fig. 1 and a plan of the model is shown in Fig. 2.

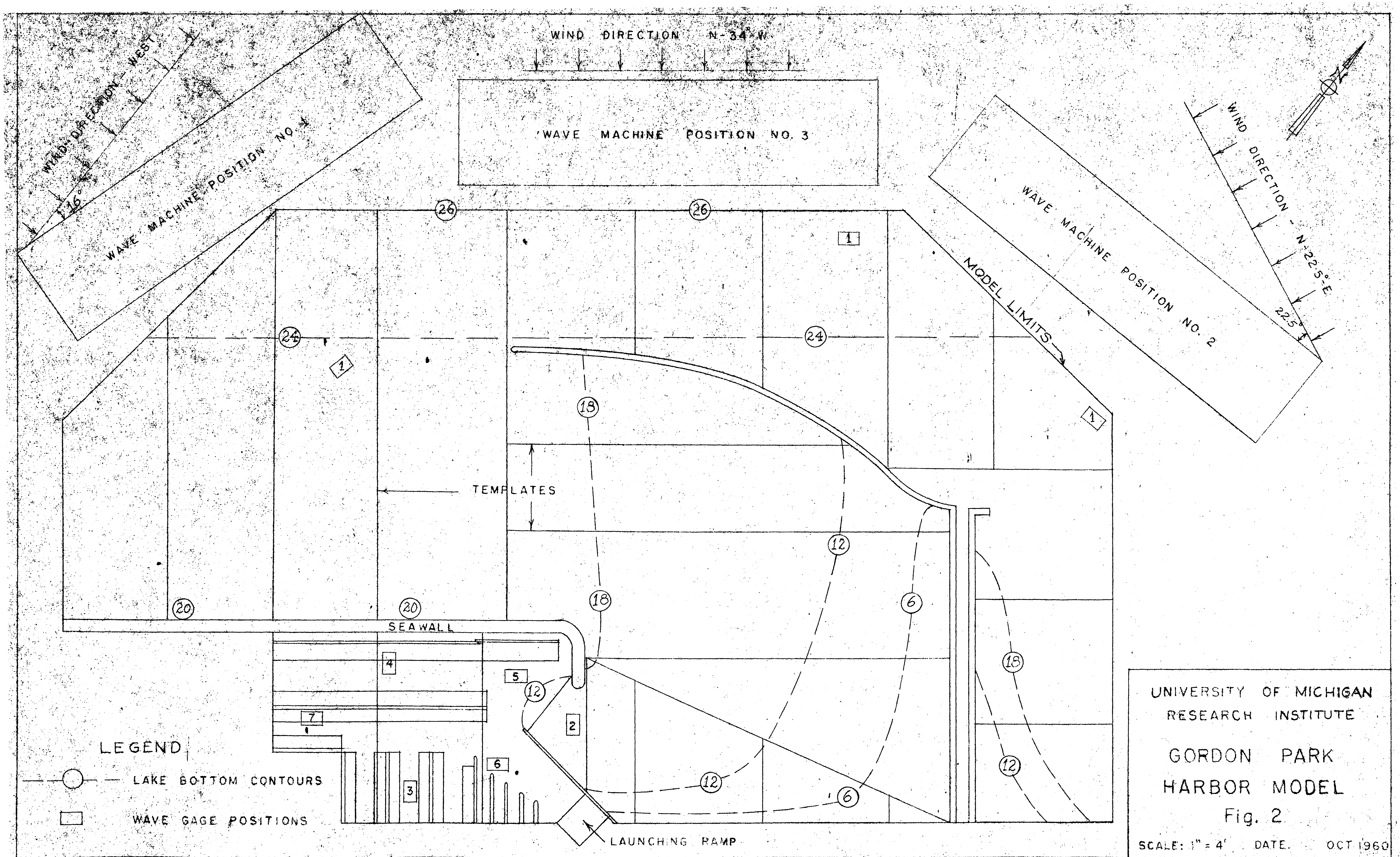
The lake bottom elevations were determined from U. S. Lake Survey charts. Templates were cut from 3/8-in. plywood and placed so that their edges represented the correct location of the bottom. The template lay-out is shown in Fig. 2. The space between the templates was filled with compacted sand and topped with an inch of cement mortar. Elevations were checked for accuracy after the mortar had hardened. Figure 3 is a photograph of the model taken during construction and Fig. 4 shows the model in operation. In Fig. 4, the wave machine is shown in the distance, the model is at the left center and the instruments used to record wave heights are in the foreground. A sand beach was placed along those portions of the walls of the tank not occupied by the model to eliminate wave reflections during the tests.

Waves were generated by a portable plunger-type wave machine. The wave machine was placed at the three principal positions shown in Fig. 2 to simulate waves from the three principal wind directions. As waves enter water depths shallower than half the wave length, they change their direction and height. Because the model limits (Fig. 1) do not extend to deep water, the wave machines were necessarily located at a depth (26 ft) where some change in wave characteristics would have already taken place. The changes in direction, due to refraction, at the wave-machine locations were computed to determine the proper orientations of the wave machine. The changes in wave direction for the three principal wind directions are given in Table I, column 8, and are shown graphically in Fig. 2.

The three wave-gage locations designated as position No. 1 in Fig. 2, were used to measure the size of the approaching wave. The plunger of the wave machine was regulated until the measured wave heights at these gage locations corresponded to the computed wave heights and periods (Table I, column 7). Wave heights were also measured at the six other gage locations shown in Fig. 2. Gage positions Nos. 3-7 provided five measuring points within the harbor and gage position No. 2 provided a measurement in the harbor entrance.

The electrical resistance gages, calibrated by raising and lowering them in still water for known amounts, provided continuously recorded graphs of wave heights and wave periods. The elevation of the water surface was checked by means of a hook gage attached to one wall of the tank.

The water level was maintained at elevation 572.5 ft above mean tide at New York during the tests. This is the approximate long-term average level of Lake Erie.


WIND DIRECTION N-34°-W
WAVE MACHINE POSITION NO. 3
WIND DIRECTION - WEST
16°
WAVE MACHINE POSITION NO.
WIND DIRECTION - N-22.5°-E
22.5°
WAVE MACHINE POSITION NO. 2
MODEL LIMITS
TEMPLATES
SEAWALL
LAUNCHING RAMP
26
24
20
18
12
6
1
2
3
4
5
6
7
LEGEND
LAKE BOTTOM CONTOURS
WAVE GAGE POSITIONS
UNIVERSITY OF MICHIGAN
RESEARCH INSTITUTE
GORDON PARK
HARBOR MODEL
SCALE: 1" = 4'
DATE. OCT 1960
Fig. 2

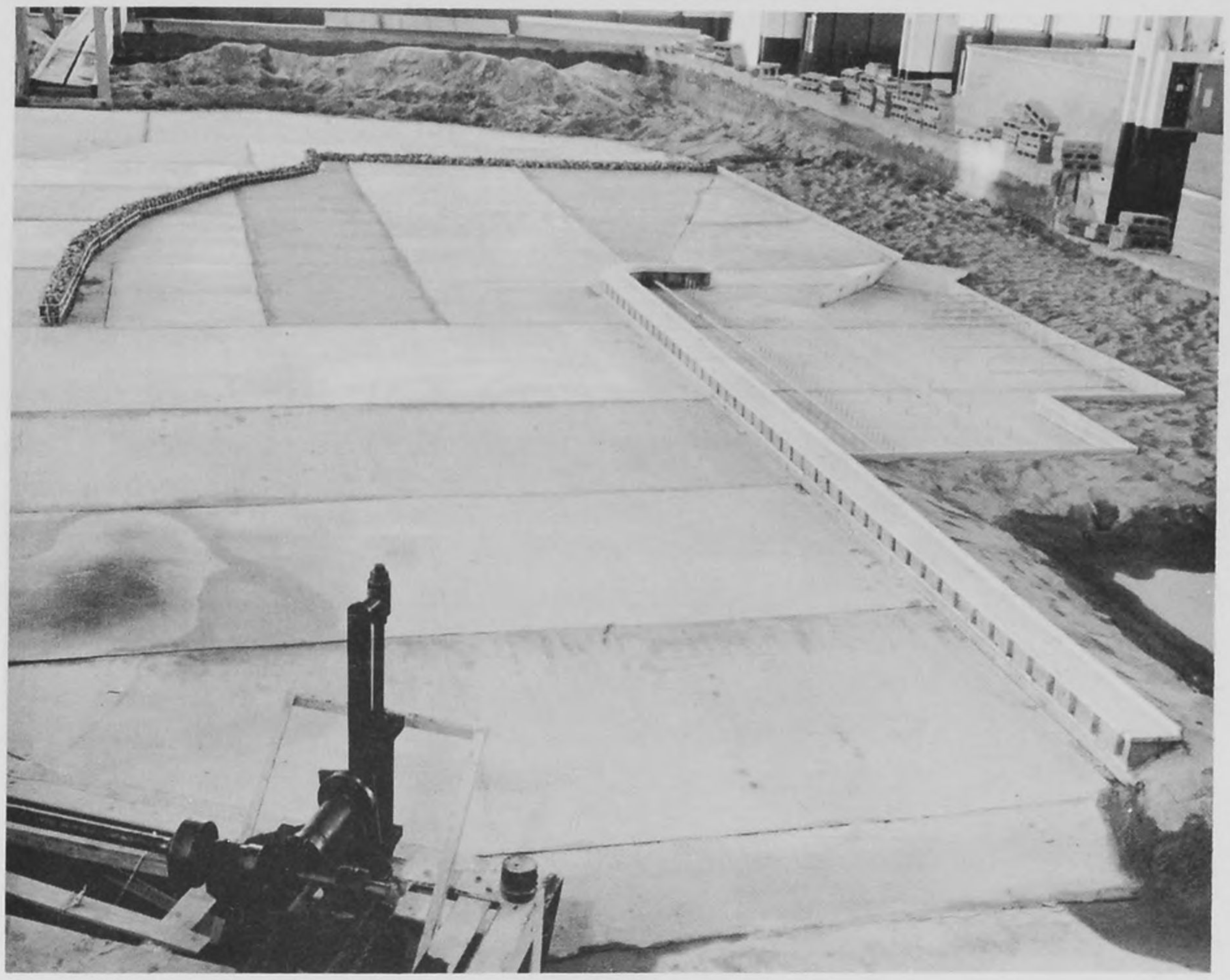


Fig. 3. View of Harbor model from the west.

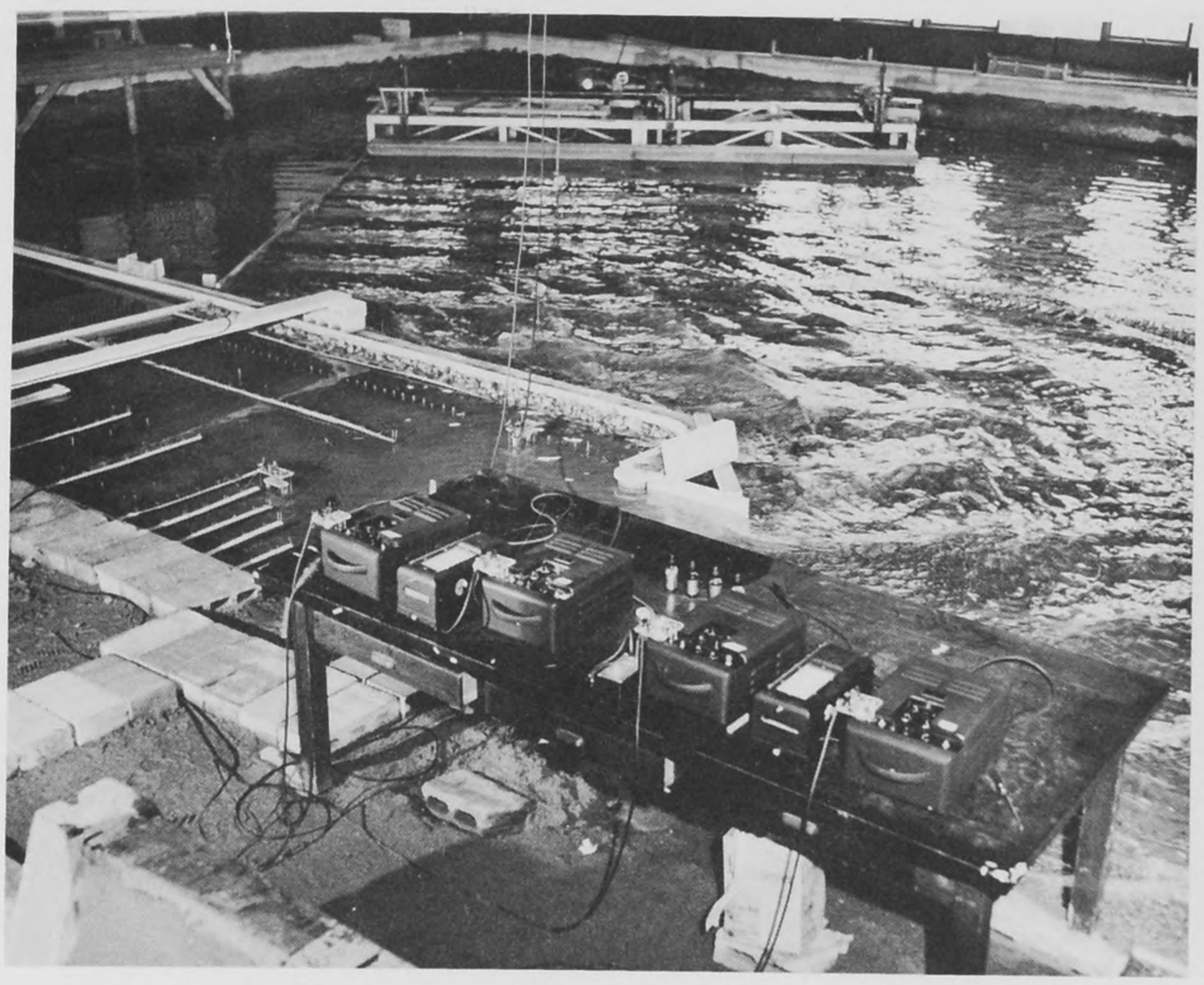


Fig. 4. View of Harbor model during a test simulating a westerly wind.

THE TESTING PROGRAM

Wave action in a harbor may be reduced by construction of barrier walls, by the installation of wave absorbers, by the use of diffusers, or by combinations of these methods. The use of sufficiently extensive barriers to keep virtually all waves out of a harbor is usually too expensive to be practical. This is true of the Gordon Park Harbor. However, small barriers, both free-standing and in conjunction with existing piers, are economically feasible and were tried in many different locations during the testing program. The most effective type of wave absorber is a beach. Because the use of a beach appeared to be out of the question at Gordon Park, other types of absorbers, namely, rubble revetments, groin systems, and submerged walls, were tested in various locations. Wave diffusers, which also act to some extent as absorbers, can be either zig-zag walls or groin systems. Both of these devices were tested extensively during the model studies.

The objective of the testing program was to determine the most economical device or combination of devices which would cause a substantial reduction in wave heights in the harbor. Additional criteria which influenced the selection of a protective scheme were the desirability of maintaining easy access to the harbor and of retaining a maximum amount of mooring area. Previous experience in working with other harbors provided information about the types and arrangements of devices which would probably be effective. All these devices were investigated in various combinations and for many different locations in the harbor area. Any particular combination of devices was referred to as a "plan." Each plan was tested first for one of the three principal wind directions. When a plan produced a satisfactory improvement in harbor conditions for the wind direction for which it was first investigated, it was studied for each of the other two principal wind directions.

All devices were first investigated for the "principal" wave heights and wave periods. Any plan which produced satisfactory results for the principal wave characteristics for all three wind directions was then tested for two other wave periods, one smaller and one larger than the "principal" period, and for one other wave height, smaller than the "principal" wave height. The plans which gave the best results were also checked for two supplementary wind directions (N 56°W and N 6°W) falling between the principal directions. Because the best plans require the use of rubble, another series of tests was made with rubble of a smaller size than that used for the original experiments. Finally, because the most effective plans consisted of three separate devices, a series of observations were made to establish the order in which the devices should be installed. In particular, it was thought desirable to determine which single device would provide the most help and should, therefore, be installed first.

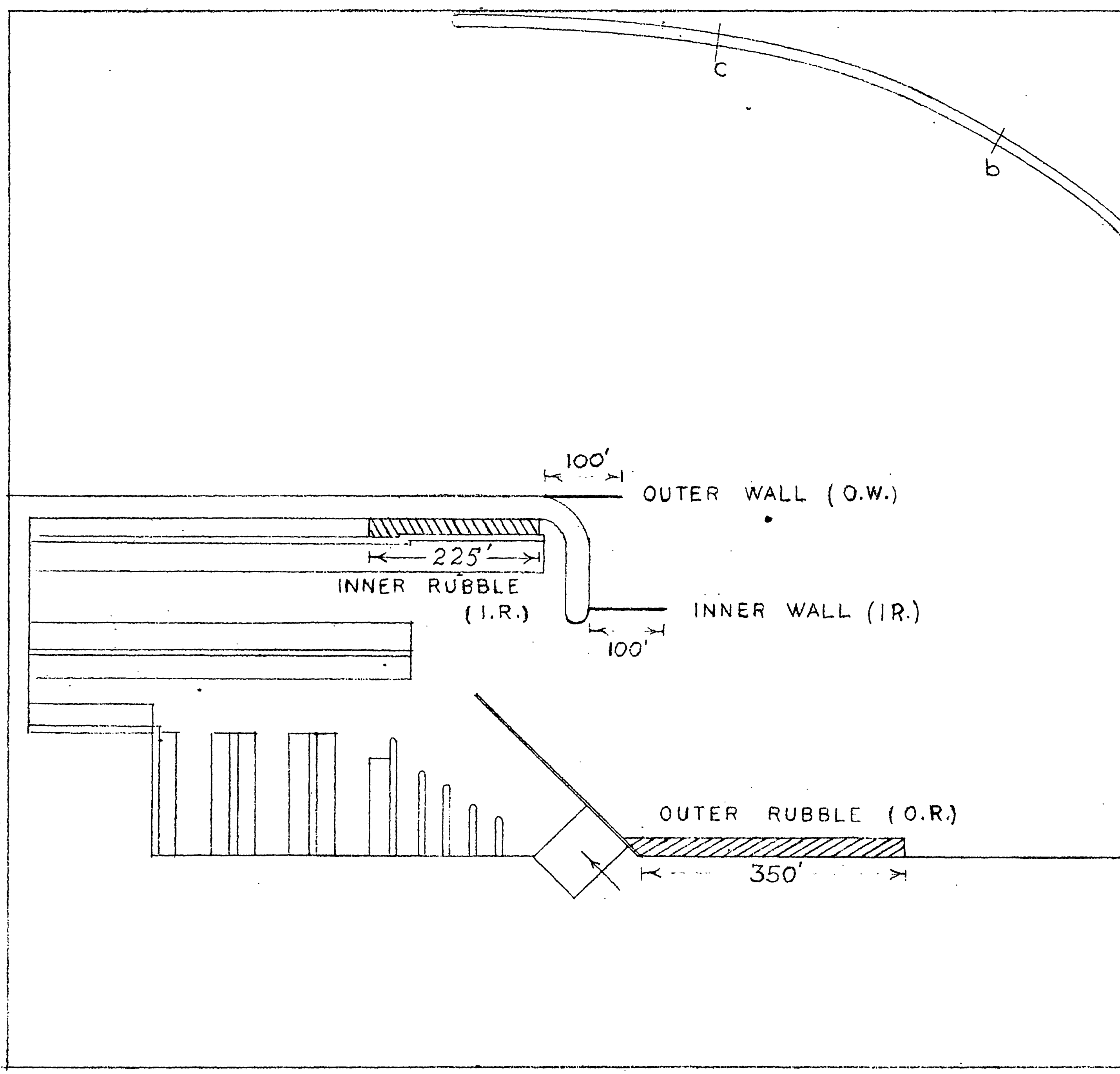
A small number of tests were also made to determine the effect on the harbor during a wind from N 22-1/2°E if portions of the outer curved breakwater were rebuilt.

THE TEST RESULTS

More than 200 different combinations of devices were tested. Of these, approximately 100 showed sufficient promise to warrant complete tests for all three principal wind directions. Many devices were found to have value only for one or two wind directions but failed to provide reduction in the wave heights for other directions. Only two combinations of devices produced a substantial reduction in wave heights for all wind directions, all wave heights, and all wave periods. Both of these plans required the use of rubble along the wall just northeast of the launching ramp. This rubble is designated as outer rubble or (OR) in Fig. 5. Both of these plans also required rubble along the inside of the harbor pier, designated as inner rubble or (IR) in Fig. 5. The rubble used for most of the tests had an average size slightly larger than 1-3/4 in. However, one series of tests was made with a finer rubble, having an average size of approximately 1/4 in. In both cases the material used was quite uniform in size. The coarser rubble retained a slope of one to one during the tests. The finer rubble assumed its own natural slope of about 2-1/2 to 1. The difference between the two plans was that one required the use of the 100-ft outer wall, designated as OW in Fig. 5, whereas the other included, instead, the 100-ft inner wall designated as IW.

The effectiveness of any plan was evaluated at each gage location by comparing the wave height determined at that location before the device was installed with the wave height which occurred after the device was installed. This method of comparison required that the deep-water wave height be kept constant during the tests. The reduction in wave height produced by any plan for each gage location was expressed as a percentage of the original wave height. Reduction percentages for the various individual gage locations were then averaged to obtain a single reduction percentage for the harbor area. This average reduction percentage for the harbor was considered the most important criterion of the effectiveness of each plan. In obtaining this final average percentage of reduction in wave heights, all five gage positions within the harbor (gage locations Nos. 3-7) were used for the principal test conditions, but for some of the supplementary tests only two or three of these gage positions were used. Results from gage No. 2 were excluded from this average because this gage was located in the entrance and therefore did not represent conditions in the mooring area. Results from gage No. 2 are presented separately.

The average reductions in wave heights within the harbor produced by the two plans described above are shown in Table II. All tests summarized in this table were made with the outer rubble and the inner rubble (see Fig. 5) in place. Under each wind direction are shown separate columns for the outer wall (OW) and the inner wall (IW) (see Fig. 5). The results are grouped according to wave heights and wave periods. The principal wave conditions (see p. 7) were used to determine the values given in the first two lines. Lines three and four give values obtained for longer and shorter wave periods, respectively,



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GORDON PARK HARBOR

CORRECTIVE DEVICES
Fig. 5

SCALE. 1" = 200'; DATE. 9 OCT. '60

whereas the results presented in line five were obtained with smaller wave heights as well as smaller wave periods. The underlined values in line one are the most important ones in the table. They were obtained for the three principal wind directions using the principal wave conditions. All other values were obtained to determine whether variations in wave height or period, or in wind direction, or in rubble size would alter the conclusions reached from the principal conditions. It will be noted that for the principal conditions, OW gives somewhat more reduction than IW for the west direction, whereas the reverse is true for the N 34°W direction. However, it is probable that these individual differences are too small to be significant. Furthermore, the average of the three underlined values for OW is the same as the average of the three corresponding values for IW. Thus, it can be concluded that OW and IW will give equally good results and the selection of one of them can be based entirely on a comparison of their costs and their effects on navigation.

TABLE II

AVERAGE REDUCTION OF WAVE HEIGHT IN HARBOR AREA

	Remarks	Wave Height at Gage No. 1 (Ft)	Wave Period (Sec)	Wind Directions — Reduction in Wave Height as % of Original Wave Height: West OW	West IW	N 56°W OW	N 56°W IW	N 34°W OW	N 34°W IW	N 6°W OW	N 6°W IW	N 22.5°E OW	N 22.5°E IW
1	a	5.7 - 6.5	6.7 - 7.5	48	41		60	49	57	60		70	69
2	b	5.7 - 6.5	6.7 - 7.5	32					66				75
3	a	4.1 - 6.7	7.8 - 8.5		42		31	66		50		56	
4	a	4.6 - 5.7	4.2 - 4.9		69		52						
5	a	3.0 - 3.3	4.2					53		42			
6	a	5.7 - 6.5	6.7 - 7.5	66	0		60	11	79			48	41
7	b	5.7 - 6.5	6.7 - 7.5	50					85				72

Notes: Lines 1, 2, 3, 4, and 5: Values are average reductions in wave heights in the harbor area.
Lines 6 and 7: Values are reductions in wave heights in the harbor entrance (Gage No. 2).
a: Coarser rubble used in IR and OR.
b: Finer rubble used in IR and OR.

The underlined values in line one of Table II also provide the best over-all measure of the effectiveness of the proposed plans. Expressed in round numbers, both plans will reduce the wave heights in the mooring area by amounts varying from 40% for westerly winds to nearly 70% for winds from N 22-1/2°E. The fact that the greatest reduction occurs for the northerly portion of the wind sector is important, because storm waves produced in the harbor by winds from these portions of the sector are twice as large as those created by westerly winds of the same magnitude. Thus the worst conditions would be improved the most by the use of either of these plans. It should be noted that waves approaching the harbor from the northerly portion of the wind sector lose a great deal of their energy as they pass over the curved outer breakwater and through shallow water inside the curved breakwater. The larger the waves, the greater is this effect. If this curved breakwater were ever demolished completely, the conditions of the harbor would be much worse during northerly winds. The effect of improving the curved breakwater is discussed at the end of this section of the report.

No other combination of devices was discovered which produced wave reductions for all three principal directions comparable in magnitude to those in line 1. Some additional reduction is obtained if the length of the rubble is extended beyond the limits indicated in Fig. 5. However, the additional improvement was small even when both OR and IR were extended along the full lengths of their respective walls.

The effect of using finer rubble for OR and IR can be seen by comparing values in line 2, Table II, with corresponding ones in line 1. It will be seen that one of the values for the finer rubble is smaller and the other two are larger than the reductions produced by the coarser rubble. It can therefore be concluded that variations in the size of the rubble, within the range of sizes used in the tests, will not materially change the over-all average effectiveness of these plans. There is an indication that the finer rubble is somewhat less effective for winds from the west and more effective for winds from the more northerly portions of the sector.

The values presented in line 3 show that these two plans also produce comparable reductions in wave height for waves having a period larger than the principal period used in lines 1 and 2, whereas those in lines 4 and 5 show the same result for smaller wave periods. Values in line 5 also show a comparable reduction in wave height when the original storm waves are much smaller than those used in the principal tests. The test results shown in the columns for the two intermediate wind directions, N 56°W and N 6°W, also have similar magnitudes and therefore provide additional evidence that these two plans are effective for winds from any portion of the selected sector.

Lines six and seven of Table II show some values obtained in the channel entrance. These are of lesser importance than values within the harbor because it can be assumed that small craft would have entered the harbor before a major storm occurs. However, these values show that wave heights in the entrance would also be substantially reduced by either of these plans.

Because these two plans consist of three devices, a series of tests was conducted to determine the best order in which to install the devices. Results of these tests, presented in Table III, show that the inner rubble (IR) is the only single device which will reduce wave heights resulting from westerly winds. Furthermore, the inner rubble produced the greatest beneficial effect for the other two wind directions. Therefore, the inner rubble should be installed first. The second most effective single device was found to be the outer rubble (OR) and the least effective was the 100-ft wall (OW or IW). There appears to be little choice as to which device should be installed second. In fact, it may be noted from the values in Tables II and III that only after all three portions of the selected plan are installed will the waves be substantially reduced for all wind directions.

TABLE III

AVERAGE REDUCTION IN WAVE HEIGHT WITHIN THE HARBOR AS PERCENTAGE OF ORIGINAL WAVE HEIGHT FOR SINGLE DEVICES AND COMBINATIONS OF TWO DEVICES

Devices Installed	Wind Direction		
	West	N 34°W	N 22.5°E
IR	21	28-44*	45
OR	0	0-24	25
IW or OW	0	0-0	15
IR + OR	18	9-33	58
IR + IW or OW	21	28-41	38
OR + IW or OW	0	44-55	63

*The larger values were obtained by eliminating from the average the results at gage No. 7. Unusual local conditions existed at this gage location during this series of tests.

A number of tests were made for the wind direction N 22.5°E to determine the effect of rebuilding portions of the existing outer curved breakwater. The breakwater was raised in two 400-ft stages as shown by the portions from a to b and from b to c, respectively, in Fig. 5. Measurements were made at each stage. The results are not as reliable as those for the other portions of this study because waves were reflected back to the wave machine from the raised breakwater with the result that the waves which reached the harbor area may have been greatly reinforced by reflections from the wave machine plunger. The tests showed that a reduction in wave height of over 50% would be brought about by raising the reach from a to b. Adding the second 400 ft, from b to c, produced an additional reduction of only about 5% for this particular wind direction. However, for more northerly winds this second portion would undoubtedly be of more value than the first portion. For westerly winds, the curved breakwater has no effect on conditions in the harbor.

SUMMARY AND RECOMMENDATION

More than 200 combinations of protective methods were examined in this model study. The most effective methods were tested for five wind directions and for a range of wave heights and wave periods. It was concluded that the two most effective plans are the ones shown in Fig. 5. Each of these plans requires the placing of rubble in the locations designated as OR and IR. The rubble should consist of material of relatively uniform size. However, the actual average size has no important influence on its effectiveness. The smaller material used in the tests corresponded to an average prototype size of one foot, whereas the larger material corresponded to an 8-ft size. The larger material was able to stand at a slope of about 1 to 1 whereas the wave action changed the slope of the smaller material to about 2-1/2 to 1, horizontal to vertical. Each of the plans also requires the use of a 100-ft wall near the harbor entrance. The two plans differ in the location of this wall. The two locations, designated as OW and IW in Fig. 5, were found to be equally effective.

Additional improvement of the harbor conditions, during northerly winds, could be obtained by improving the outer curved breakwater. It would be desirable to raise the portion from a to c in Fig. 5. Even in its present condition, this curved breakwater provides a great deal of protection to Gordon Park Harbor.

AIIM SCANNER TEST CHART # 2

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Times Roman

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Century Schoolbook Bold

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News Gothic Bold Reversed

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Bodoni Italic

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Greek and Math Symbols

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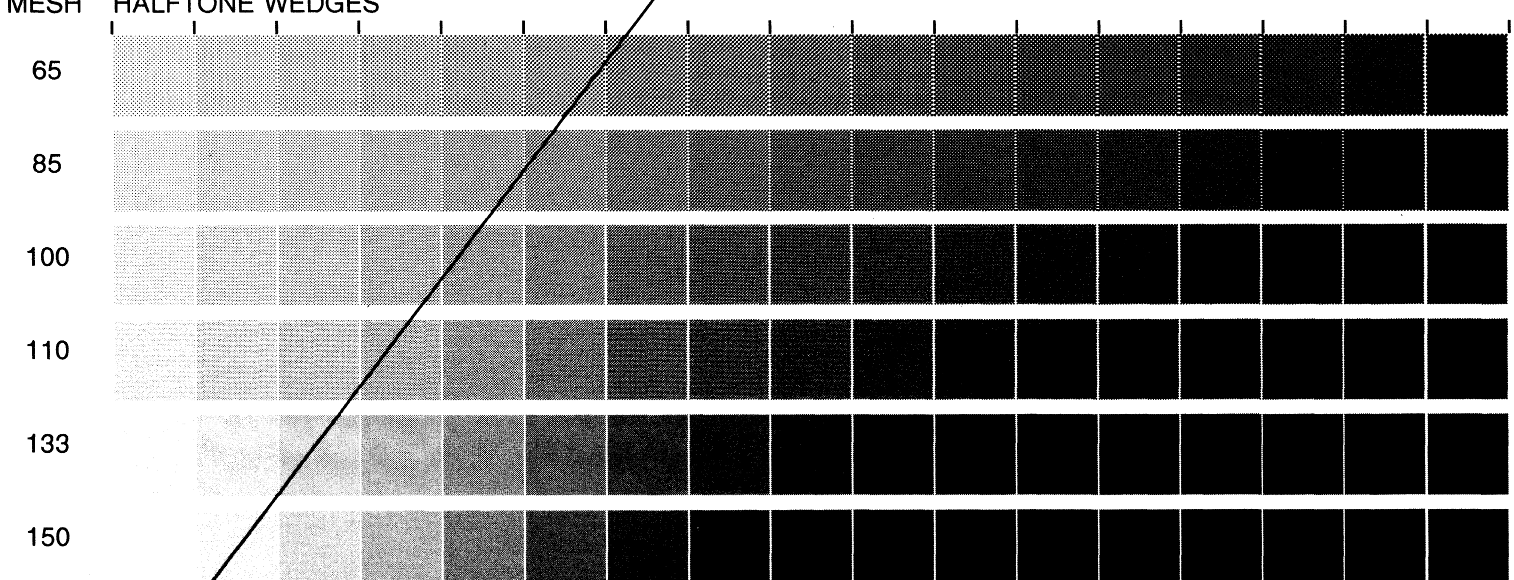
MESH HALFTONE WEDGES



RIT ALPHANUMERIC RESOLUTION TEST OBJECT, RT-1-71

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