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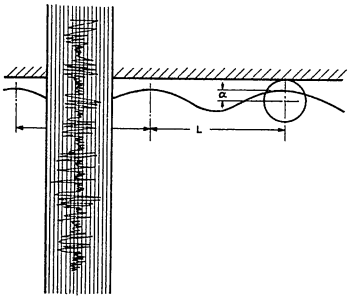
MODEL STUDY FOR HARBOR OF REFUGE FOR LIGHT DRAFT VESSELS AT PORT AUSTIN, MICHIGAN



TECHNICAL REPORT NO. 2
LAKE HYDRAULICS LABORATORY
DEPARTMENT OF CIVIL ENGINEERING
BY: E.F. BRATER APP. BY: C.O. WISLER

PROJECT M805 CONTRACT W-20-064-ENG 1775
DETROIT DISTRICT, CORPS OF ENGINEERS
UNITED STATES ARMY
IN COOPERATION WITH
MICHIGAN STATE WATERWAYS COMMISSION

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MODEL STUDIES FOR HARBOR OF REFUGE

FOR

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BY

E. F. BRATER
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Project M805

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October 10, 1949

PHOTOLITHOPRINTED BY CUSHING - MALLOY, INC.
ANN ARBOR, MICHIGAN, UNITED STATES OF AMERICA
1949

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FOR

LIGHT DRAFT VESSELS AT PORT AUSTIN, MICHIGAN

INTRODUCTION

Port Austin, Michigan is located near the tip of the "thumb" area of Michigan as shown in Drawing 1, p. 17. From the west and northwest it is exposed to a fetch of approximately 25 miles on Saginaw Bay and the open waters of Lake Huron extend toward the north for a distance of 125 miles. It is proposed to construct a harbor of refuge for light draft vessels at Port Austin. The primary purpose of the model study is to determine the relative effectiveness of various breakwater arrangements in protecting the harbor area from waves. The magnitudes of the currents generated by the wave action were also determined for each of the plans. The results of the tests, when considered in conjunction with the costs of the various plans will provide the basis for selecting the most suitable harbor arrangment for Port Austin.

The study was made as a result of a contract dated November 8, 1948, between the University of Michigan Engineering Research Institute and the Detroit District, Corps of Engineers, U.S. Army. The initiation of the work was expedited by the interest and financial support of the Michigan State Waterways Commission.

Throughout the model study frequent consultations were held with the following personnel of the Detroit District: Colonel Louis J. Rumaggi, District Engineer, Tom C. Trelfa, Charles R. Dickinson, Harley F. Lawhead and Charles E. Lee. Mr. William H. Booth Jr. of the Great Lakes Division Office, Corps of Engineers visited the laboratory at various stages of the work.

E. W. Kiefer, Chairman, Leonard H. Thomson, Secretary, and Bert Robb, Executive Secretary of the Michigan State Waterways Commision visited the laboratory on several occasions.

The University of Michigan Lake Hydraulics Laboratory, where the work was done, is a facility of the Engineering Research Institute and the Department of Civil Engineering of the College of Engineering. Professor A. E. White is Director and Professor C. W. Good is Assistant Director of the Engineering Research Institute. Professor Earnest Boyce is Chairman of the Department of Civil Engineering and Ivan C. Crawford is Dean of the College of Engineering. Professor C. O. Wisler is in charge of Hydraulic Engineering and the laboratory is under the supervision of E. F. Brater, Associate Professor of Civil Engineering. Mr. L. D. Stair was in charge of the construction and testing of the models. The data were reduced and the drawings prepared by D. C. Woo. Mr. W. C. Schroeder and Mr. Robert Charmillon assisted in all phases of the laboratory work.

THE MODEL

The model was constructed in a tank having the dimensions 90 feet by 54 feet. An undistorted linear scale of 1 to 75 was used. This permitted the reproduction of an area extending more than a mile along the shore and more than half a mile into the lake as shown in Drawing 2, p. 18. Templates were cut from 3/8-inch waterproof plywood in accordance with sounding data and topographic charts supplied by the Corps of Engineers. The templates were spaced at intervals of either 2-feet 8-inches or 1-foot 4-inches in the vicinity of the harbor and at intervals of 5-feet 4-inches in the more remote regions as shown in Drawing 2. The model consisted of an inch thick layer of cement mortar placed on a base of firmly compacted sand. The mortar was carefully screeded so that its surface conformed with the edges of the templates. The model breakwaters were constructed of low stress concrete.

The accuracy of the model was first checked by means of an engineer's level. An additional, more delicate check was obtained by filling the tank to various water surface elevations and checking the locations of the shore lines thus formed against the positions of the corresponding lake bottom contours.

METHOD OF CONDUCTING TESTS

The waves were generated by means of a plunger-type wave machine 30 feet in length. The wave machine is shown in Plate 1, p. 61. The amplitude and period of the plunger motion was varied to produce waves of the required height, length and period. The wave machine, being portable, was shifted in location to simulate the three wind directions tested.

Wave heights were measured by electric resistance gages and recorded by means of oscillographs. The calibrations of the resistance gages were checked systematically during the tests. The wave height at any point was determined by computing the average of the highest one third of 180 successive waves. The instruments described above are shown in Plate 1.

Surface currents were measured by timing the movements of small wooden floats with reference to coordinate lines on the model. Currents in the harbor entrance of Plan 1 were determined by means of submerged floats.

The elevation of the water surface was checked by means of a hook gage mounted on a wall of the wave tank. The change in level due to evaporation and leakage averaged two thousandths of a foot over a twenty-four hour period and was corrected prior to the running of each test.

THE TESTING PROGRAM

Five breakwater arrangements, designated in Plans 1, 2, 3, 4 and 5, were tested. All of these arrangements together with typical breakwater cross-sections are shown in Drawing 3, p. 19. The section designated as Type B was used throughout except for the outermost 300 feet of the west breakwater of Plan 2 which was Type A.

A limited number of tests were run on variations of Plans 2 and 5. These were designated as Plans 2a and 5a respectively. For certain wind directions the wave heights near the mouth of Bird Creek were measured with the west breakwaters of Plans 2, 3, 4 and 5 temporarily extended 150 feet towards the shore. No special designations were given to these variations and the results were shown on the drawings along with those of the regular tests.

Plans 1 and 2 each consisted of two straight segments of breakwater with a dredged entrance channel 150 feet wide between them. In each case the total length of breakwaters was 2290 feet. The distance from toe to toe of breakwaters at the harbor entrance was 200 feet for Plan 1 and 185 feet for Plan 2. The entire harbor area of Plan 2 was moved approximately 200 feet to the east of the location of Plan 1 in order to remove the entrance from a region of large wave height. In Plan 1 the two segments of breakwater were nearly symmetrical whereas in Plan 2 the west breakwater extended beyond the outer end of the east breakwater.

Plans 3, 4 and 5 consisted of a single breakwater made up of two connected straight segments as shown in Drawing 3. In Plan 4 the ends of the breakwater were at the same locations as Plan 3 but the angle between the two straight segments was changed. Plan 5 consisted of the same arrangement as Plan 3 but the outer 100 feet of breakwater was removed and the dredged entrance width increased accordingly. In each case the entrance was located approximately 600 feet east of the entrance in Plan 2. The dredged entrance width was 290 feet for plans 3 and 4, and 365 feet in the case of Plan 5. The lengths of the breakwaters for plans 3, 4 and 5 were 1925 feet, 1975 feet, and 1825 feet respectively.

Plan 2a consisted of the same arrangement as Plan 2 but a 260 foot segment of the east breakwater was raised to prevent overtopping by waves. Plan 2a is shown in Drawing 19, p. 39.

Plan 5a differed from Plan 5 in that the breakwater was extended 50 feet toward the lake as shown in Drawing 47, p. 40. Plan 5a was therefore intermediate between plans 3 and 5.

TEST CONDITIONS

The basic wave data were prepared by H. F. Lawhead and C. E. Lee of the Detroit District Office. Deep water wave heights were computed from records of wind velocity and duration. It was found from preliminary studies that the topography to the east of Port Austin caused deep water waves generated by winds from directions east of north to refract and approach the harbor area in substantially the same direction as waves from the north if they reached the harbor area at all. Consequently, it was decided that the model study should be based on winds from the following three directions; north, northwest by north, and west-northwest. The frequencies of waves of various sizes from these directions are shown graphically in Appendix C, p. 85. For each wind direction a "large" wave and a "small" wave was projected against the harbor. A summary of the characteristics of the waves used in the tests is given in Table I. Refraction diagrams for the "large" waves from the three directions were prepared by the Corps of Engineers. These are reproduced in Appendix C on pages 79, 81 and 83. The refraction diagrams served as the basis for computing the required wave height at a selected gaging station located in the model at a point outside the influence of the breakwater.

TABLE I

SUMMARY OF WAVE DATA

	Small Wave			Large Wave		
	N	NW-N	WNW	N	NW-N	WNW
Deep Water Wave Height (Ft.)	4.5	4.5	4.5	13.0	10.0	9.0
Deep Water Wave Length (Ft.)	81.9	81.9	81.9	196.8	113.1	103.7
Wave Period (Seconds)	4.0	4.0	4.0	6.2	4.7	4.5
Frequency*	62	68	37	0.8	0.9	1.0

* Number of times wave height will be equaled or exceeded in three years.

It is believed that the larger waves would give an indication of the disturbance inside the harbor when severe Lake Huron storms have reached their full intensity and are producing near maximum waves at the harbor site. The smaller waves occur more frequently and might be thought of as representing conditions that would commonly exist when small boats are entering the harbor to seek refuge from a major storm before it has reached its full intensity. Finally, the smaller waves permit the comparison of the various harbor arrangements under conditions of no overtopping of the breakwaters by storm waves, whereas in the case of the larger waves the overtopping effect was considerable.

Low-water datum for Lake Huron is at elevation 578.5. The crests of the breakwaters were set 8 feet above low-water datum. Throughout the tests the lake elevation was kept 3 feet above low-water datum. Thus, the crests of the breakwaters were 5 feet above the still water level of the lake. The lake stage used in the tests was determined from a consideration of the records of the U. S. Lake Survey's water level recorder at Harbor Beach, Michigan, covering a number of storm periods. The records show that the rise in stage at this locality due to storm conditions is not a very significant factor and that during the past 60 years a stage of 581.5 has been exceeded infrequently and then only for relatively short periods and to a rather minor extent.

PRESENTATION OF RESULTS

All the data obtained from the tests are presented graphically in Appendix A, pp. 17 - 58. Photographs showing harbor conditions during large wave tests are shown in Appendix B, pp. 61 - 76. In Appendix A the drawings showing the measured wave heights are presented first. The results obtained from Plan 1 are shown in sequence on pages 21 to 26. The drawings for Plans

2, 3, 4 and 5, are grouped according to wave height and wind direction to facilitate comparison of these four plans. They are shown on pages 27 to 37. The drawings showing the results of current measurements are shown on pages 44 to 58.

All drawings and plates are numbered in the order of sequence of testing and may be located by means of the List of Illustrations which is given near the front of this report.

Wave Heights.

Wave heights were measured at from 25 to 35 locations for each test. The measured values were recorded on the drawings at the gage locations together with an arrow indicating the direction in which the predominant wave was traveling. With these measured values as a basis, lines of equal wave height were drawn. Regions where the wave heights were less than 1.5 feet, and where they were greater than 5.0 feet, were hatched.

Some numerical averages are found to be useful in analyzing the test data. In Table II are shown three groups of averages for each wind direction, for both the large and small waves. The first group consists of the measurements made at stations near the harbor entrance. The second group comprises those made inside the harbor and the third consists of the results from five measuring stations near the mouth of Bird Creek. The division lines between the areas covered by these three groups, are shown as dashed lines in Drawing 3, p. 19.

Currents.

The magnitude and direction of velocities in and around the harbor were shown on the drawings by the use of arrows. The lengths of the arrows were made proportional to the velocities according to the scale indicated on the drawings. Paths followed by the floats were shown by means of dotted

TABLE II

AVERAGE WAVE HEIGHTS

	Plan	Entrance			Harbor			Bird Creek Area		
		N	NW-N	WNW	N	NW-N	WNW	N	NW-N	WNW
Large Wave	1.	10.0	5.8	3.6	4.3	2.4	1.1	5.0	2.9	0.7
	2.	4.6	3.6	3.0	1.1	0.8	0.4	1.6	0.6	0.3
	3.	4.0	4.6	4.0	1.7	1.2	0.4	1.1	0.7	0.0
	4.	4.6	5.1	4.3	1.6	1.3	0.5	0.6	0.9	0.3
	5.	5.5	5.1	4.6	1.4	1.0	0.5	0.5	0.4	0.2
Small Wave	1.	3.6	3.0	2.9	1.0	0.7	0.7	1.3	0.7	0.3
	2.	2.0	1.7	1.2	0.1	0.1	0.0	0.1	0.1	0.1
	3.	2.6	2.2	1.8	0.2	0.1	0.0	0.1	0.0	0.0
	4.	3.2	2.7	2.0	0.4	0.0	0.0	0.3	0.0	0.0
	5.	3.8	3.1	3.0	0.4	0.1	0.0	0.1	0.0	0.0

lines. In some locations the direction of the path assumed by the float varied with time so that occasionally different paths emanated from the same point. In Plan 1 near the harbor entrance, where floats were used which traveled just beneath the surface, the paths were shown as dashed lines. A summary of the maximum velocities occuring in various locations is given in Table III. These values do not necessarily occur at the same point for each plan.

TABLE III

MAXIMUM CURRENTS FOUND IN VARIOUS HARBOR LOCATIONS

Values are in mi. per hour

Plan	Entrance			Harbor			Bird Creek Area			Between Shore and Inner End of Breakwater		
	N	NW-N	WNW	N	NW-N	WNW	N	NW-N	WNW	N	NW-N	WNW
1	0.8	1.2	1.9	1.2	0.9	1.7	1.2	0.8	1.0	1.2	1.5	1.7
2	2.5	2.7	1.9	2.3	2.2	3.5	1.0	1.9	2.2	1.2	3.3	2.6
3	1.8	2.2	1.8	1.5	1.3	1.5	0.8	1.3	1.3	1.2	1.6	1.8
4	1.5	2.2	1.7	1.4	1.5	1.5	1.0	0.7	0.4	2.3	2.3	2.0
5	2.1	2.3	2.3	1.5	1.3	2.0	1.1	1.8	1.4	1.3	1.9	2.0

ANALYSIS OF RESULTS

To aid in the determination of the relative effectiveness of the various plans in reducing wave actions, Tables IV and V were prepared. In Table IV is given a set of values obtained by numbering the average wave heights of Table II from 1 to 5 in the order of ascending size. Thus, the best plan for any wind direction and wave size is numbered 1, the next best 2, and so on. The sum of the values for each plan is shown in the right hand column. Table V gives a summation of the values of Table IV for each wind direction and wave size. These two tables provide only a relative comparison between the plans. To determine the extent of the advantage of one plan over

TABLE IV

NUMERICAL EVALUATION OF THE VARIOUS PLANS

		Entrance			Harbor			Bird Creek Area			
	Plan	N	NW-N	WNW	N	NW-N	WNW	N	NW-N	WNW	Summation
Large Wave	1	5	5	2	5	5	5	5	5	5	42.0
	2	2.5	1	1	1	1	1.5	4	2	3.5	17.5
	3	1	2	3	4	3	1.5	3	3	1	21.5
	4	2.5	3.5	4	3	4	3.5	2	4	3.5	30.0
	5	4	3.5	5	2	2	3.5	1	1	2	24.0
Small Wave	1	4	4	4	5	5	5	5	5	5	42.0
	2	1	1	1	1	3	2.5	2	4	4	19.5
	3	2	2	2	2	3	2.5	2	2	2	19.5
	4	3	3	3	3.5	1	2.5	4	2	2	24.0
	5	5	5	5	3.5	3	2.5	2	2	2	30.0

TABLE V

SUMMARY OF THE NUMERICAL EVALUATION OF THE VARIOUS PLANS

Plan	Large Wave			Small Wave		
	N	NW-N	WNW	N	NW-N	WNW
1	15	15	12	14	14	14
2	7.5	4	6	4	8	7.5
3	8	8	5.5	6	7	6.5
4	7.5	11.5	11	10.5	6	7.5
5	7	6.5	10.5	10.5	10	9.5

another it is necessary to refer to the original test results as given in the drawings and in Tables II and III.

Plan I

This plan provided relatively inadequate protection from storm waves. Wave heights inside the harbor were from 2 to 10 times higher than in the case of the other arrangements.

Plan 2

This arrengement gave excellent protection from wave action. However, the currents were higher for this plan than for any of the others.

Plan 2a

It was noted that overtopping of the east breakwater of Plan 2 was largely confined to a portion about 260 feet long. A number of wave height determinations were made with this portion raised sufficiently to prevent overtopping. The resulting reduction in harbor wave heights is shown in Drawing 19, p. 39. It was also found that an increase in the breakwater elevation of 2.3 feet was insufficient to prevent overtopping whereas an additional 2.3 feet stopped it completely.

Plan 3

This arrangement provided very good protection from wave action, being only slightly less effective than Plan 2 in this respect. The currents were found to be smaller than for any other plan except Plan 1.

Plan 4

This plan was adequate in all respects but it was somewhat less effective than Plan 3.

Plan 5

This arrangement would also provide a satisfactory harbor. However, the wave heights were not reduced as much as in Plan 3 and the currents were consistently greater than those of Plan 3.

Plan 5a

For this plan measurements were made at only seven stations near the harbor entrance as shown in Drawings 47 - 50 pp.40 - 43. Average values for these seven stations together with the averages for the corresponding stations of Plans 3 and 5 are shown in Table VI. It will be seen that the values from Plan 5a are greater than those of Plan 3 and smaller than those of Plan 5.

TABLE VI

Wind Direction	Plan 3	Plan 5a	Plan 5
NW-N Large	4.26	4.26	4.56
NW-N Small	2.03	2.49	3.01
WNW Large	3.56	3.81	4.40
WNW Small	1.39	2.03	2.76

CONCLUSIONS

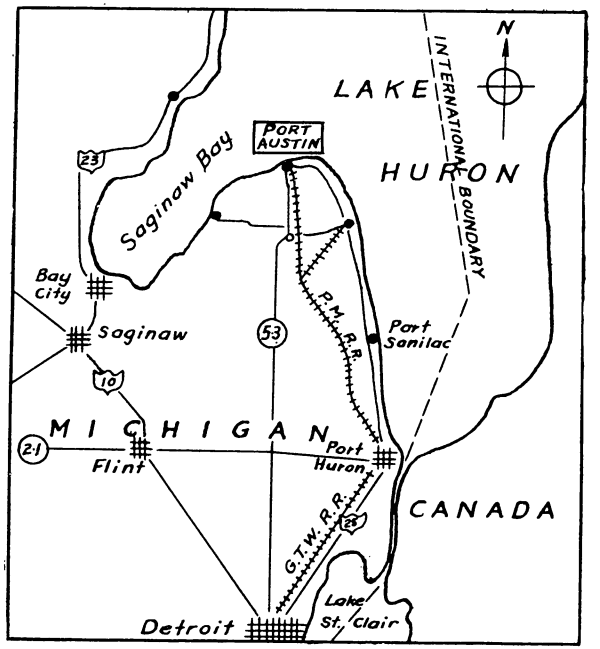
Plans 2 and 3 provided the best protection from wave action. However, Plan 3 was better than Plan 2 in regard to currents. Therefore, because of the lower estimated cost of Plan 3 it is to be preferred over Plan 2.

Plan 4 gave satisfactory results but they were somewhat inferior to those of Plan 3. Therefore, because Plan 4 would be more expensive to construct than Plan 3 it may be eliminated from further consideration.

Although Plan 5 was not quite as effective as Plan 3, Plan 5 has the advantages of a wider entrance channel and a somewhat lower cost. The choice between Plans 3 and 5 therefore depends upon whether these factors outweigh the advantages of the lower wave heights and currents provided by Plan 3.

APPENDIX A

DRAWINGS



Scale of Miles

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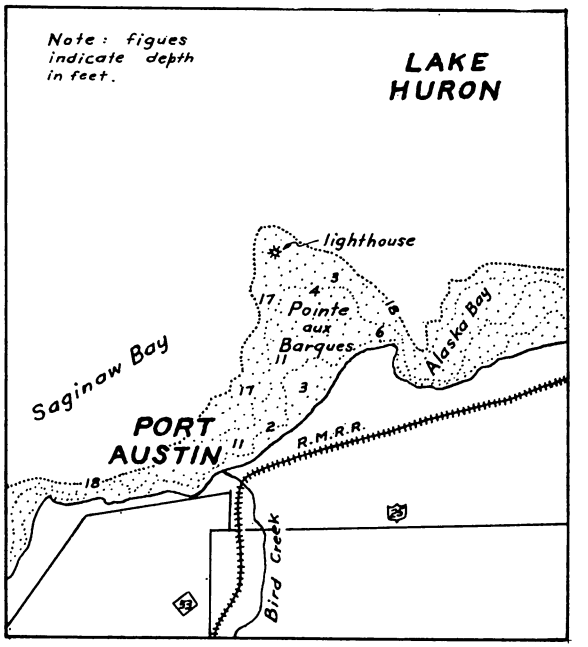

Scale of Miles

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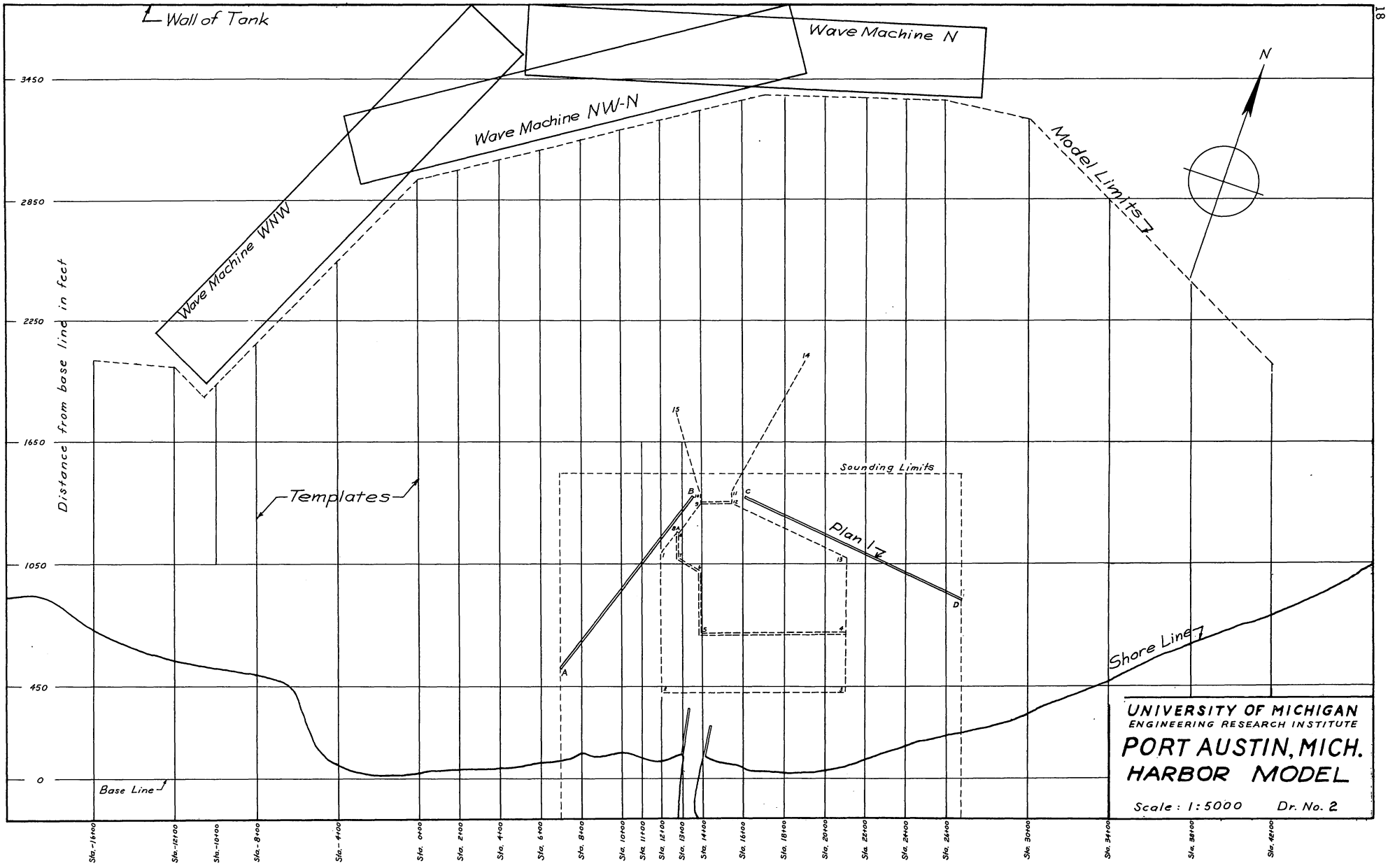
HARBOR MODEL

LOCATION MAP

Dr. No. 1



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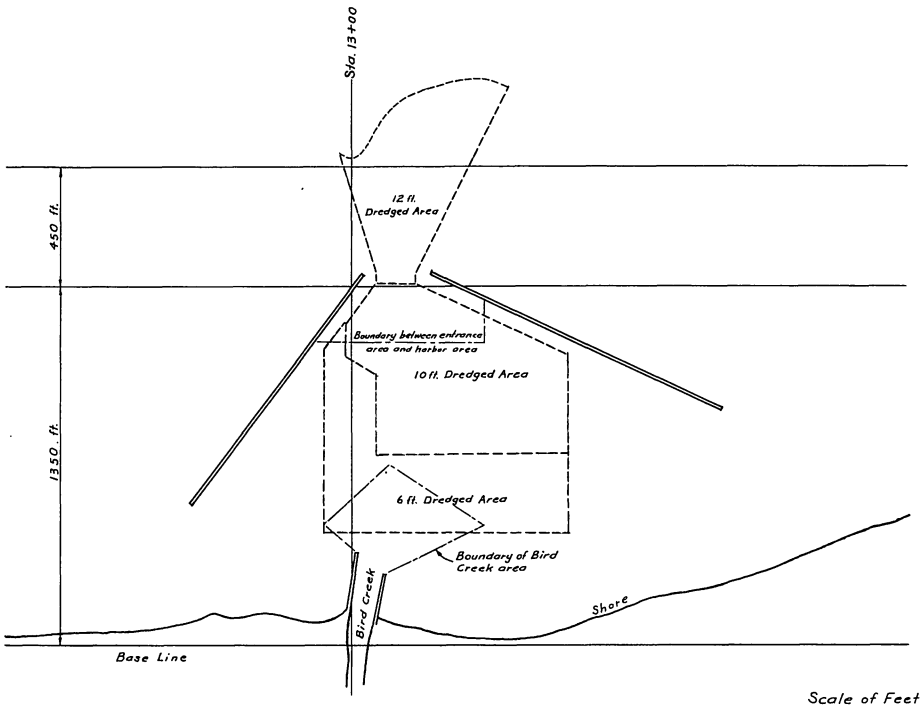
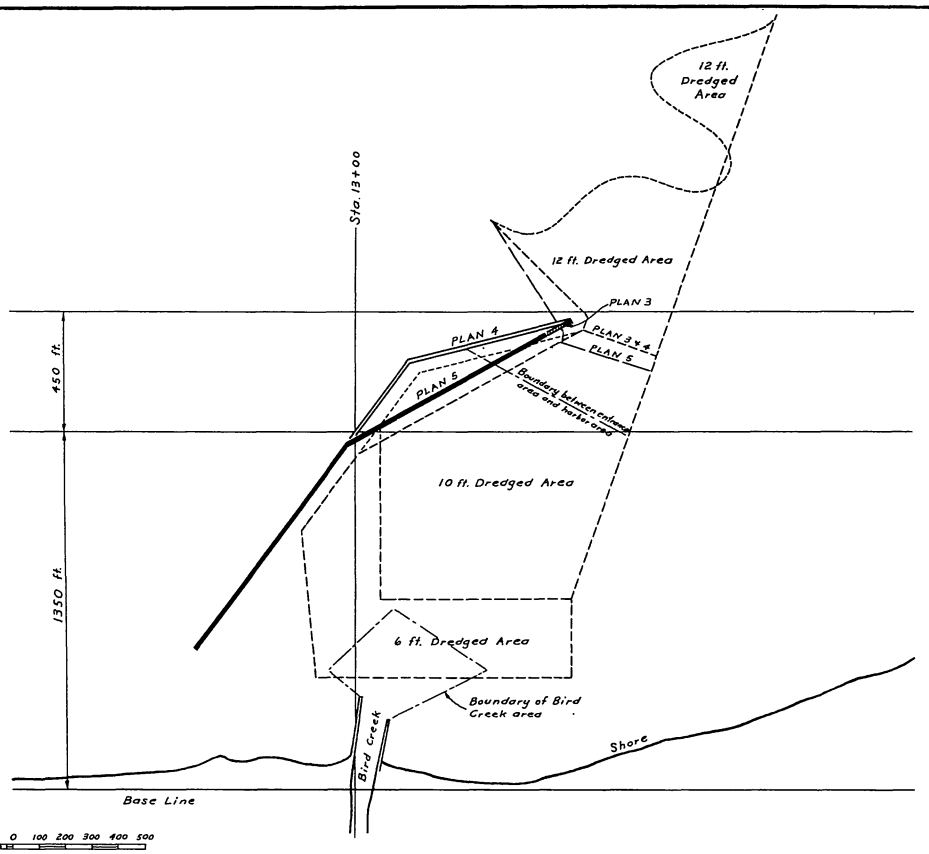
PORT AUSTIN, MICH.
HARBOR MODEL

Scale : 1:5000 Dr. No. 2

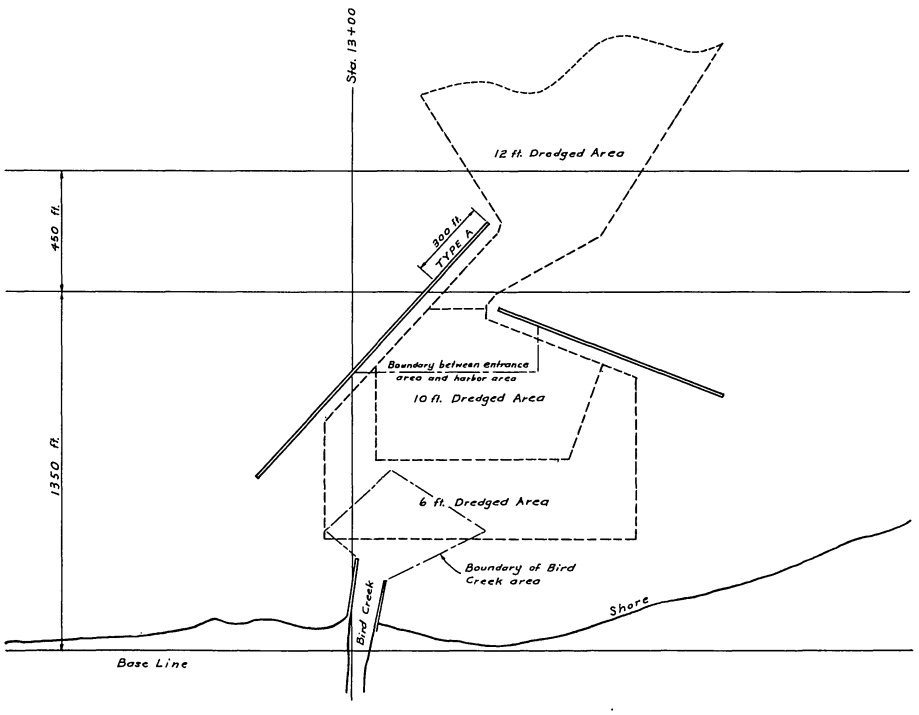


PLAN — 1



PLANS — 3, 4, 5

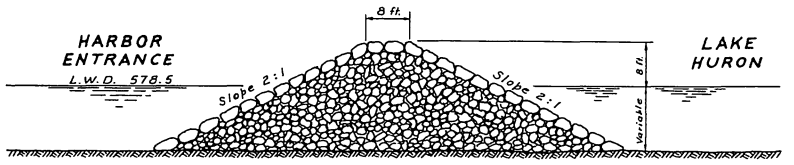
Scale of Feet: 100 0 100 200 300 400 500



PLAN — 2

Scale of Feet: 100 0 100 200 300 400 500

N



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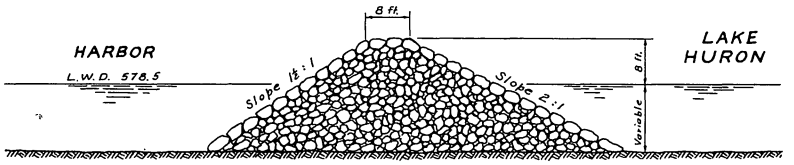

TYPE B

SECTIONS

Scale of Feet

10 0 10 20 30 40 50

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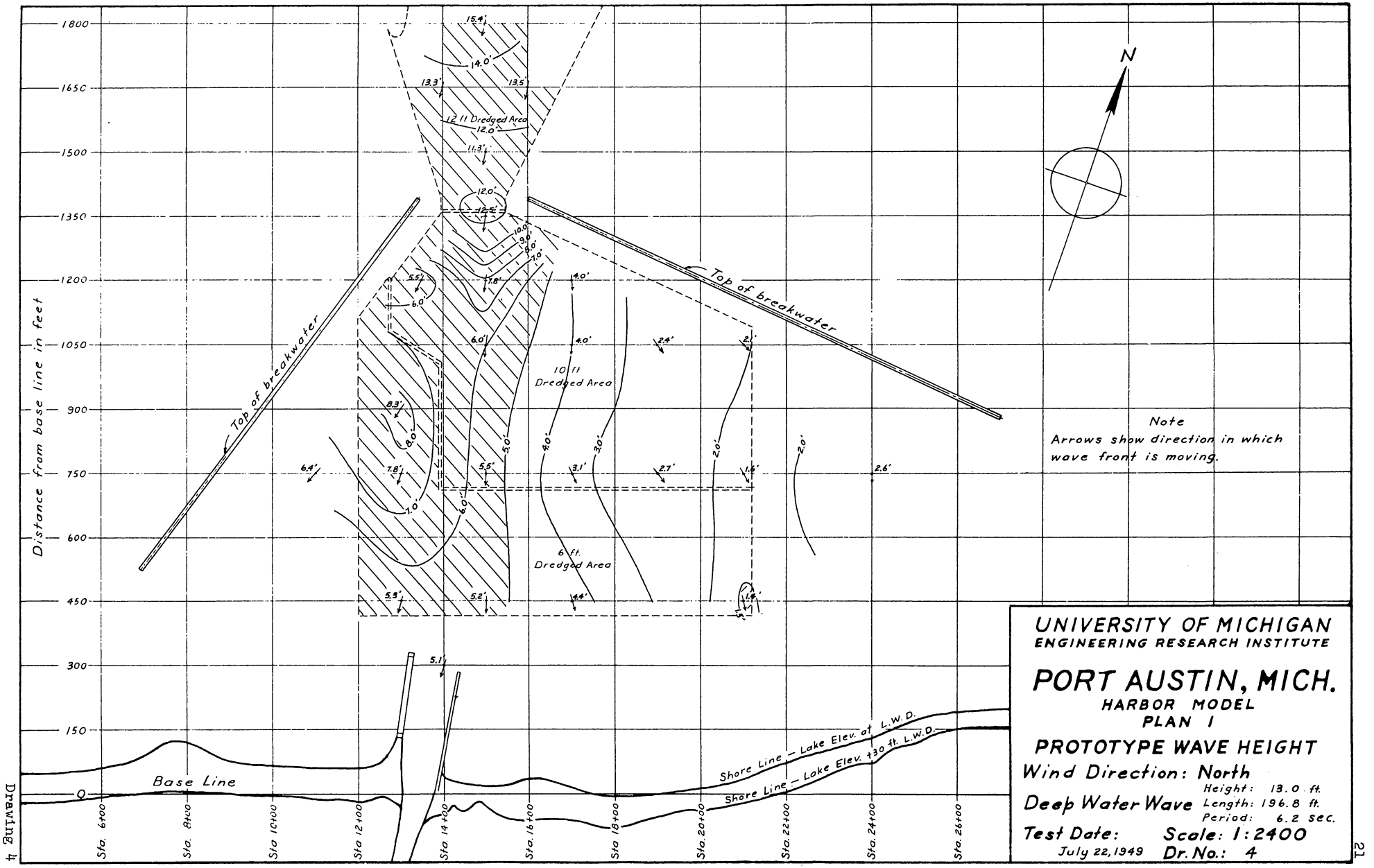
HARBOR MODEL

BREAKWATER ARRANGEMENTS AND SECTIONS

Dr. No. 3



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PORT AUSTIN, MICH.

HARBOR MODEL
PLAN 1

PROTOTYPE WAVE HEIGHT

Wind Direction: North

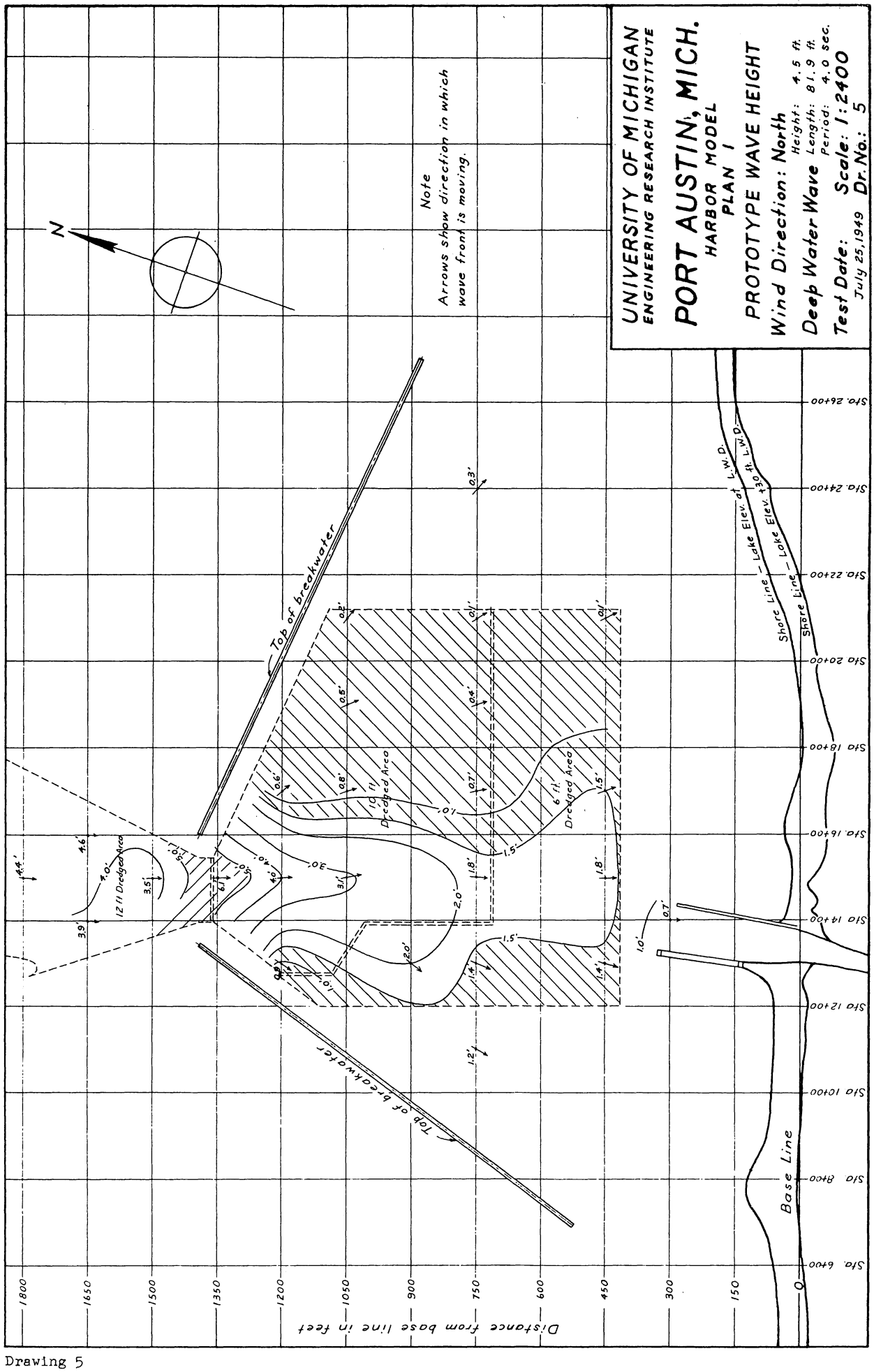
Deep Water Wave — Height: 13.0 ft. Length: 196.8 ft. Period: 6.2 sec.

Test Date: July 22, 1949

Scale: 1:2400

Dr. No.: 4

Drawing 4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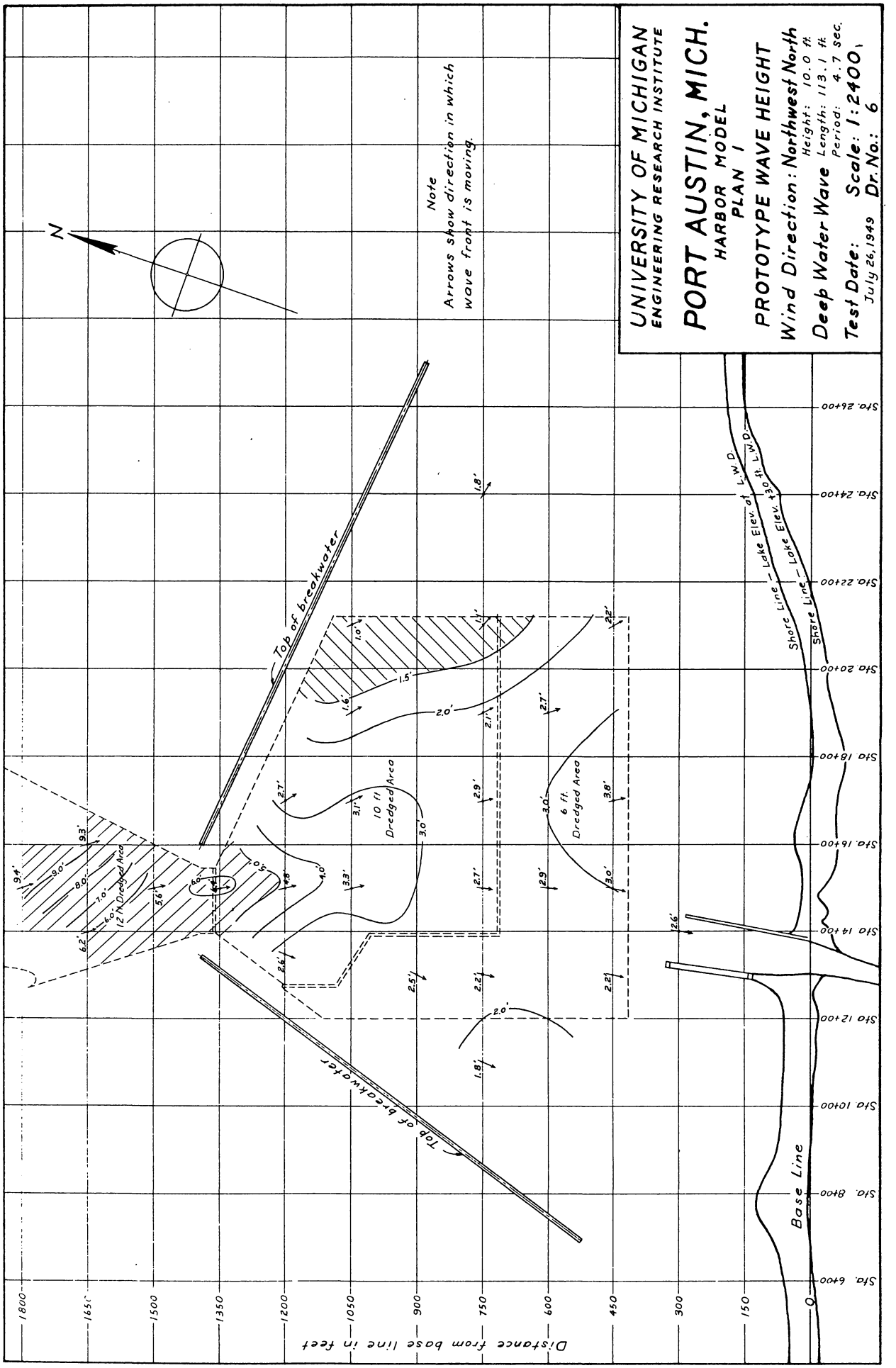
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 1
PROTOTYPE WAVE HEIGHT
Wind Direction: North
Deep Water Wave Height: 4.5 ft. Length: 81.9 ft. Period: 4.0 sec.
Test Date: July 25, 1949 Scale: 1:2400 Dr. No.: 5
Note
Arrows show direction in which wave front is moving.
N
Top of breakwater
Top of breakwater
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Shore Line — Lake Elev. at L.W.D.
Shore Line — Lake Elev. +3.0 ft. L.W.D.
Base Line
Sta. 6+00
Sta. 8+00
Sta. 10+00
Sta. 12+00
Sta. 14+00
Sta. 16+00
Sta. 18+00
Sta. 20+00
Sta. 22+00
Sta. 24+00
Sta. 26+00
Distance from base line in feet
0
150
300
450
600
750
900
1050
1200
1350
1500
1650
1800

Drawing 5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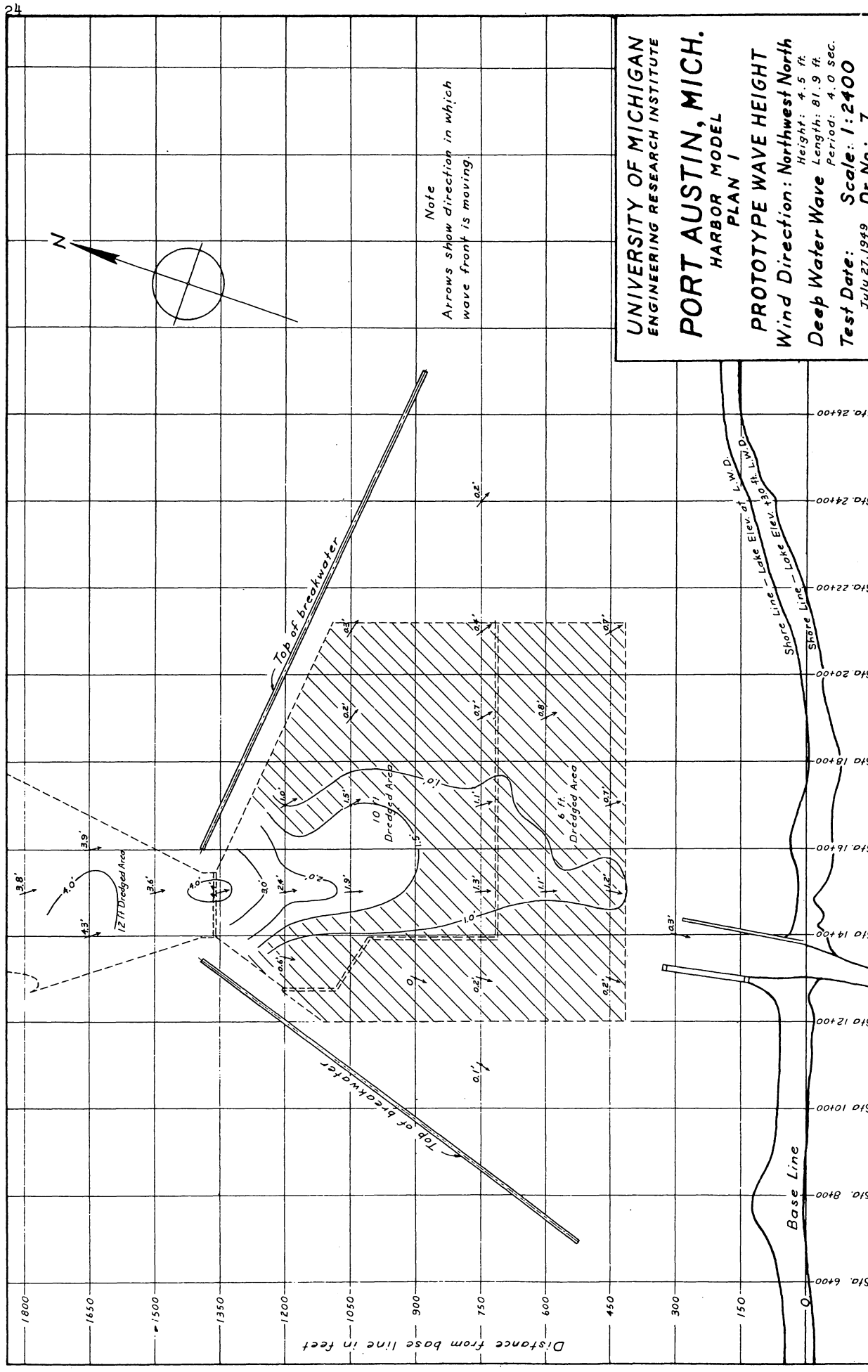
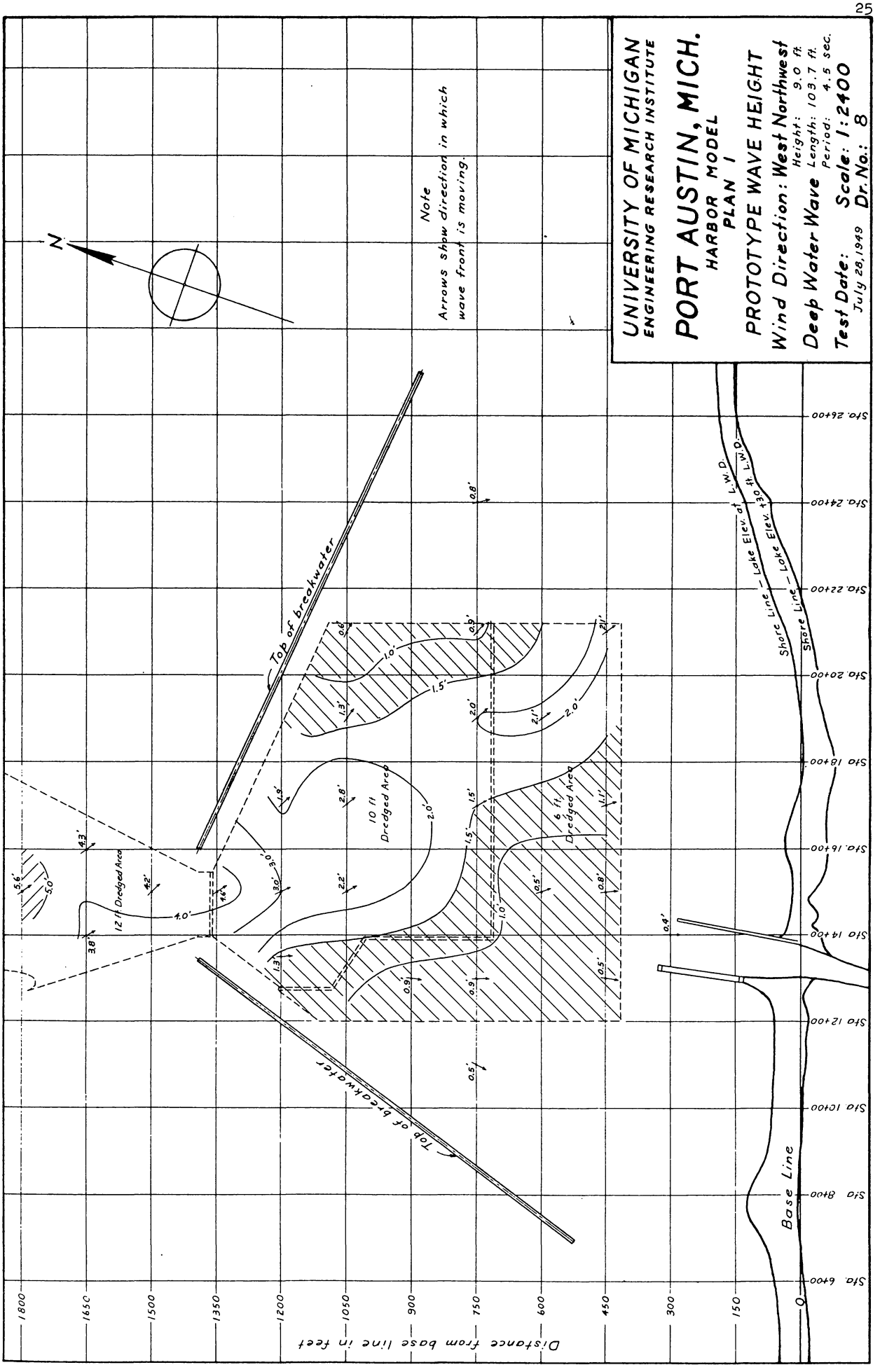
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 1
PROTOTYPE WAVE HEIGHT
Wind Direction: Northwest North
Deep Water Wave Height: 10.0 ft. Length: 113.1 ft. Period: 4.7 sec.
Test Date: July 26, 1949 Scale: 1:2400, Dr. No.: 6
Note
Arrows show direction in which wave front is moving.
N
Top of breakwater
Top of breakwater
10 ft. Dredged Area
6 ft. Dredged Area
12 ft. Dredged Area
Shore Line — Lake Elev. at L.W.D.
Shore Line — Lake Elev. +30 ft. L.W.D.
Base Line
Sta. 6+00
Sta. 8+00
Sta. 10+00
Sta. 12+00
Sta. 14+00
Sta. 16+00
Sta. 18+00
Sta. 20+00
Sta. 22+00
Sta. 24+00
Sta. 26+00
Distance from base line in feet
0
150
300
450
600
750
900
1050
1200
1350
1500
1651
1800

Drawing 6


UNIVERSITY OF MICHIGAN
ENGINEERING RESEARCH INSTITUTE
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 1
PROTOTYPE WAVE HEIGHT
Wind Direction: Northwest North
Deep Water Wave
Height: 4.5 ft.
Length: 81.9 ft.
Period: 4.0 sec.
Test Date: July 27, 1949
Scale: 1:2400
Dr. No.: 7
Note
Arrows show direction in which wave front is moving.
N
Top of breakwater
Top of breakwater
12 ft Dredged Area
10 ft Dredged Area
6 ft. Dredged Area
Shore Line – Lake Elev. at L.W.D.
Shore Line – Lake Elev. +30 ft. L.W.D.
Base Line
Sta. 6+00
Sta. 8+00
Sta 10+00
Sta 12+00
Sta 14+00
Sta 16+00
Sta 18+00
Sta. 20+00
Sta. 22+00
Sta. 24+00
Sta. 26+00
Distance from base line in feet
0
150
300
450
600
750
900
1050
1200
1350
1500
1650
1800

Drawing 7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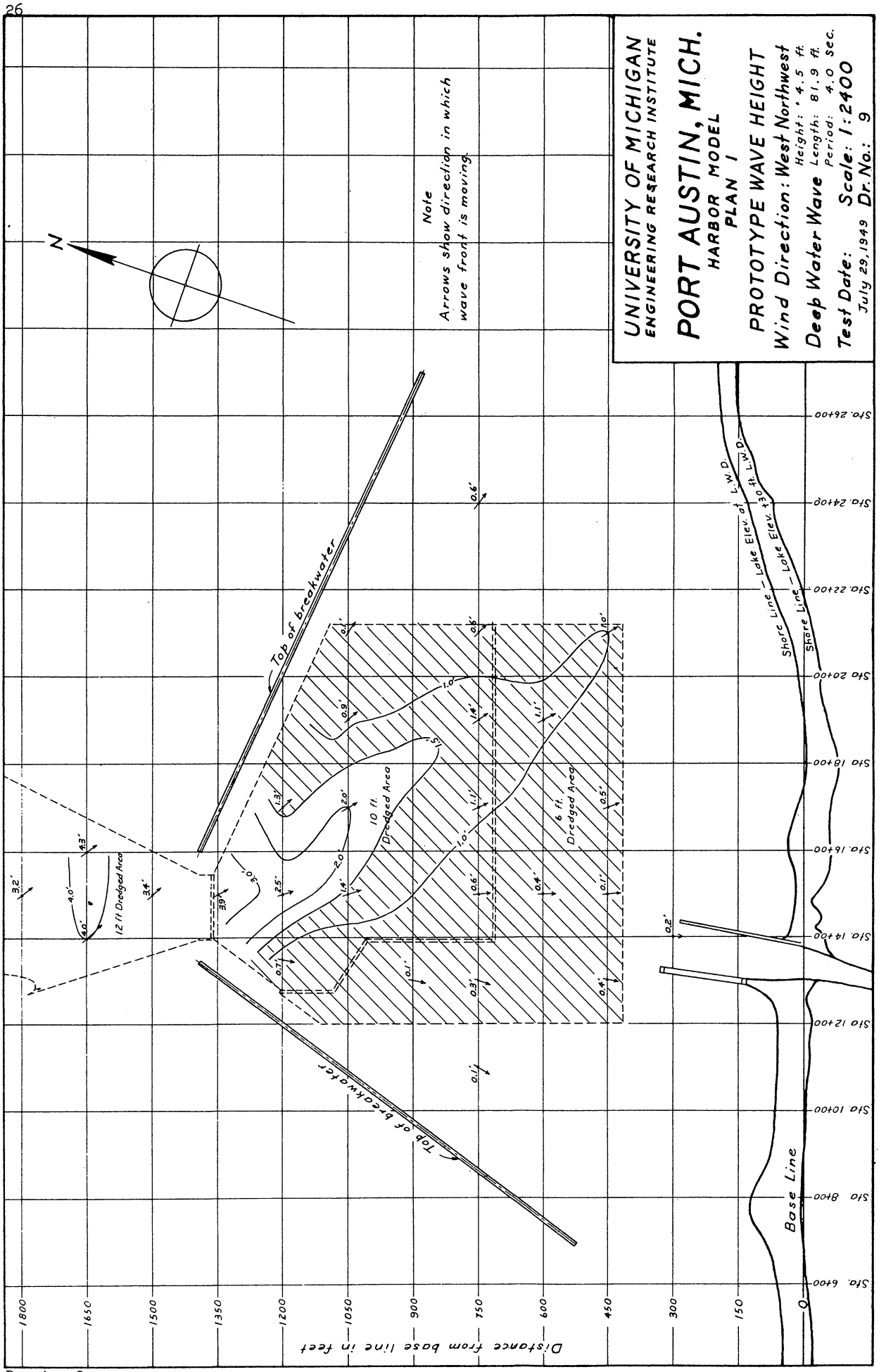
ENGINEERING RESEARCH INSTITUTE
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 1
PROTOTYPE WAVE HEIGHT
Wind Direction: West Northwest
Deep Water Wave Height: 9.0 ft. Length: 103.7 ft. Period: 4.5 sec.
Test Date: July 28, 1949 Scale: 1:2400 Dr. No.: 8
Note
Arrows show direction in which wave front is moving.
N
Top of breakwater
Top of breakwater
12 ft Dredged Area
10 ft Dredged Area
6 ft Dredged Area
Shore Line — Lake Elev. at L.W.D.
Shore Line — Lake Elev. +30 ft. L.W.D.
Base Line
Distance from base line in feet
Sta. 64+00
Sta. 8+00
Sta. 10+00
Sta. 12+00
Sta. 14+00
Sta. 16+00
Sta. 18+00
Sta. 20+00
Sta. 22+00
Sta. 24+00
Sta. 26+00
0
150
300
450
600
750
900
1050
1200
1350
1500
1650
1800

Drawing 8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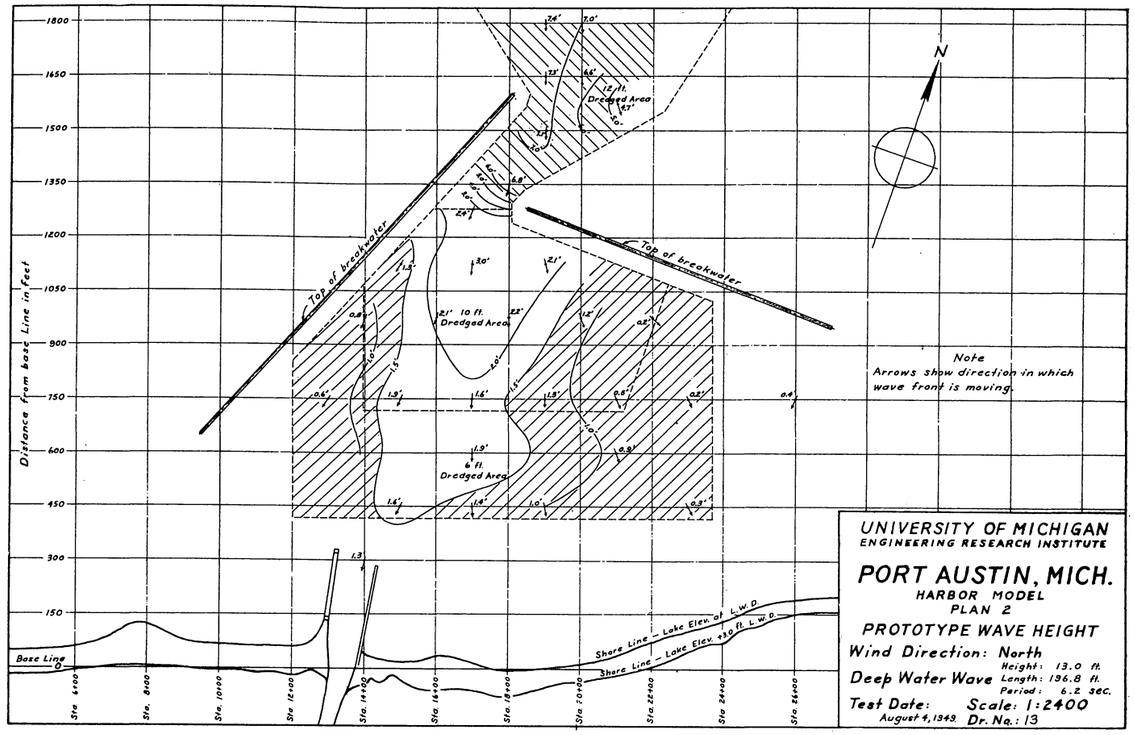
ENGINEERING RESEARCH INSTITUTE
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 1
PROTOTYPE WAVE HEIGHT
Wind Direction: West Northwest
Deep Water Wave Height: 4.5 ft. Length: 81.9 ft. Period: 4.0 sec.
Test Date: July 29, 1949 Scale: 1:2400 Dr. No.: 9
Note
Arrows show direction in which wave front is moving
N
Top of breakwater
Top of breakwater
10 ft. Dredged Area
6 ft. Dredged Area
12 ft Dredged Area
Shore Line — Lake Elev. at L.W.D.
Shore Line — Lake Elev. +30 ft. L.W.D.
Base Line
Sta. 6+00
Sta. 8+00
Sta. 10+00
Sta. 12+00
Sta. 14+00
Sta. 16+00
Sta. 18+00
Sta. 20+00
Sta. 22+00
Sta. 24+00
Sta. 26+00
Distance from base line in feet
0
150
300
450
600
750
900
1050
1200
1350
1500
1650
1800

Drawing 9



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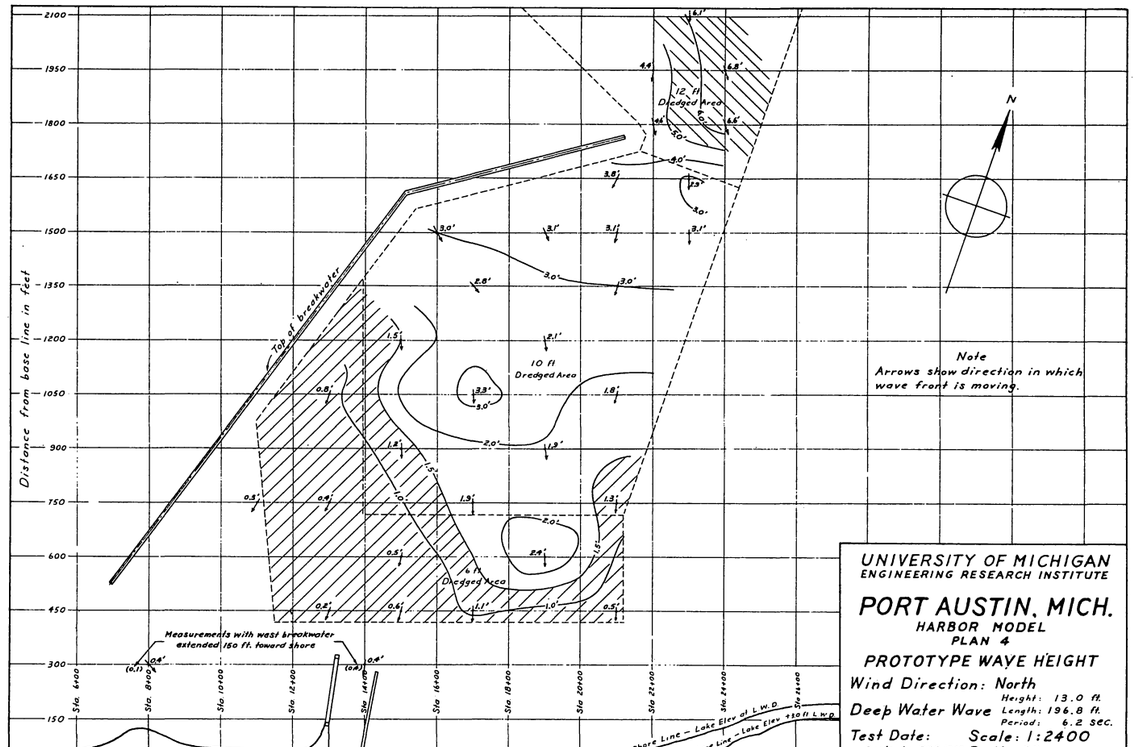
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 2

PROTOTYPE WAVE HEIGHT
Wind Direction: North
Deep Water Wave Height: 13.0 ft. Length: 196.8 ft. Period: 6.2 SEC.
Test Date: August 4, 1949 Scale: 1:2400 Dr. No.: 13



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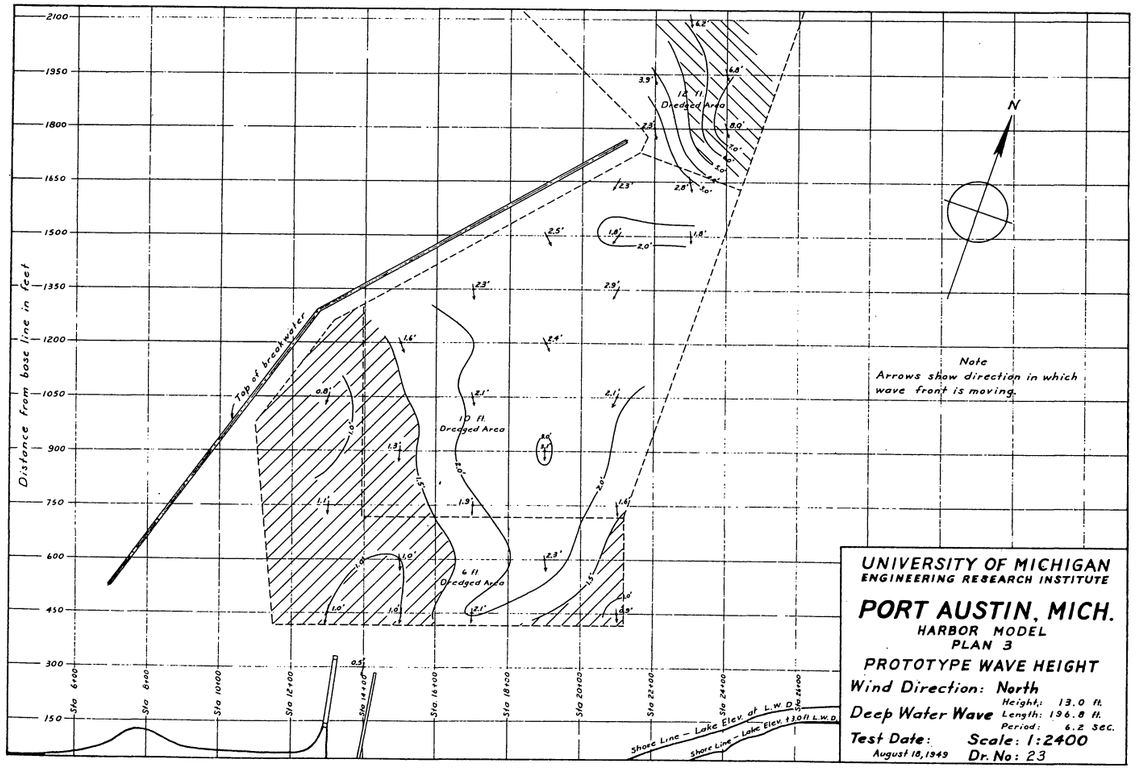
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 4

PROTOTYPE WAVE HEIGHT
Wind Direction: North
Deep Water Wave Height: 13.0 ft. Length: 196.8 ft. Period: 6.2 SEC.
Test Date: September 7&8, 1949 Scale: 1:2400 Dr. No.: 32



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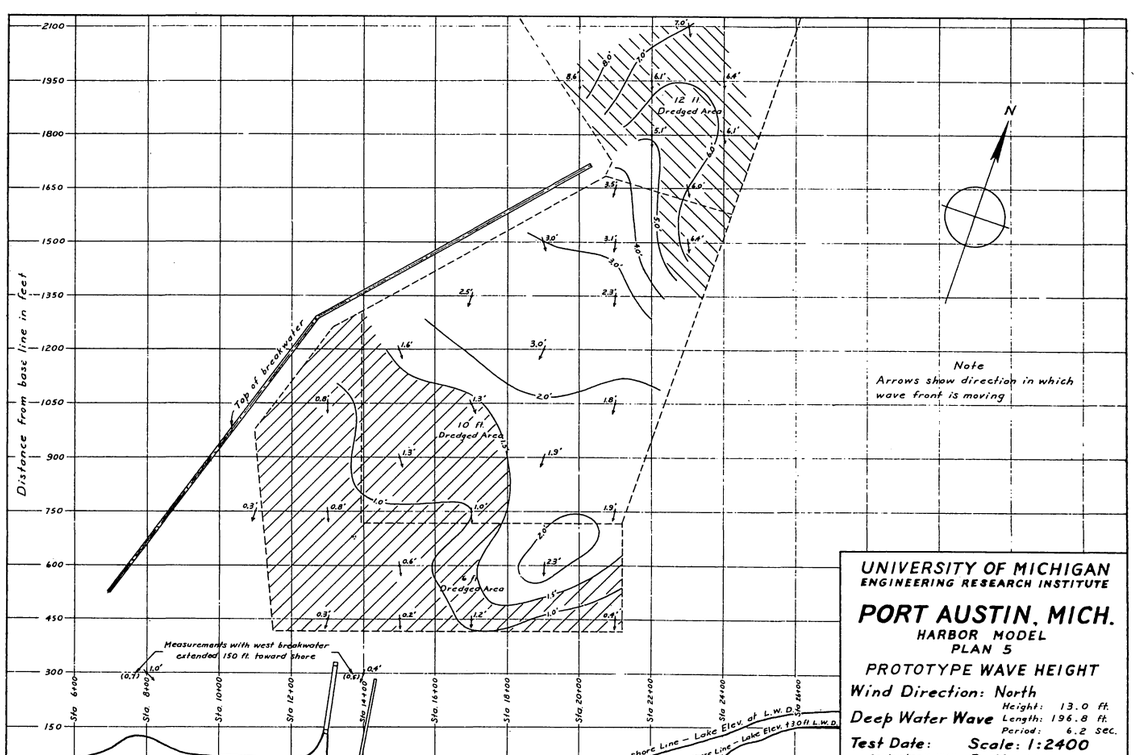
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 3

PROTOTYPE WAVE HEIGHT
Wind Direction: North
Deep Water Wave Height: 13.0 ft. Length: 196.8 ft. Period: 6.2 SEC.
Test Date: August 18, 1949 Scale: 1:2400 Dr. No: 23



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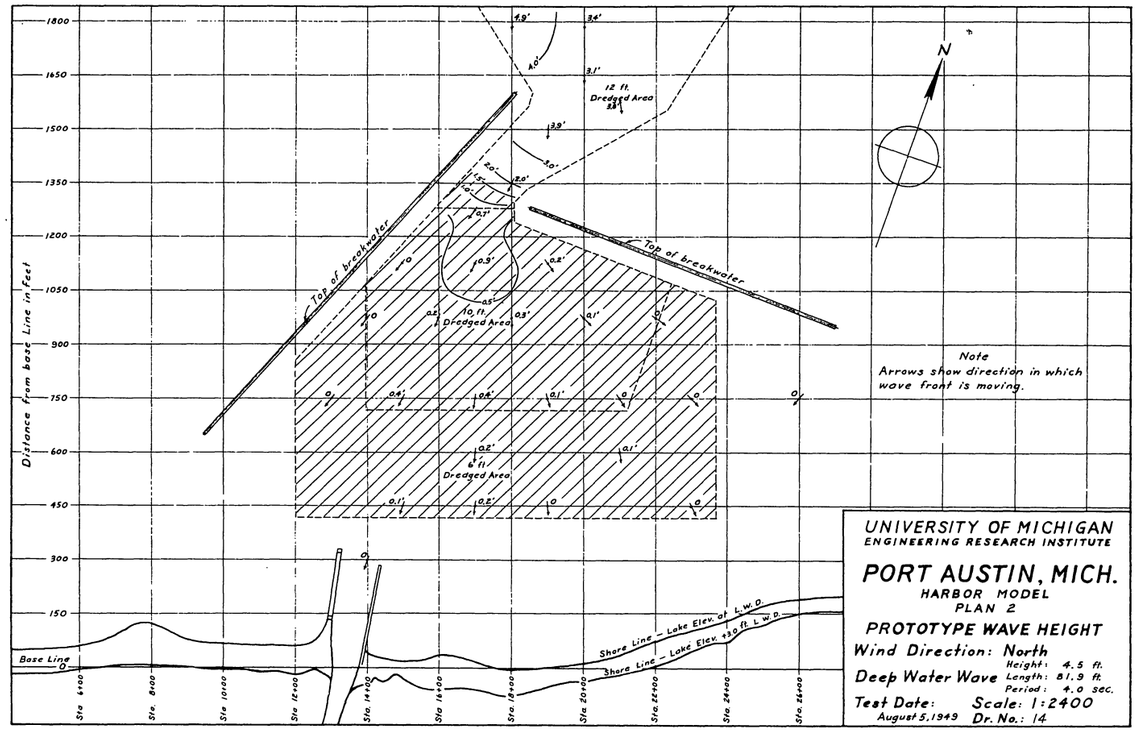
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 5

PROTOTYPE WAVE HEIGHT
Wind Direction: North
Deep Water Wave Height: 13.0 ft. Length: 196.8 ft. Period: 6.2 SEC.
Test Date: September 15, 1949 Scale: 1:2400 Dr. No: 41



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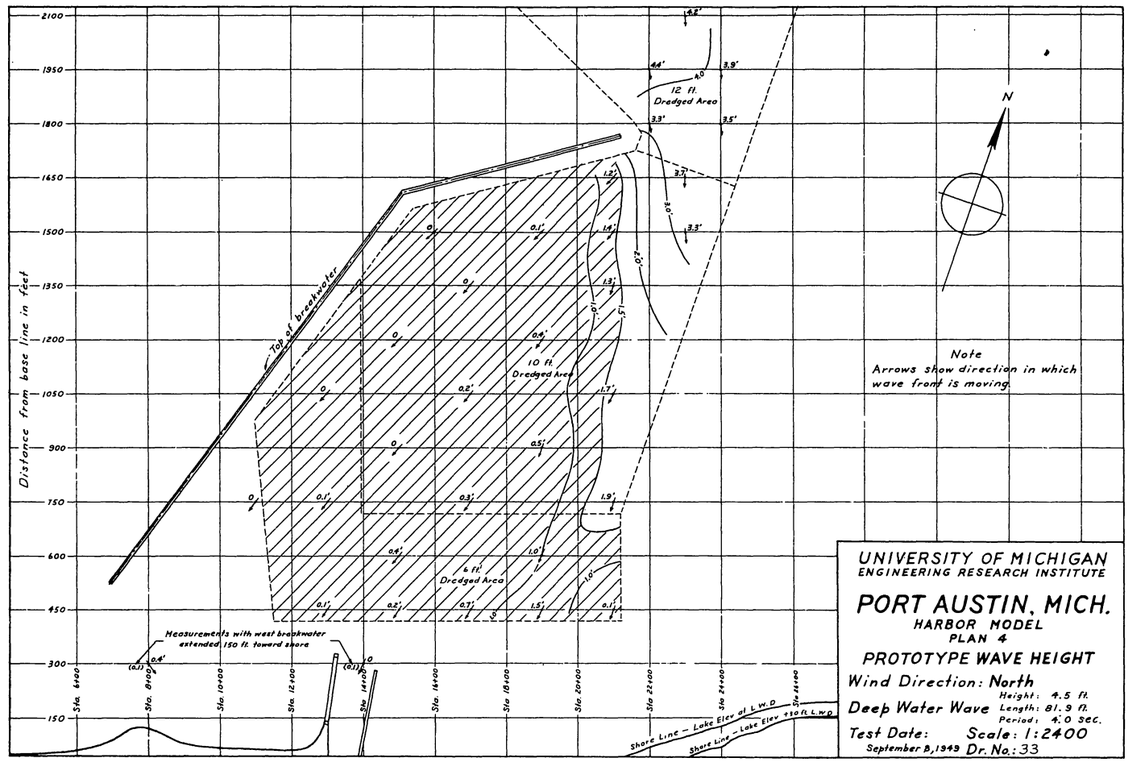
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 2

PROTOTYPE WAVE HEIGHT
Wind Direction: North
Deep Water Wave Height: 4.5 ft. Length: 81.9 ft. Period: 4.0 sec.
Test Date: August 5, 1949 Scale: 1:2400 Dr. No.: 14



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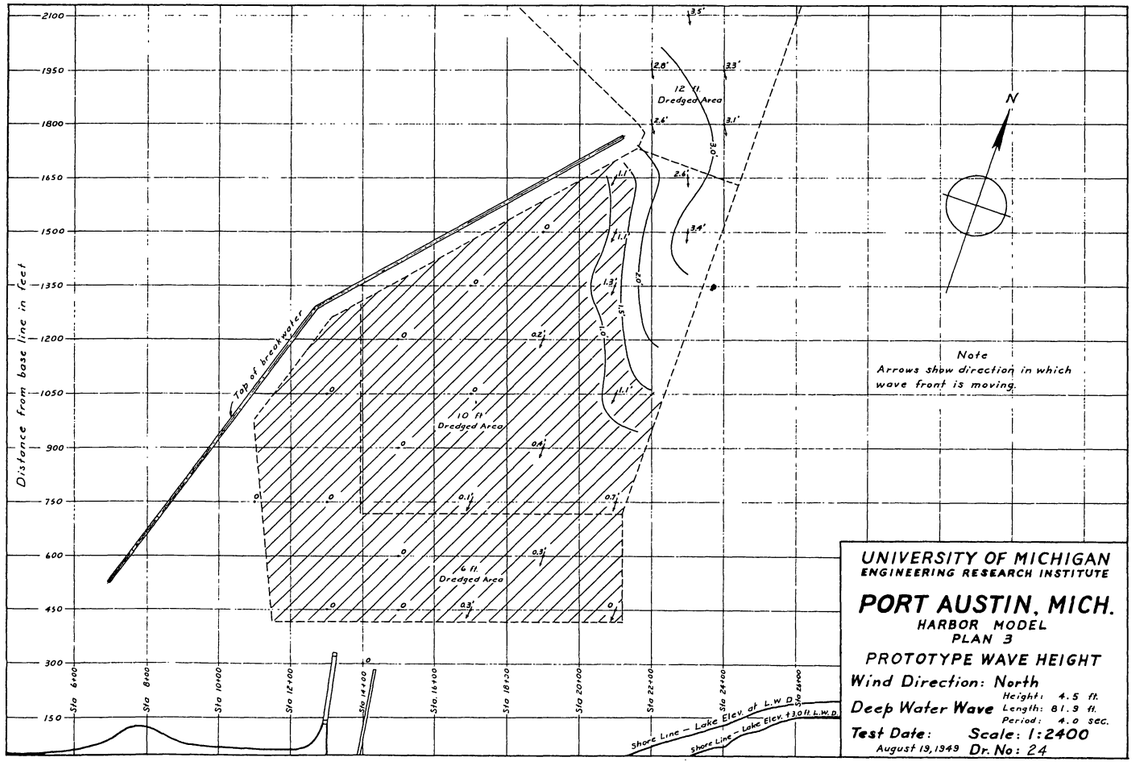
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 4

PROTOTYPE WAVE HEIGHT
Wind Direction: North
Deep Water Wave Height: 4.5 ft. Length: 81.9 ft. Period: 4.0 sec.
Test Date: September 8, 1949 Scale: 1:2400 Dr. No.: 33



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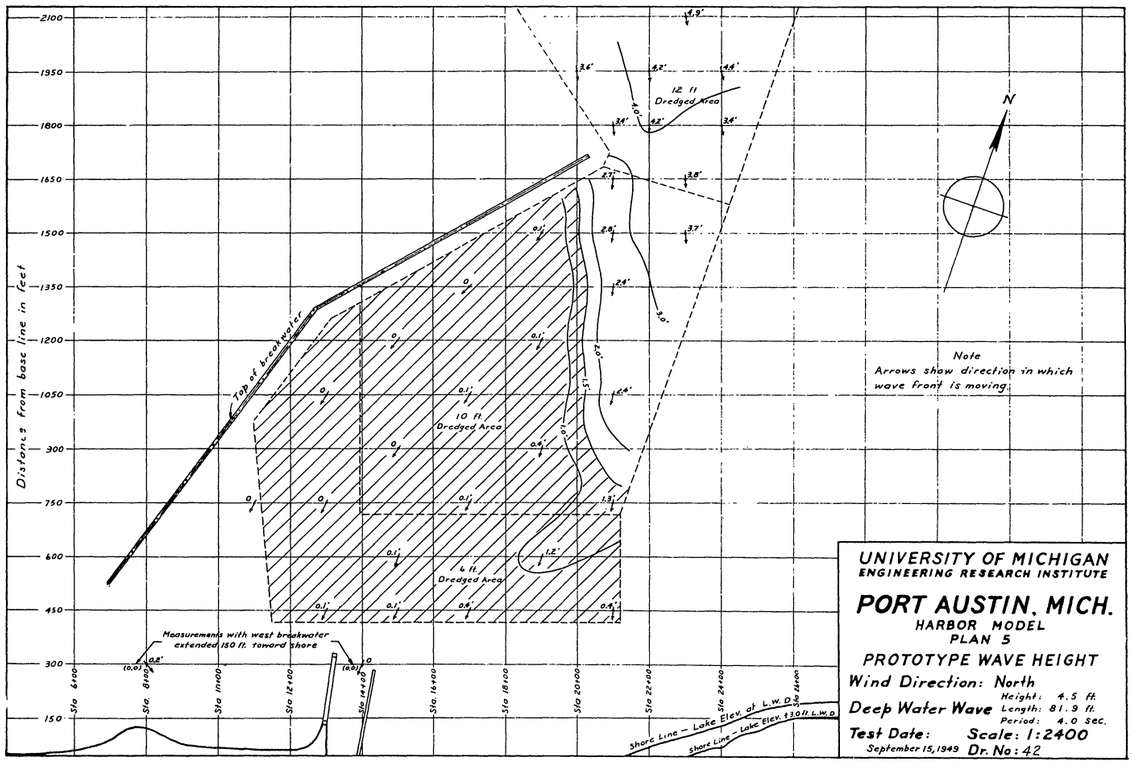
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 3

PROTOTYPE WAVE HEIGHT
Wind Direction: North
Deep Water Wave Height: 4.5 ft. Length: 81.9 ft. Period: 4.0 sec.
Test Date: August 13, 1949 Scale: 1:2400 Dr. No.: 24



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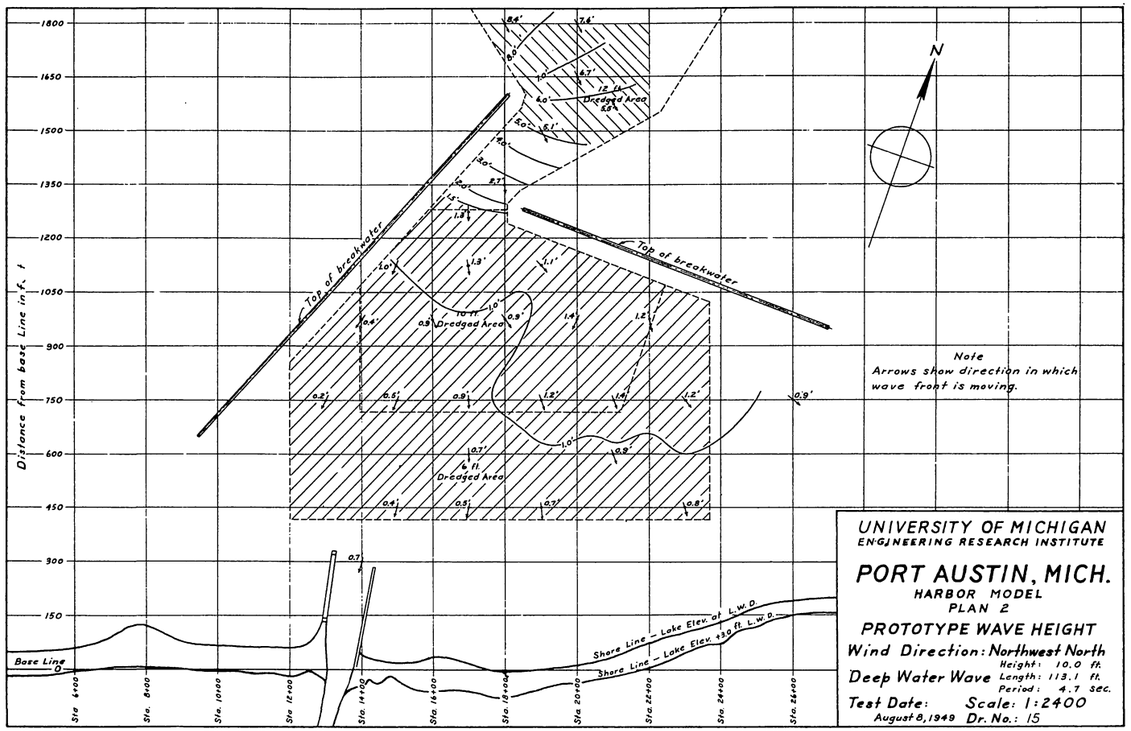
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 5

PROTOTYPE WAVE HEIGHT
Wind Direction: North
Deep Water Wave Height: 4.5 ft. Length: 81.9 ft. Period: 4.0 sec.
Test Date: September 15, 1949 Scale: 1:2400 Dr. No.: 42



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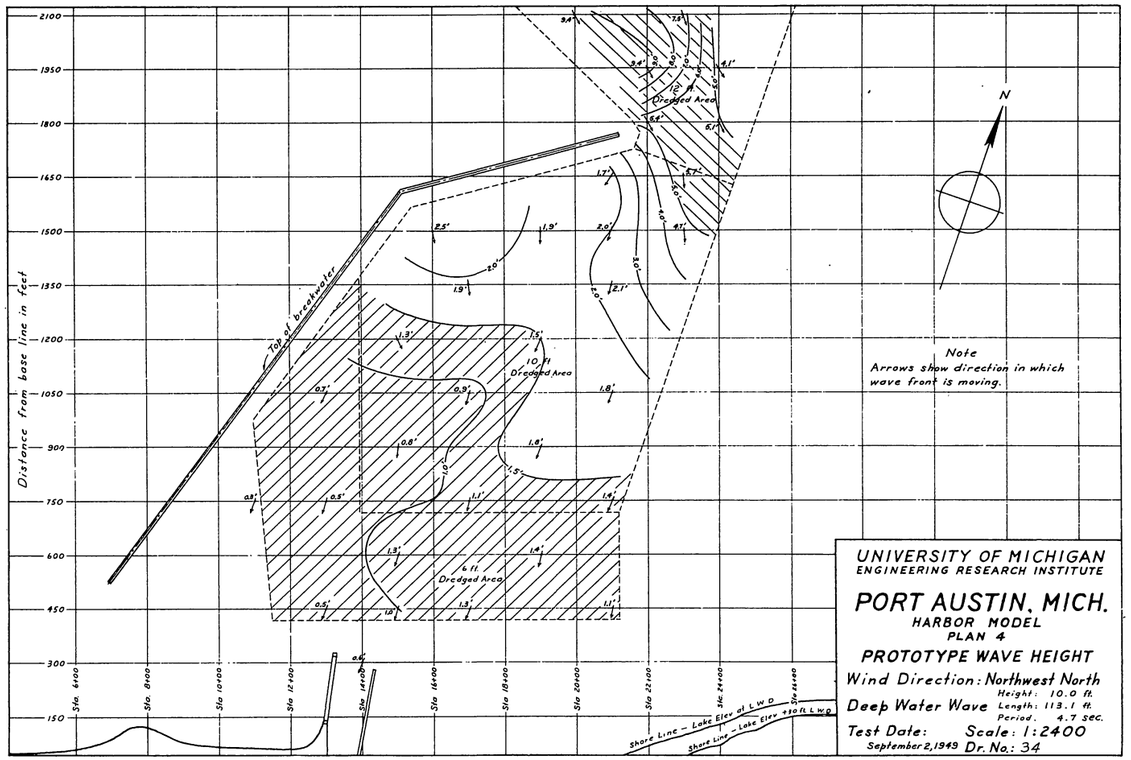
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 2

PROTOTYPE WAVE HEIGHT
Wind Direction: Northwest North
Deep Water Wave Height: 10.0 ft. Length: 113.1 ft. Period: 4.7 sec.
Test Date: August 8, 1949 Scale: 1:2400 Dr. No.: 15



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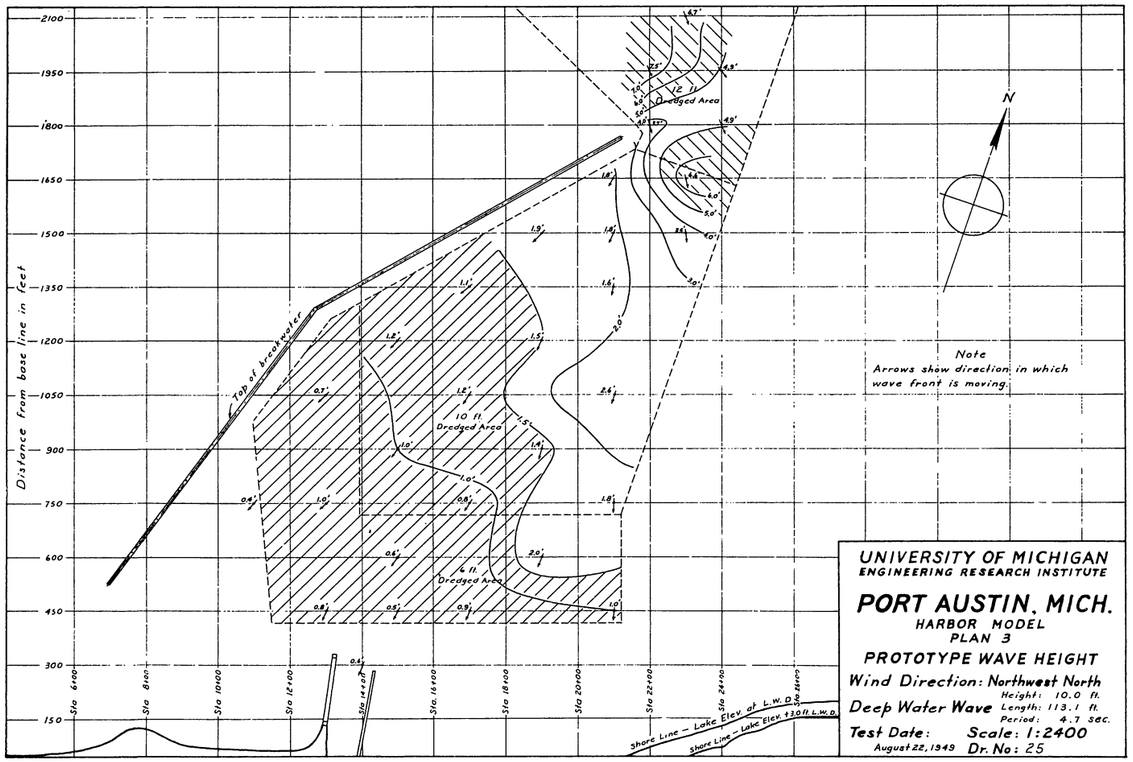
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 4

PROTOTYPE WAVE HEIGHT
Wind Direction: Northwest North
Deep Water Wave Height: 10.0 ft. Length: 113.1 ft. Period: 4.7 sec.
Test Date: September 2, 1949 Scale: 1:2400 Dr. No.: 34



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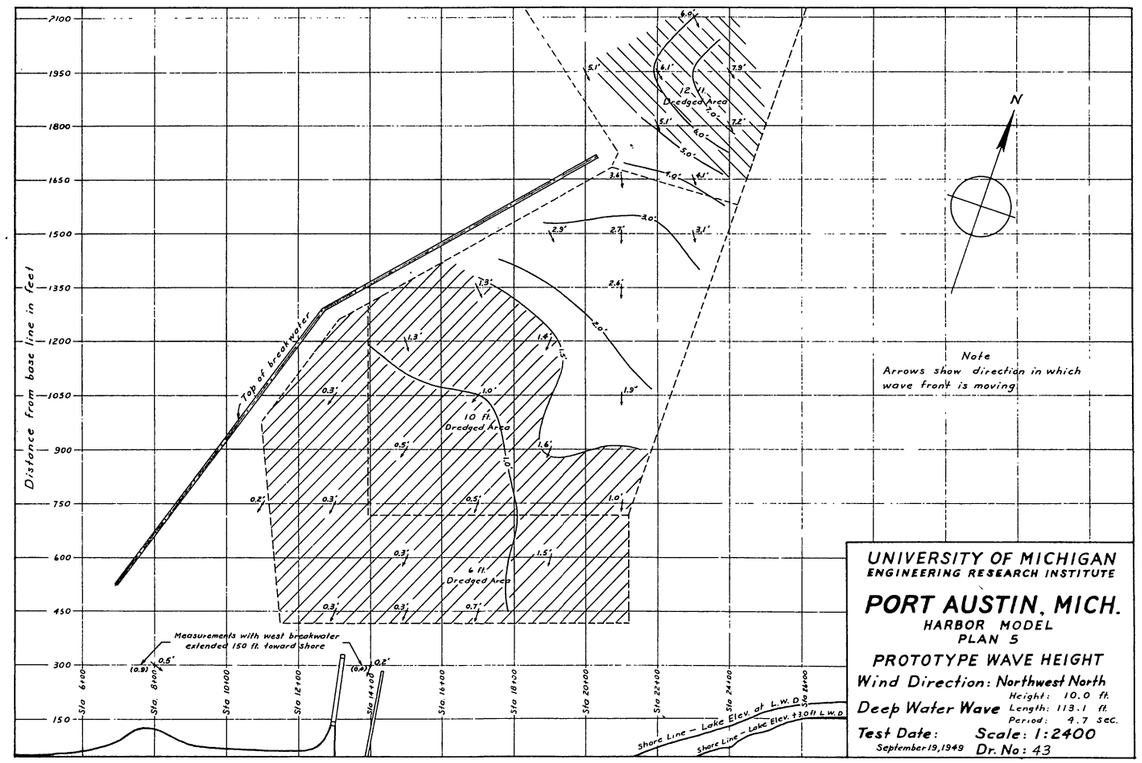
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 3

PROTOTYPE WAVE HEIGHT
Wind Direction: Northwest North
Deep Water Wave Height: 10.0 ft. Length: 113.1 ft. Period: 4.7 sec.
Test Date: August 22, 1949 Scale: 1:2400 Dr. No: 25



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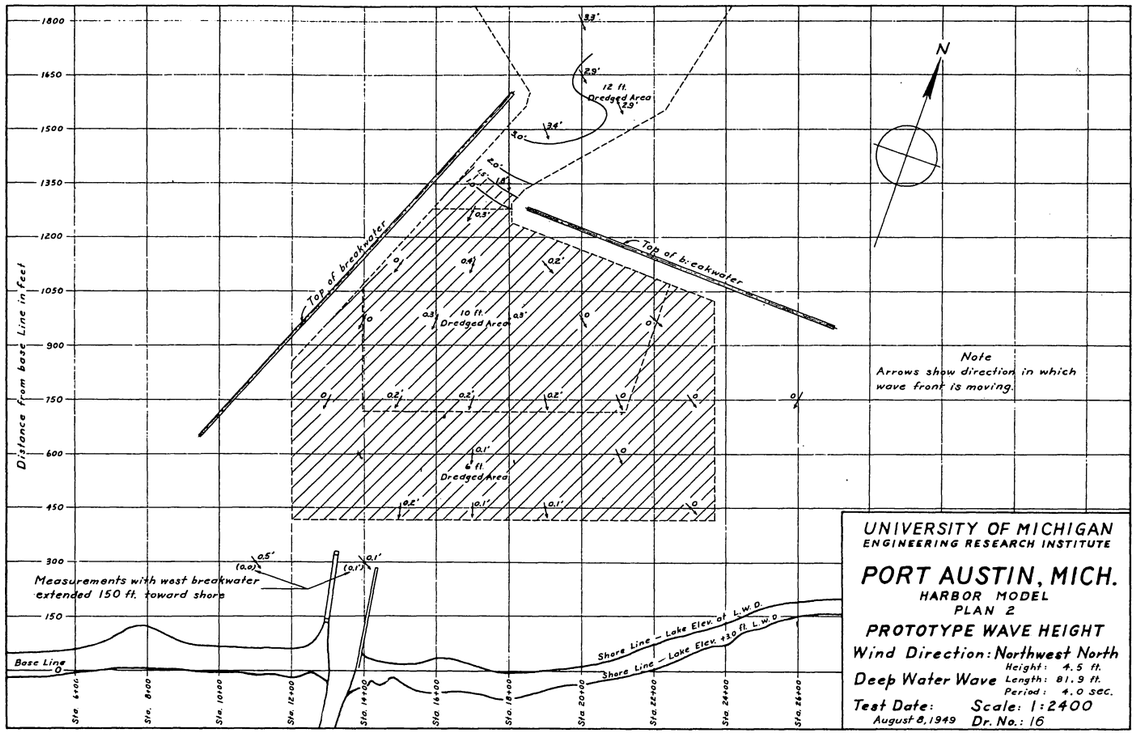
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 5

PROTOTYPE WAVE HEIGHT
Wind Direction: Northwest North
Deep Water Wave Height: 10.0 ft. Length: 113.1 ft. Period: 4.7 sec.
Test Date: September 19, 1949 Scale: 1:2400 Dr. No: 43



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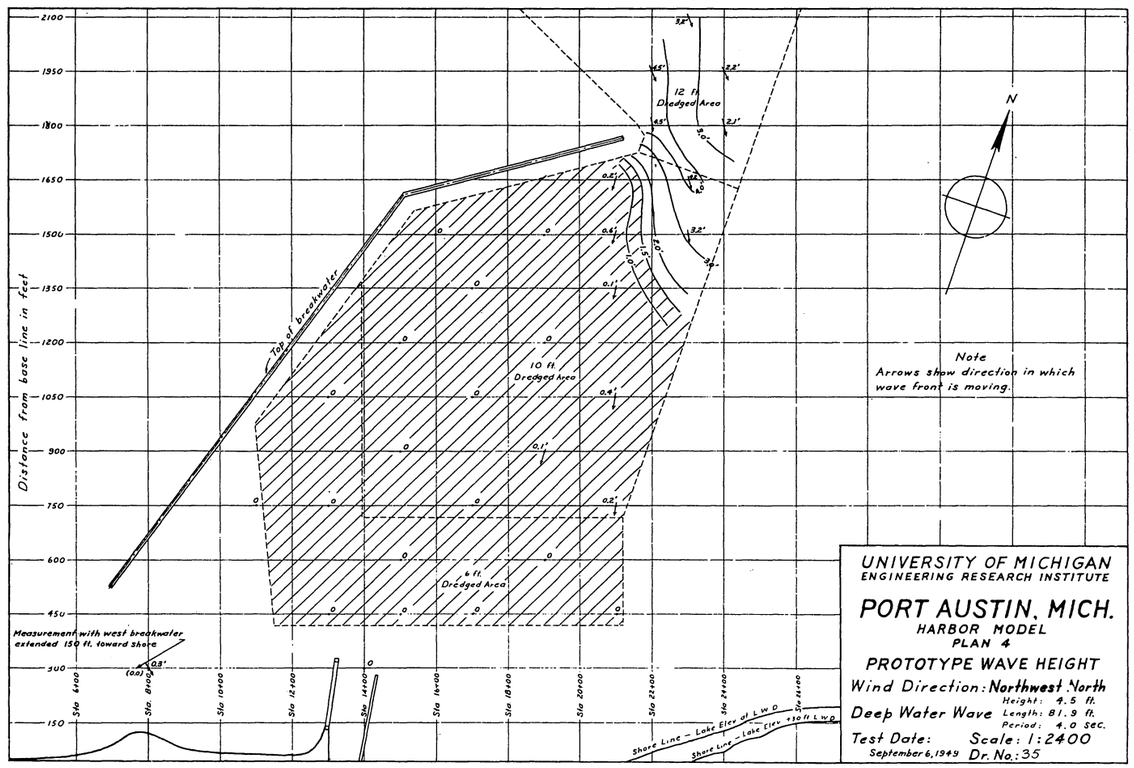
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 2

PROTOTYPE WAVE HEIGHT
Wind Direction: Northwest North
Deep Water Wave Height: 4.5 ft. Length: 81.9 ft. Period: 4.0 sec.
Test Date: August 8, 1949 Scale: 1:2400 Dr. No.: 16



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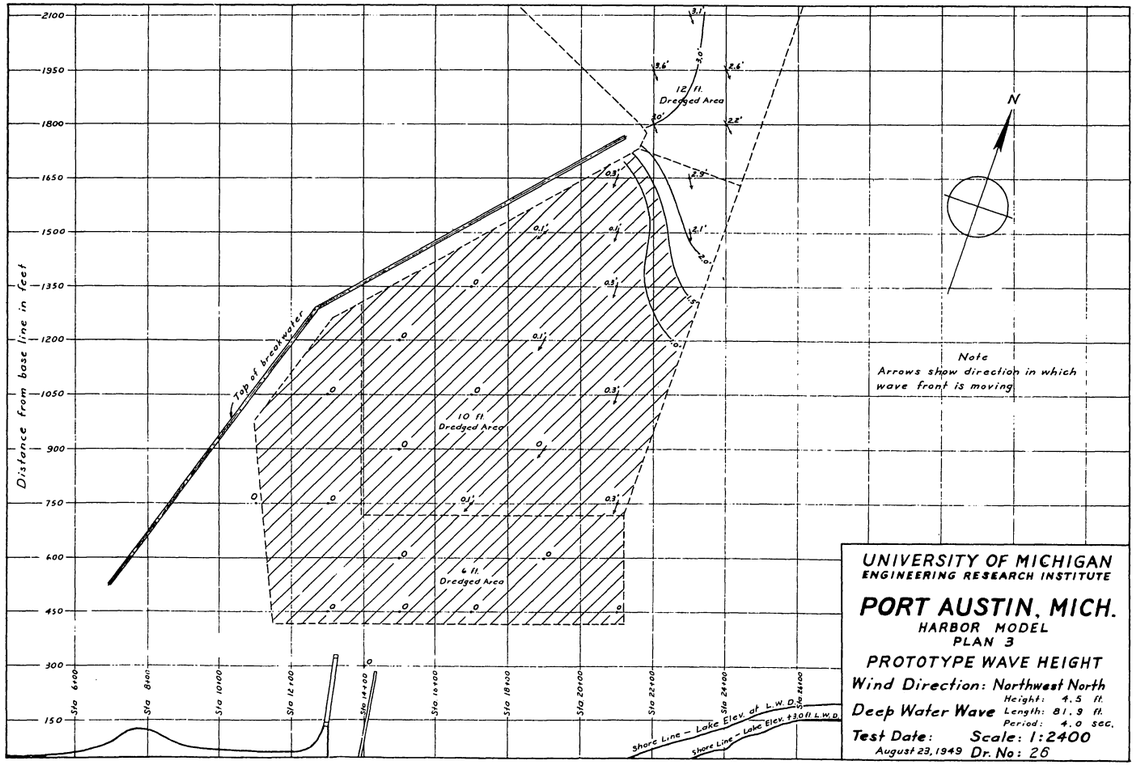
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 4

PROTOTYPE WAVE HEIGHT
Wind Direction: Northwest North
Deep Water Wave Height: 4.5 ft. Length: 81.9 ft. Period: 4.0 sec.
Test Date: September 6, 1949 Scale: 1:2400 Dr. No.: 35



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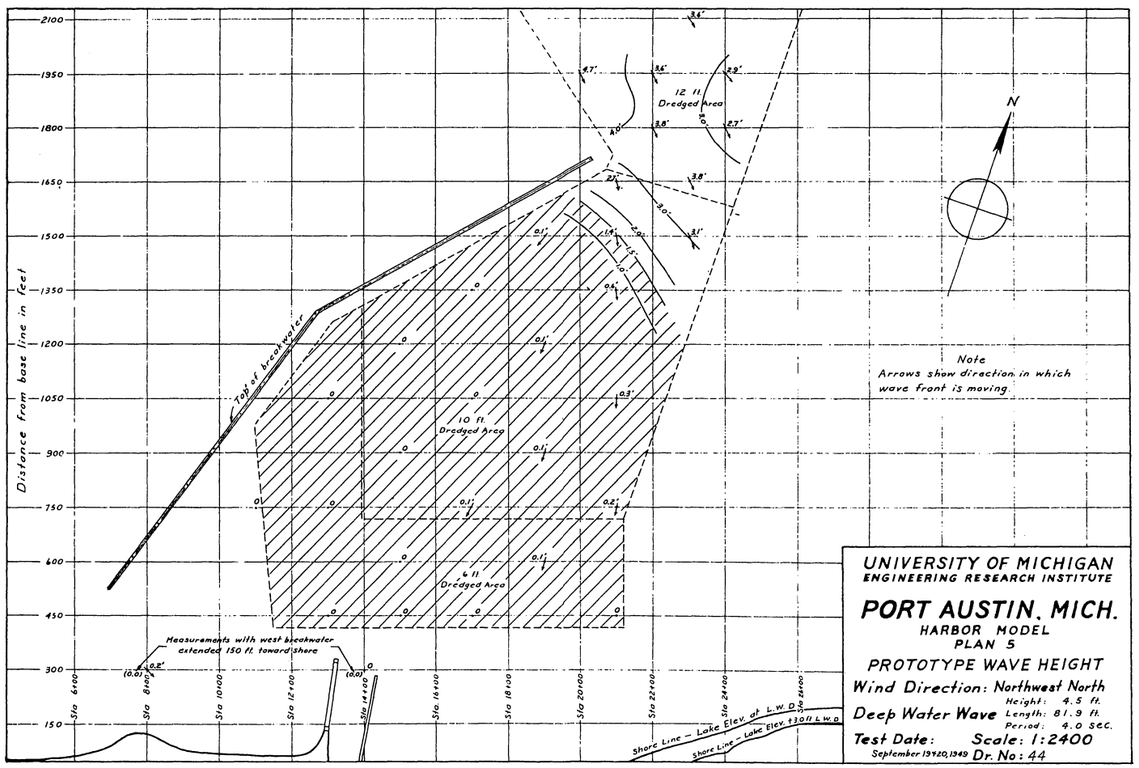
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 3

PROTOTYPE WAVE HEIGHT
Wind Direction: Northwest North
Deep Water Wave Height: 4.5 ft. Length: 81.9 ft. Period: 4.0 sec.
Test Date: August 23, 1949 Scale: 1:2400 Dr. No: 26



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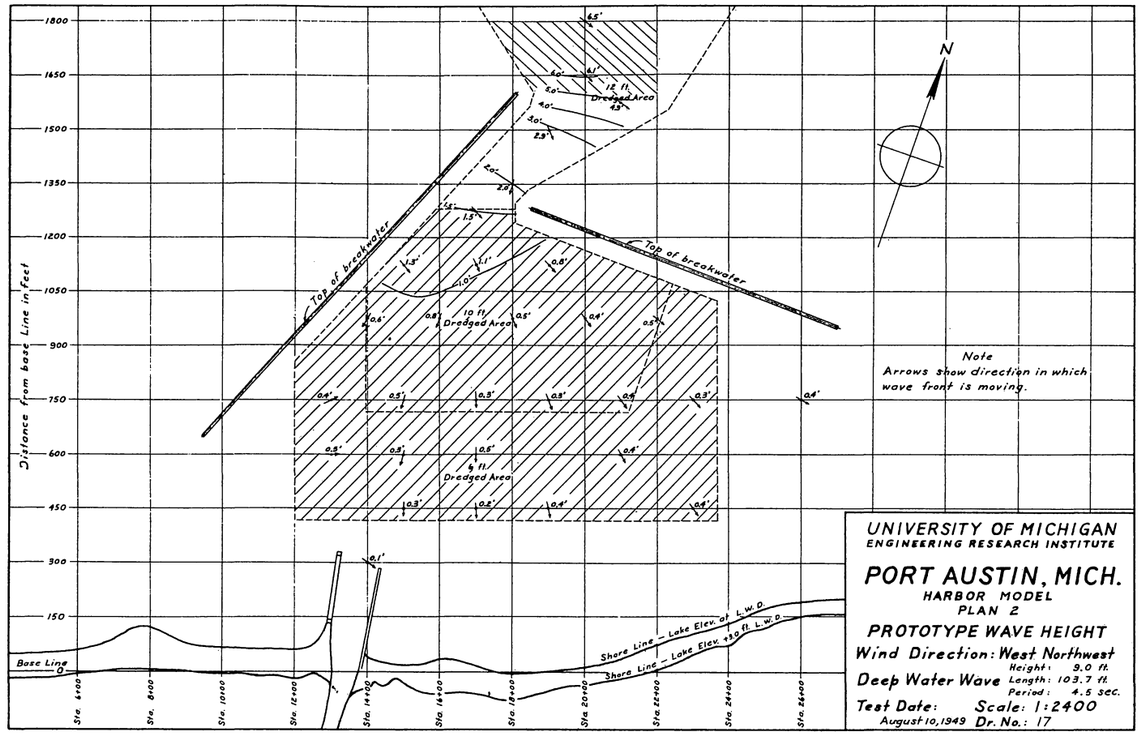
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 5

PROTOTYPE WAVE HEIGHT
Wind Direction: Northwest North
Deep Water Wave Height: 4.5 ft. Length: 81.9 ft. Period: 4.0 sec.
Test Date: September 13 & 20, 1949 Scale: 1:2400 Dr. No: 44



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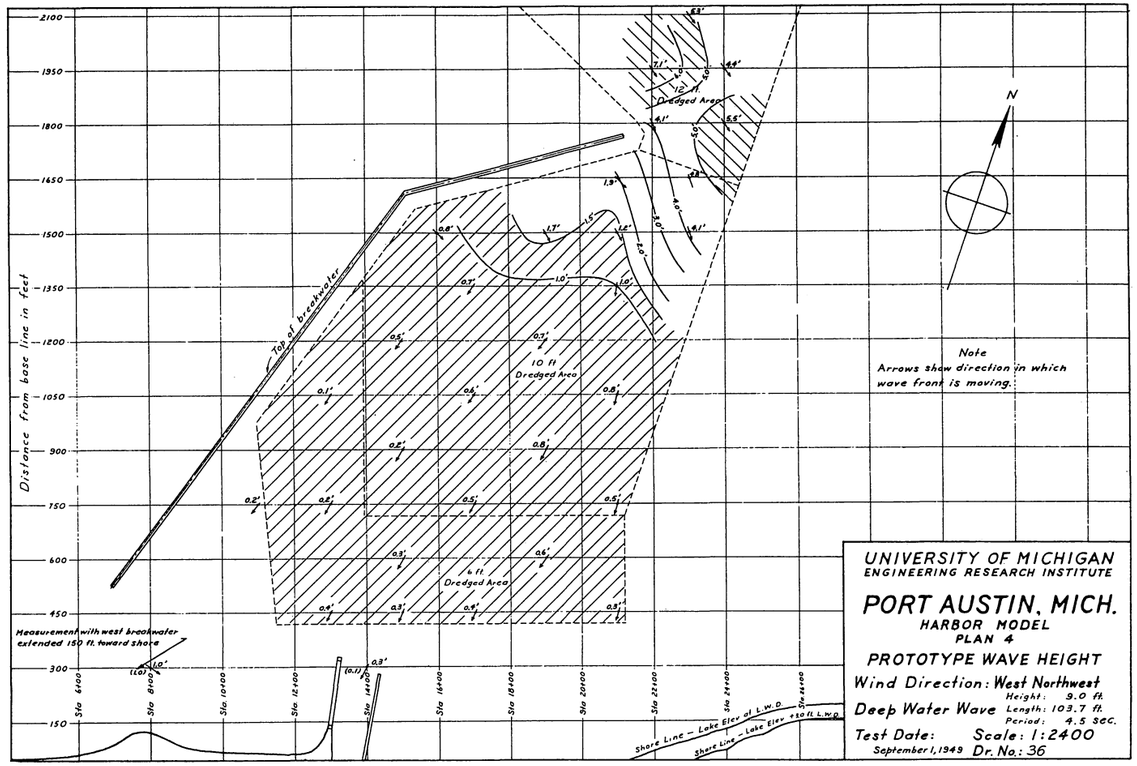
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 2

PROTOTYPE WAVE HEIGHT
Wind Direction: West Northwest
Deep Water Wave Height: 9.0 ft. Length: 103.7 ft. Period: 4.5 SEC.
Test Date: August 10, 1949 Scale: 1:2400 Dr. No.: 17



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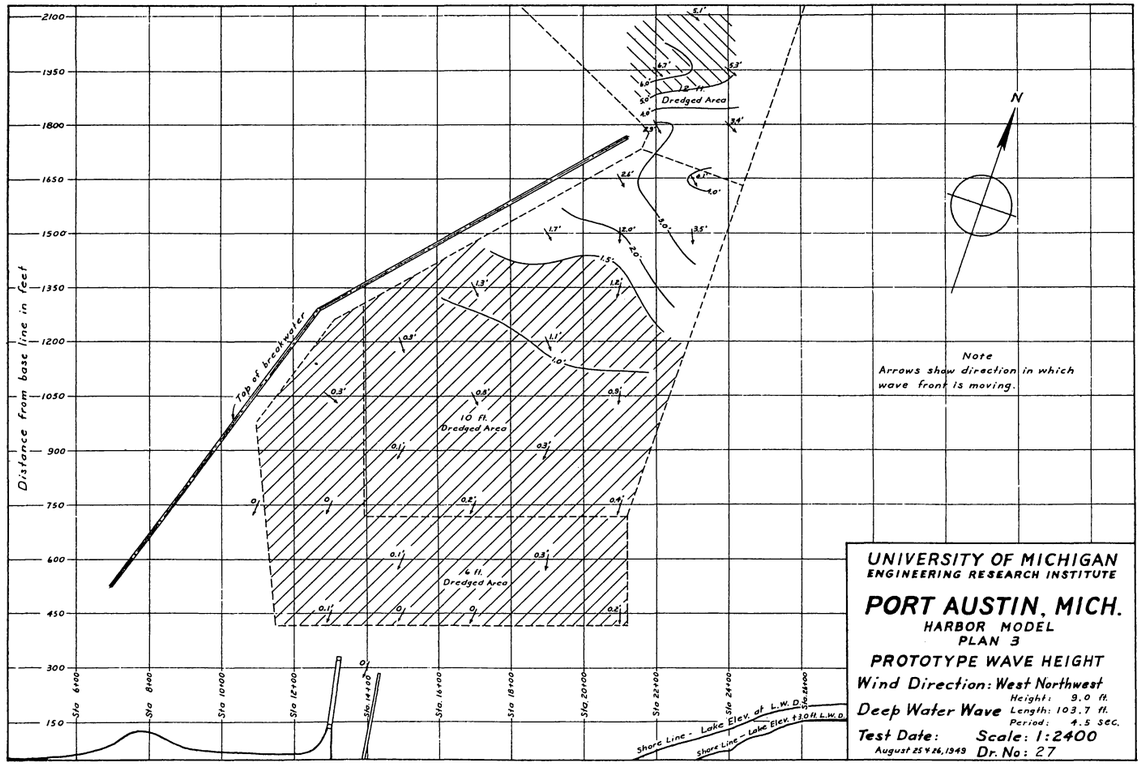
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 4

PROTOTYPE WAVE HEIGHT
Wind Direction: West Northwest
Deep Water Wave Height: 9.0 ft. Length: 103.7 ft. Period: 4.5 SEC.
Test Date: September 1, 1949 Scale: 1:2400 Dr. No.: 36



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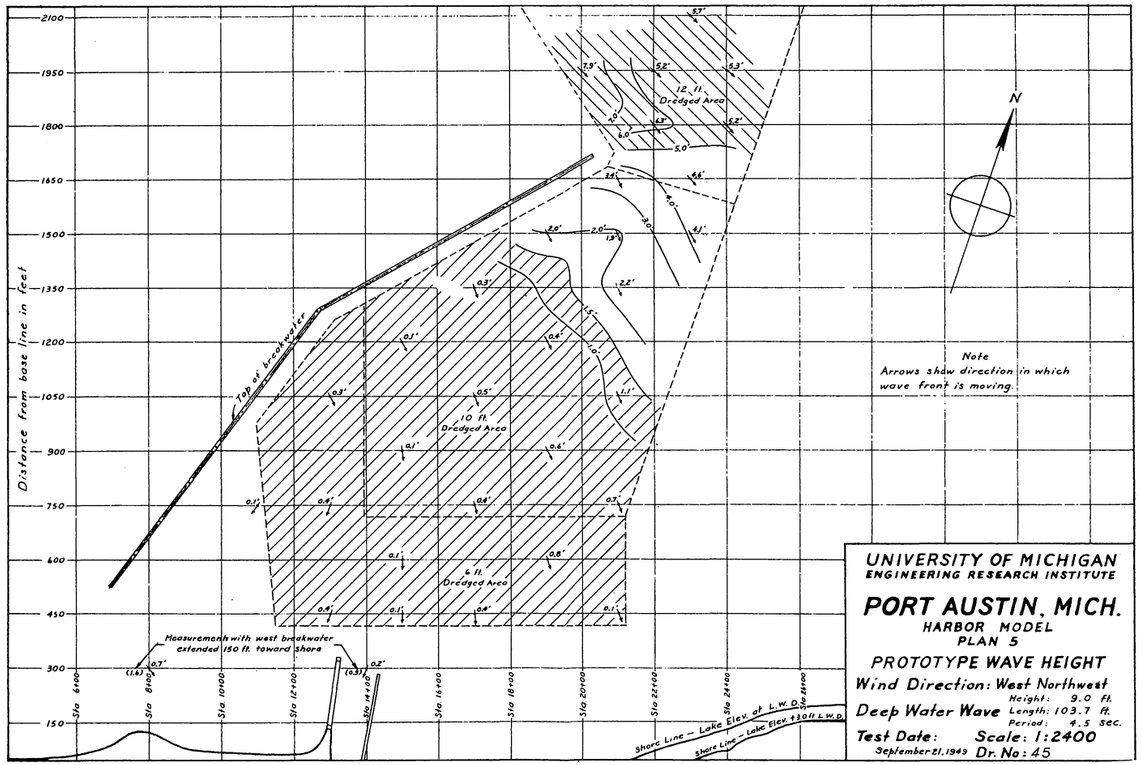
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 3

PROTOTYPE WAVE HEIGHT
Wind Direction: West Northwest
Deep Water Wave Height: 9.0 ft. Length: 103.7 ft. Period: 4.5 SEC.
Test Date: August 25 & 26, 1949 Scale: 1:2400 Dr. No: 27



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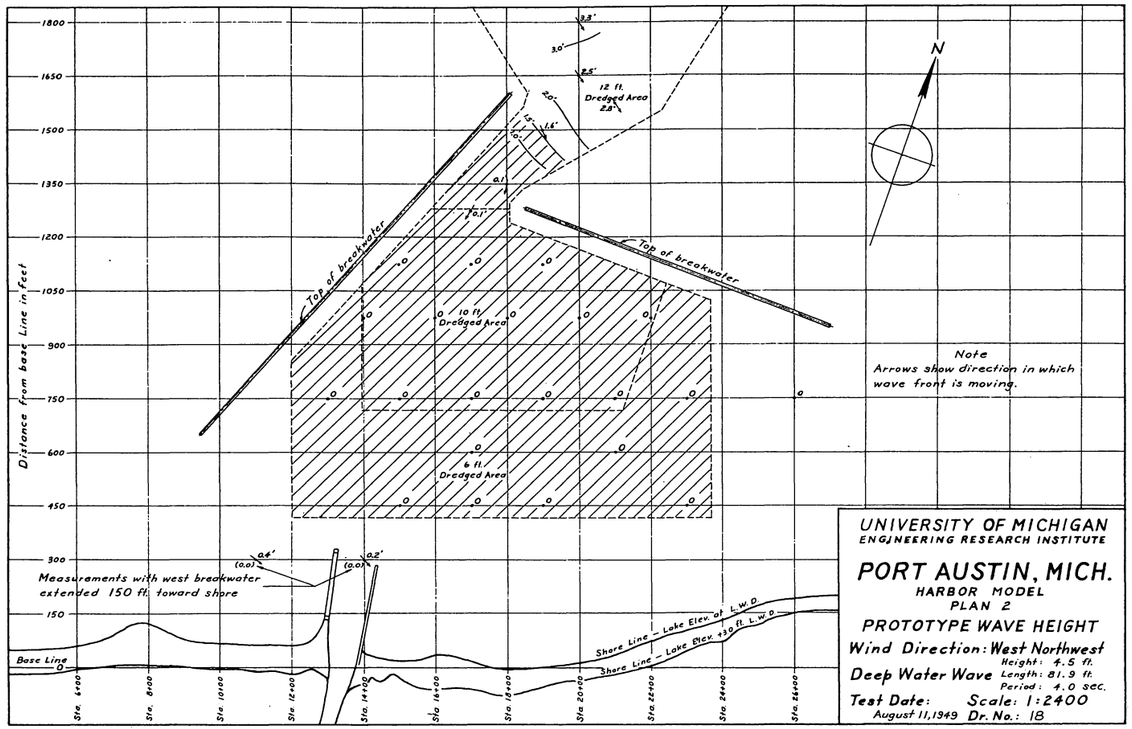
ENGINEERING RESEARCH INSTITUTE

PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 5

PROTOTYPE WAVE HEIGHT
Wind Direction: West Northwest
Deep Water Wave Height: 9.0 ft. Length: 103.7 ft. Period: 4.5 SEC.
Test Date: September 21, 1949 Scale: 1:2400 Dr. No: 45



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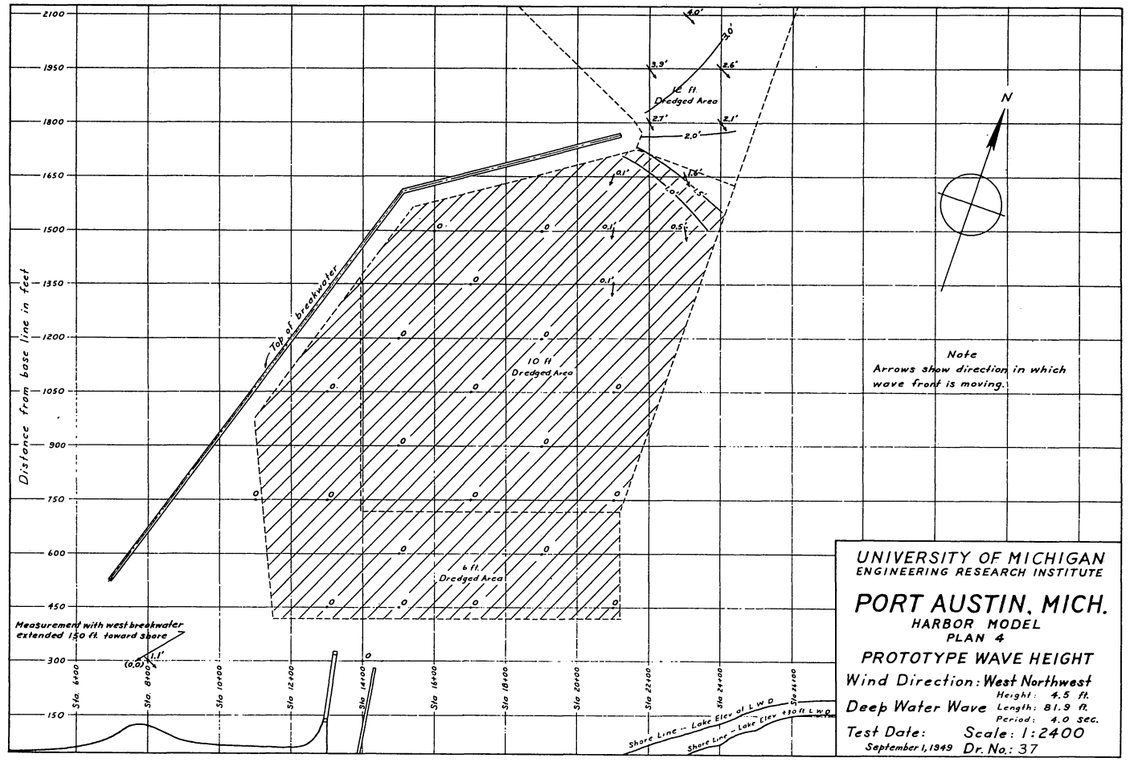
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 2

PROTOTYPE WAVE HEIGHT
Wind Direction: West Northwest
Deep Water Wave Height: 4.5 ft. Length: 81.9 ft. Period: 4.0 sec.
Test Date: August 11, 1949 Scale: 1:2400 Dr. No.: 18



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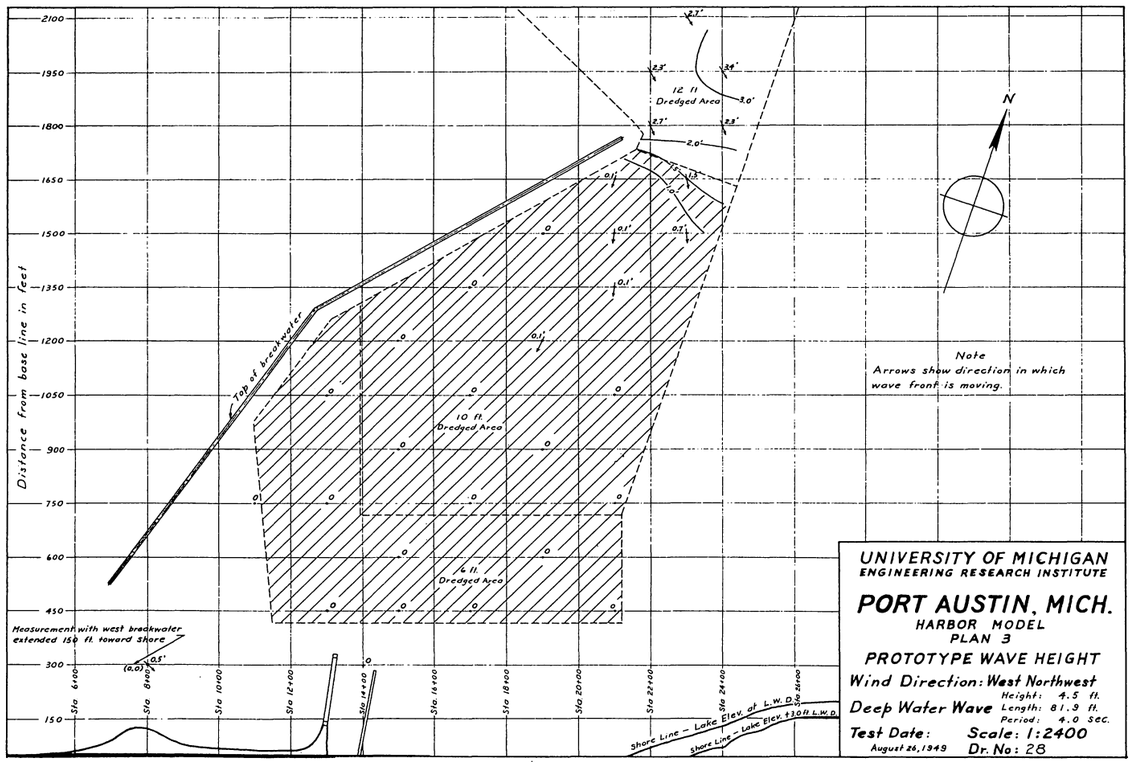
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 4

PROTOTYPE WAVE HEIGHT
Wind Direction: West Northwest
Deep Water Wave Height: 4.5 ft. Length: 81.9 ft. Period: 4.0 sec.
Test Date: September 1, 1949 Scale: 1:2400 Dr. No.: 37



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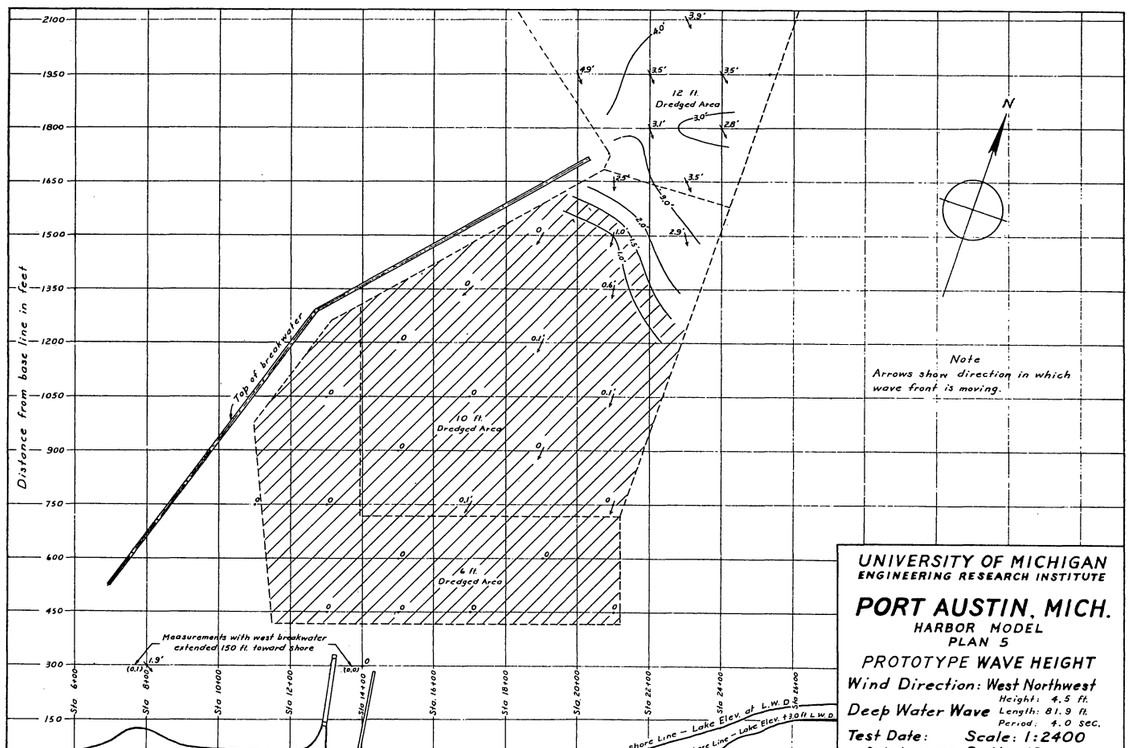
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 3

PROTOTYPE WAVE HEIGHT
Wind Direction: West Northwest
Deep Water Wave Height: 4.5 ft. Length: 81.9 ft. Period: 4.0 sec.
Test Date: August 26, 1949 Scale: 1:2400 Dr. No: 28



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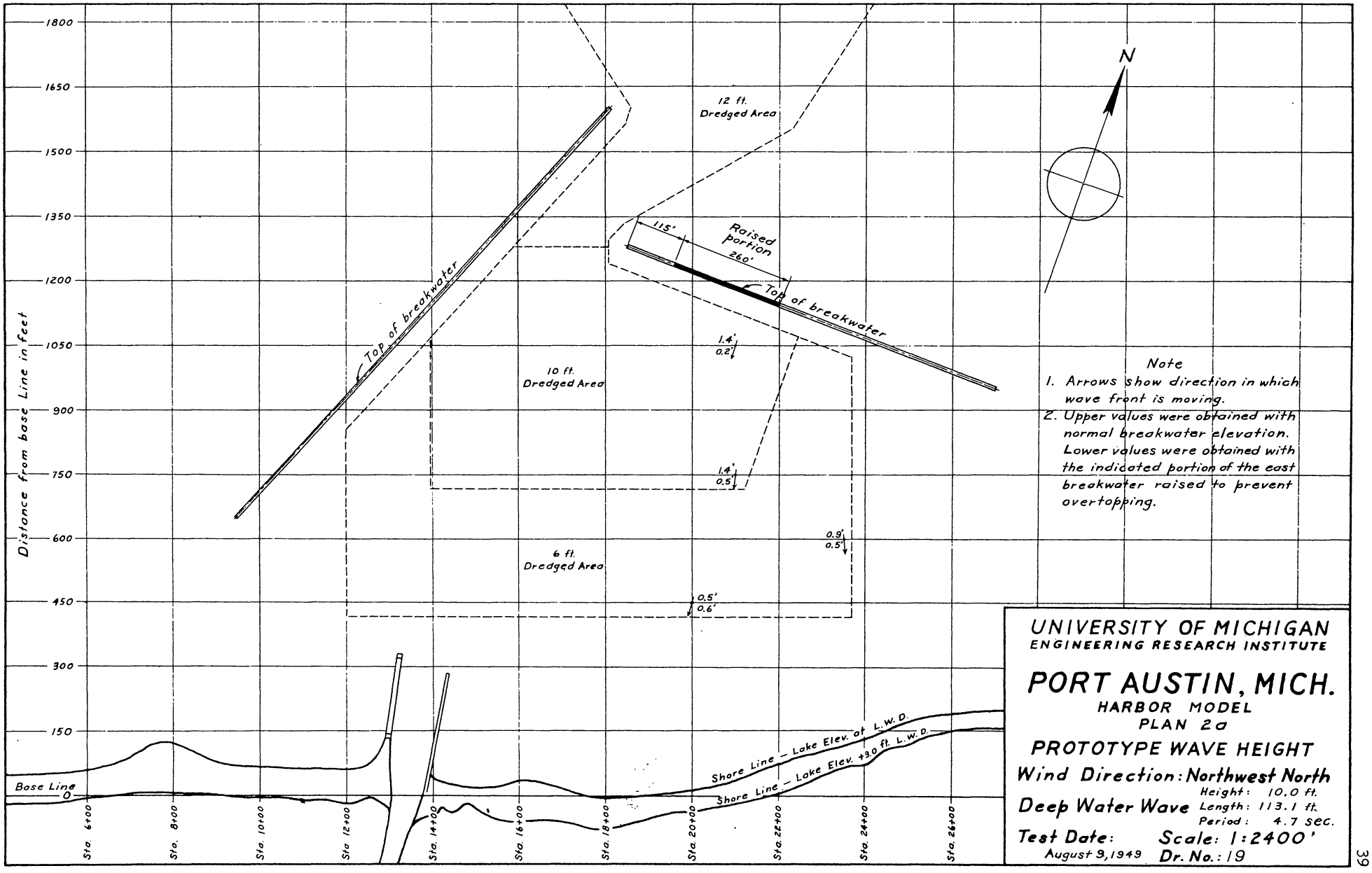
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 5

PROTOTYPE WAVE HEIGHT
Wind Direction: West Northwest
Deep Water Wave Height: 4.5 ft. Length: 81.9 ft. Period: 4.0 sec.
Test Date: September 20, 1949 Scale: 1:2400 Dr. No: 46



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PORT AUSTIN, MICH.

HARBOR MODEL
PLAN 2a

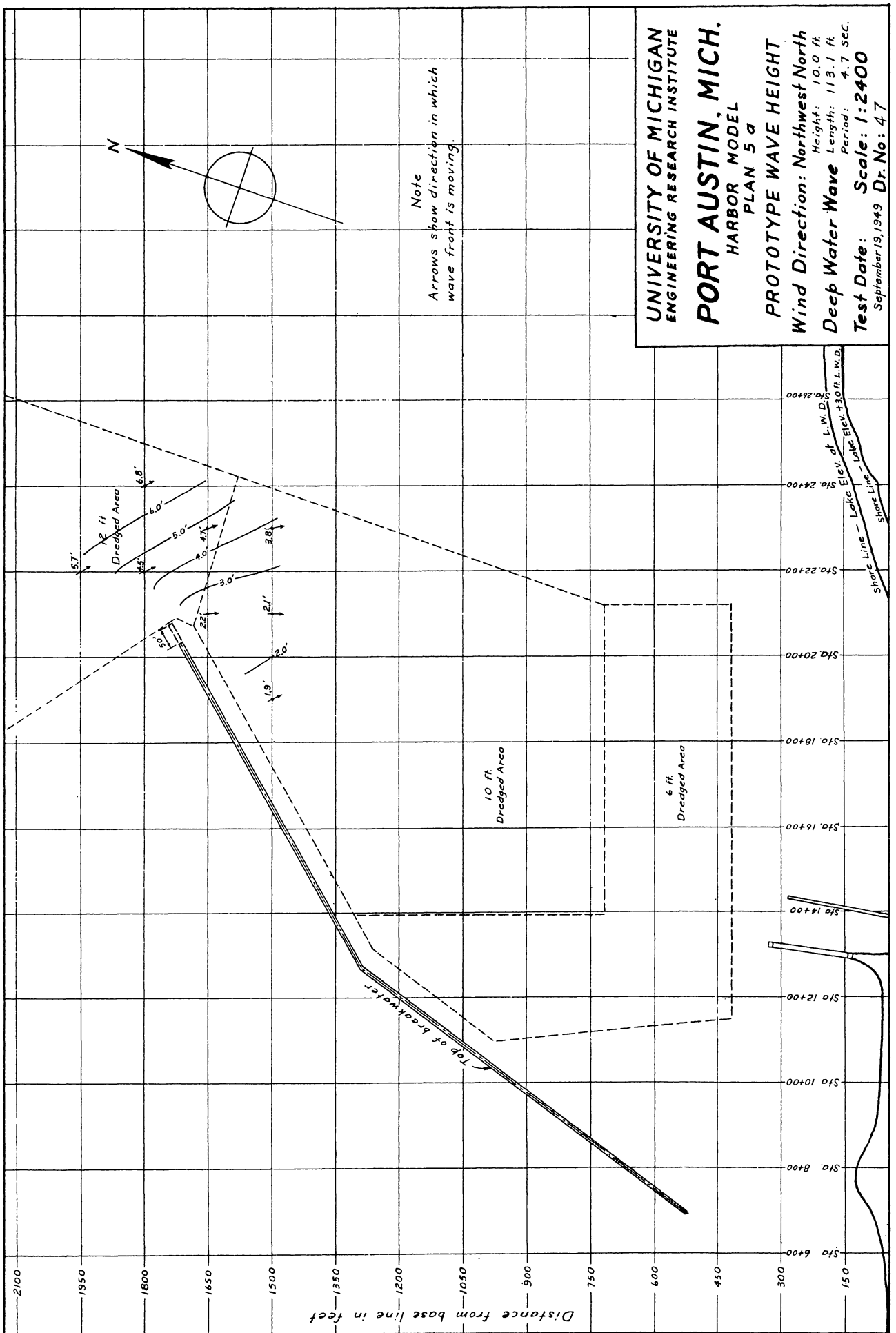
PROTOTYPE WAVE HEIGHT

Wind Direction: Northwest North

Deep Water Wave Height: 10.0 ft. Length: 113.1 ft. Period: 4.7 sec.

Test Date: August 9, 1949 **Scale:** 1:2400' **Dr. No.:** 19

Drawing 19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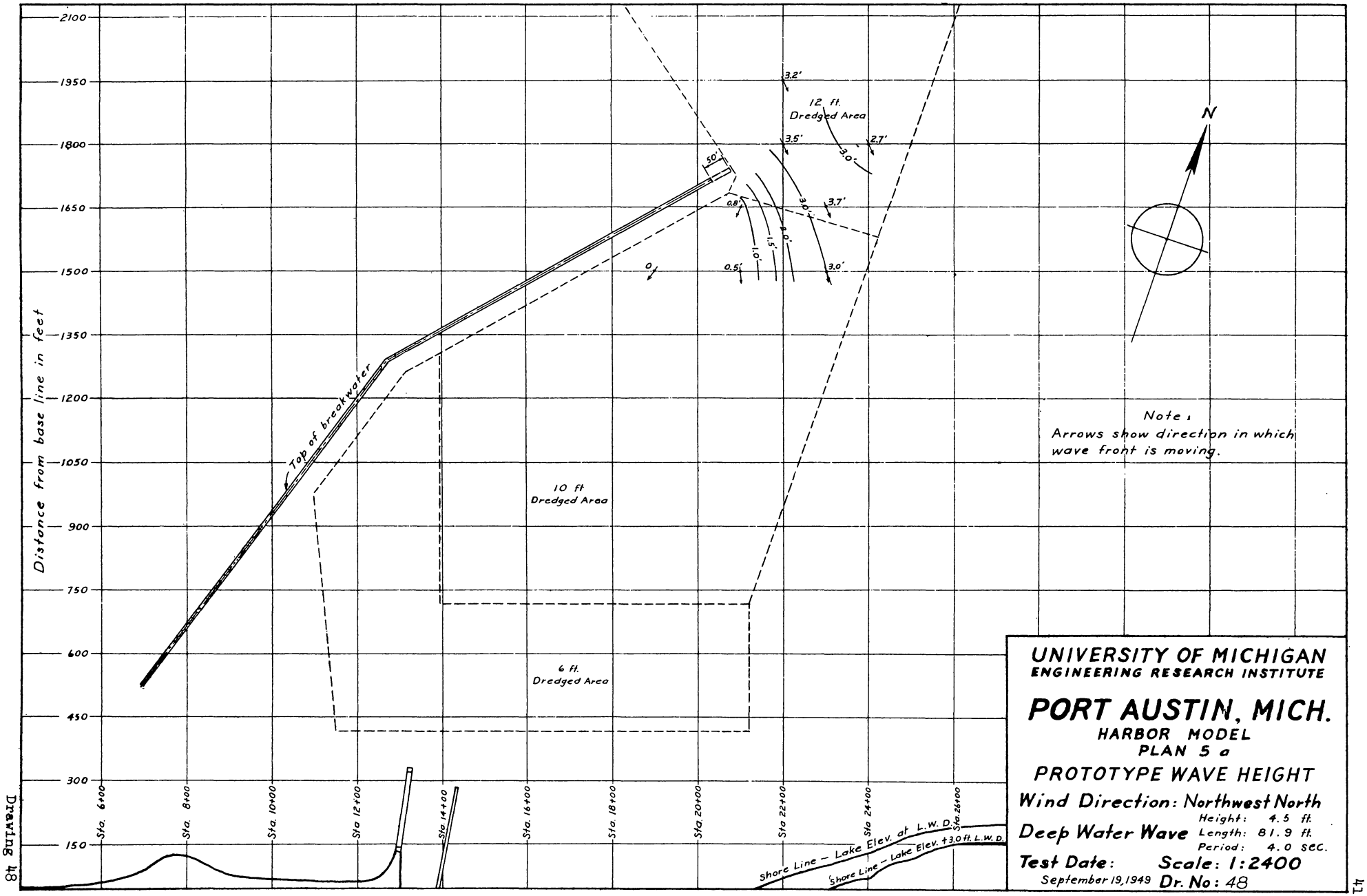
ENGINEERING RESEARCH INSTITUTE
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 5 a
PROTOTYPE WAVE HEIGHT
Wind Direction: Northwest North
Deep Water Wave Height: 10.0 ft. Length: 113.1 ft. Period: 4.7 sec.
Test Date: September 19, 1949 Scale: 1:2400 Dr. No: 47
Note
Arrows show direction in which wave front is moving.
N
12 ft Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Top of Breakwater
Shore Line — Lake Elev. at L.W.D.
Shore Line — Lake Elev. +3.0 ft. L.W.D.
Sta. 26+00
Sta. 24+00
Sta. 22+00
Sta. 20+00
Sta. 18+00
Sta. 16+00
Sta. 14+00
Sta. 12+00
Sta. 10+00
Sta. 8+00
Sta. 6+00
Distance from base line in feet
2100
1950
1800
1650
1500
1350
1200
1050
900
750
600
450
300
150
6.8'
6.0'
5.0'
4.7'
4.5'
4.0'
3.8'
3.0'
2.1'
2.2'
2.0'
1.9'
5.0'
5.7'

Drawing 47



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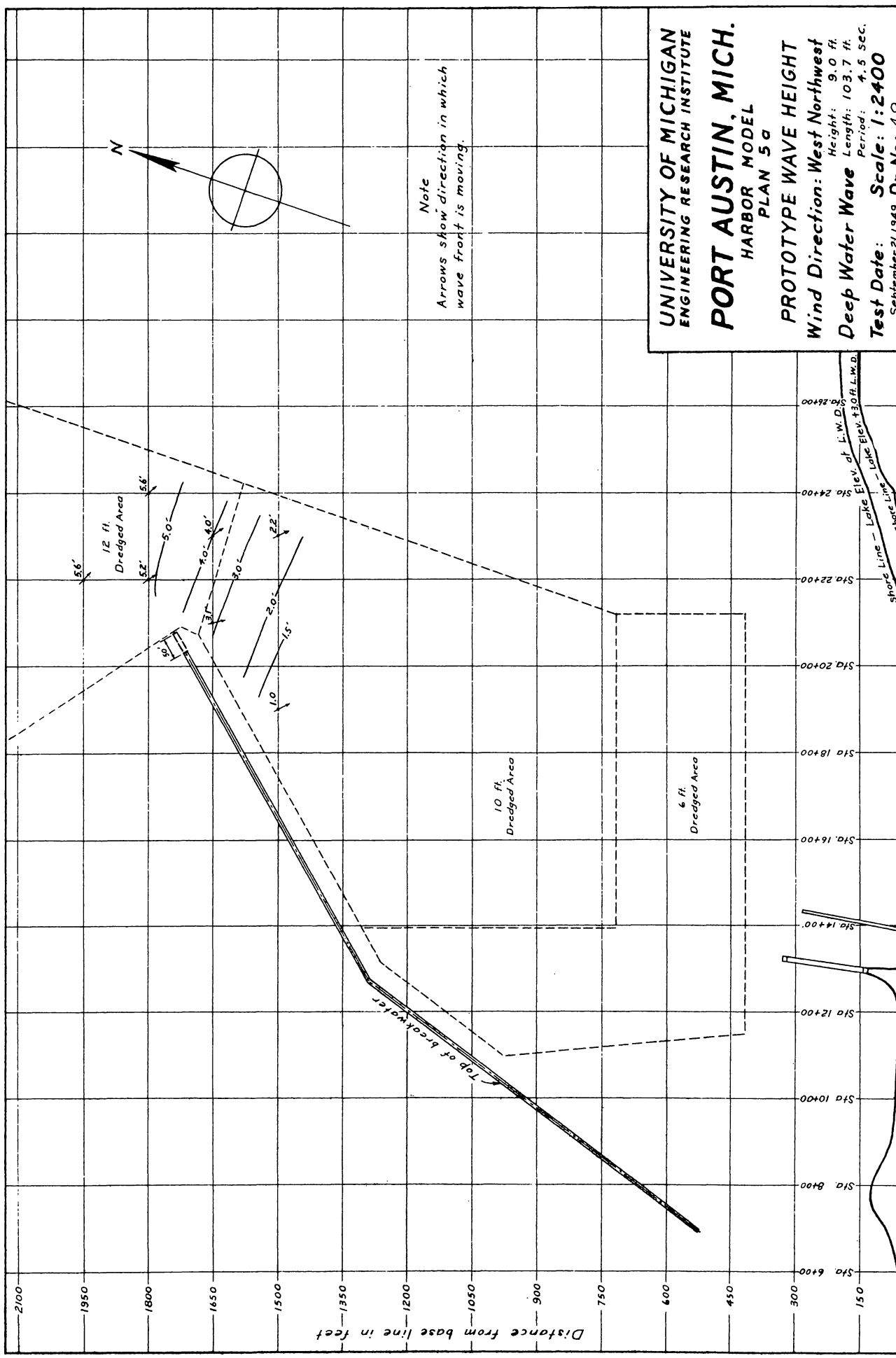
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 5 a
PROTOTYPE WAVE HEIGHT

Wind Direction: Northwest North

Deep Water Wave Height: 4.5 ft. Length: 81.9 ft. Period: 4.0 sec.

Test Date: September 19, 1949 **Scale:** 1:2400 **Dr. No:** 48

Drawing 48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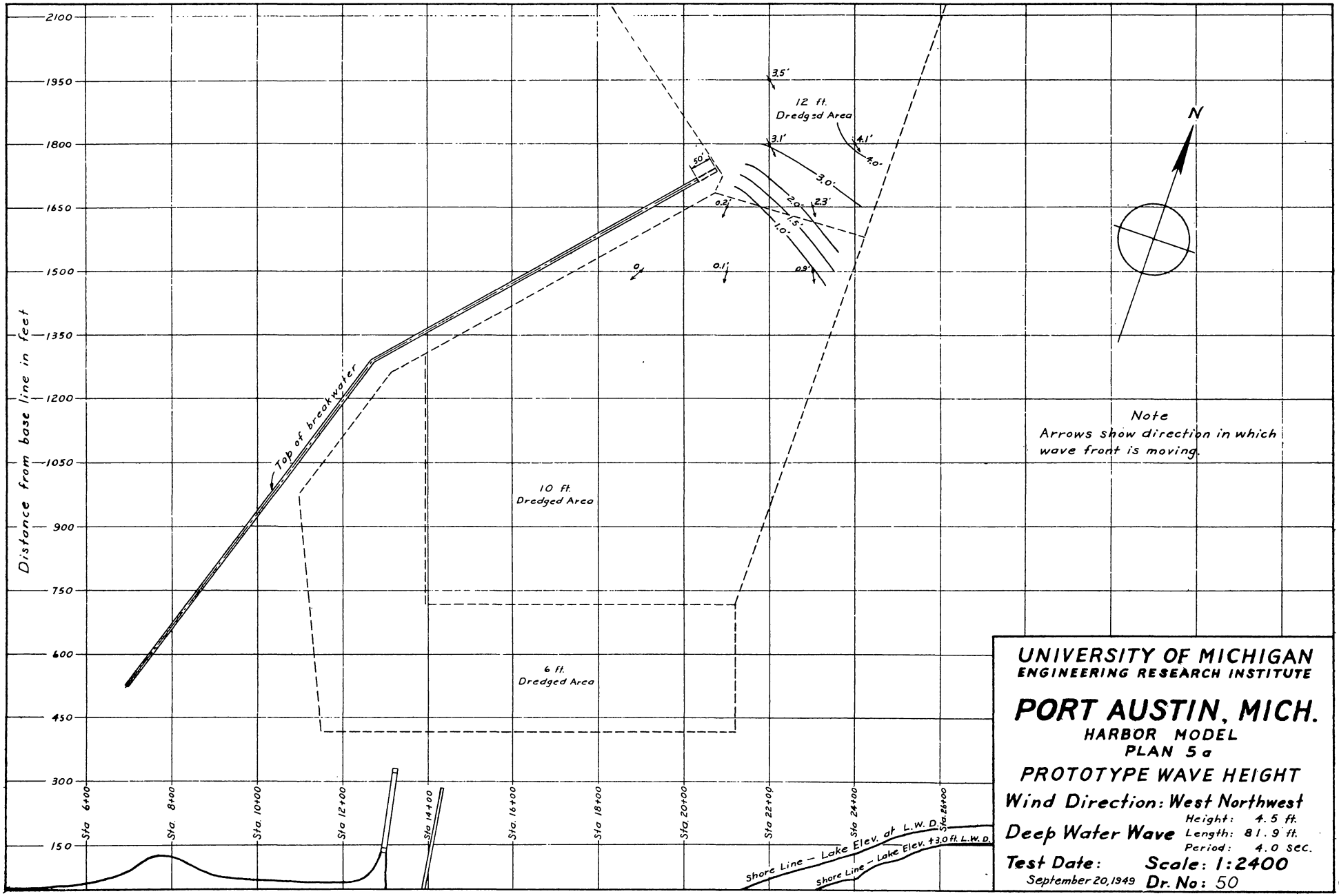
ENGINEERING RESEARCH INSTITUTE
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 5a
PROTOTYPE WAVE HEIGHT
Wind Direction: West Northwest
Deep Water Wave Height: 9.0 ft. Length: 103.7 ft. Period: 4.5 sec.
Test Date: September 21, 1949 Scale: 1:2400 Dr. No: 49
Note
Arrows show direction in which wave front is moving.
N
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Top of breakwater
Shore Line — Lake Elev. of L.W.D.
Shore Line — Lake Elev. +3.0 ft. L.W.D.
Distance from base line in feet
Sta. 26+00
Sta. 24+00
Sta. 22+00
Sta. 20+00
Sta. 18+00
Sta. 16+00
Sta. 14+00
Sta. 12+00
Sta. 10+00
Sta. 8+00
Sta. 6+00
2100
1950
1800
1650
1500
1350
1200
1050
900
750
600
450
300
150

Drawing 49



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PORT AUSTIN, MICH.

HARBOR MODEL
PLAN 5a

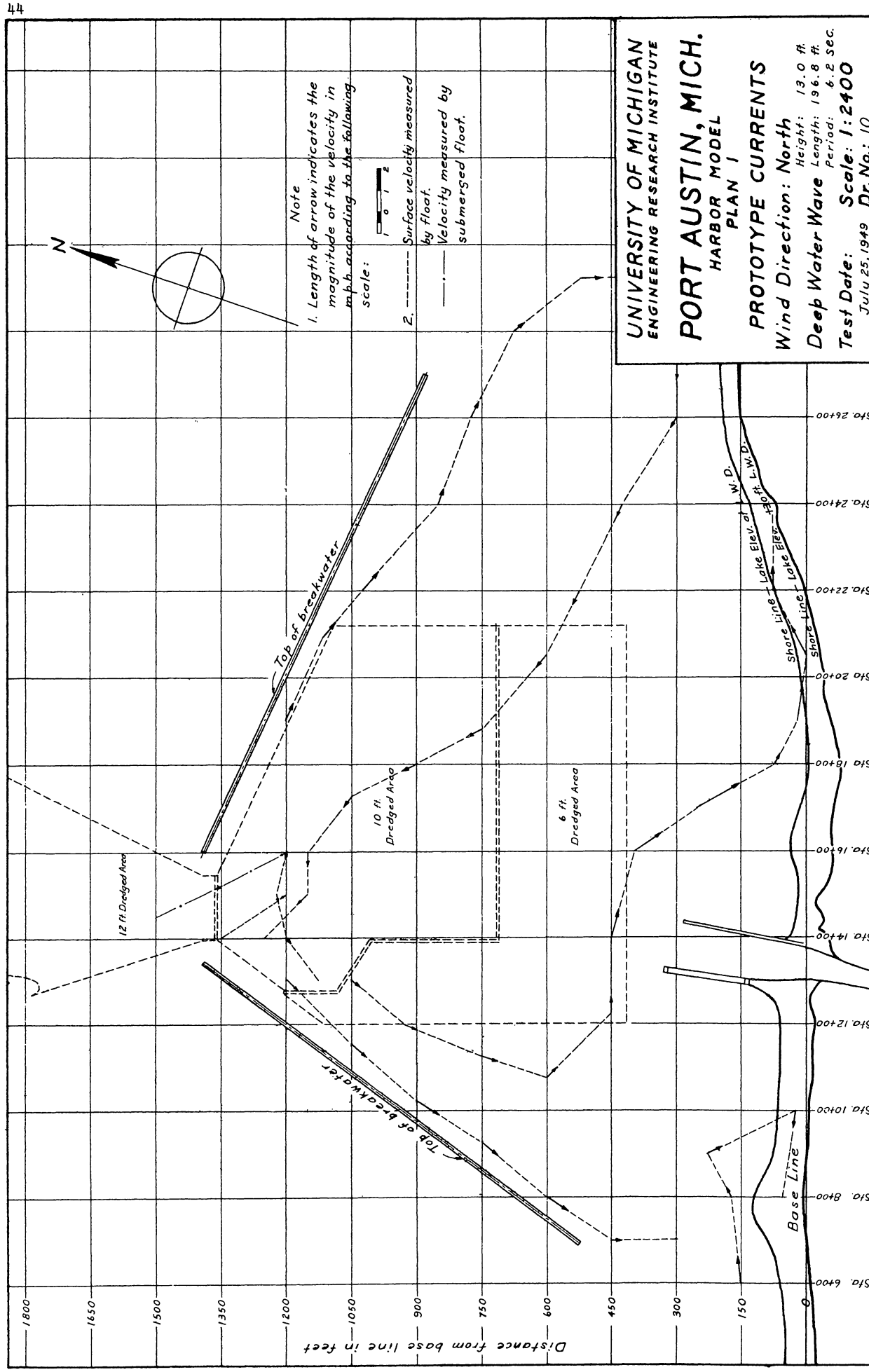
PROTOTYPE WAVE HEIGHT

Wind Direction: West Northwest

Deep Water Wave Height: 4.5 ft. Length: 81.9 ft. Period: 4.0 sec.

Test Date: September 20, 1949 **Scale: 1:2400** **Dr. No:** 50

Drawing 50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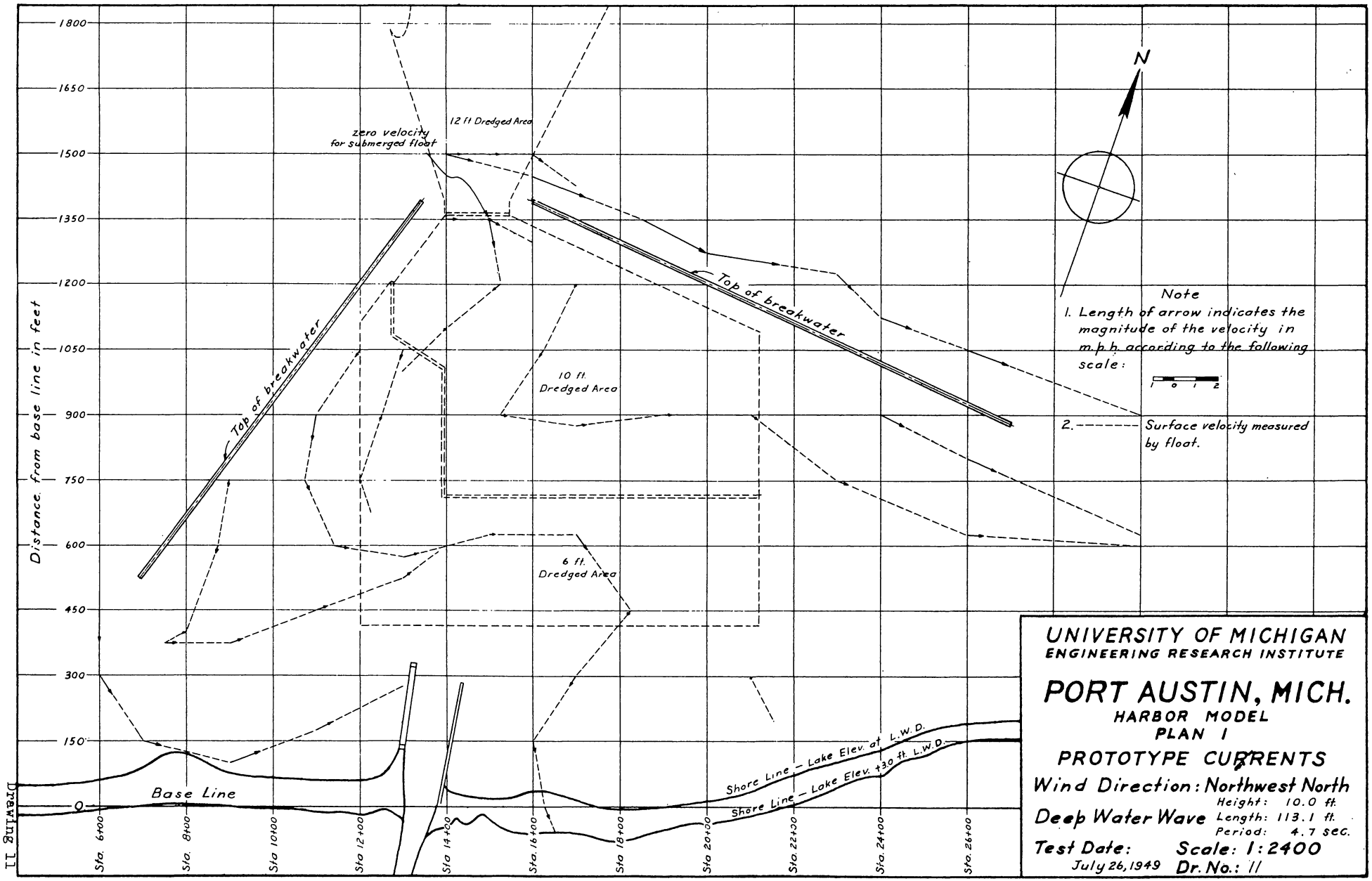
ENGINEERING RESEARCH INSTITUTE
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 1
PROTOTYPE CURRENTS
Wind Direction: North
Deep Water Wave Height: 13.0 ft. Length: 196.8 ft. Period: 6.2 sec.
Test Date: July 25, 1949 Scale: 1:2400 Dr. No.: 10
Note
1. Length of arrow indicates the magnitude of the velocity in m.p.h. according to the following scale:
0 1 2
2. -------- Surface velocity measured by float.
—·— Velocity measured by submerged float.
N
Top of breakwater
Top of breakwater
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Shore Line
Lake Elev. at +0 ft. L.W.D.
Lake Elev.
Shore Line
Base Line
Sta. 6+00
Sta. 8+00
Sta. 10+00
Sta. 12+00
Sta. 14+00
Sta. 16+00
Sta. 18+00
Sta. 20+00
Sta. 22+00
Sta. 24+00
Sta. 26+00
Distance from base line in feet
0
150
300
450
600
750
900
1050
1200
1350
1500
1650
1800

Drawing 10



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PORT AUSTIN, MICH.

HARBOR MODEL
PLAN 1

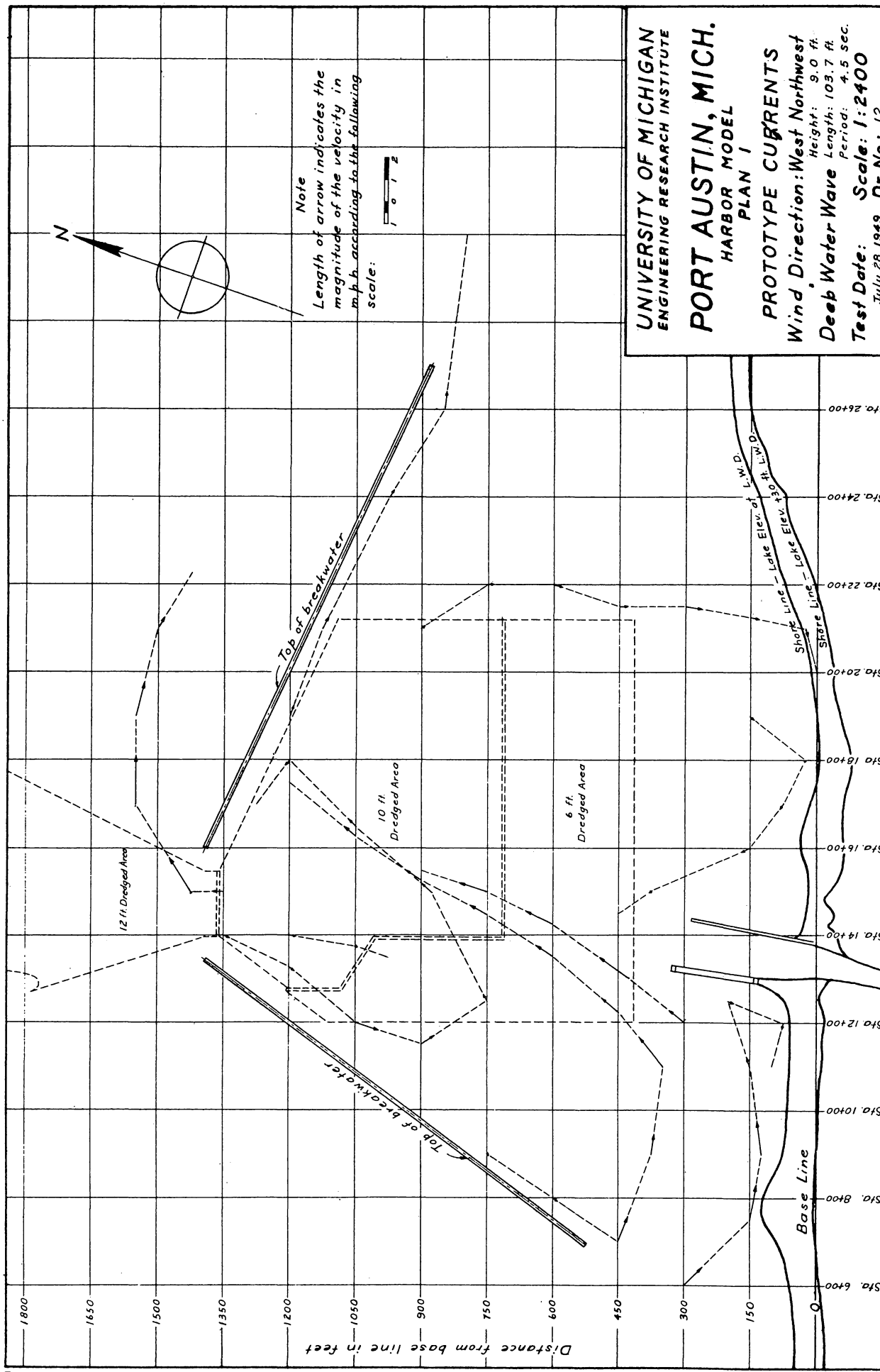
PROTOTYPE CURRENTS

Wind Direction: Northwest North

Deep Water Wave Height: 10.0 ft. Length: 113.1 ft. Period: 4.7 SEC.

Test Date: July 26, 1949 Scale: 1:2400 Dr. No.: 11

Drawing 11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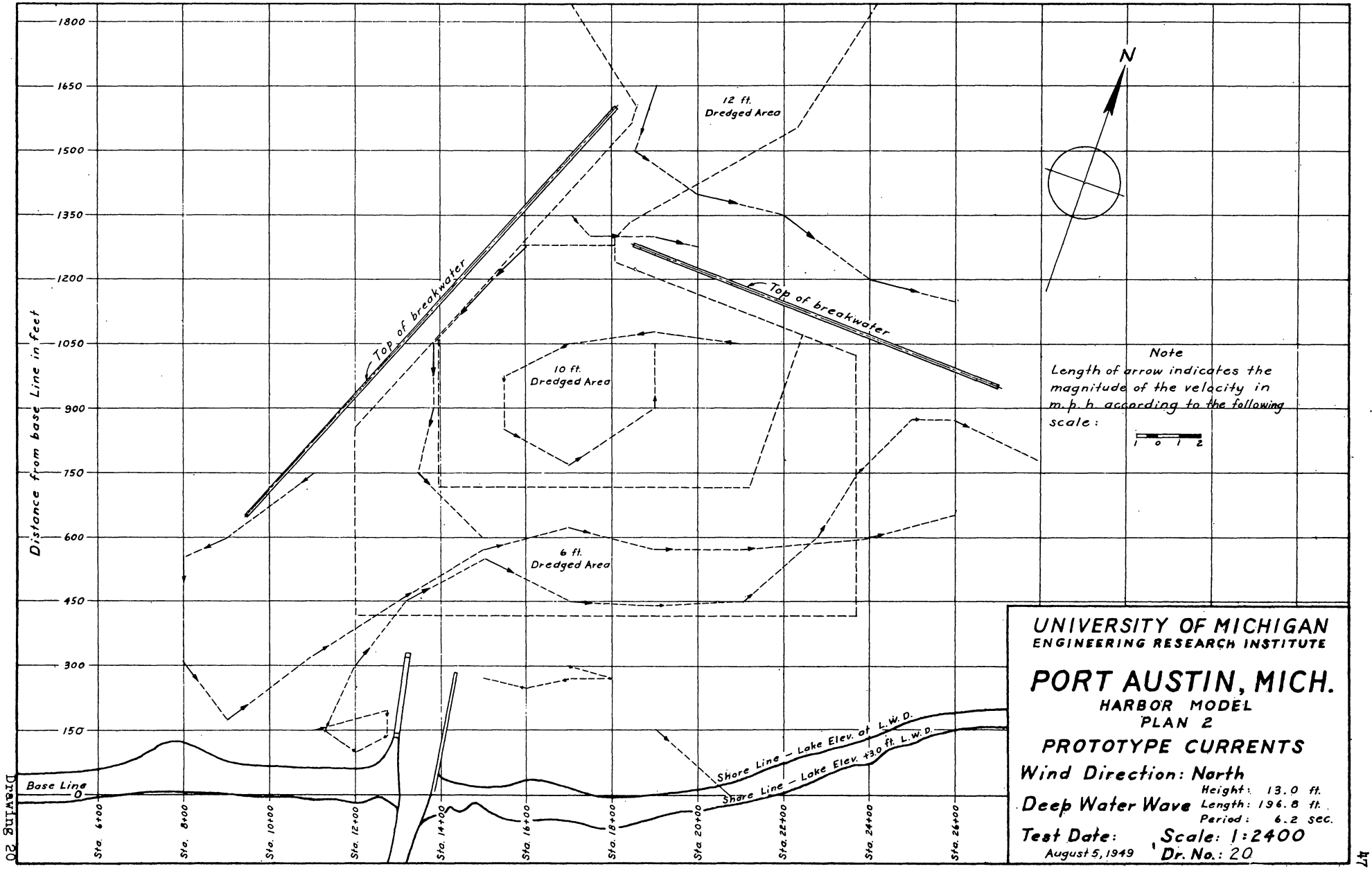
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 1
PROTOTYPE CURRENTS
Wind Direction: West Northwest
Height: 9.0 ft.
Deep Water Wave Length: 103.7 ft.
Period: 4.5 sec.
Test Date: July 28, 1949
Scale: 1:2400
Dr. No.: 12
Note
Length of arrow indicates the magnitude of the velocity in m.p.h. according to the following scale:
0 1 2
N
Top of breakwater
Top of breakwater
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Shore Line — Lake Elev. of L.W.D.
Shore Line — Lake Elev. +30 ft. L.W.D.
Base Line
Sta. 6+00
Sta. 8+00
Sta. 10+00
Sta. 12+00
Sta. 14+00
Sta. 16+00
Sta. 18+00
Sta. 20+00
Sta. 22+00
Sta. 24+00
Sta. 26+00
Distance from base line in feet
0
150
300
450
600
750
900
1050
1200
1350
1500
1650
1800

Drawing 12



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PORT AUSTIN, MICH.

HARBOR MODEL
PLAN 2

PROTOTYPE CURRENTS

Wind Direction: North

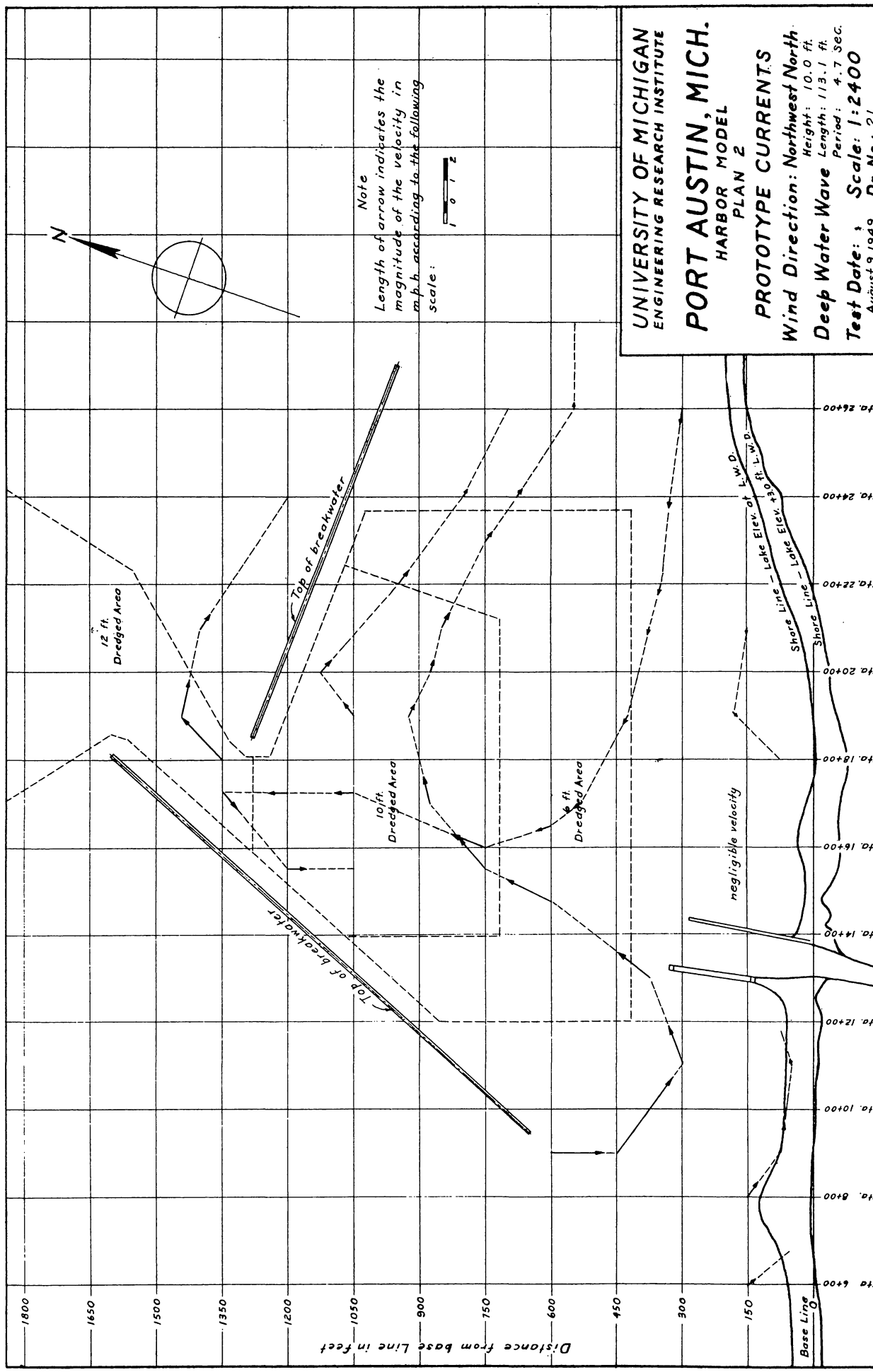
Deep Water Wave — Height: 13.0 ft. Length: 196.8 ft. Period: 6.2 sec.

Test Date: August 5, 1949

Scale: 1:2400

Dr. No.: 20

Drawing 20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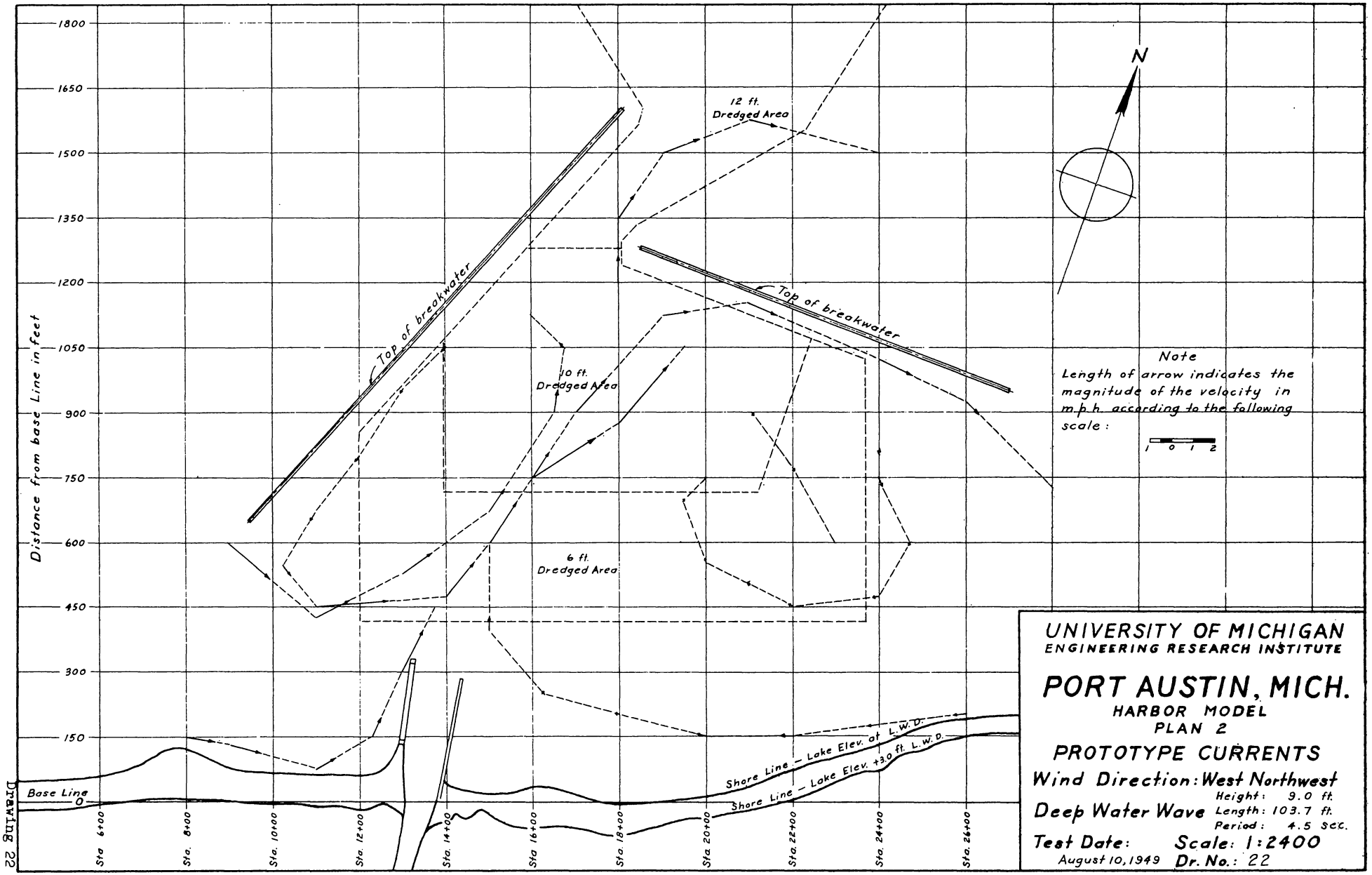
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 2
PROTOTYPE CURRENTS
Wind Direction: Northwest North
Height: 10.0 ft.
Deep Water Wave Length: 113.1 ft.
Period: 4.7 Sec.
Test Date: 1 Scale: 1:2400
August 9, 1949 Dr. No.: 21
Note
Length of arrow indicates the magnitude of the velocity in m.p.h. according to the following scale:
0 1 2
N
Top of breakwater
12 ft. Dredged Area
10 ft. Dredged Area
8 ft. Dredged Area
negligible velocity
Shore Line — Lake Elev. of L.W.D.
Shore Line — Lake Elev. +3.0 ft. L.W.D.
Base Line
Sta. 6+00
Sta. 8+00
Sta. 10+00
Sta. 12+00
Sta. 14+00
Sta. 16+00
Sta. 18+00
Sta. 20+00
Sta. 22+00
Sta. 24+00
Sta. 26+00
Distance from base Line in feet
0
150
300
450
600
750
900
1050
1200
1350
1500
1650
1800

Drawing 21



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PORT AUSTIN, MICH.

HARBOR MODEL
PLAN 2

PROTOTYPE CURRENTS

Wind Direction: West Northwest

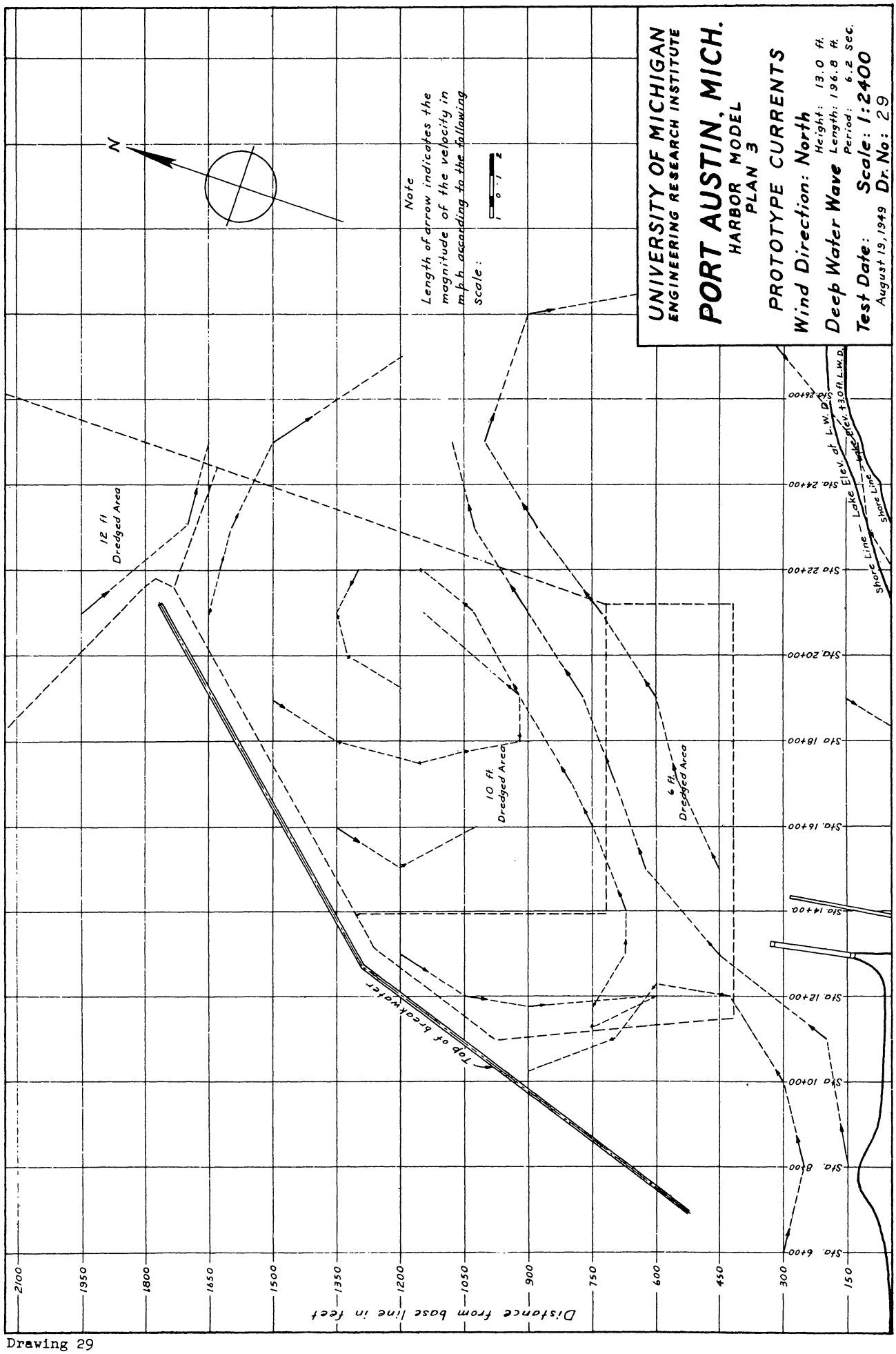
Deep Water Wave — Height: 9.0 ft. Length: 103.7 ft. Period: 4.5 sec.

Test Date: August 10, 1949

Scale: 1:2400

Dr. No.: 22

Drawing 22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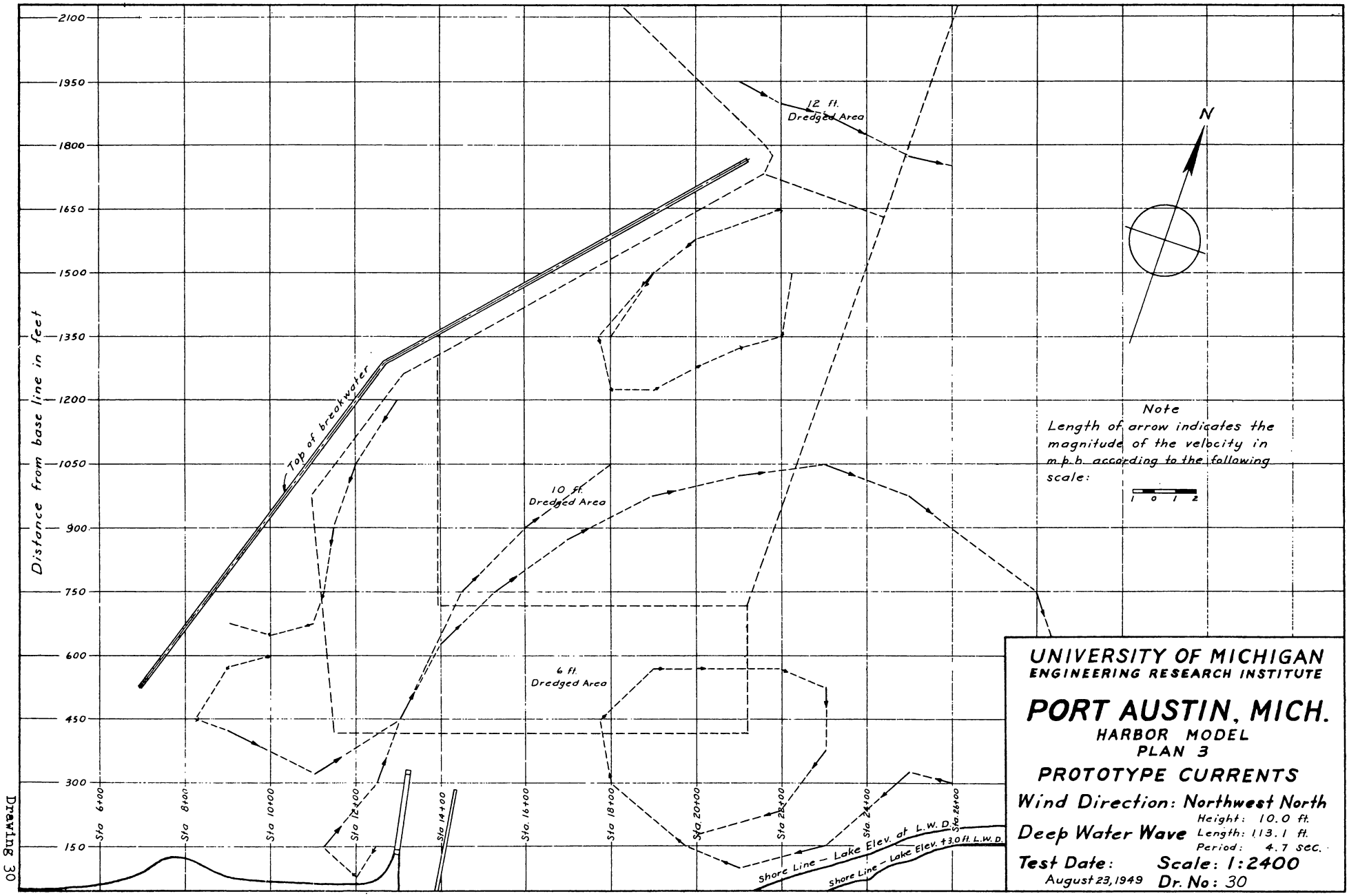
ENGINEERING RESEARCH INSTITUTE
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 3
PROTOTYPE CURRENTS
Wind Direction: North
Deep Water Wave Height: 13.0 ft. Length: 196.8 ft. Period: 6.2 sec.
Test Date: August 19, 1949
Scale: 1:2400
Dr. No: 29
Note
Length of arrow indicates the magnitude of the velocity in m.p.h. according to the following scale:
0 1 2
N
12 ft Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Top of breakwater
Shore Line — Lake Elev. at L.W.D.
Shore Line — Lake Elev. +3.0 ft. L.W.D.
Sta. 26+00
Sta. 24+00
Sta. 22+00
Sta. 20+00
Sta. 18+00
Sta. 16+00
Sta. 14+00
Sta. 12+00
Sta. 10+00
Sta. 8+00
Sta. 6+00
Distance from base line in feet
2100
1950
1800
1650
1500
1350
1200
1050
900
750
600
450
300
150

Drawing 29



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PORT AUSTIN, MICH.

HARBOR MODEL
PLAN 3

PROTOTYPE CURRENTS

Wind Direction: Northwest North

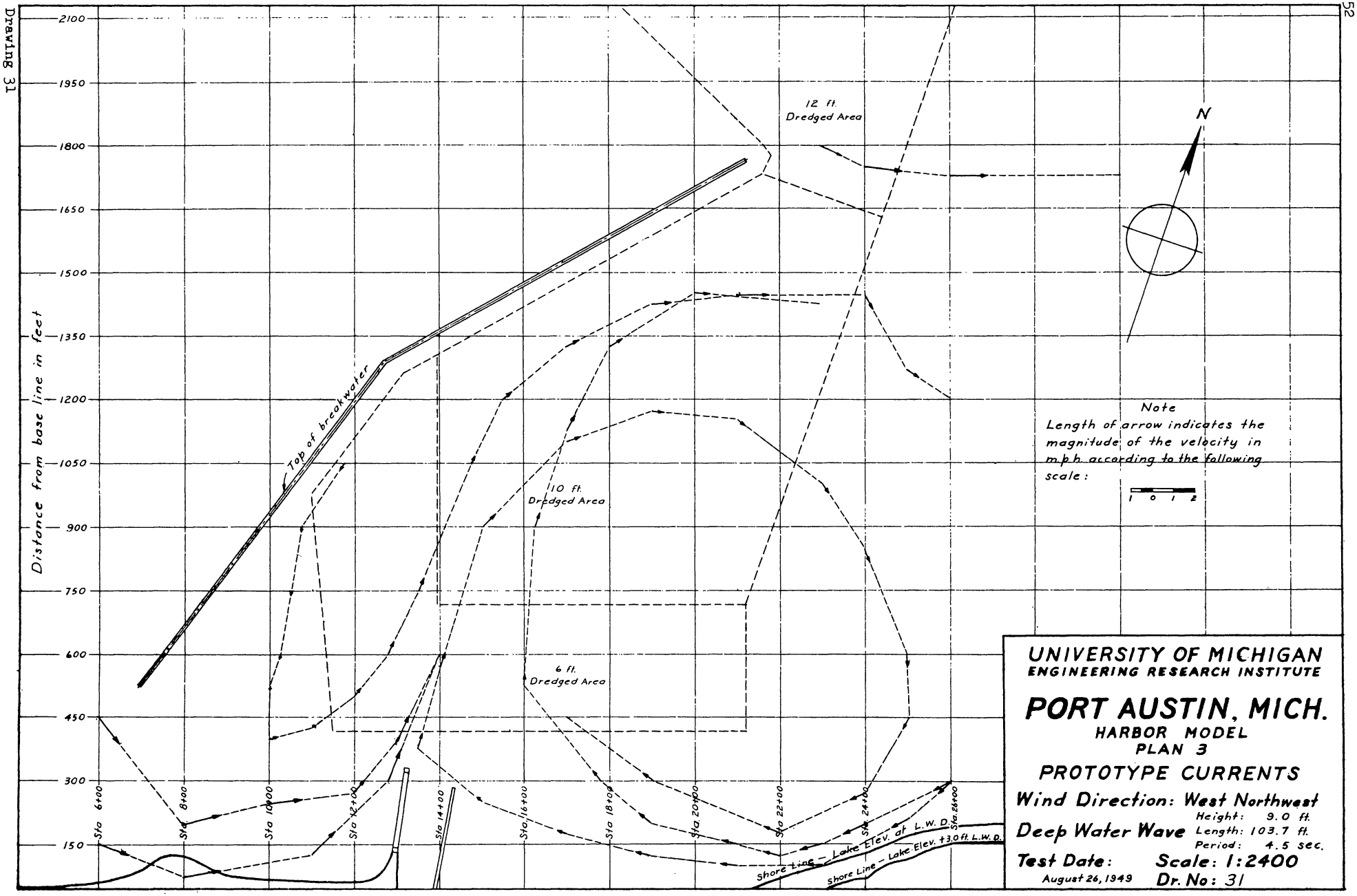
Deep Water Wave Height: 10.0 ft. Length: 113.1 ft. Period: 4.7 sec.

Test Date: August 23, 1949

Scale: 1:2400

Dr. No: 30

Drawing 30



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PORT AUSTIN, MICH.

HARBOR MODEL
PLAN 3

PROTOTYPE CURRENTS

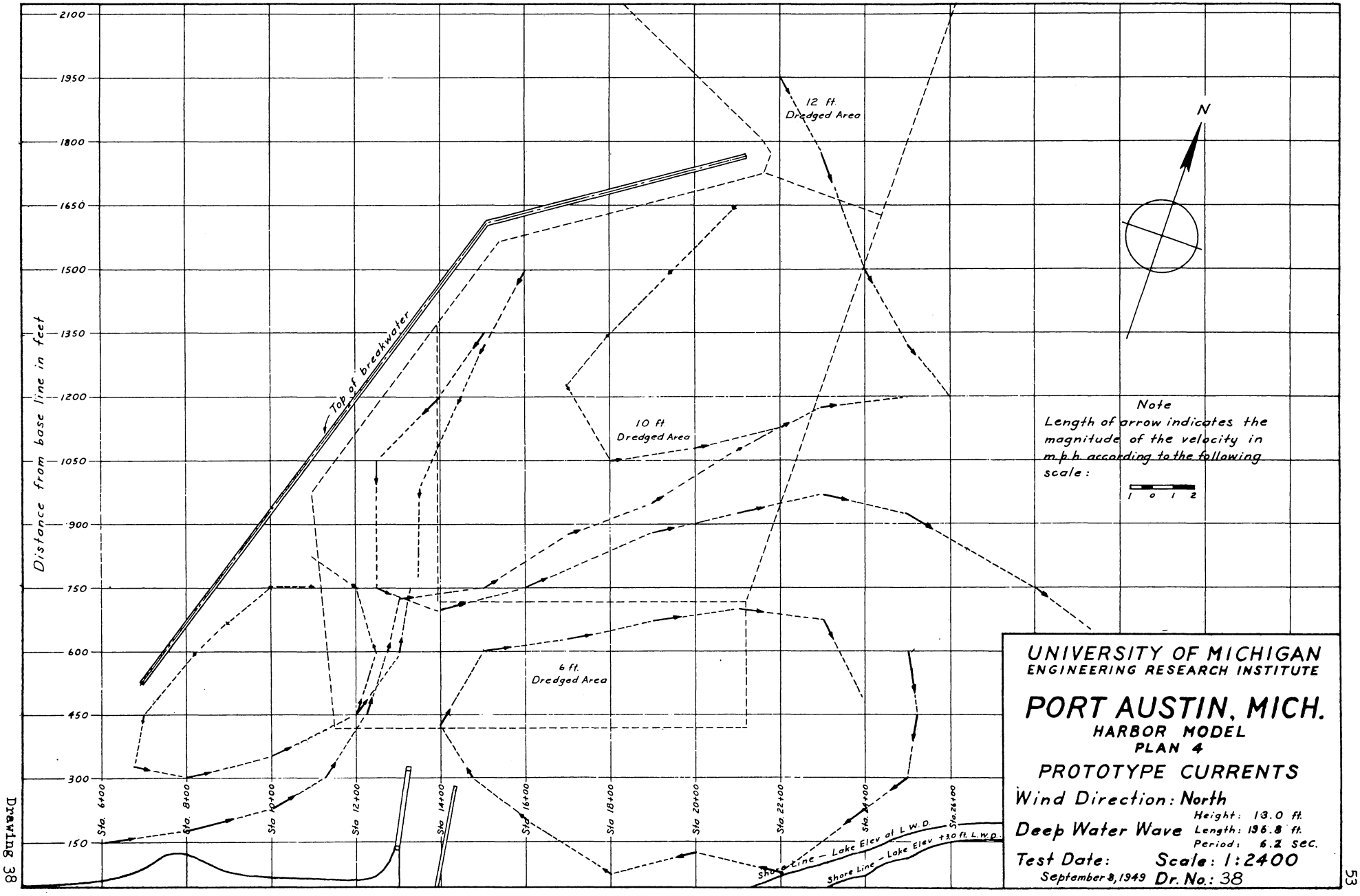
Wind Direction: West Northwest

Deep Water Wave Height: 9.0 ft. Length: 103.7 ft. Period: 4.5 sec.

Test Date: August 26, 1949

Scale: 1:2400

Dr. No: 31



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PORT AUSTIN, MICH.

HARBOR MODEL
PLAN 4

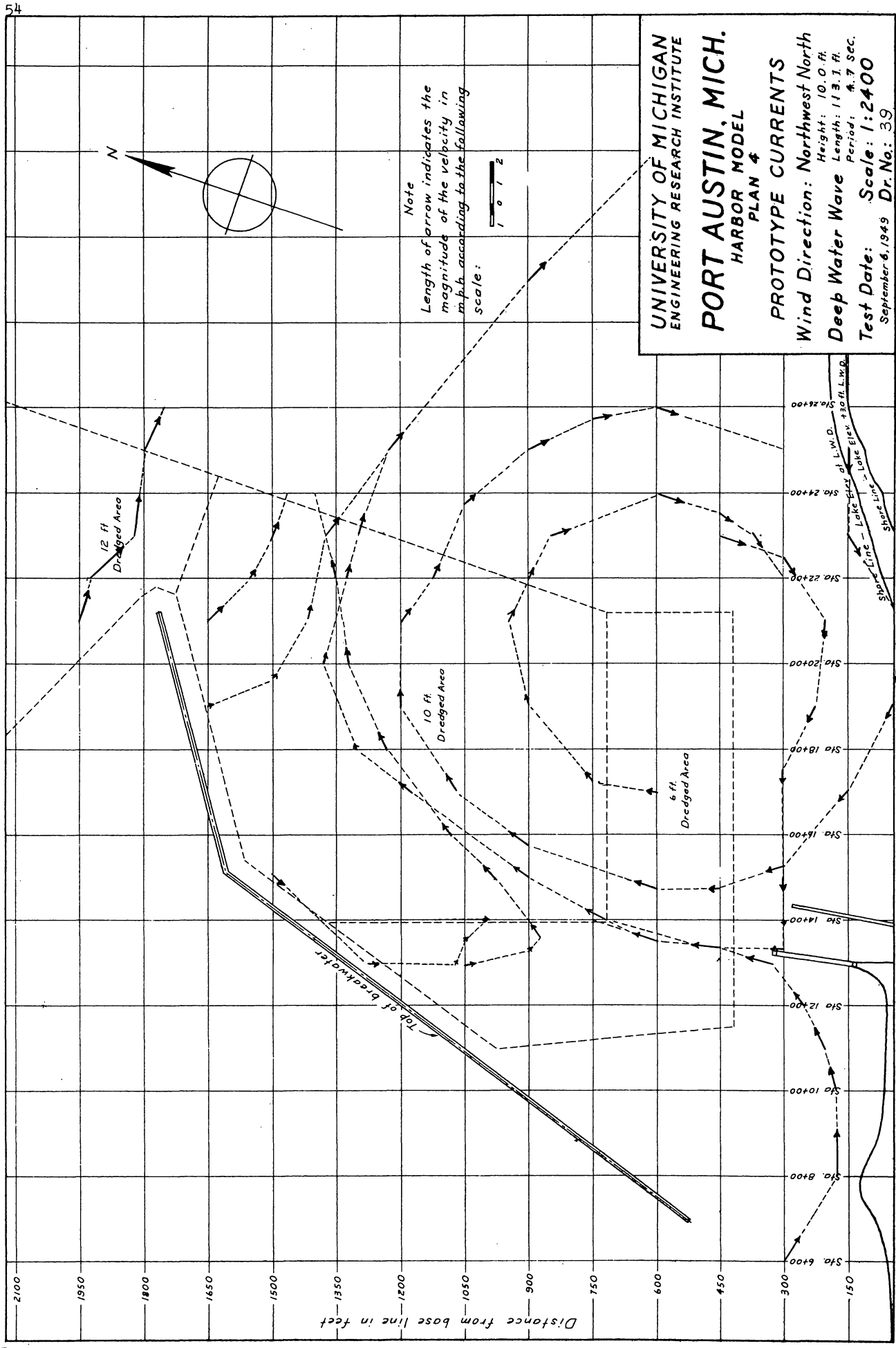
PROTOTYPE CURRENTS

Wind Direction: North

Deep Water Wave Height: 13.0 ft. Length: 196.8 ft. Period: 6.2 sec.

Test Date: September 8, 1949 Scale: 1:2400 Dr. No.: 38

Drawing 38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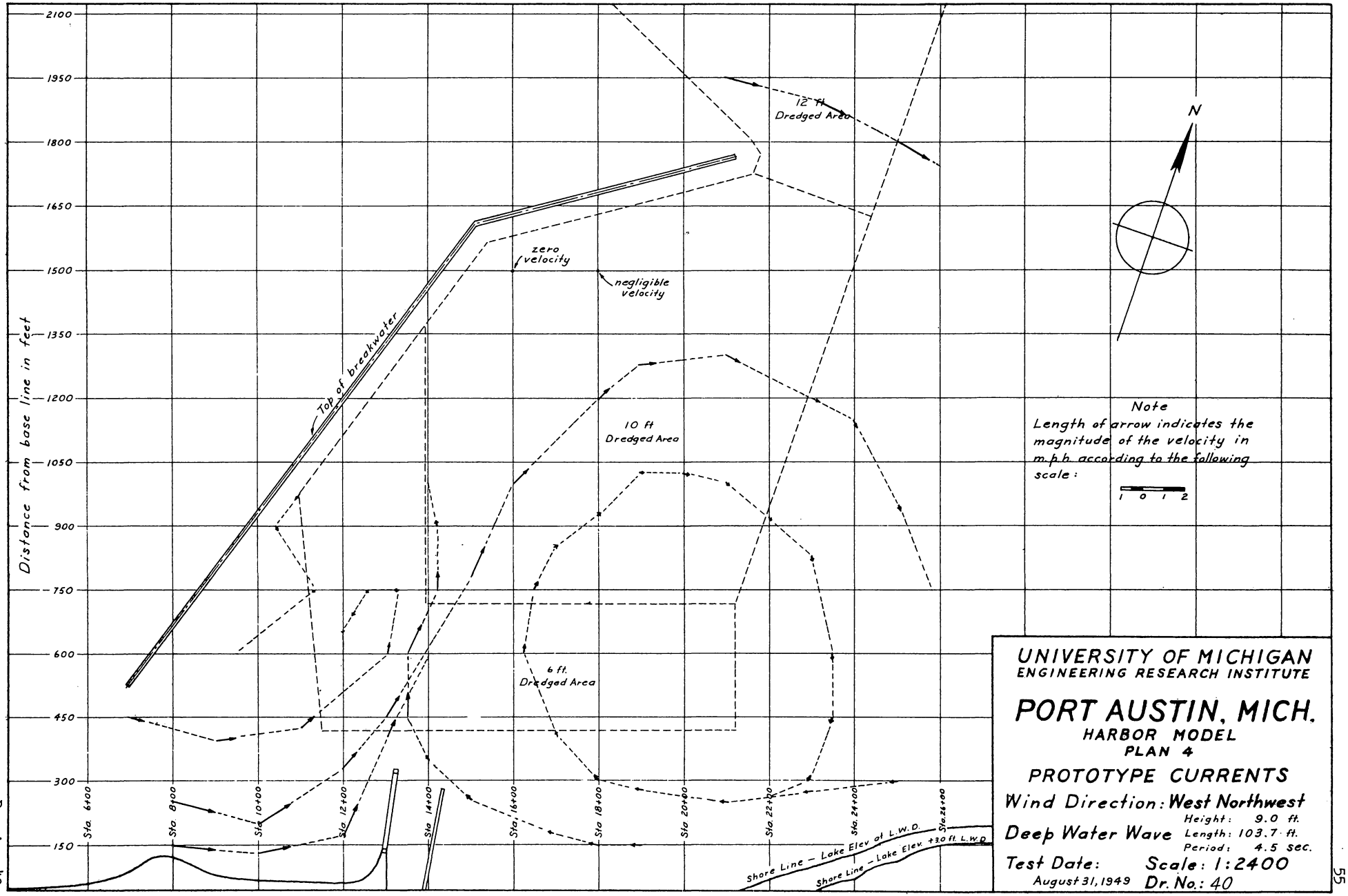
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 4
PROTOTYPE CURRENTS
Wind Direction: Northwest North
Height: 10.0 ft.
Deep Water Wave Length: 113.1 ft.
Period: 4.7 sec.
Test Date: Scale: 1:2400
September 6, 1949 Dr. No.: 39
Note
Length of arrow indicates the magnitude of the velocity in m.p.h. according to the following scale:
1 0 1 2
N
12 ft Dredged Area
10 ft Dredged Area
6 ft. Dredged Area
Top of breakwater
Shore Line — Lake Elev. of L.W.D.
Shore Line — Lake Elev. +130 ft. L.W.D.
Sta. 26+00
Sta. 24+00
Sta. 22+00
Sta. 20+00
Sta. 18+00
Sta. 16+00
Sta. 14+00
Sta. 12+00
Sta. 10+00
Sta. 8+00
Sta. 6+00
Distance from base line in feet
2100
1950
1800
1650
1500
1350
1200
1050
900
750
600
450
300
150

Drawing 39



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PORT AUSTIN, MICH.

HARBOR MODEL
PLAN 4

PROTOTYPE CURRENTS

Wind Direction: West Northwest

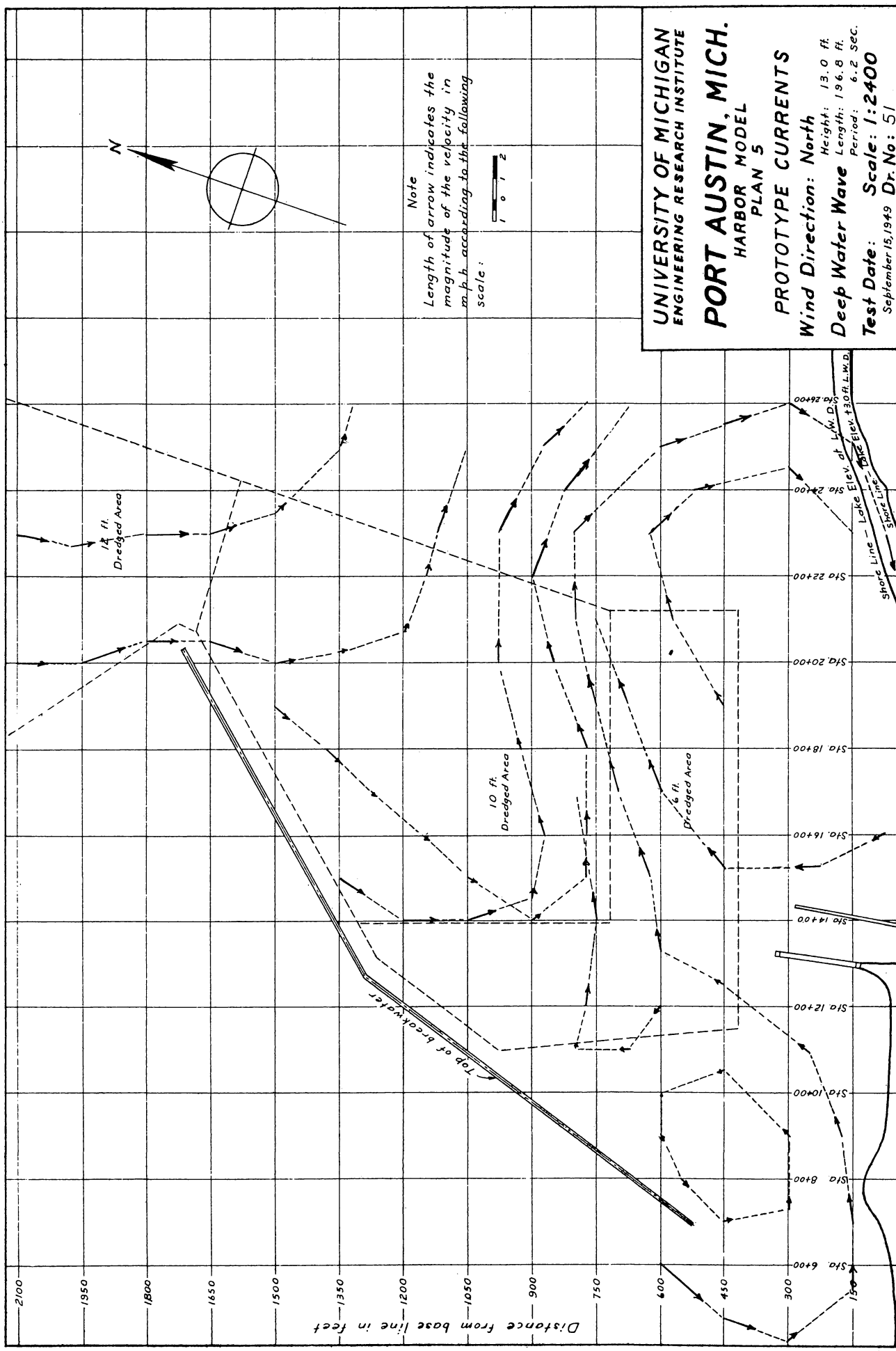
Deep Water Wave Height: 9.0 ft. Length: 103.7 ft. Period: 4.5 sec.

Test Date: August 31, 1949

Scale: 1:2400

Dr. No.: 40

Drawing 40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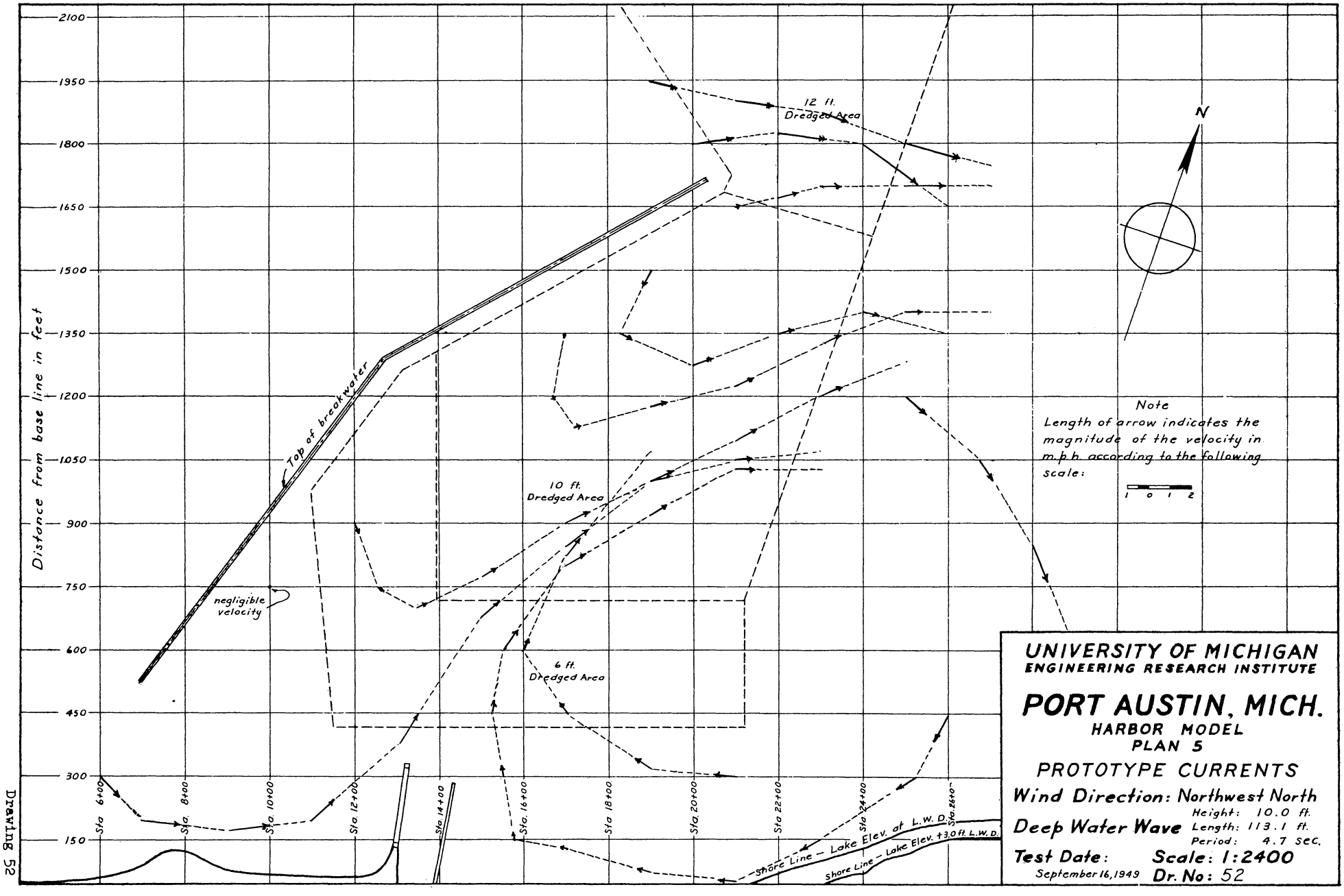
ENGINEERING RESEARCH INSTITUTE
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 5
PROTOTYPE CURRENTS
Wind Direction: North
Deep Water Wave Height: 13.0 ft. Length: 196.8 ft. Period: 6.2 sec.
Test Date: September 15, 1949 Scale: 1:2400 Dr. No: 51
Note
Length of arrow indicates the magnitude of the velocity in m.p.h. according to the following scale:
1 0 1 2
N
14 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Top of breakwater
Shore Line — Lake Elev. at L.W.D.
Shore Line — Lake Elev. +3.0 ft. L.W.D.
Sta. 26+00
Sta. 24+00
Sta. 22+00
Sta. 20+00
Sta. 18+00
Sta. 16+00
Sta. 14+00
Sta. 12+00
Sta. 10+00
Sta. 8+00
Sta. 6+00
Distance from base line in feet
2100
1950
1800
1650
1500
1350
1200
1050
900
750
600
450
300
150

Drawing 51


Distance from base line in feet
2100
1950
1800
1650
1500
1350
1200
1050
900
750
600
450
300
150
Sta 6+00
Sta 8+00
Sta 10+00
Sta 12+00
Sta 14+00
Sta 16+00
Sta 18+00
Sta 20+00
Sta 22+00
Sta 24+00
Sta 26+00
Top of breakwater
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
negligible velocity
Shore Line – Lake Elev. at L.W.D.
Shore Line – Lake Elev. +3.0 ft. L.W.D.
N
Note
Length of arrow indicates the magnitude of the velocity in m.p.h. according to the following scale:
1 0 1 2
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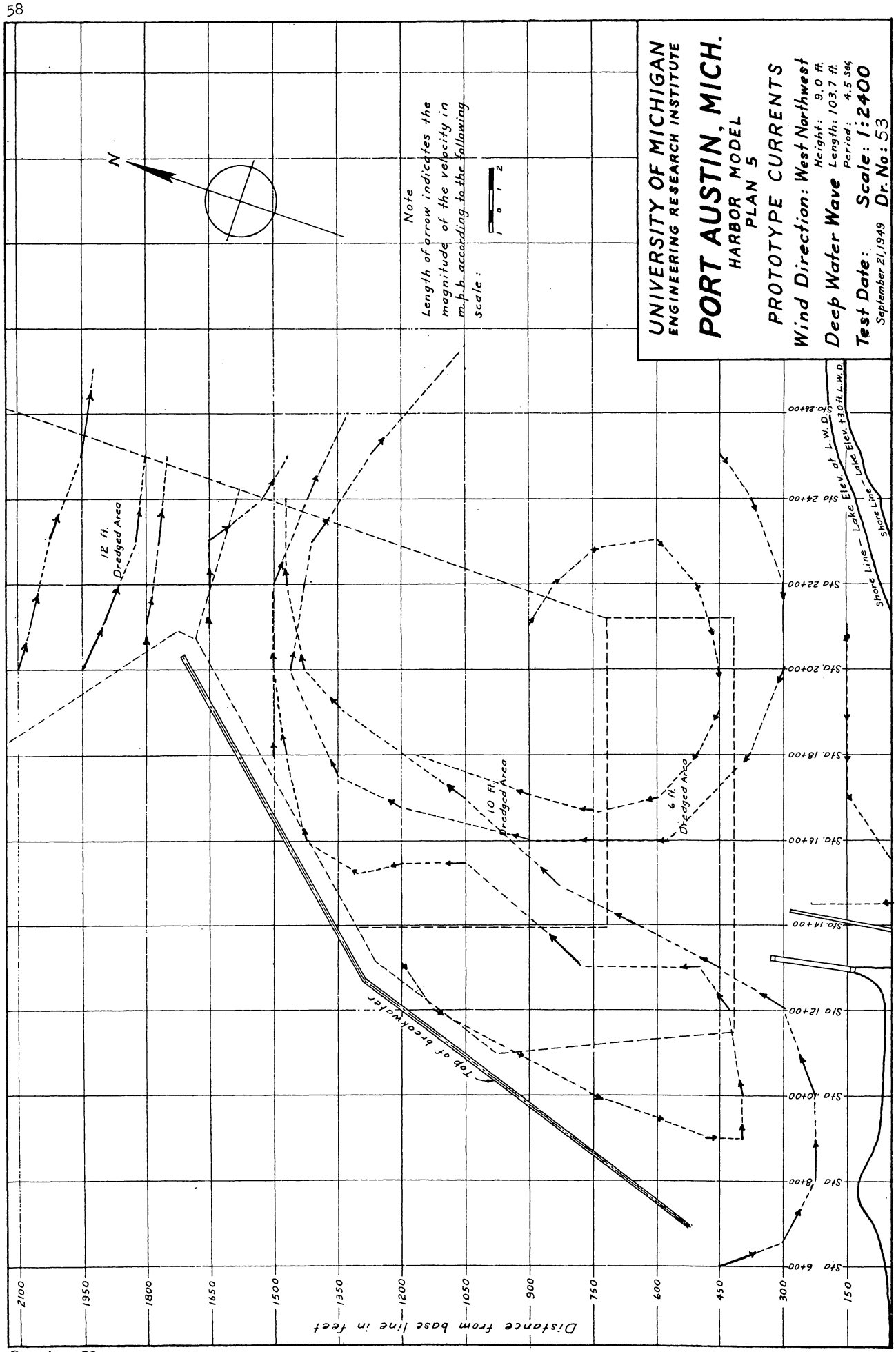
ENGINEERING RESEARCH INSTITUTE
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 5
PROTOTYPE CURRENTS
Wind Direction: Northwest North
Deep Water Wave Height: 10.0 ft. Length: 113.1 ft. Period: 4.7 sec.
Test Date: September 16, 1949
Scale: 1:2400
Dr. No: 52

Drawing 52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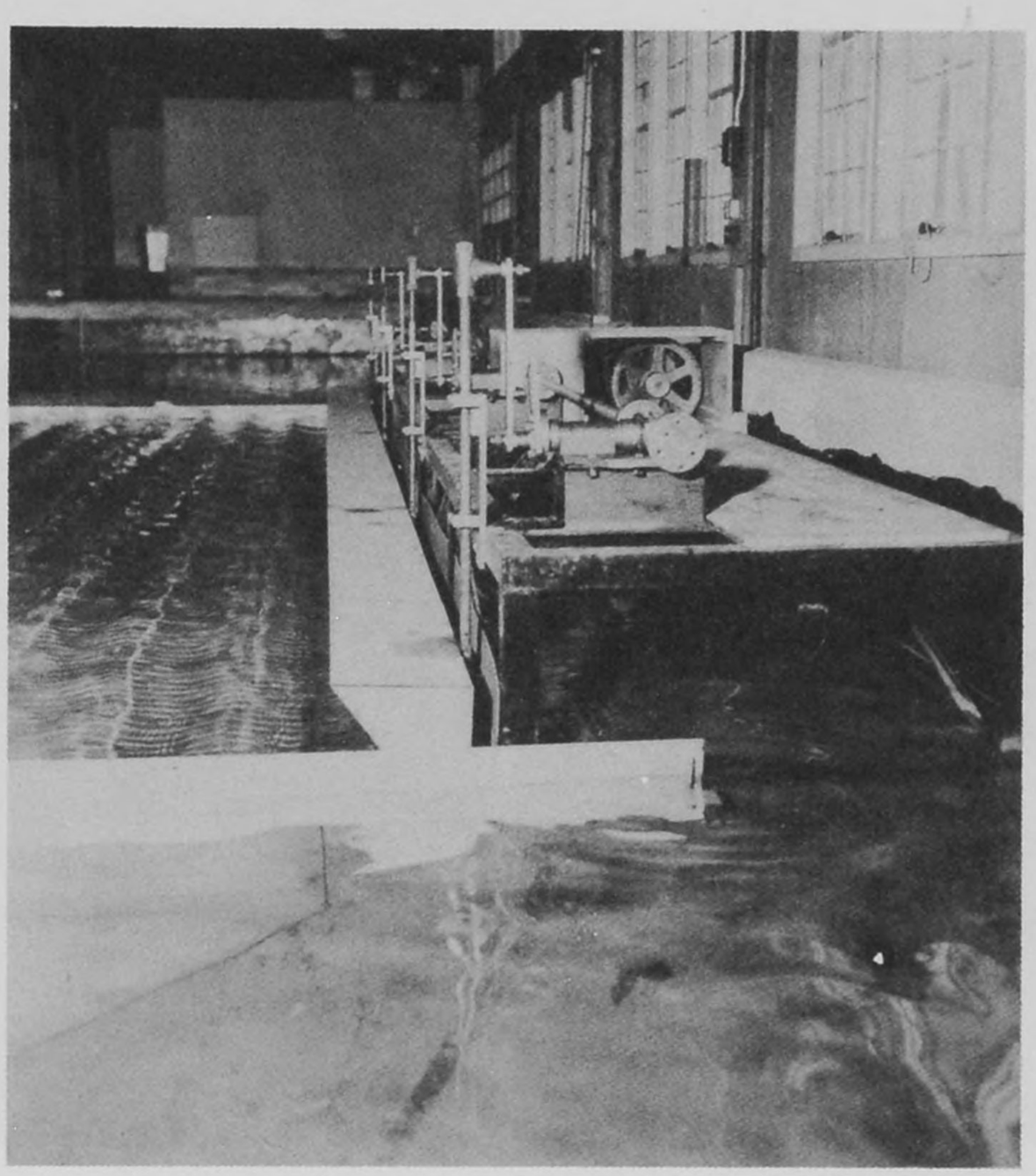
ENGINEERING RESEARCH INSTITUTE
PORT AUSTIN, MICH.
HARBOR MODEL
PLAN 5
PROTOTYPE CURRENTS
Wind Direction: West Northwest
Deep Water Wave Height: 9.0 ft. Length: 103.7 ft. Period: 4.5 sec
Test Date: September 21, 1949
Scale: 1:2400
Dr. No: 53
Note
Length of arrow indicates the magnitude of the velocity in m.p.h. according to the following scale:
0 1 2
N
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Top of breakwater
Shore Line – Lake Elev. at L.W.D.
Shore Line – Lake Elev. +3.0 ft. L.W.D.
Sta. 24+00
Sta. 22+00
Sta. 20+00
Sta. 18+00
Sta. 16+00
Sta. 14+00
Sta. 12+00
Sta. 10+00
Sta. 8+00
Sta. 6+00
Distance from base line in feet
2100
1950
1800
1650
1500
1350
1200
1050
900
750
600
450
300
150

Drawing 53

APPENDIX B

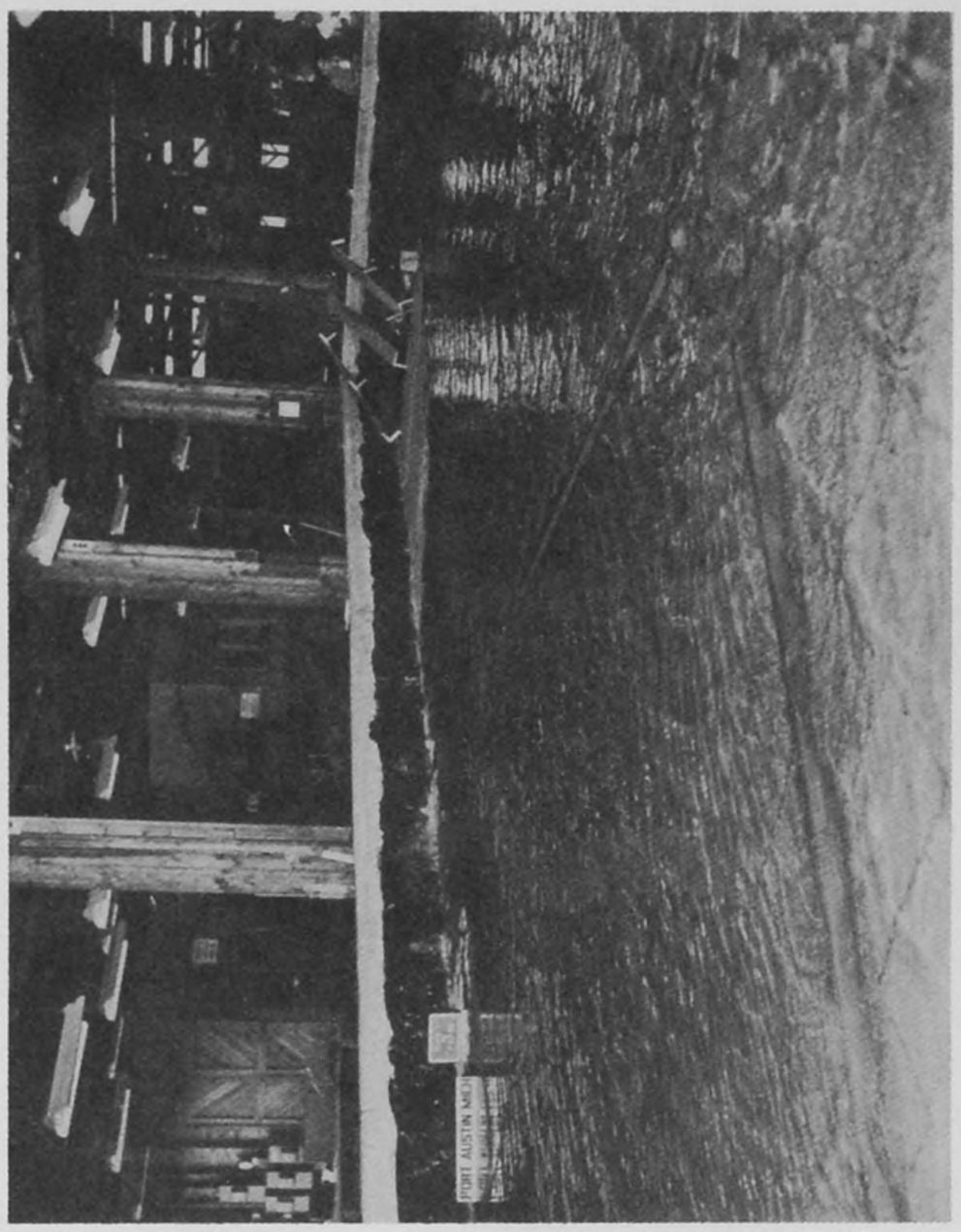
PHOTOGRAPHS

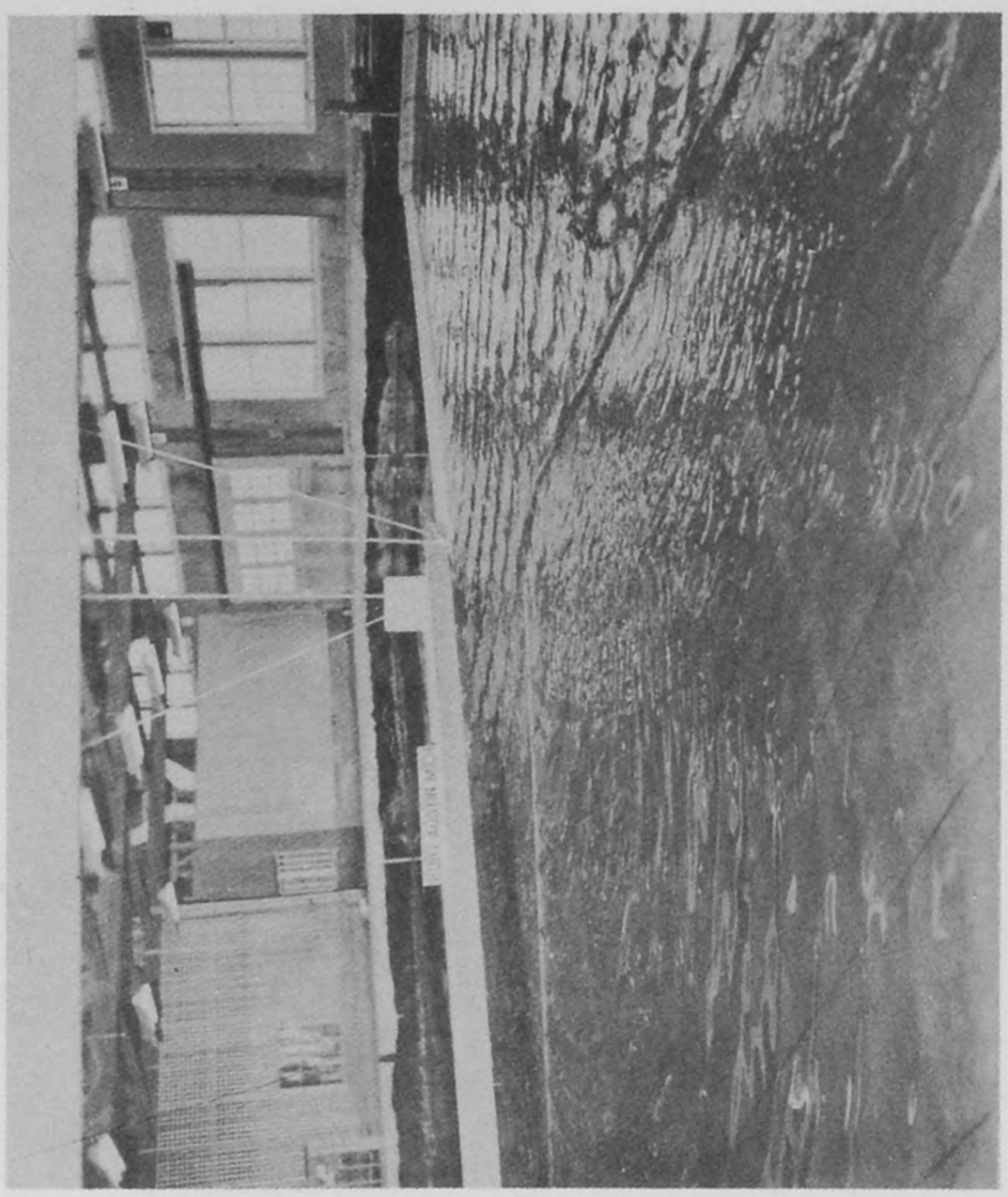


WAVE MACHINE

INSTRUMENTS

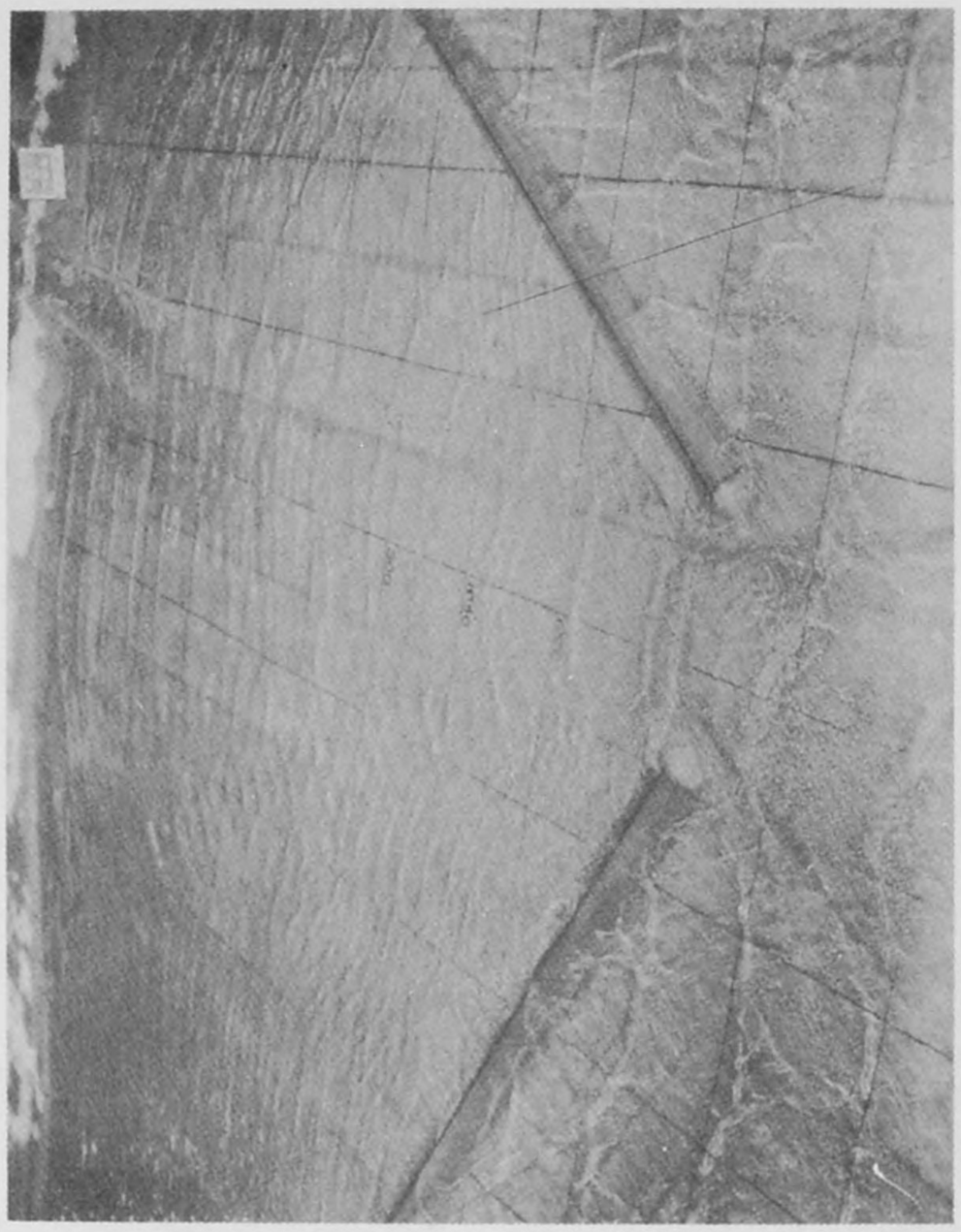
PORT AUSTIN, MICHIGAN
HARBOR MODEL
PLATE 1

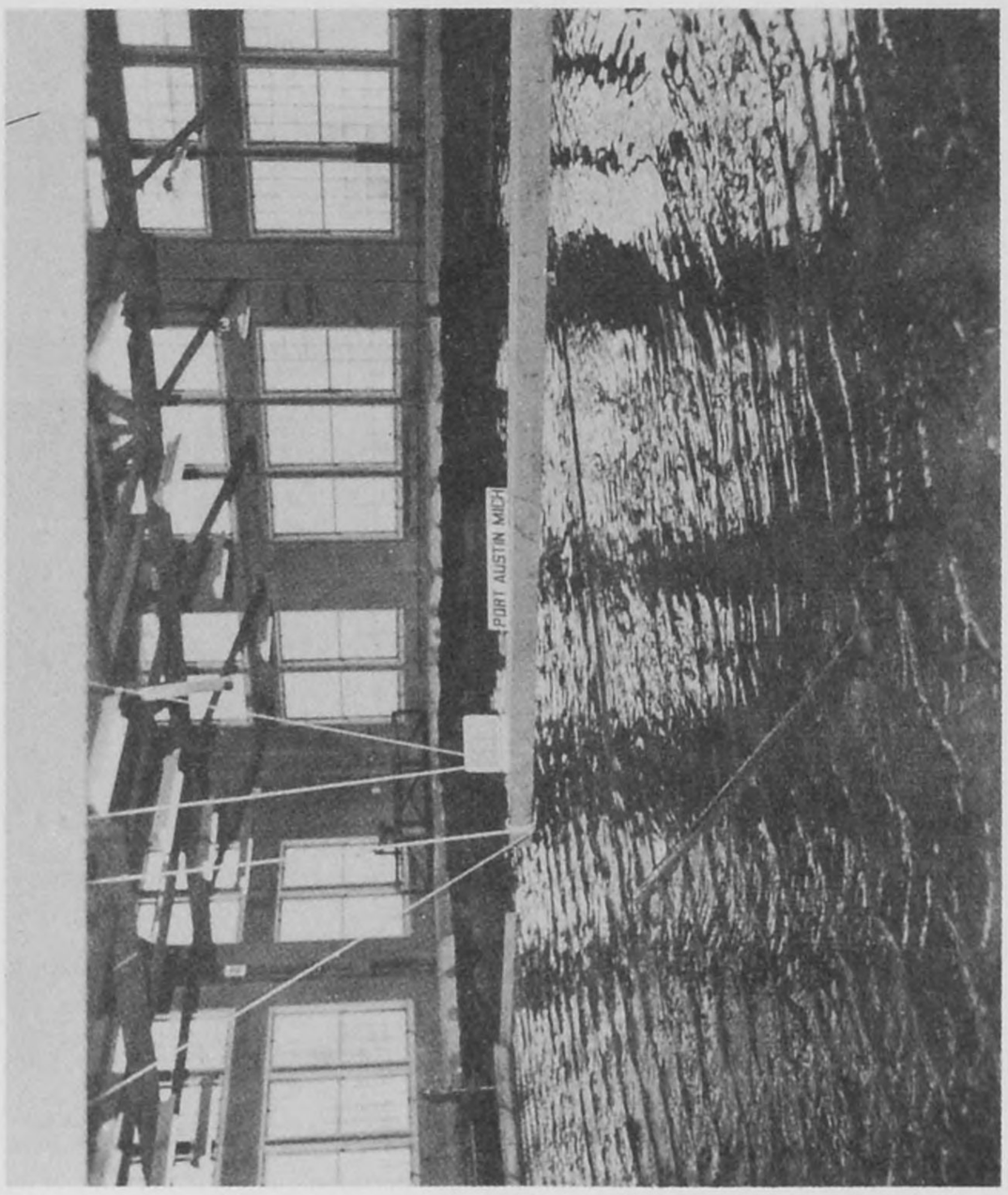




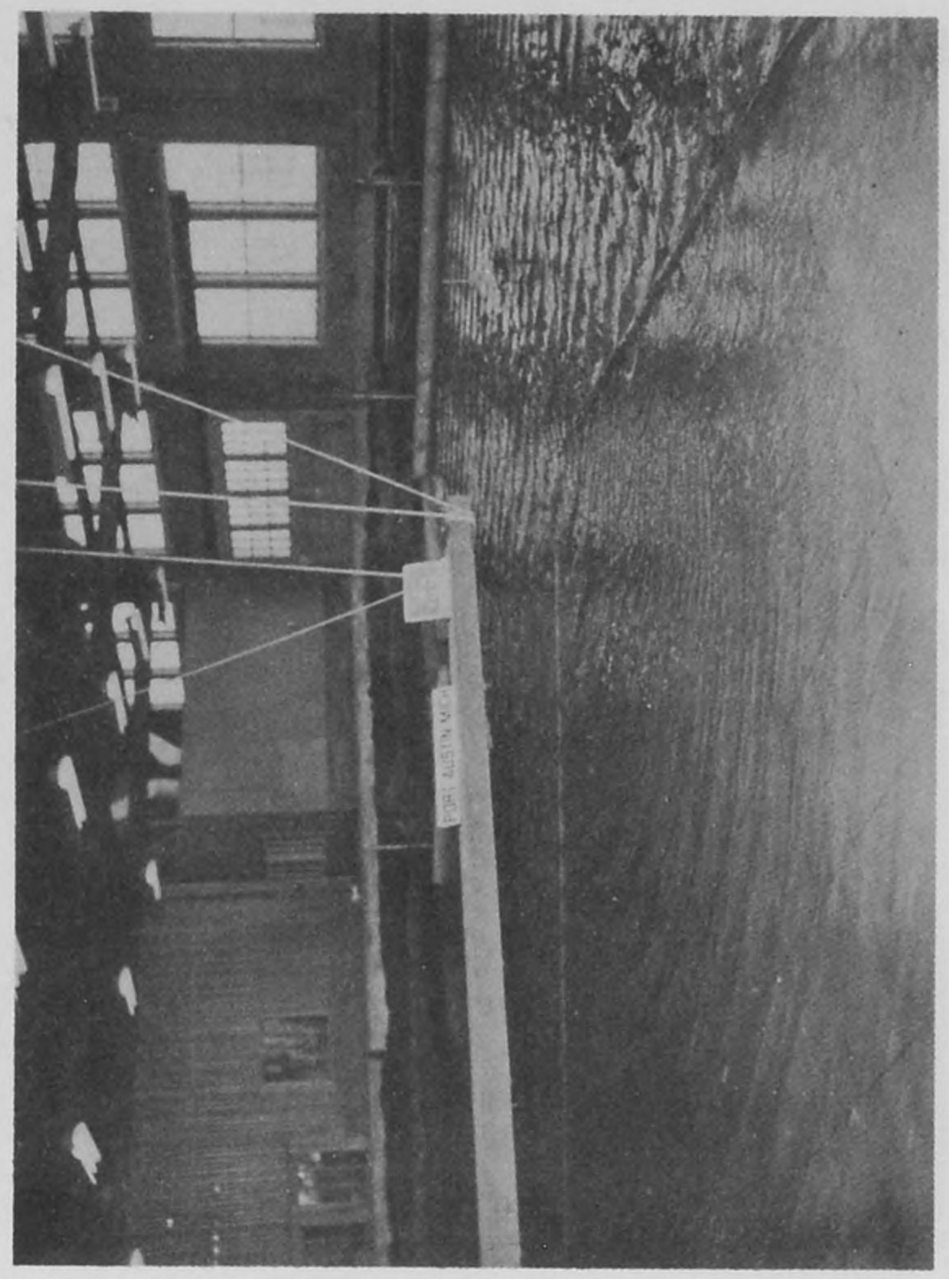
WIND

PLAN 1 - NORTH

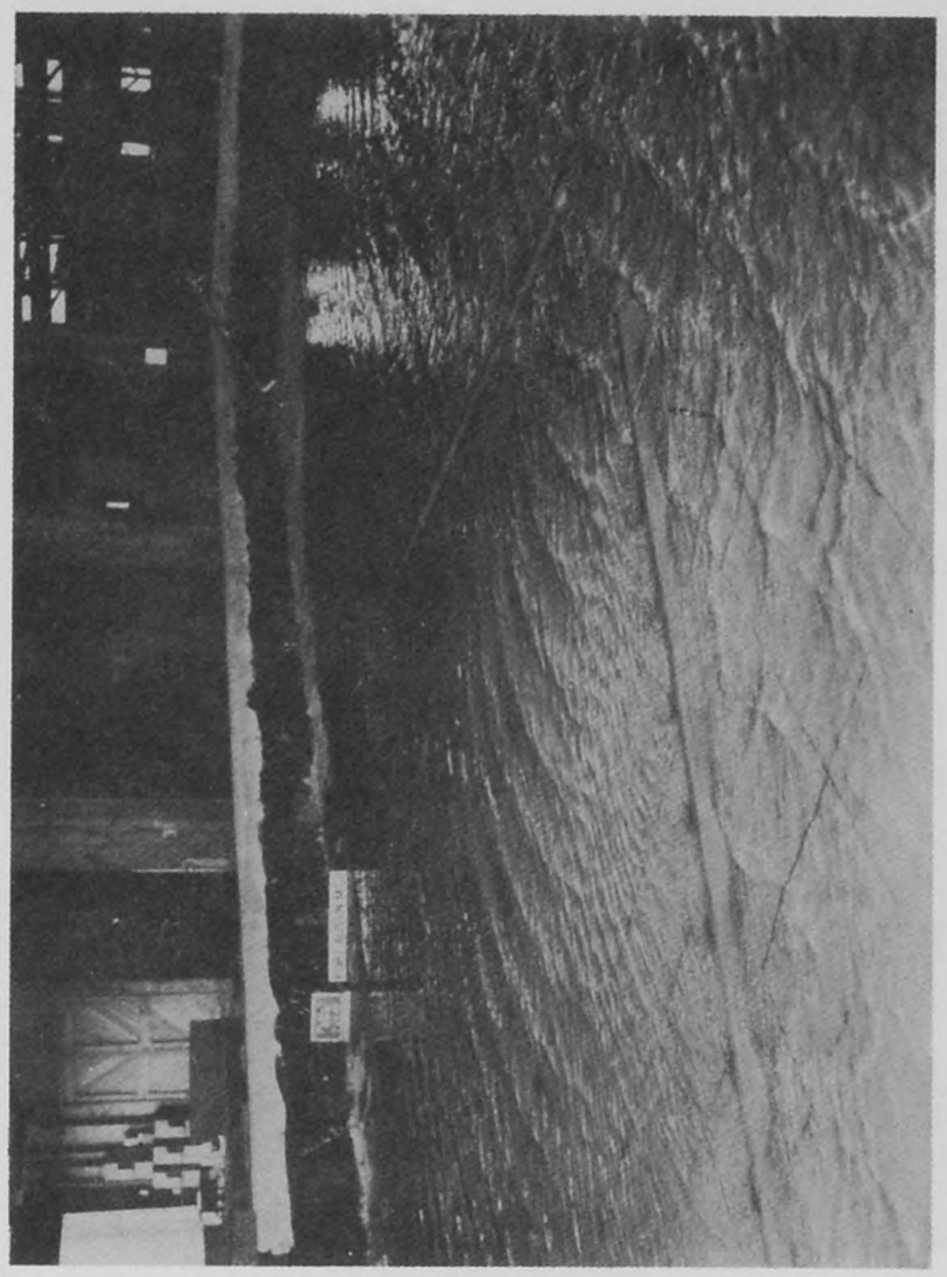




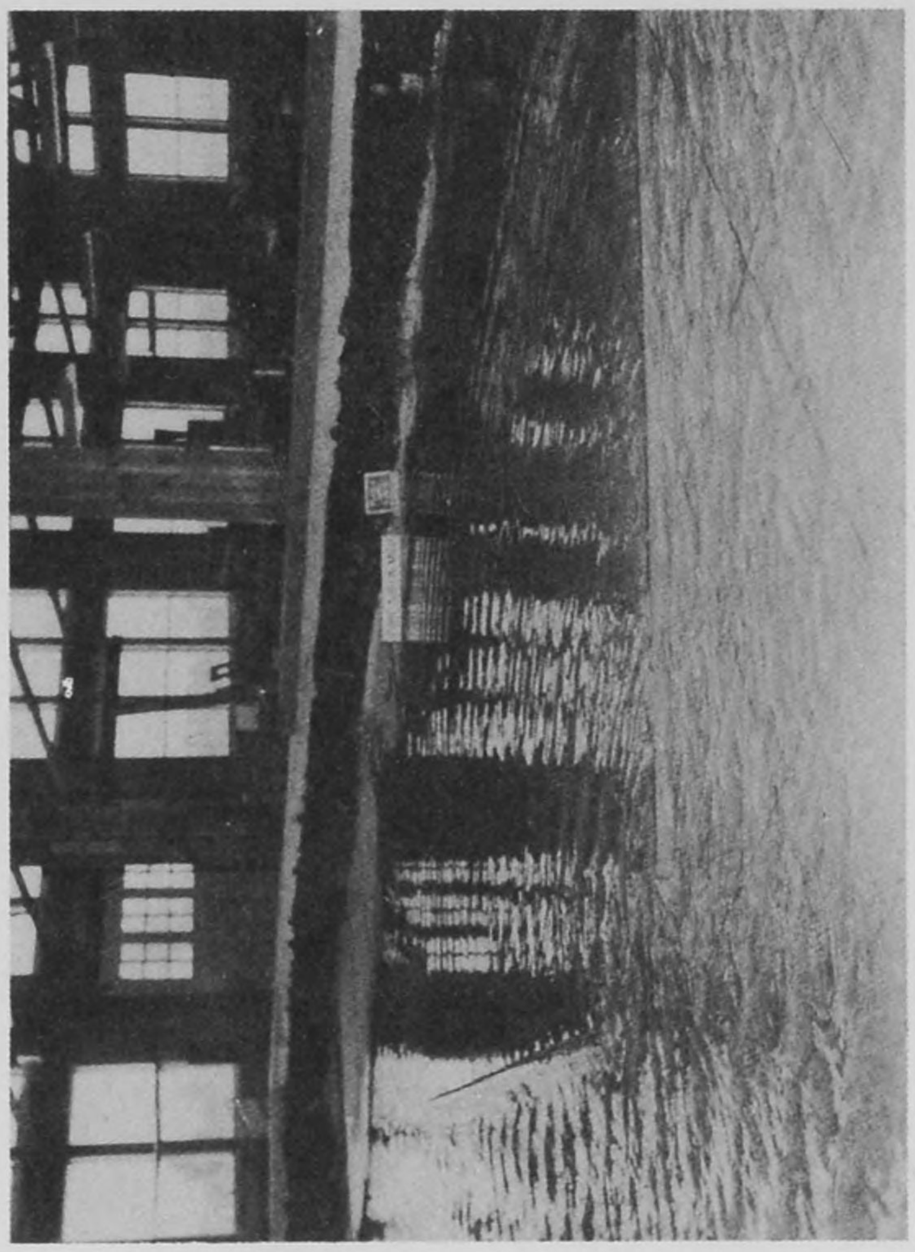
PORT AUSTIN, MICHIGAN
HARBOR MODEL
PLATE 2

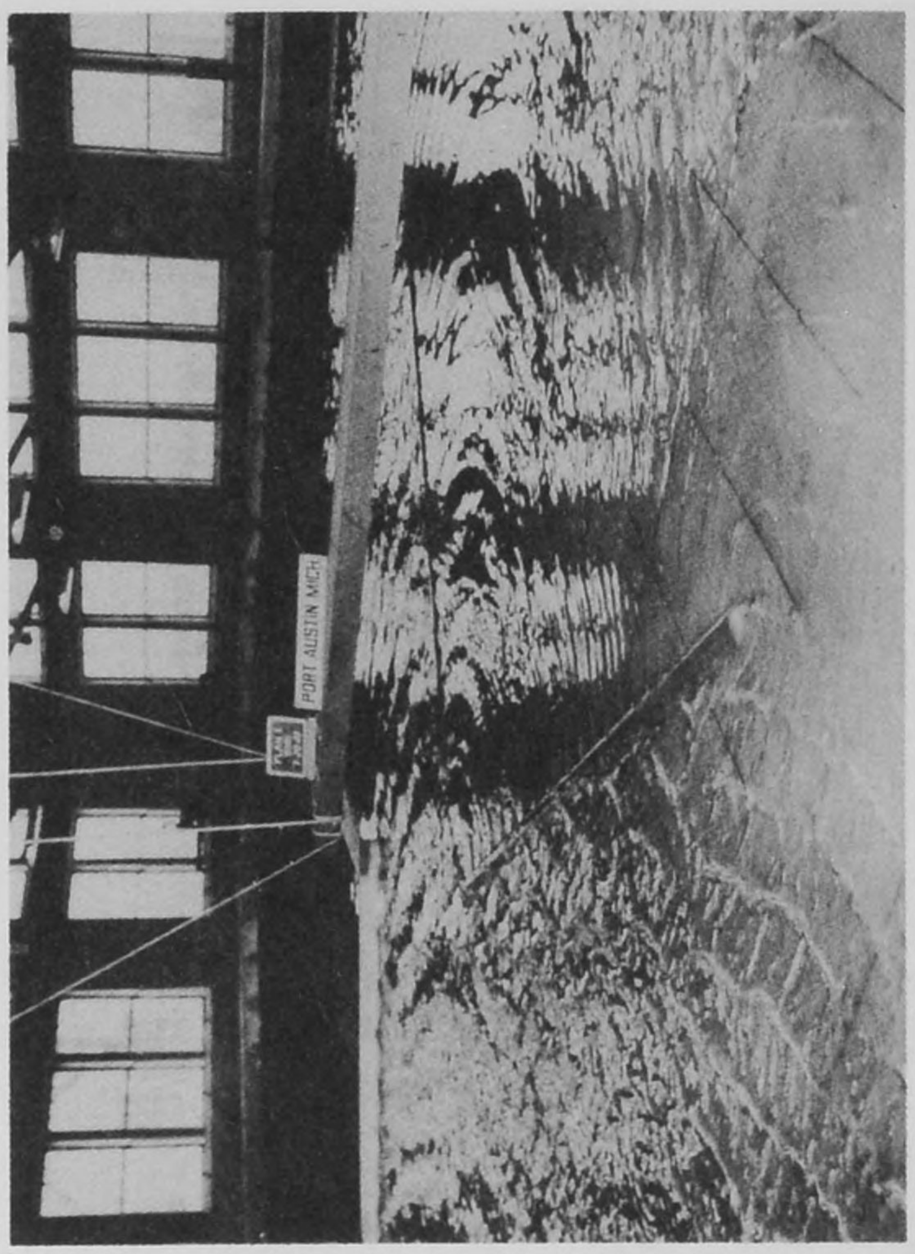


PLAN 1 - NORTHWEST-NORTH WIND

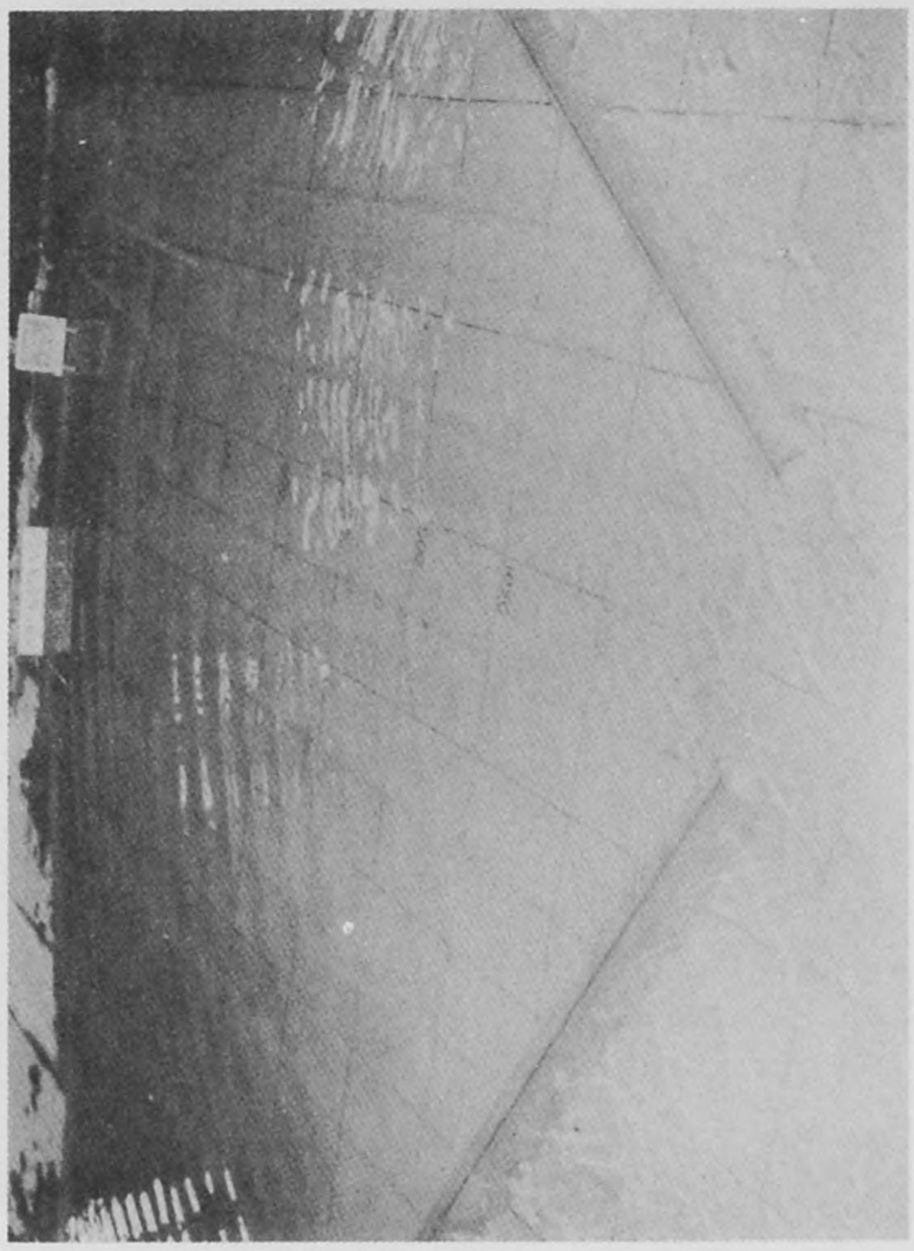


PORT AUSTIN, MICHIGAN
HARBOR MODEL
PLATE 3

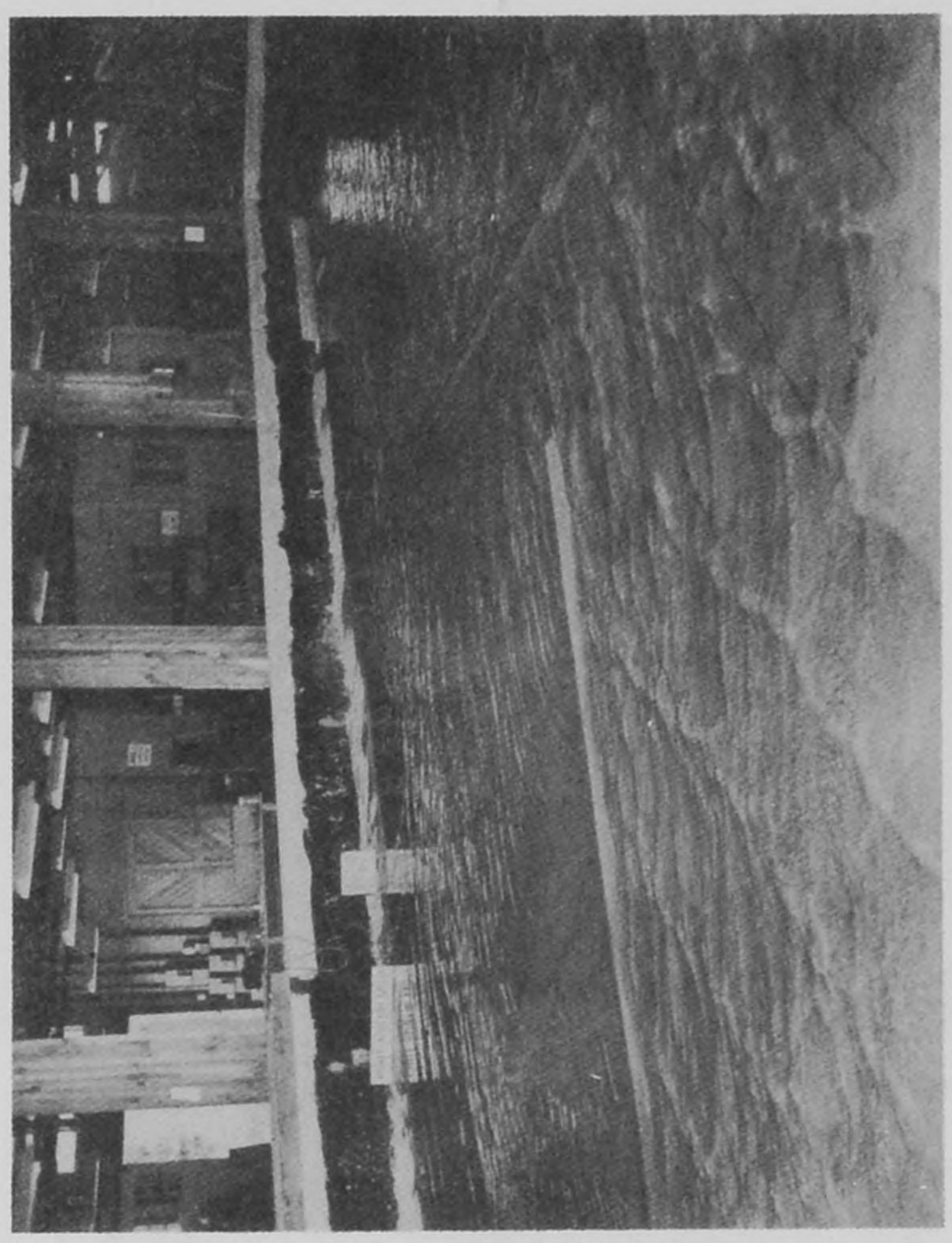




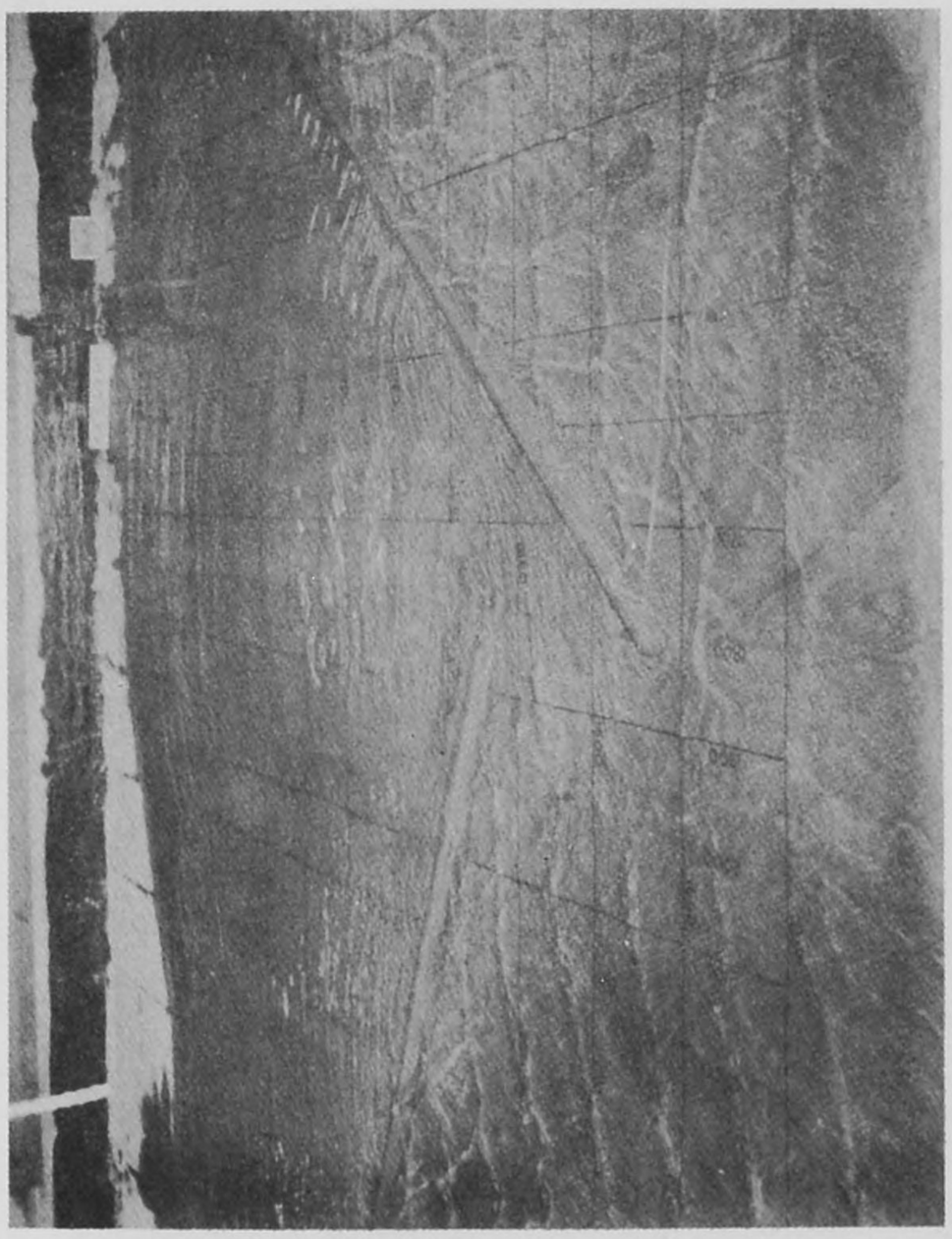
PLAN 1 - WEST-NORTHWEST WIND

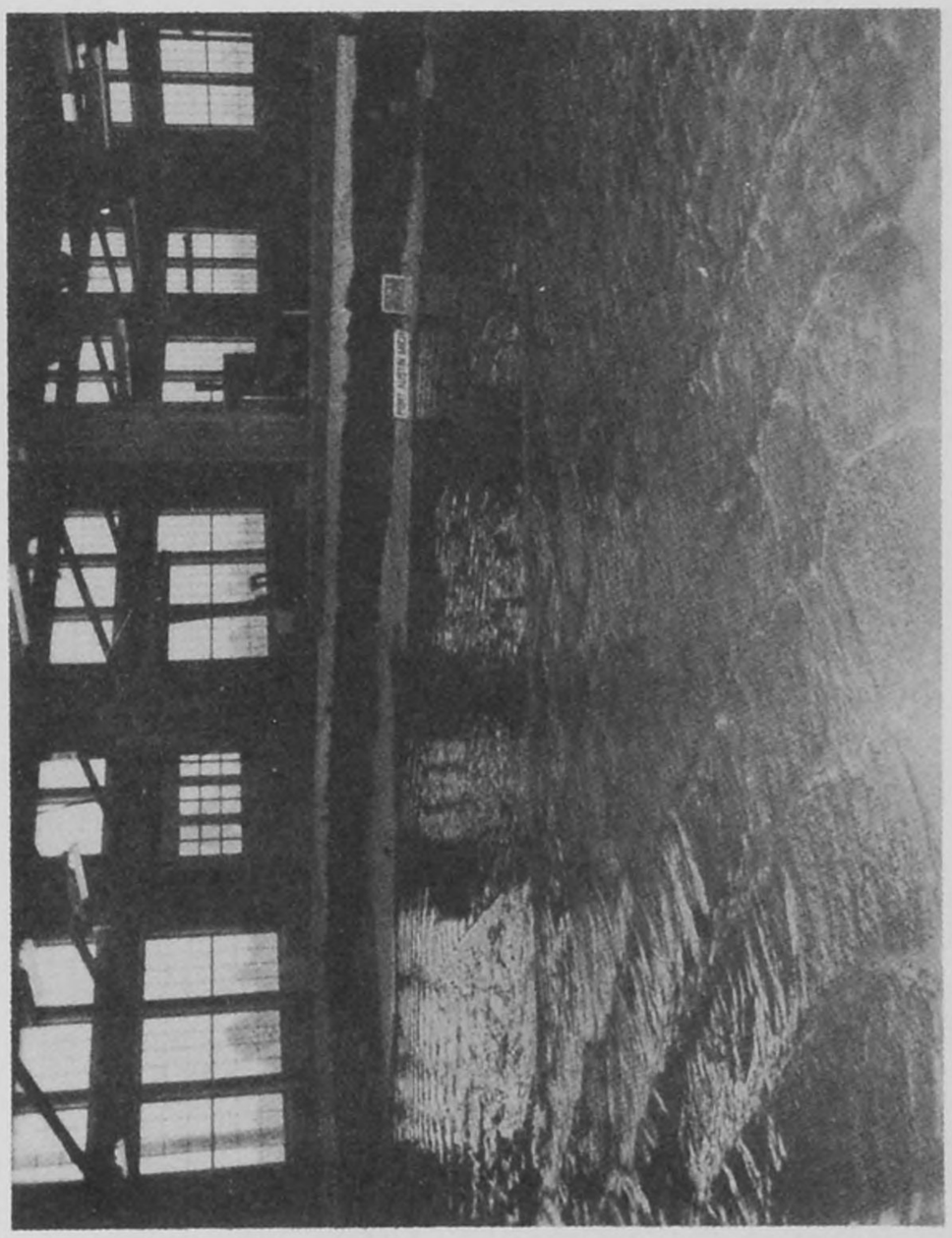


PORT AUSTIN, MICHIGAN
HARBOR MODEL
PLATE 4

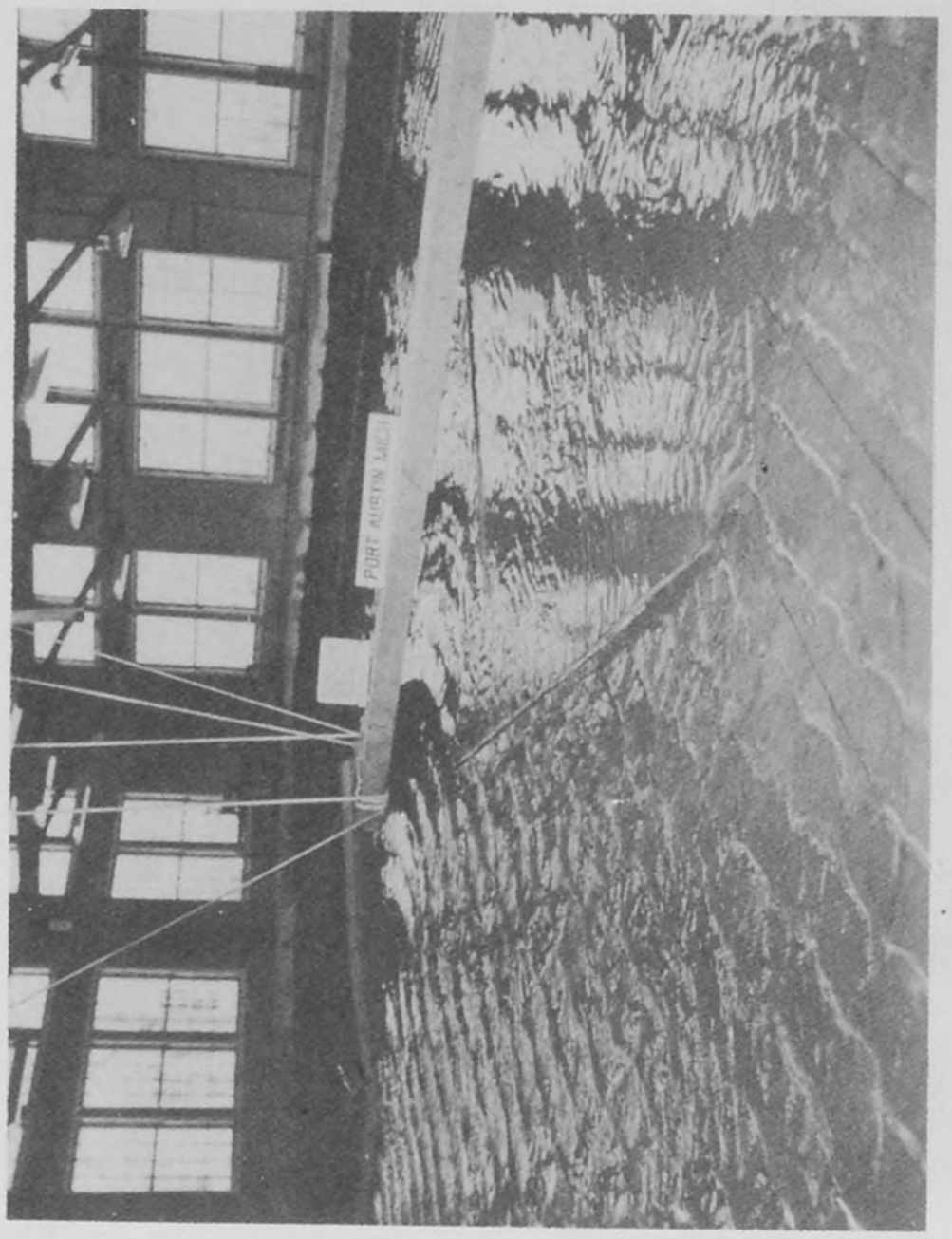


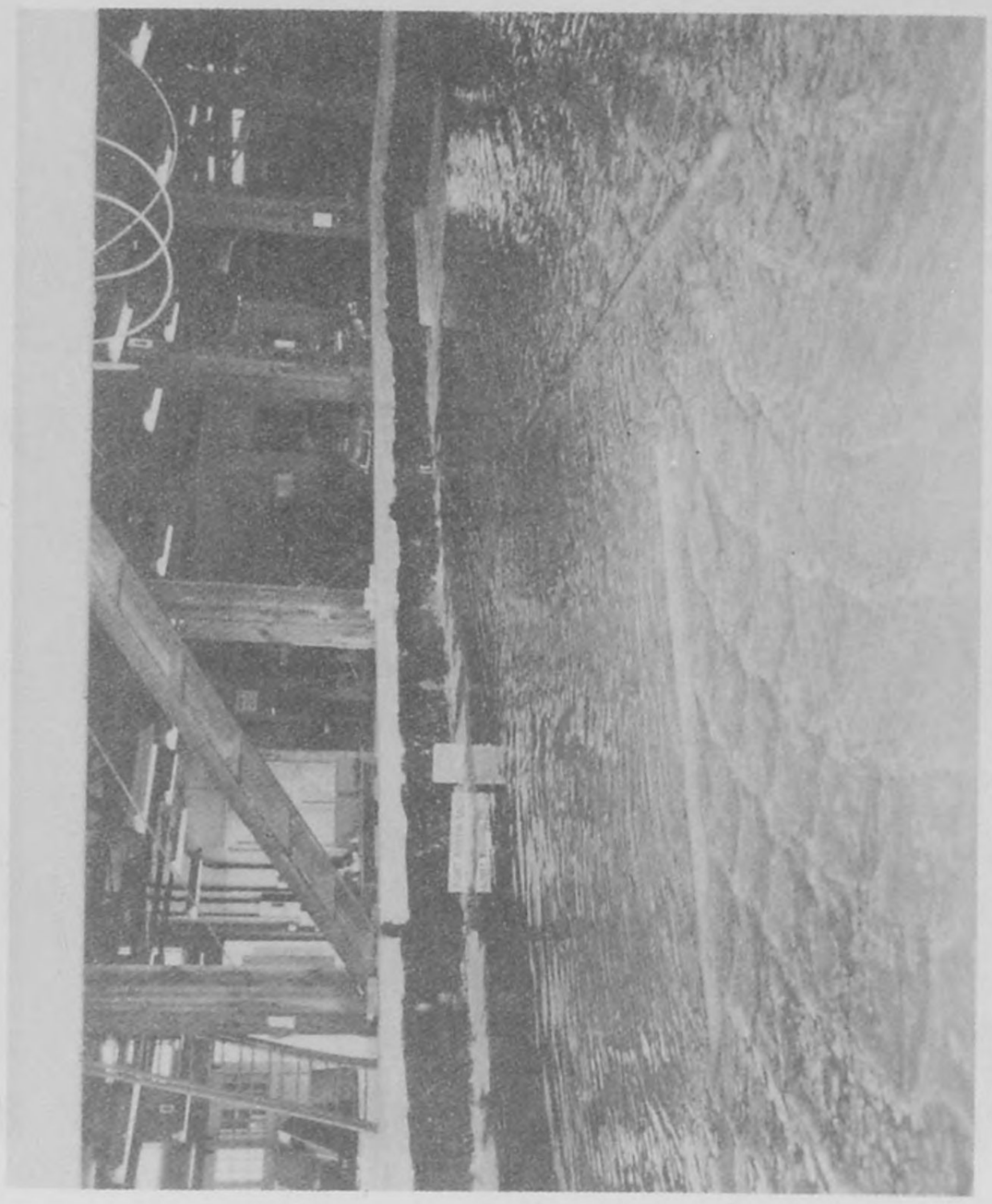
PLAN 2 - NORTH WIND



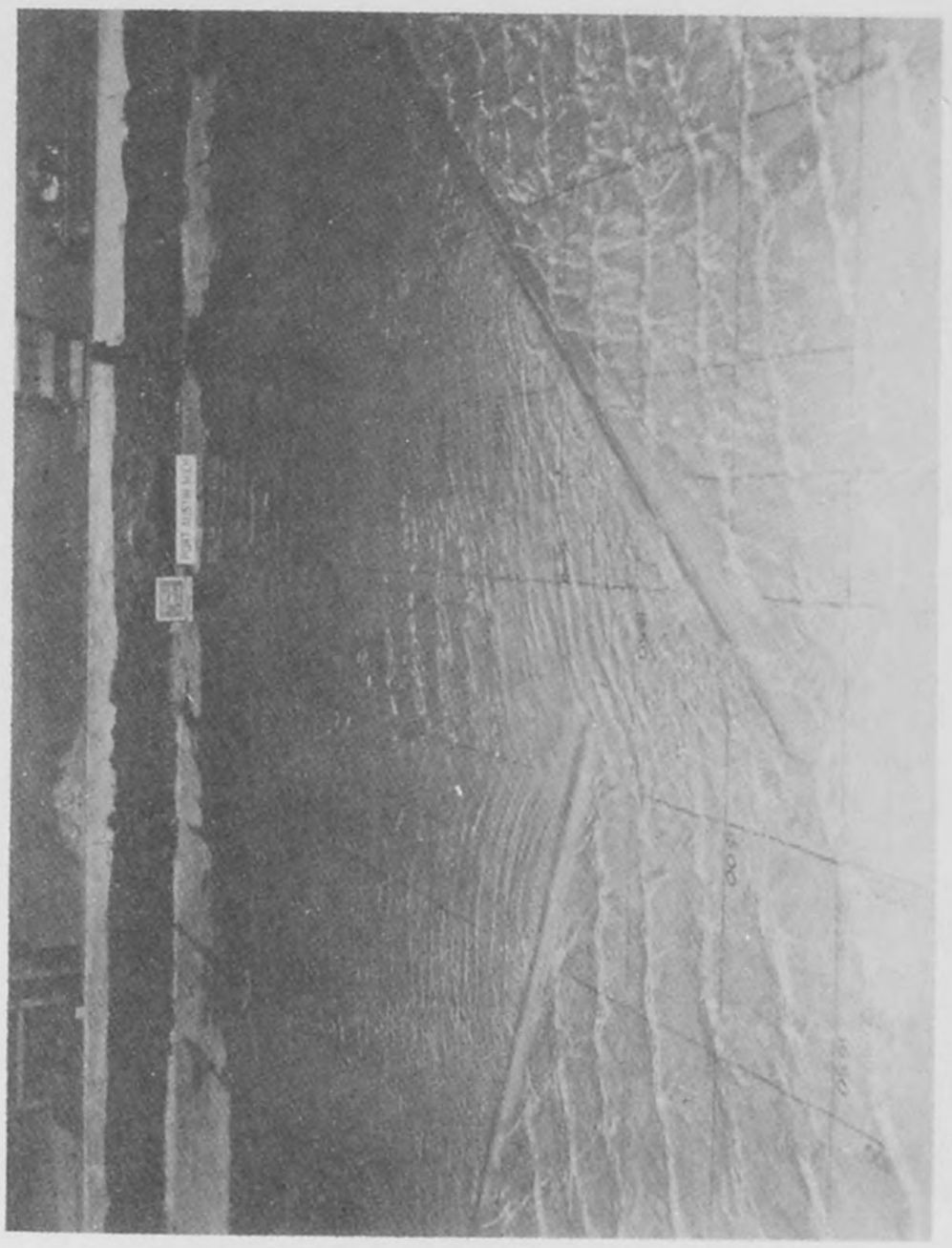


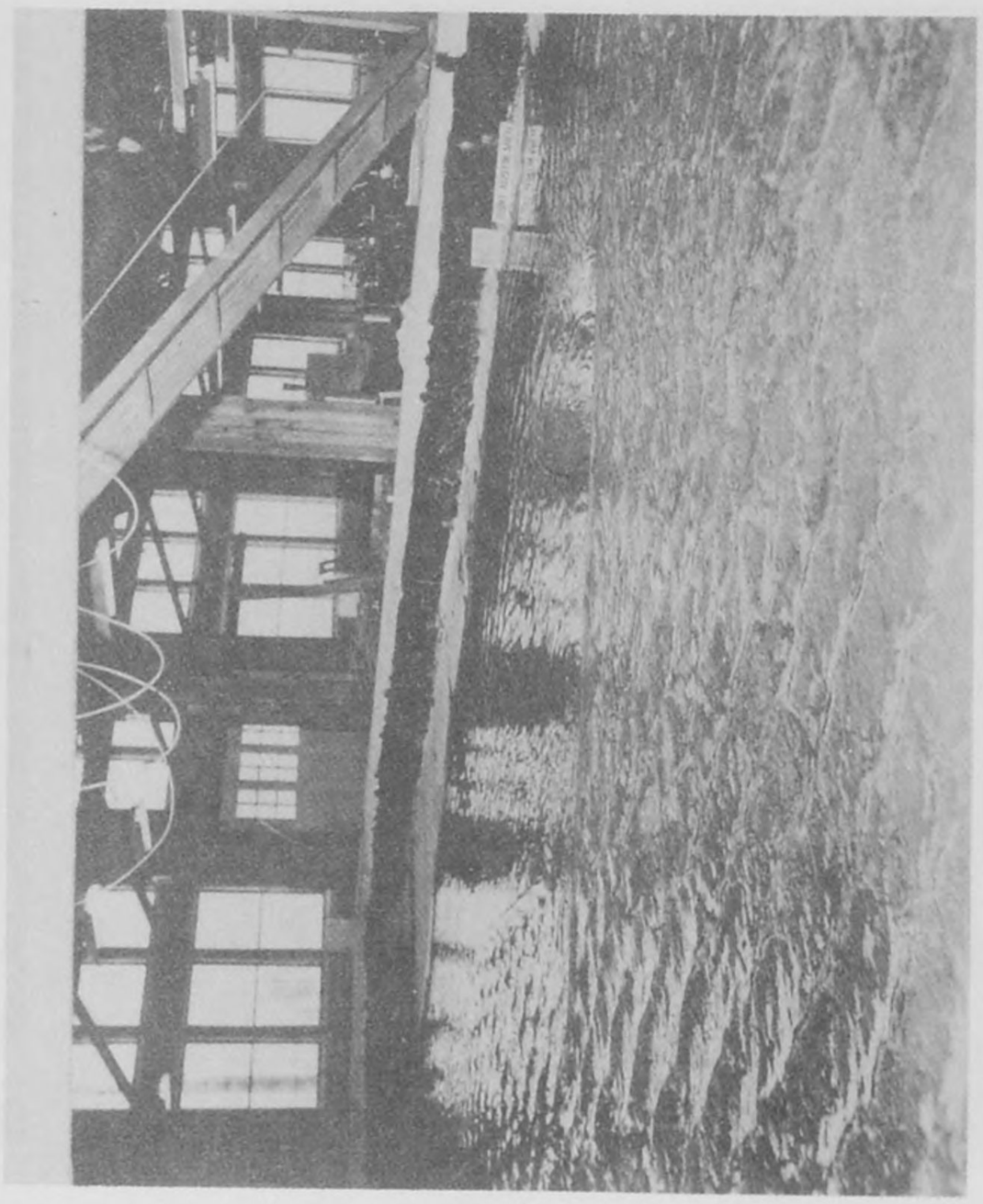
PORT AUSTIN, MICHIGAN
HARBOR MODEL
PLATE 5





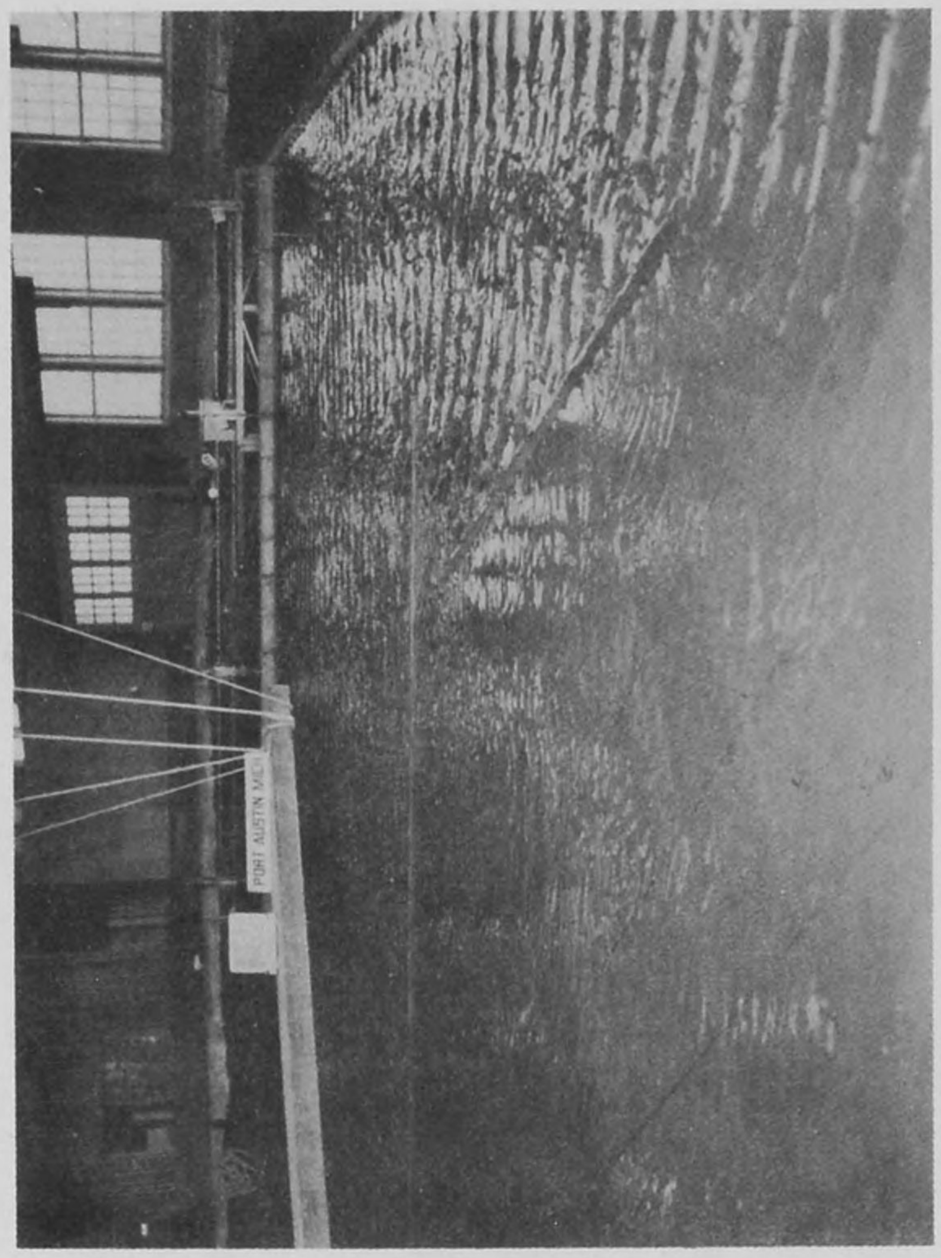
PLAN 1 - NORTHWEST WIND

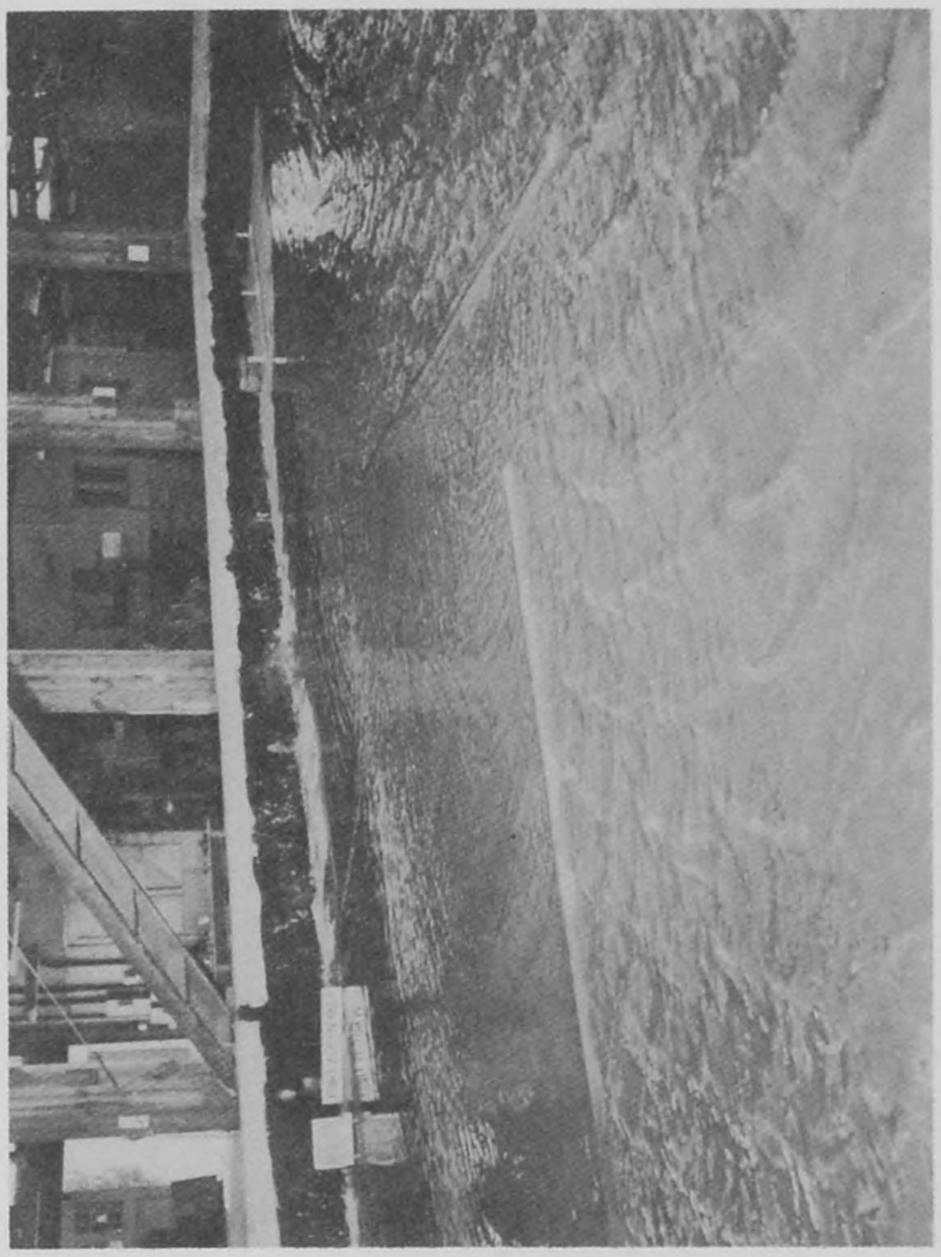




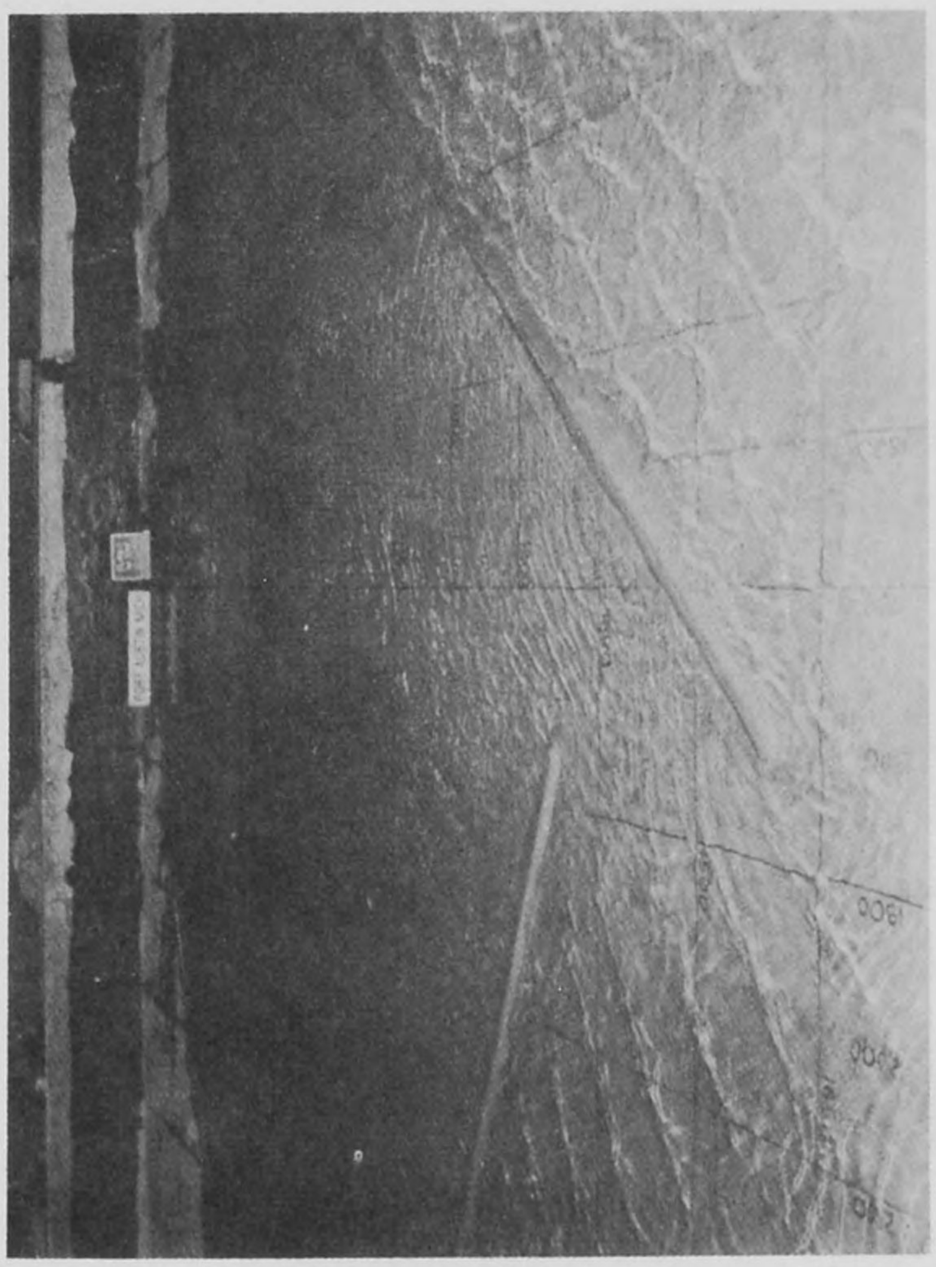
PLAN 2 - NORTHWEST WIND

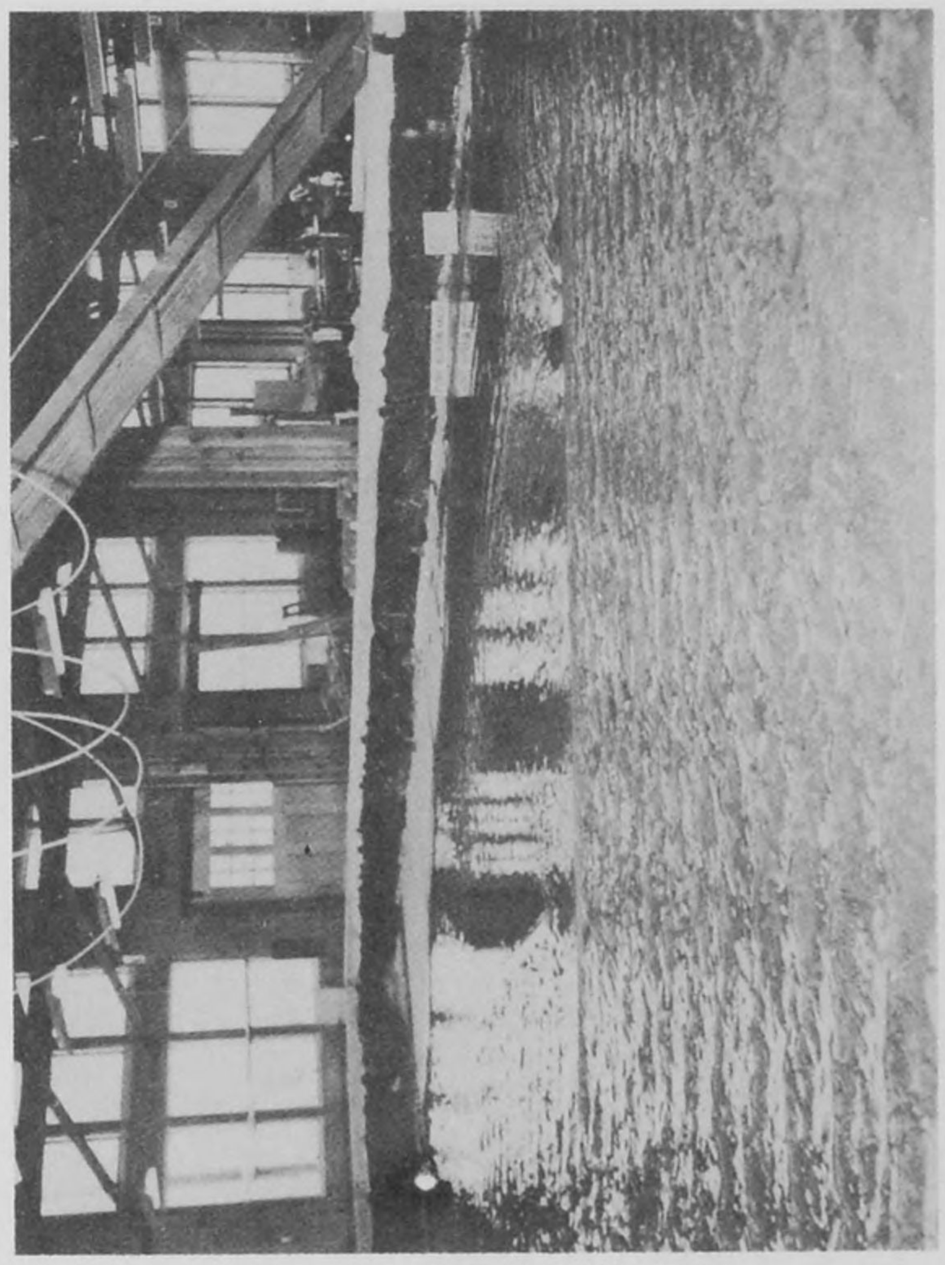
PORT AUSTIN, MICHIGAN
HARBOR MODEL
PLATE 6



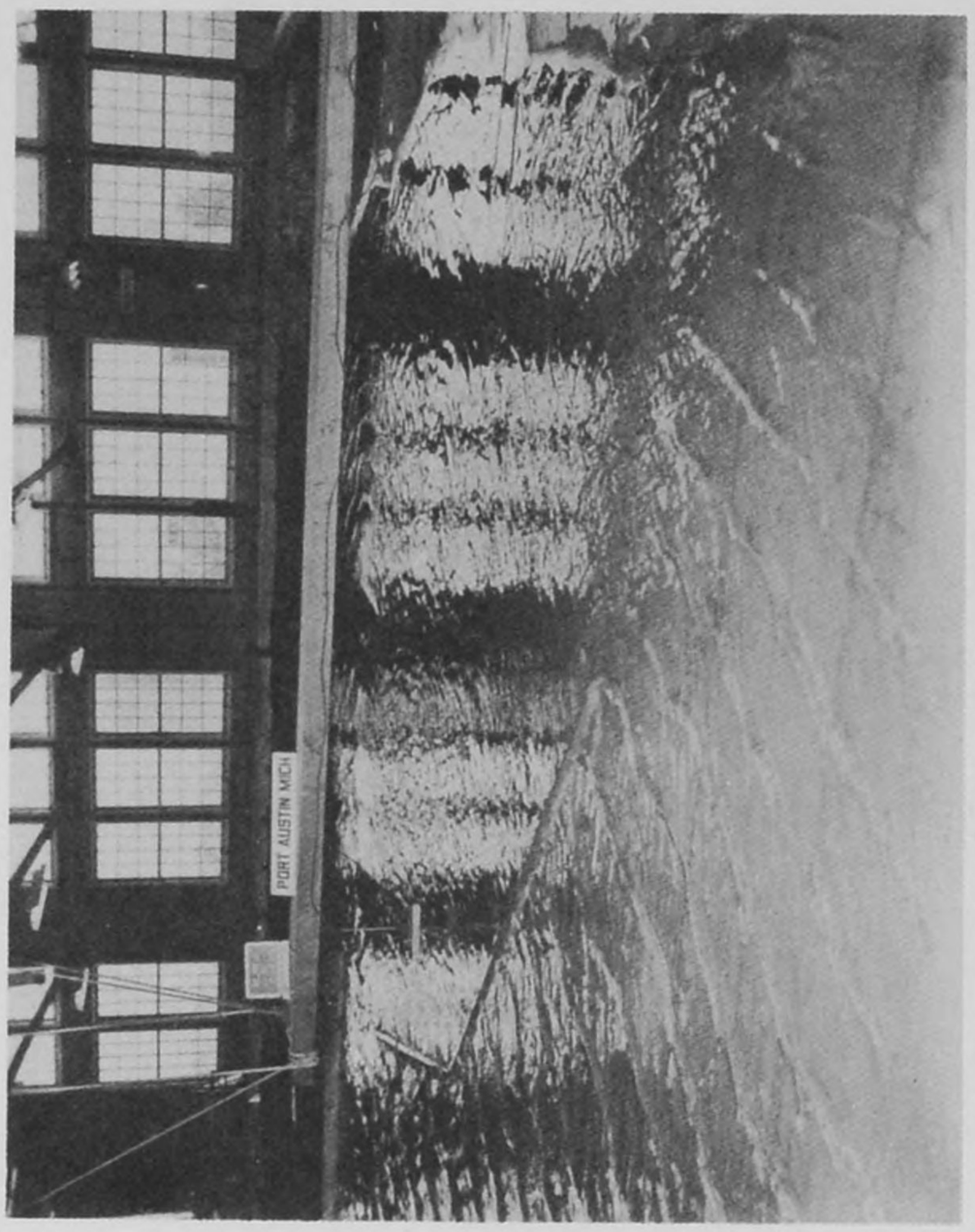


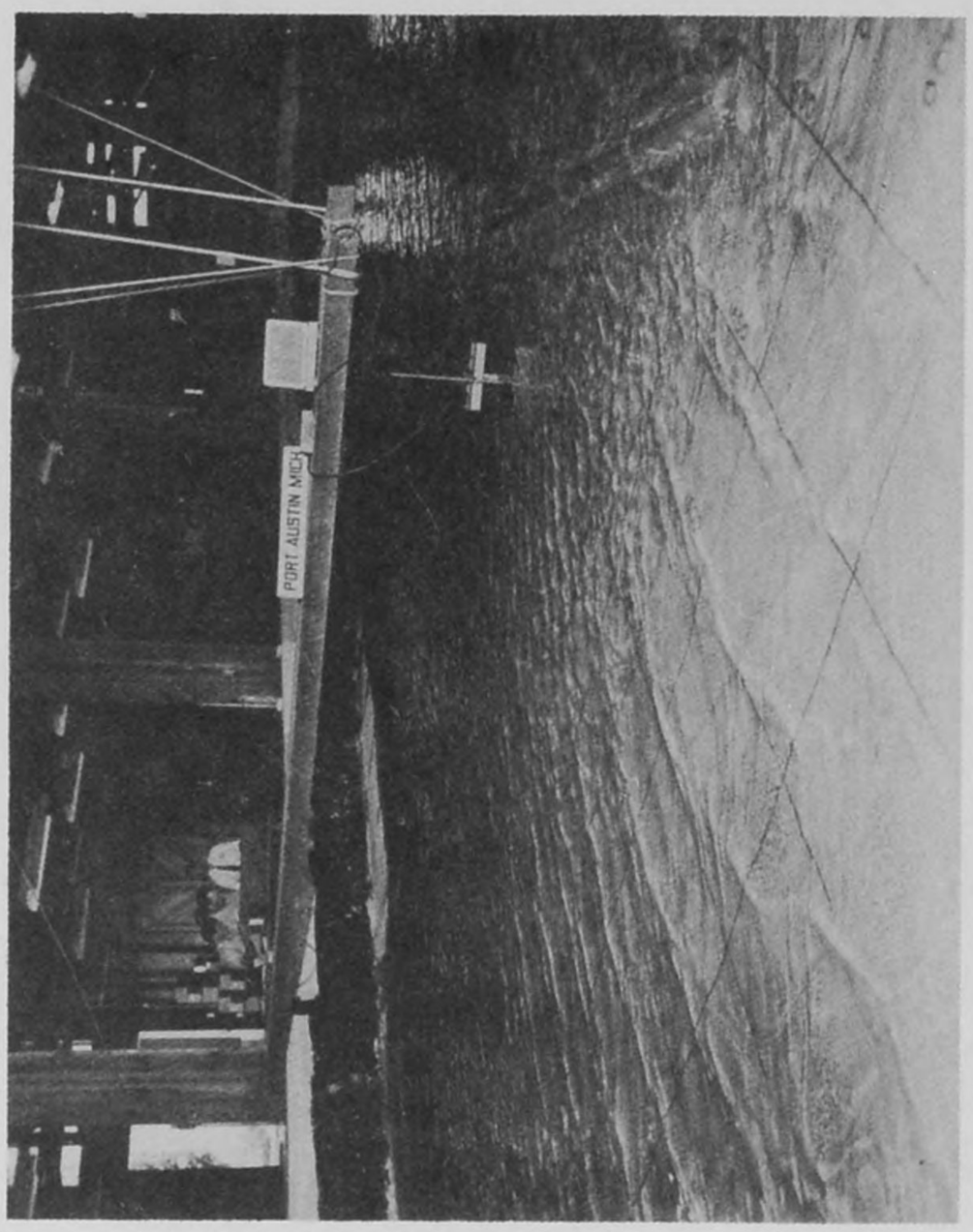
PLAN 2 - WEST-NORTHWEST WIND



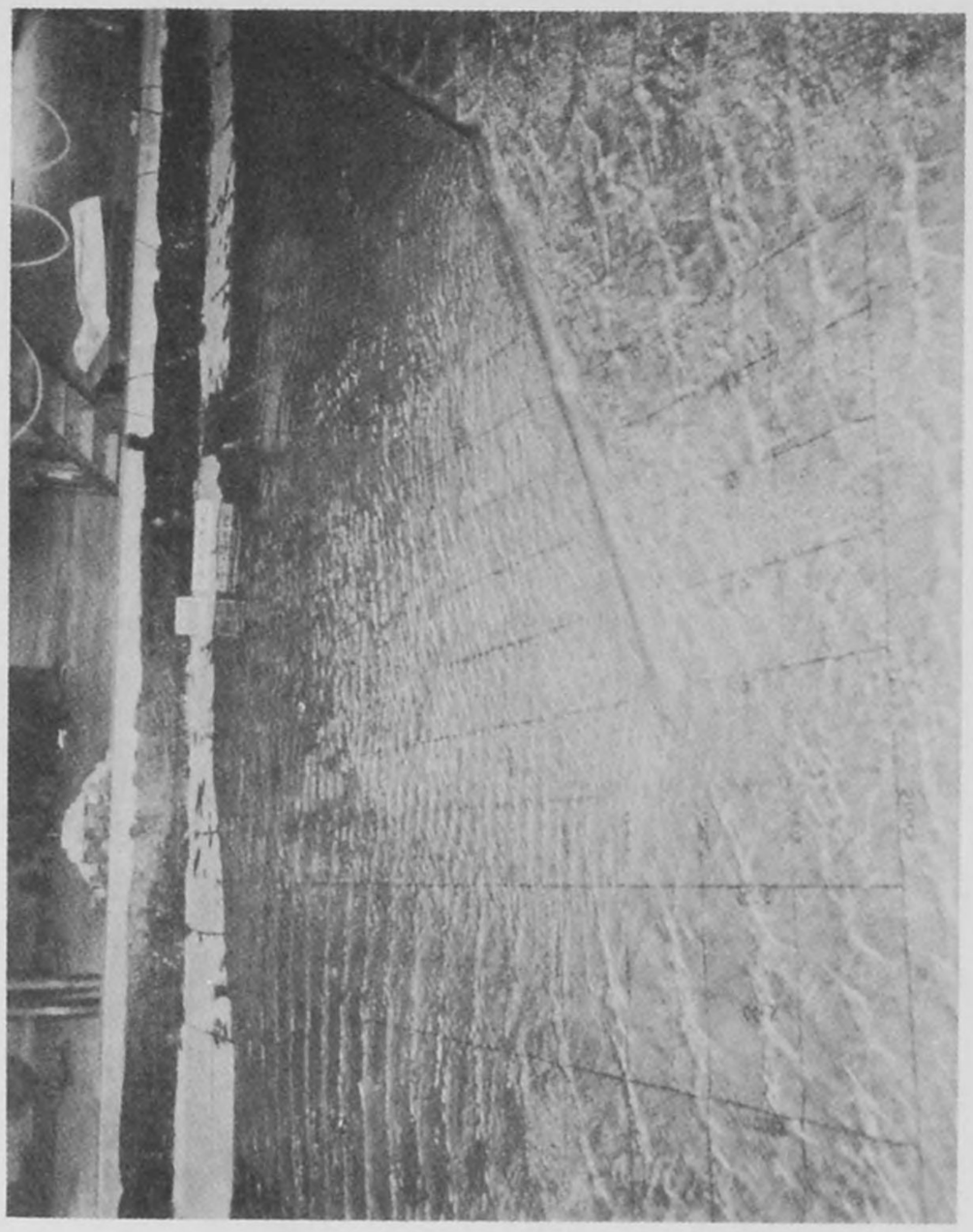


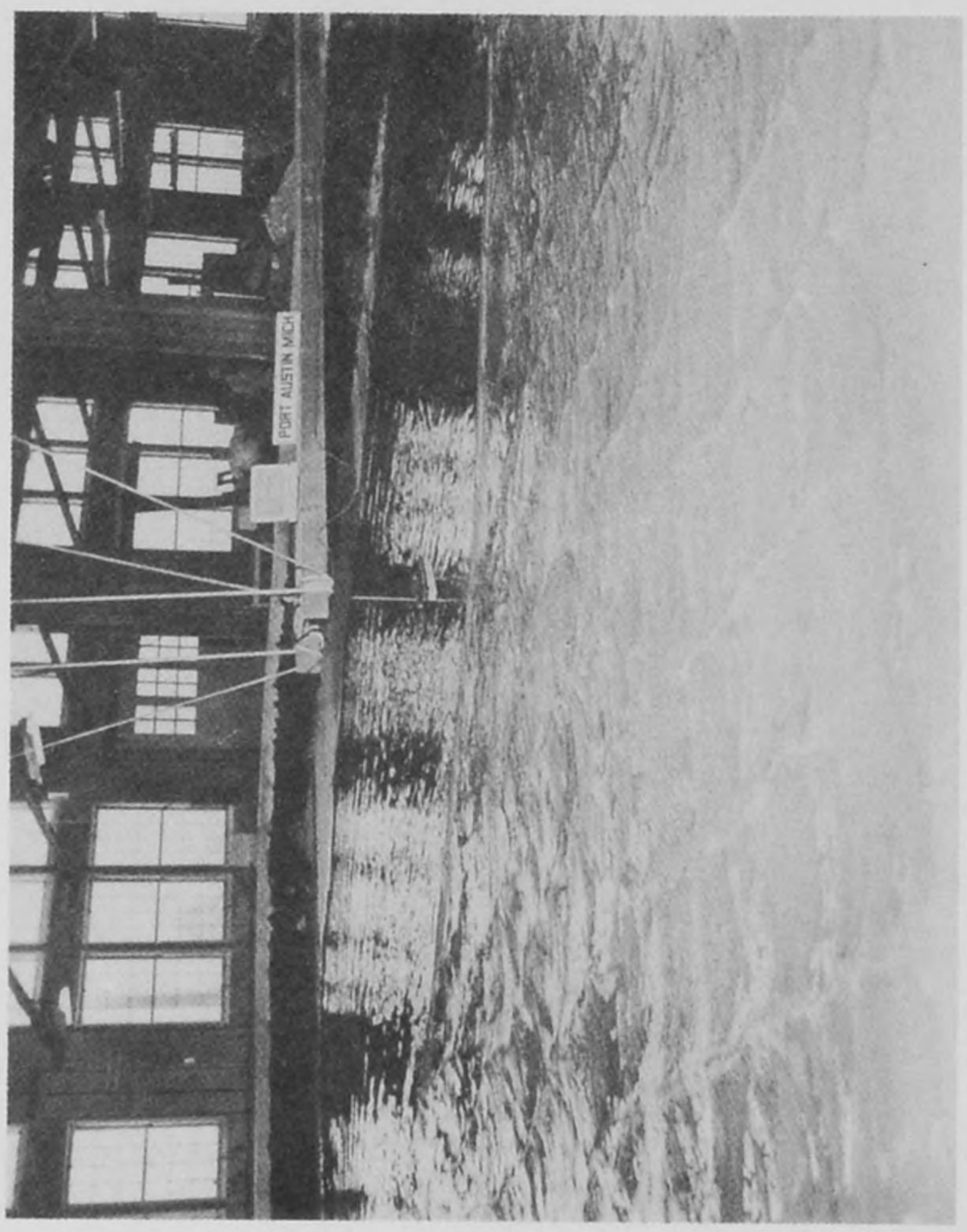
PORT AUSTIN, MICHIGAN
HARBOR MODEL
PLATE 7



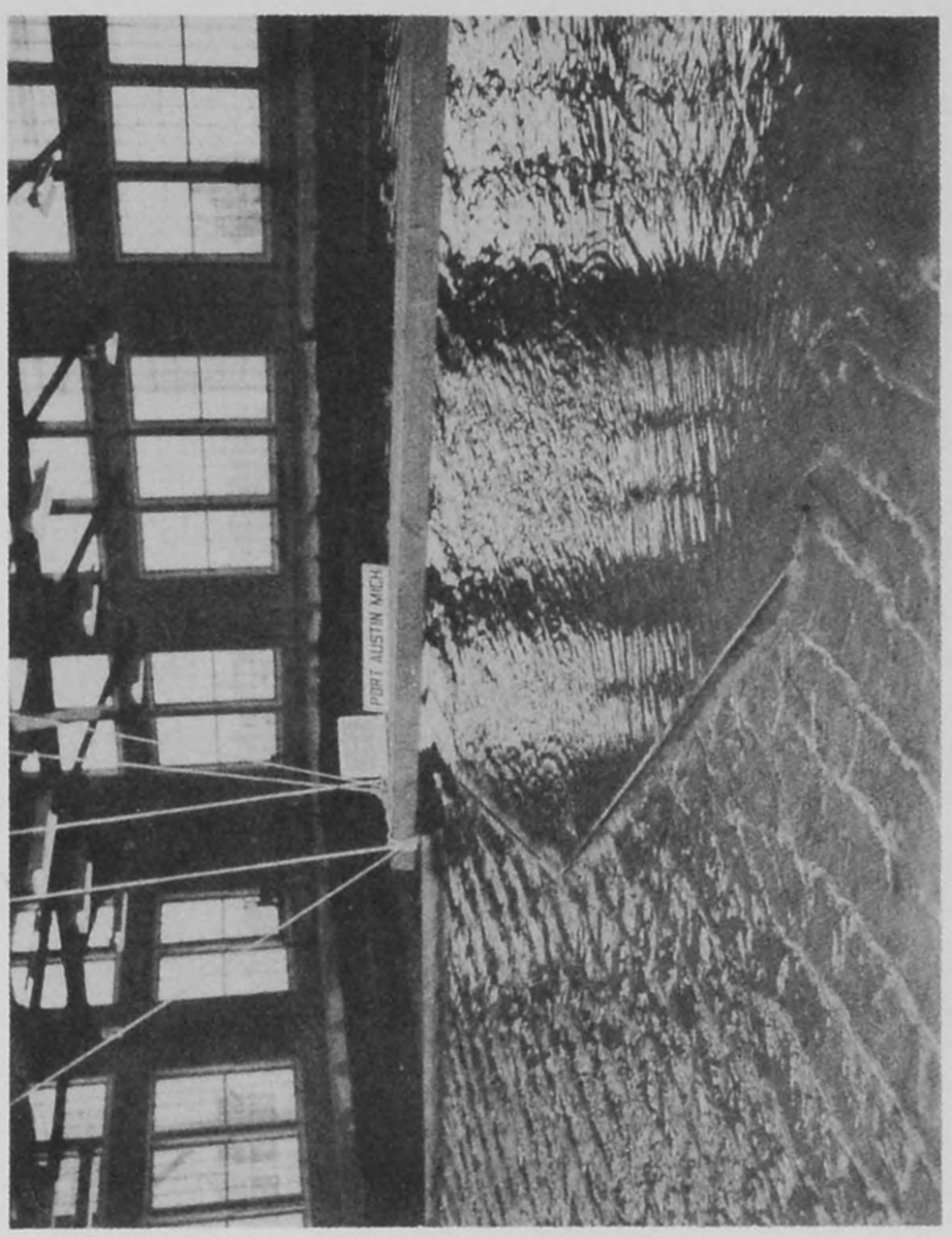


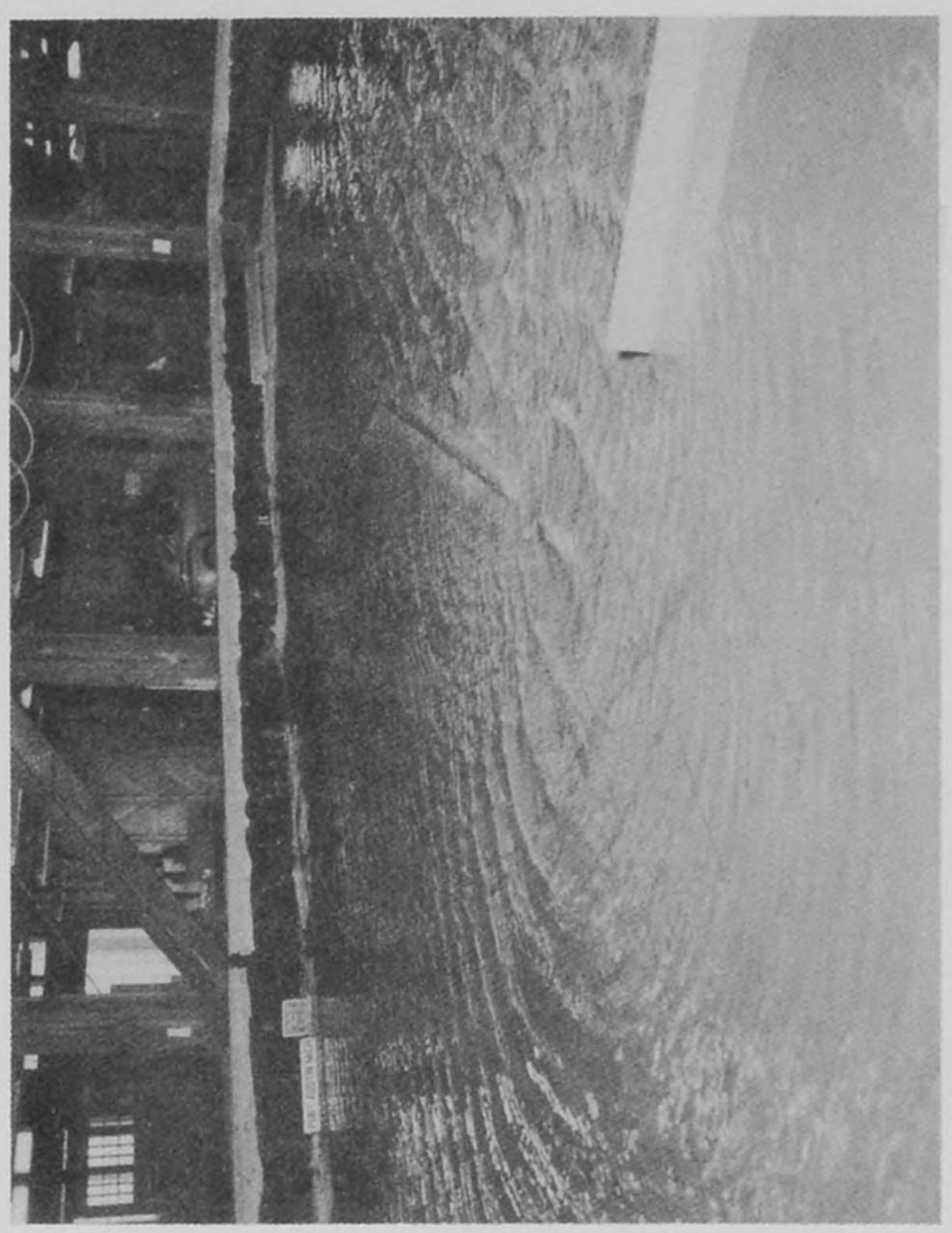
PLAN 3 - NORTH WIND

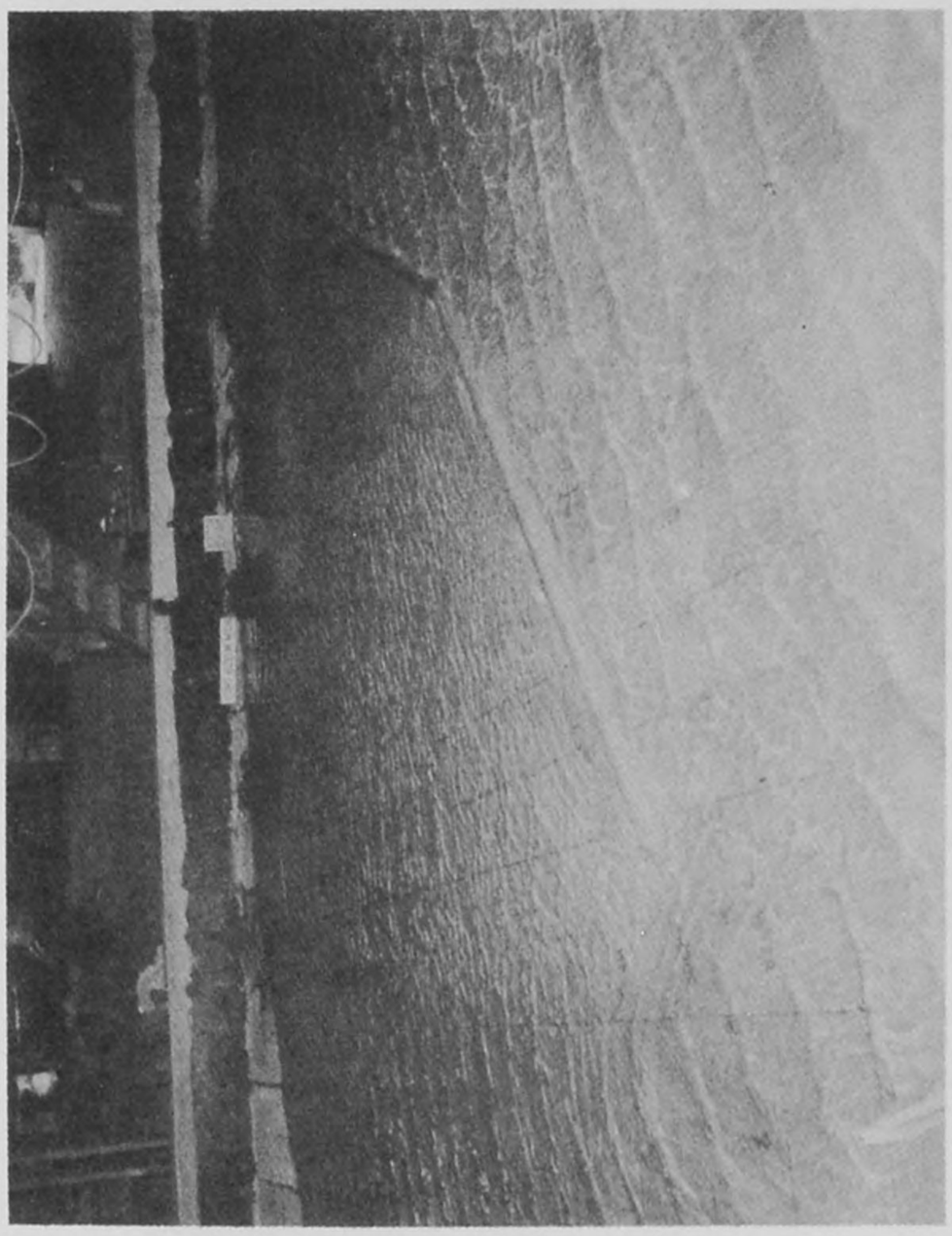


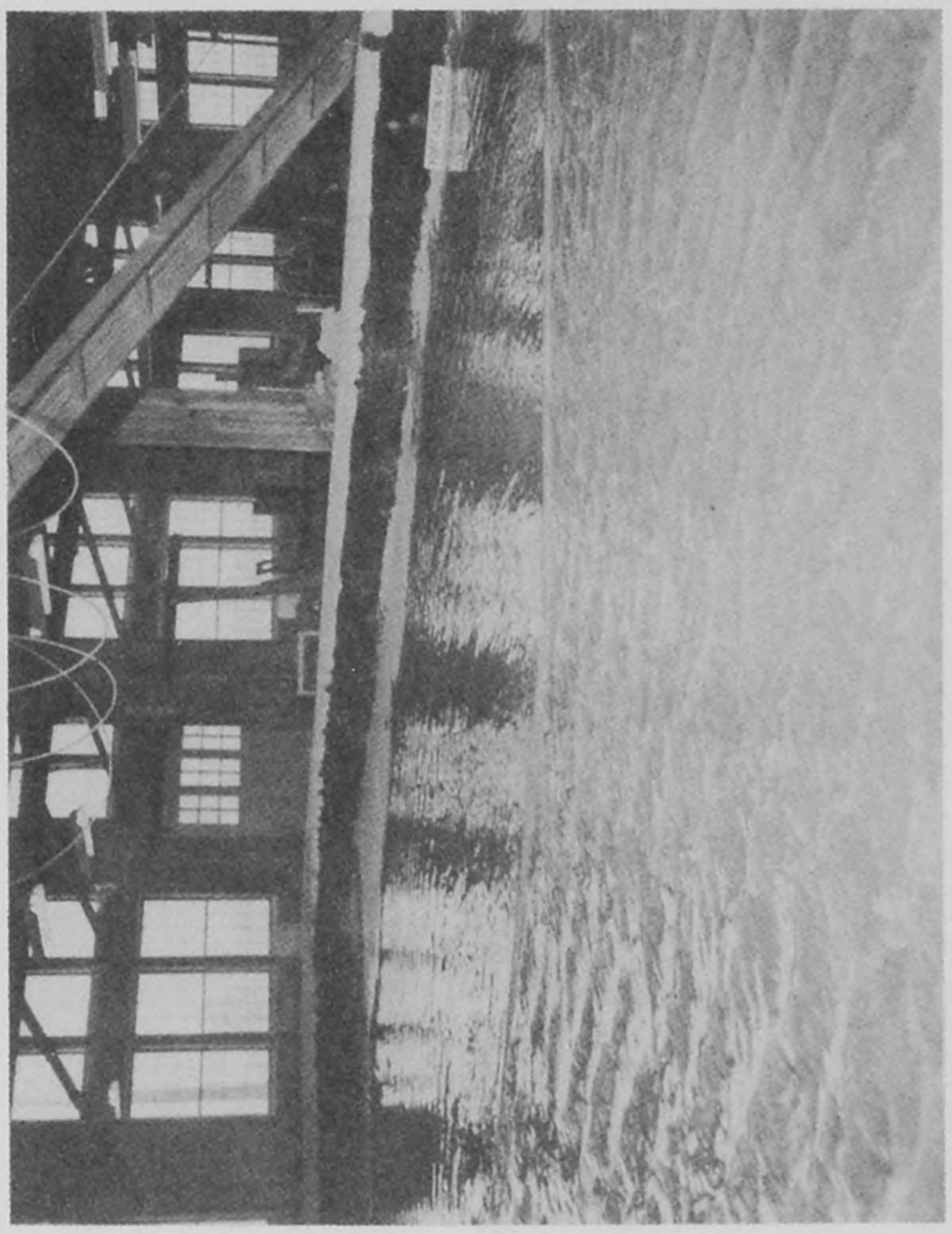


PORT AUSTIN, MICHIGAN
HARBOR MODEL
PLATE 8



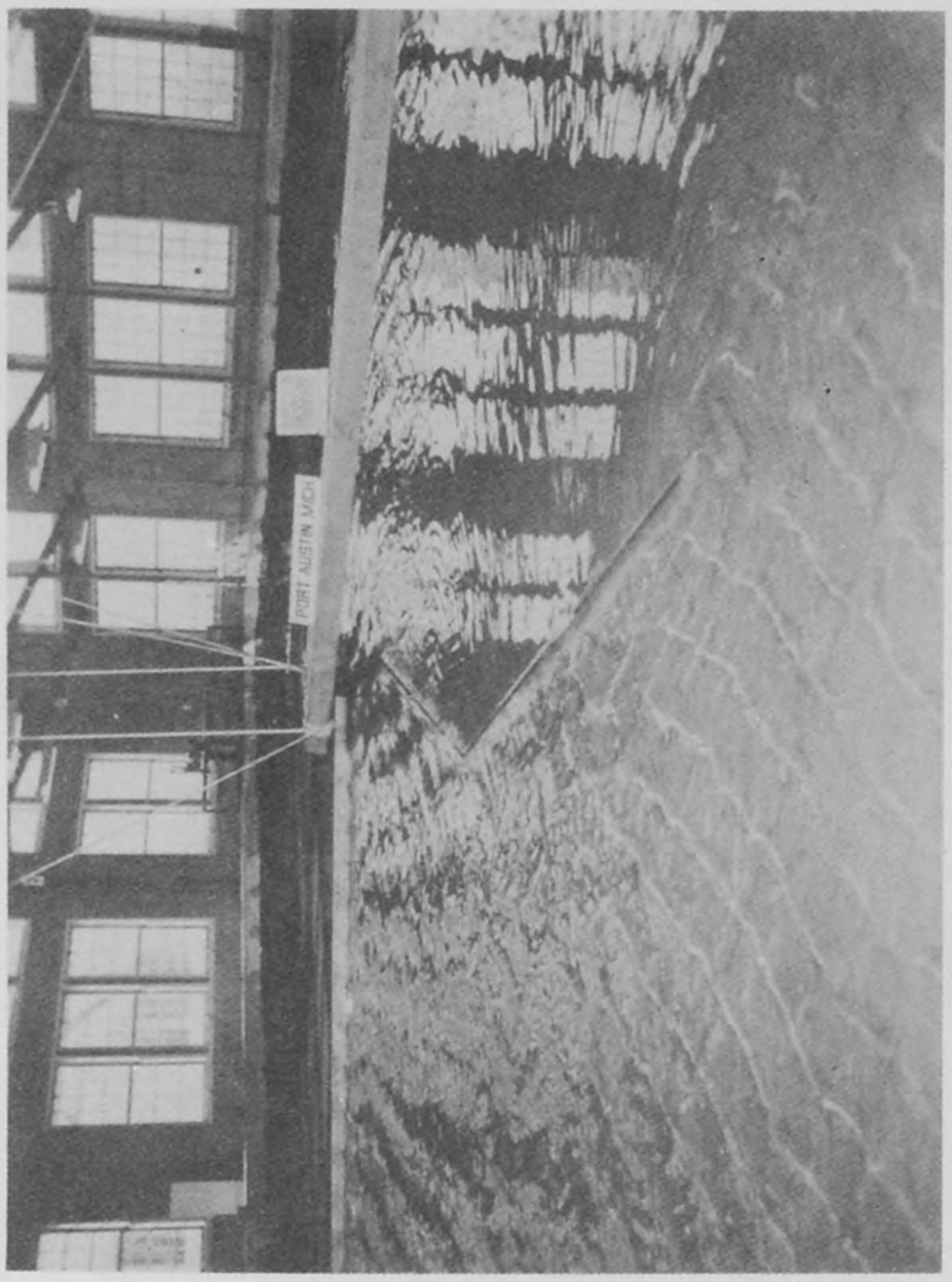


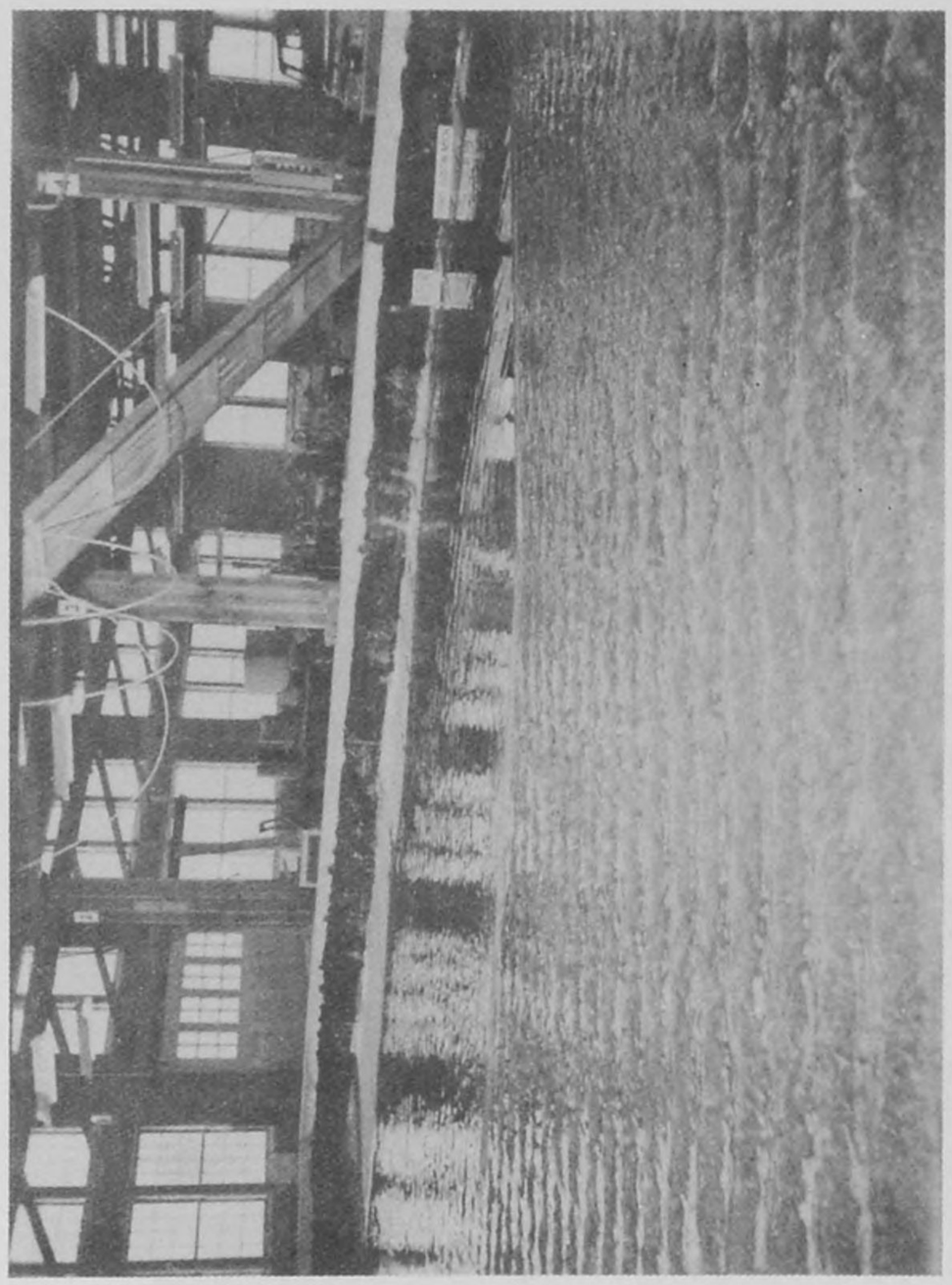




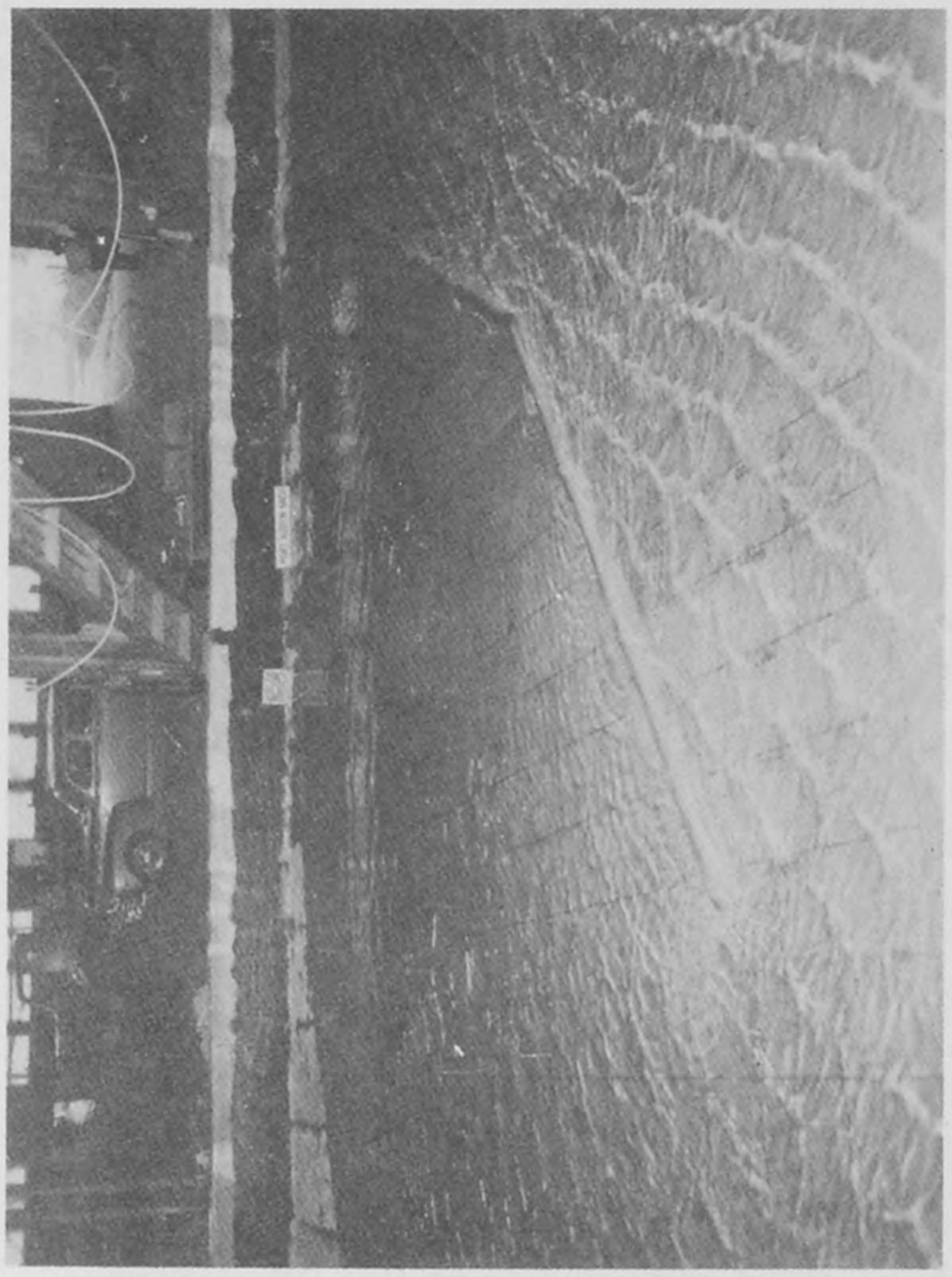
PLAN 3 - NORTHWEST-NORTH WIND

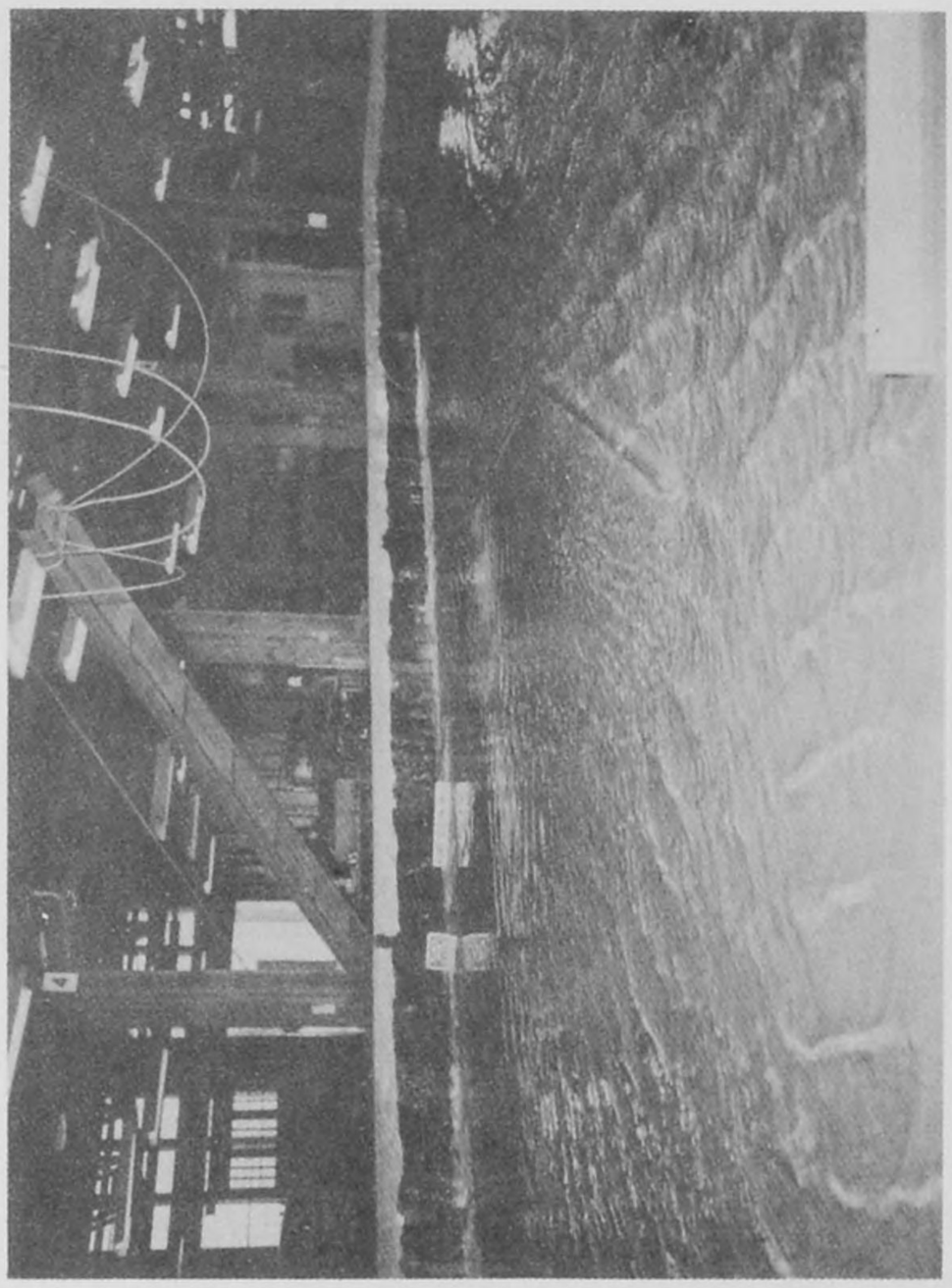
PORT AUSTIN, MICHIGAN
HARBOR MODEL
PLATE 9



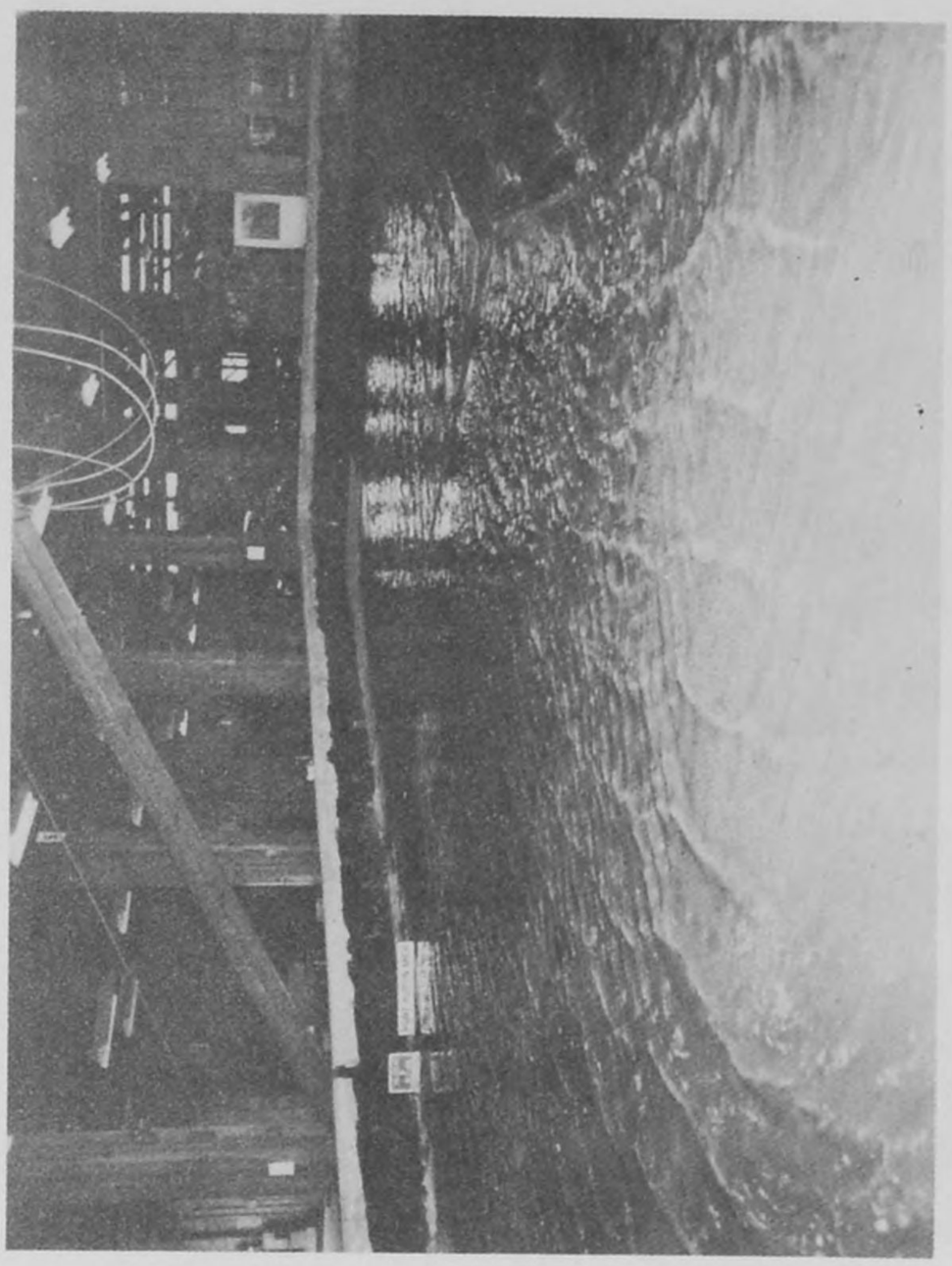


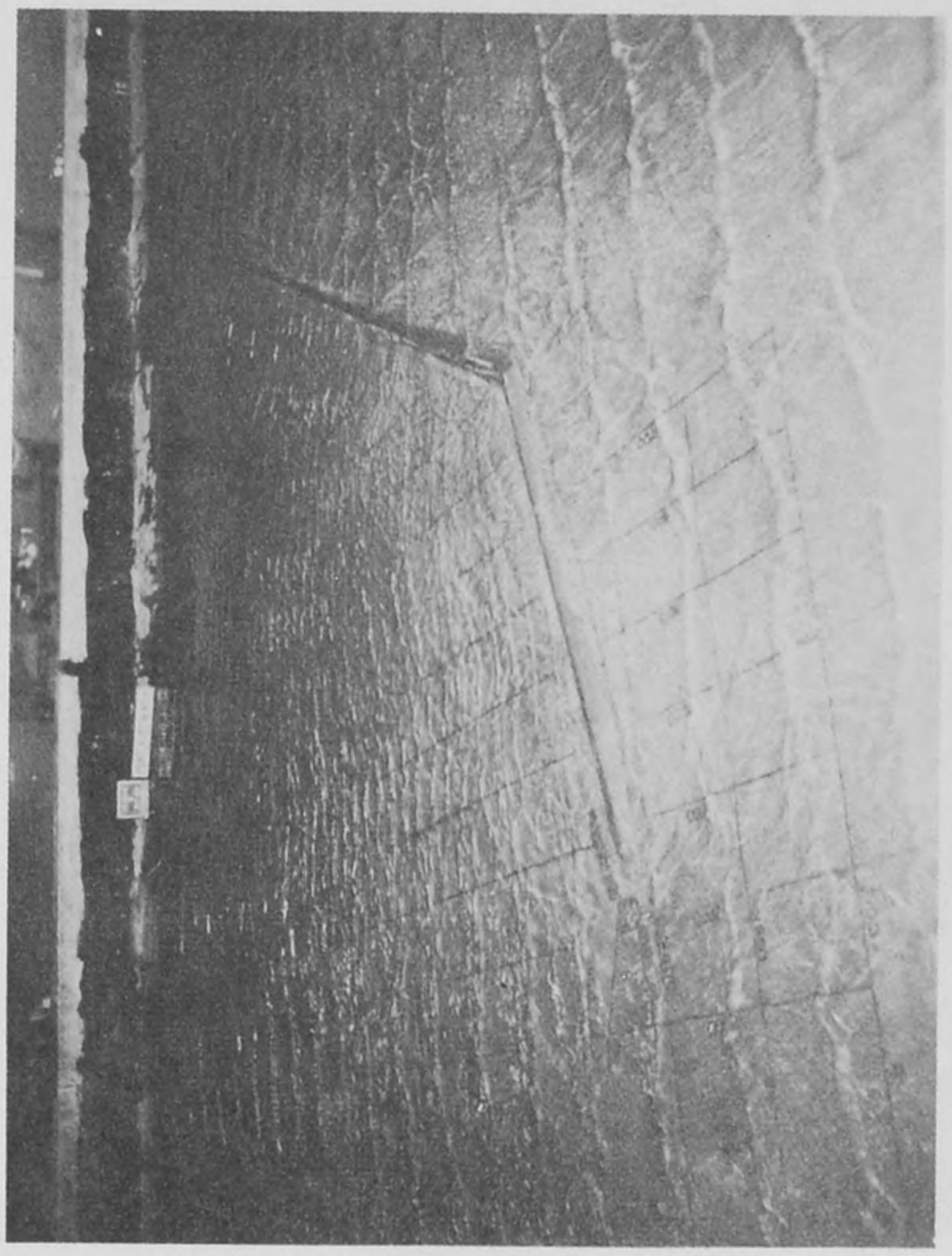
PLAN 3 - WEST-NORTHWEST WIND

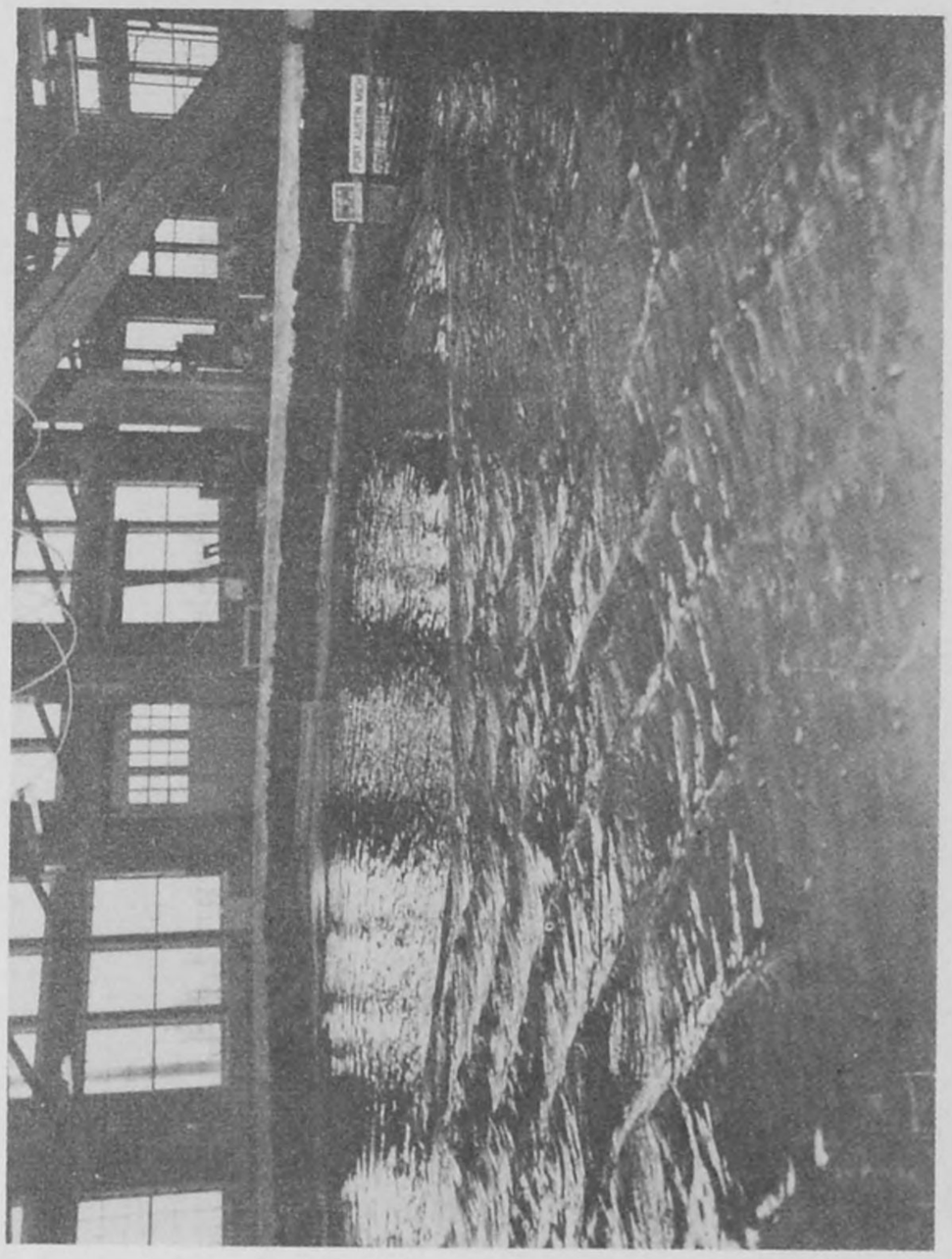




PORT AUSTIN, MICHIGAN
HARBOR MODEL
PLATE 10

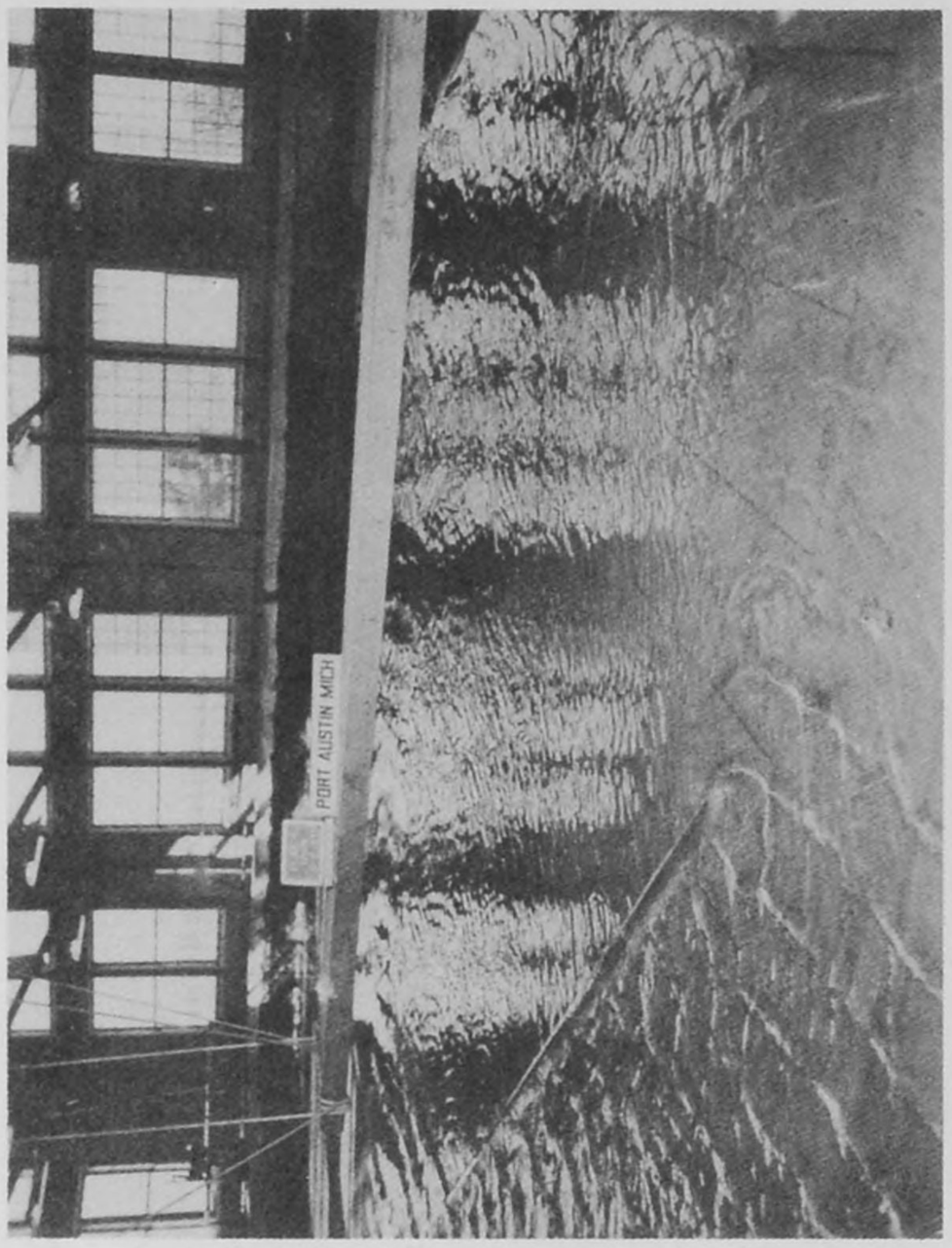




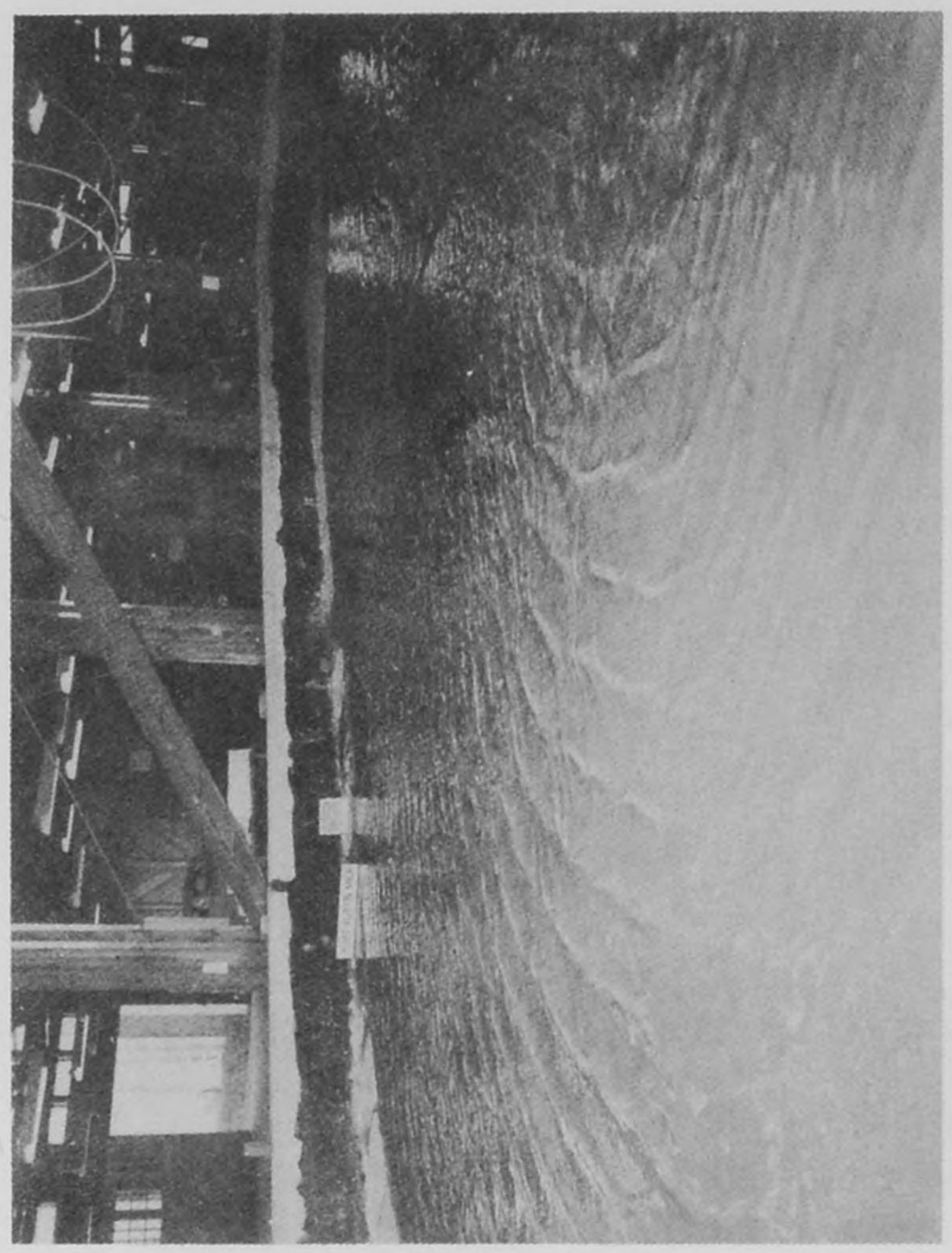


PLAN 4 - NORTH WIND

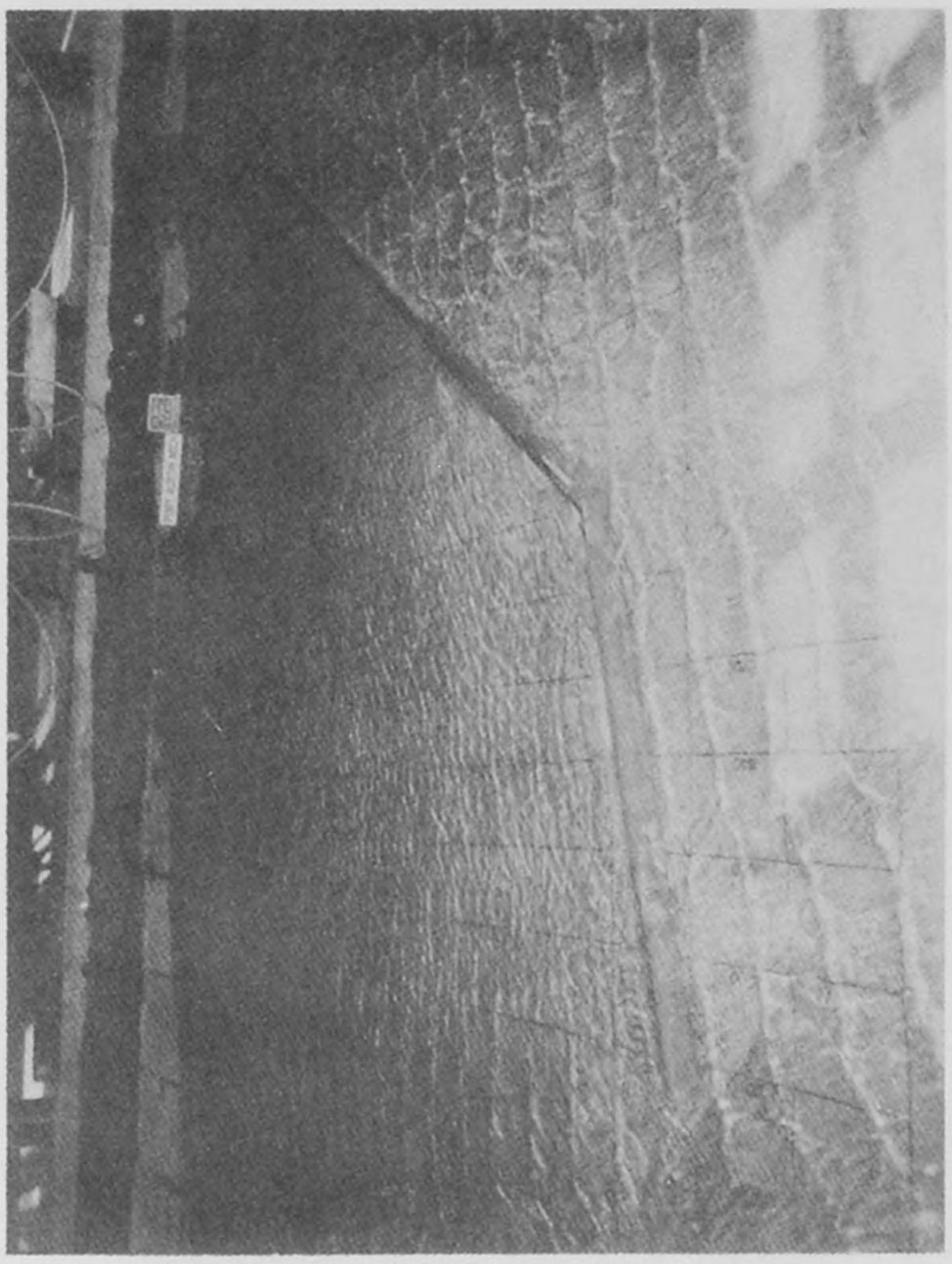
PORT AUSTIN, MICHIGAN
HARBOR MODEL
PLATE 11



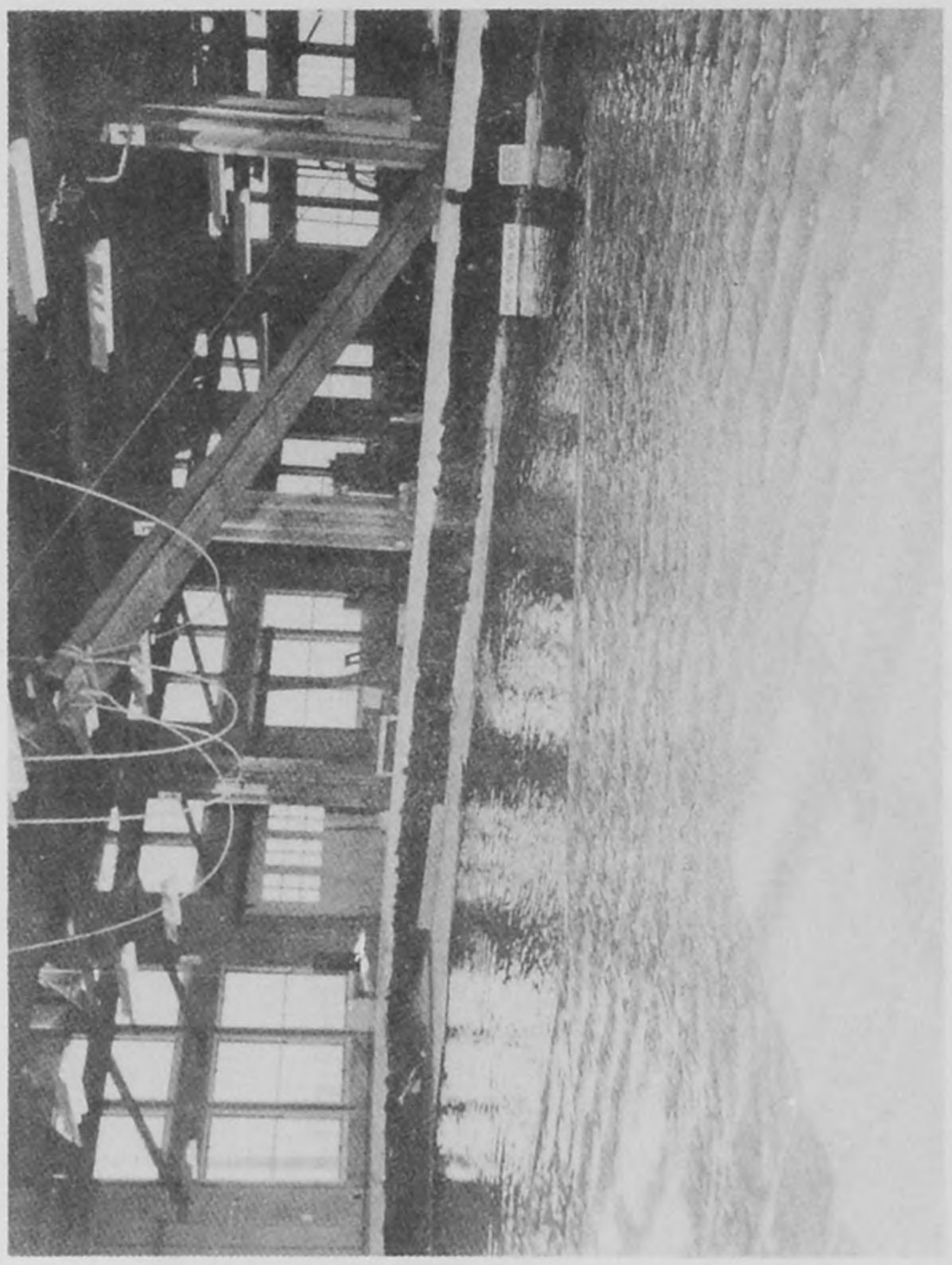
PLAN 1 - NORTHWEST WIND



PLAN 2 - NORTH WIND

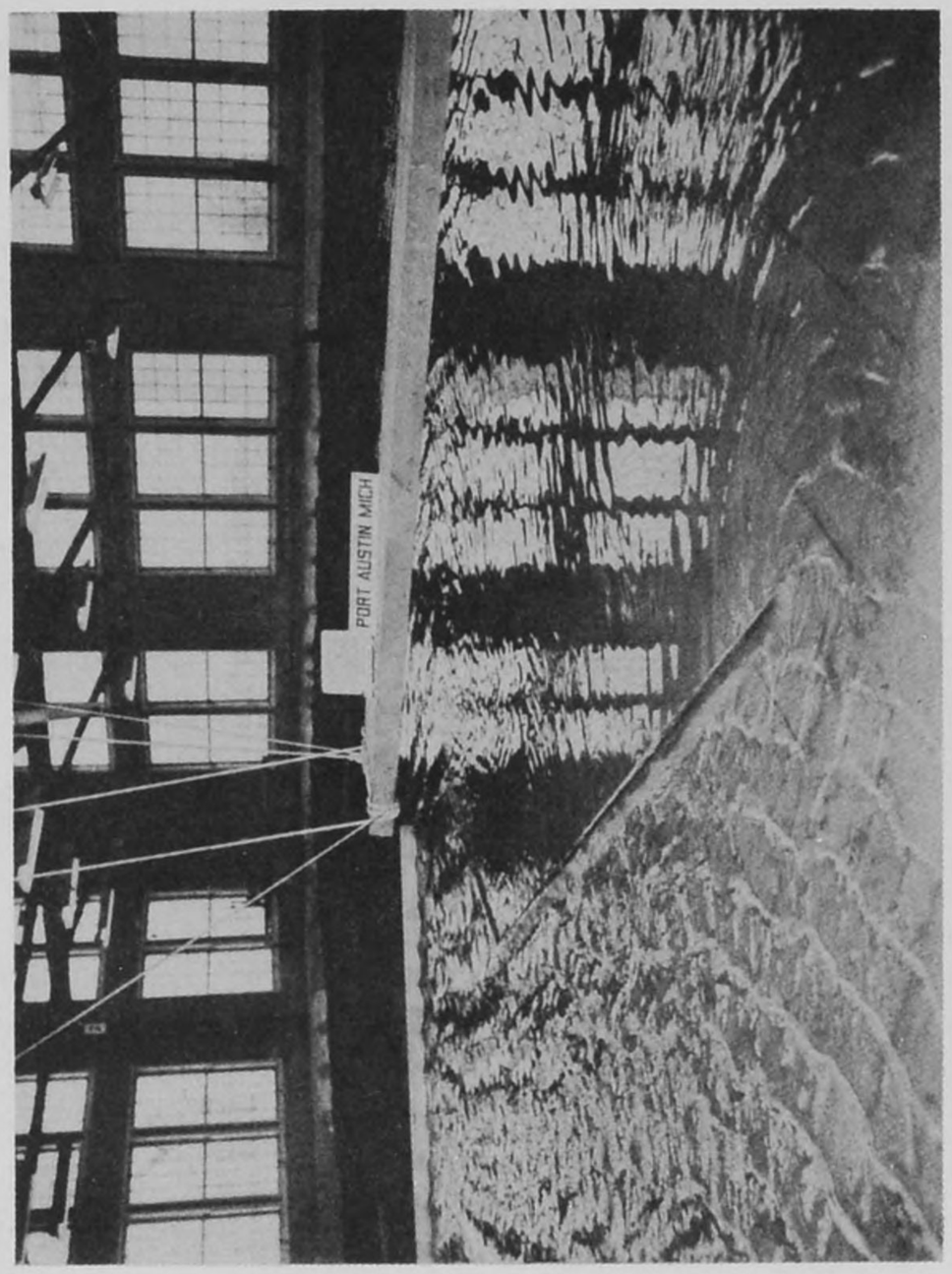


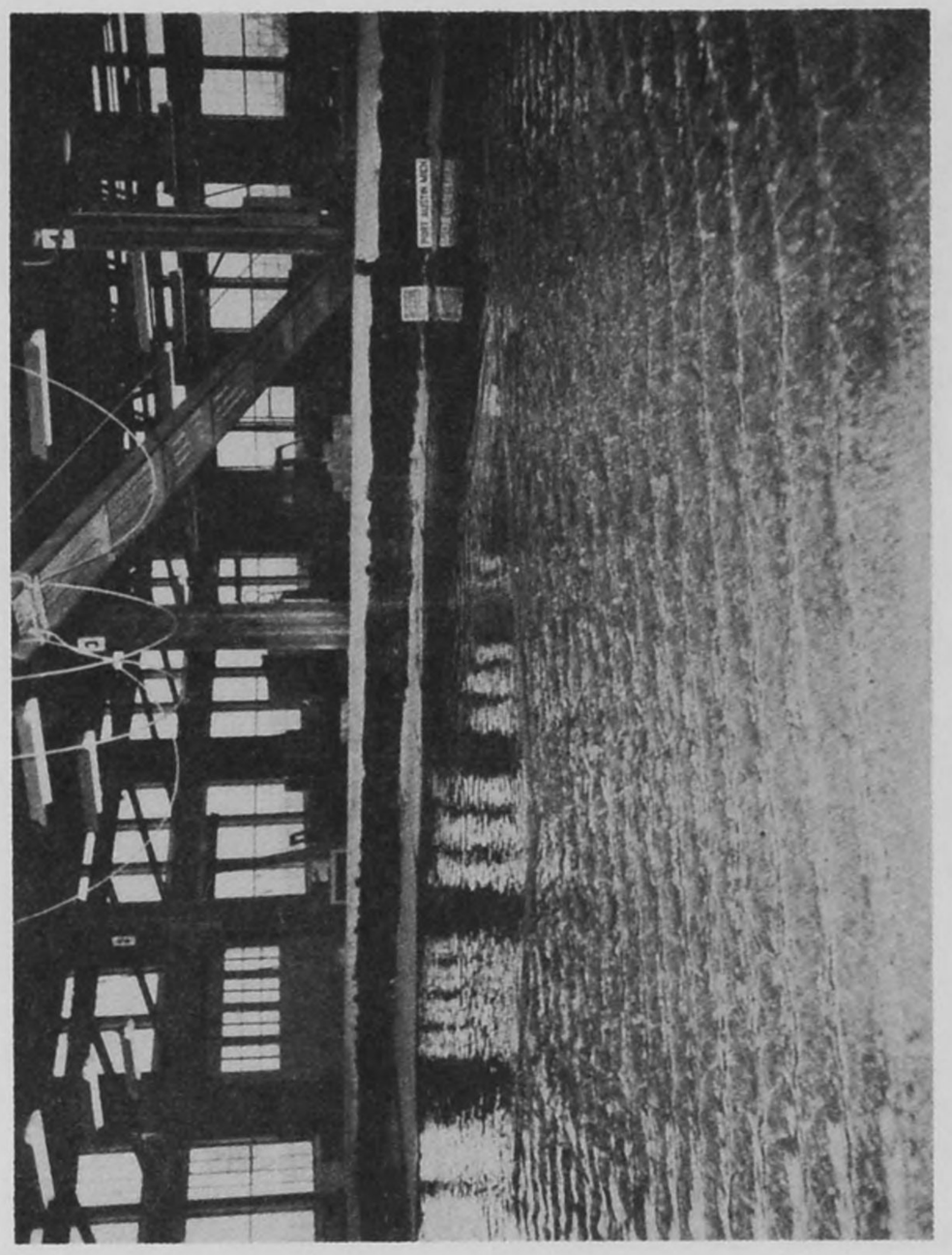
PLAN 3 - NORTHEAST WIND



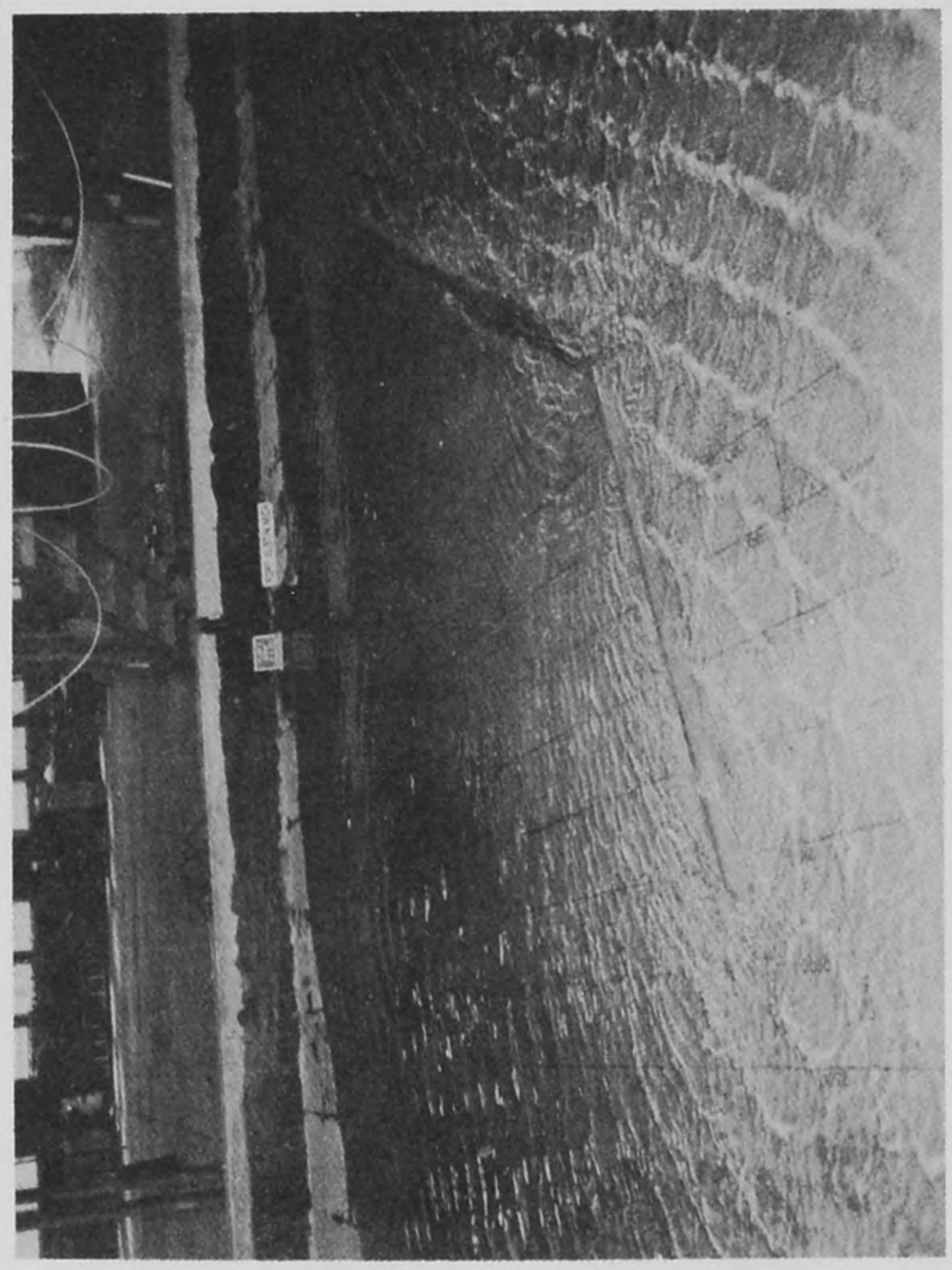
PLAN 4 - NORTHWEST WIND

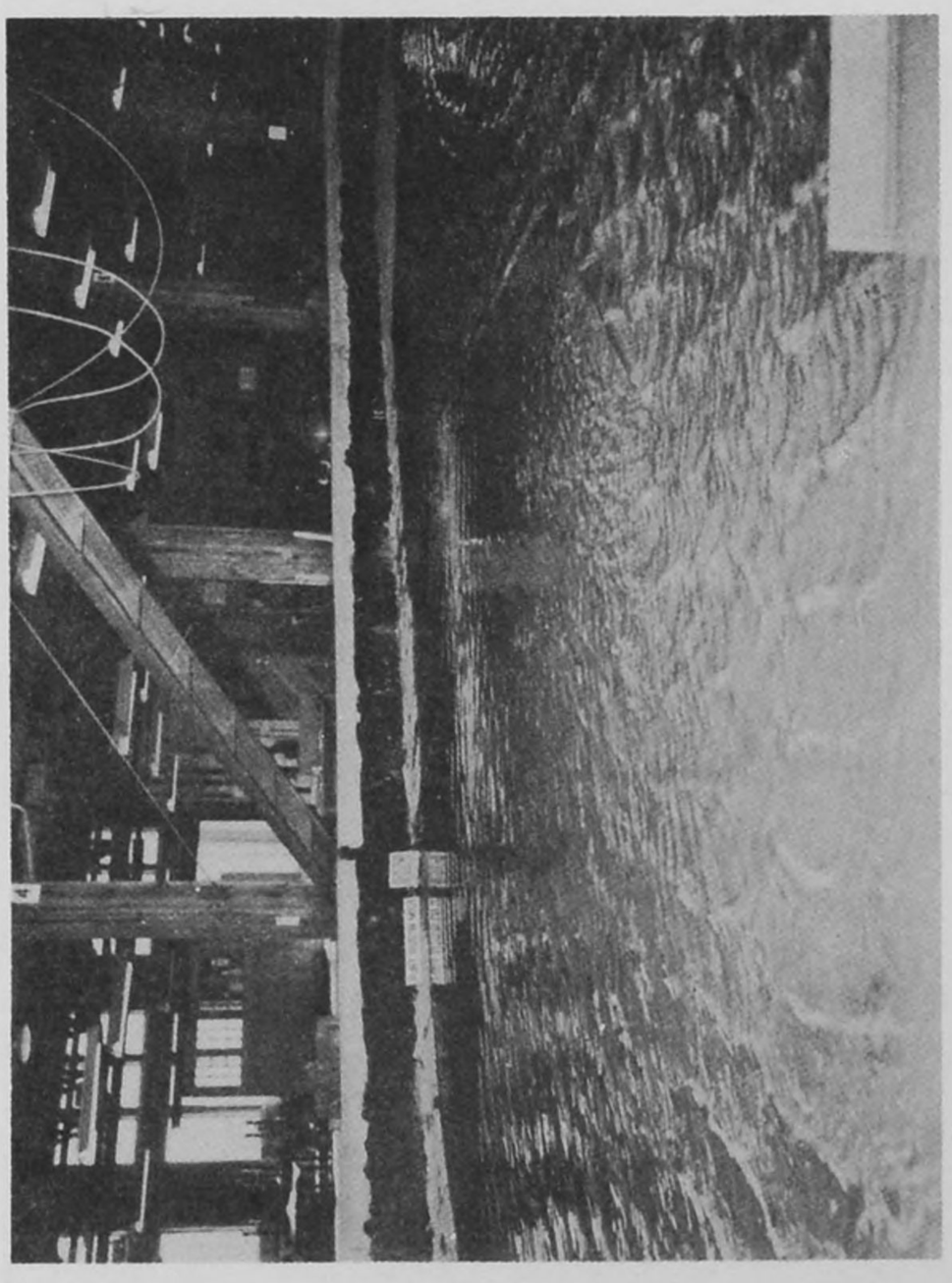
PORT AUSTIN, MICHIGAN
HARBOR MODEL
PLATE 12



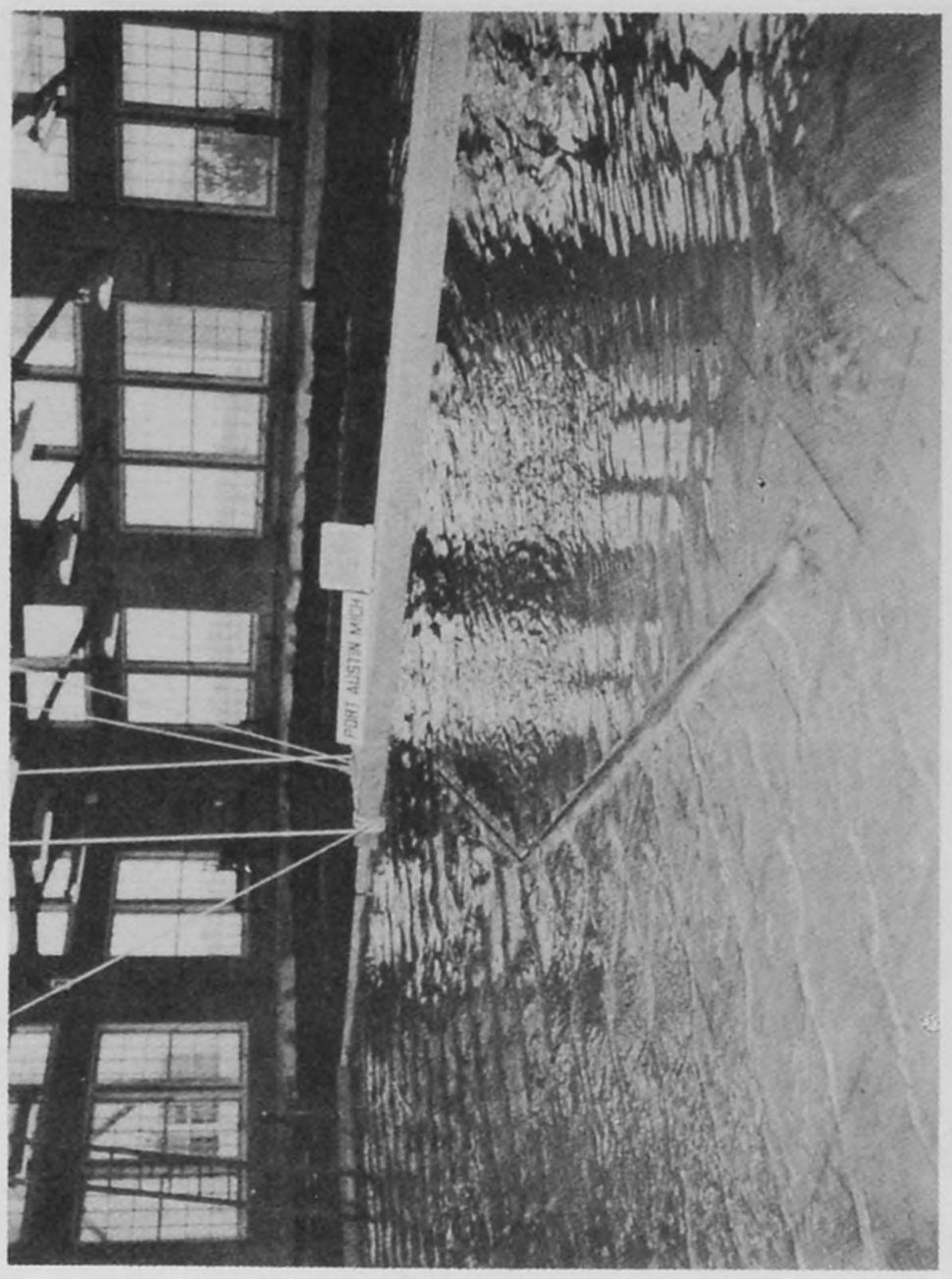


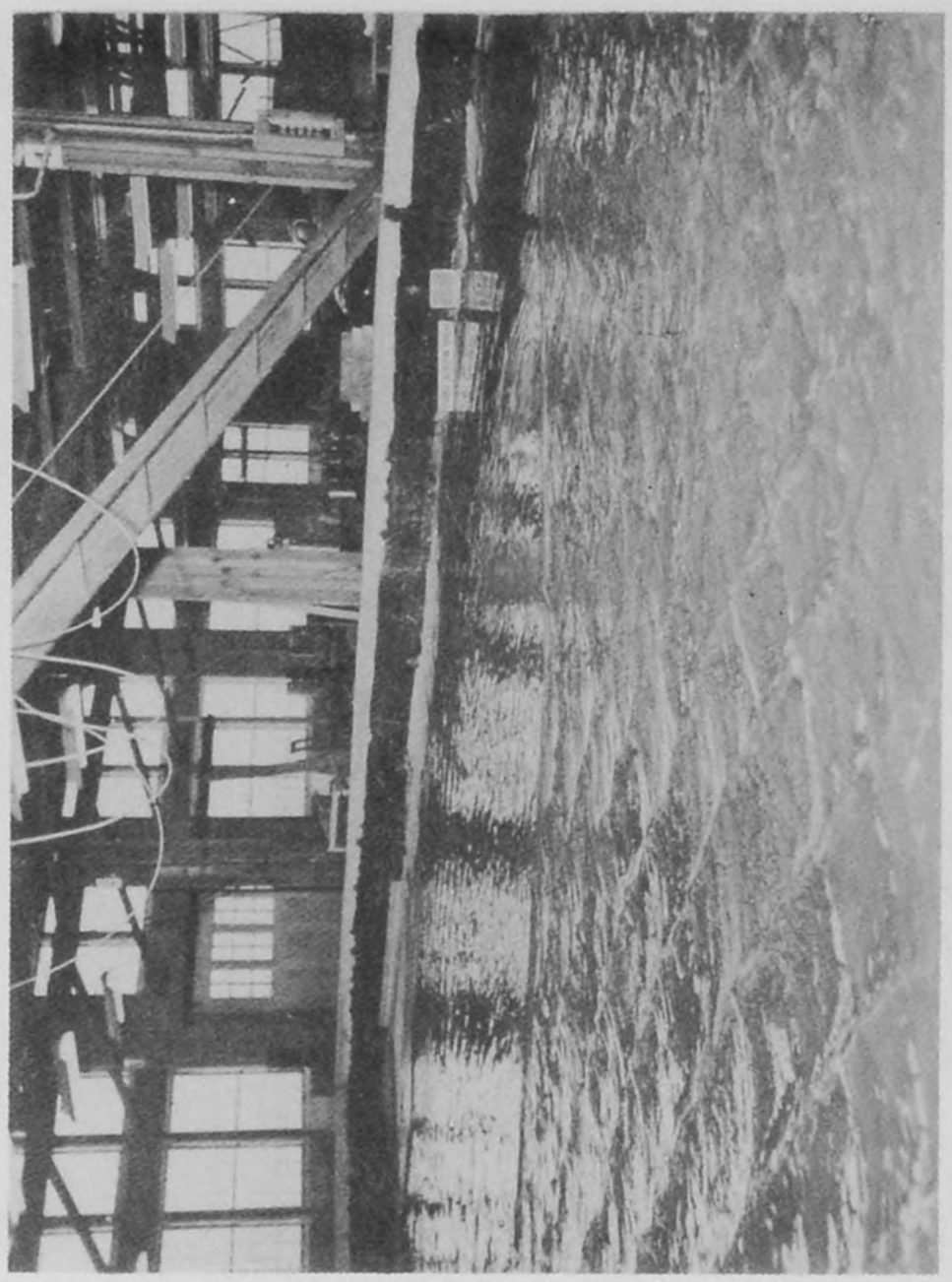
PLAN 4 - WEST-NORTHWEST WIND



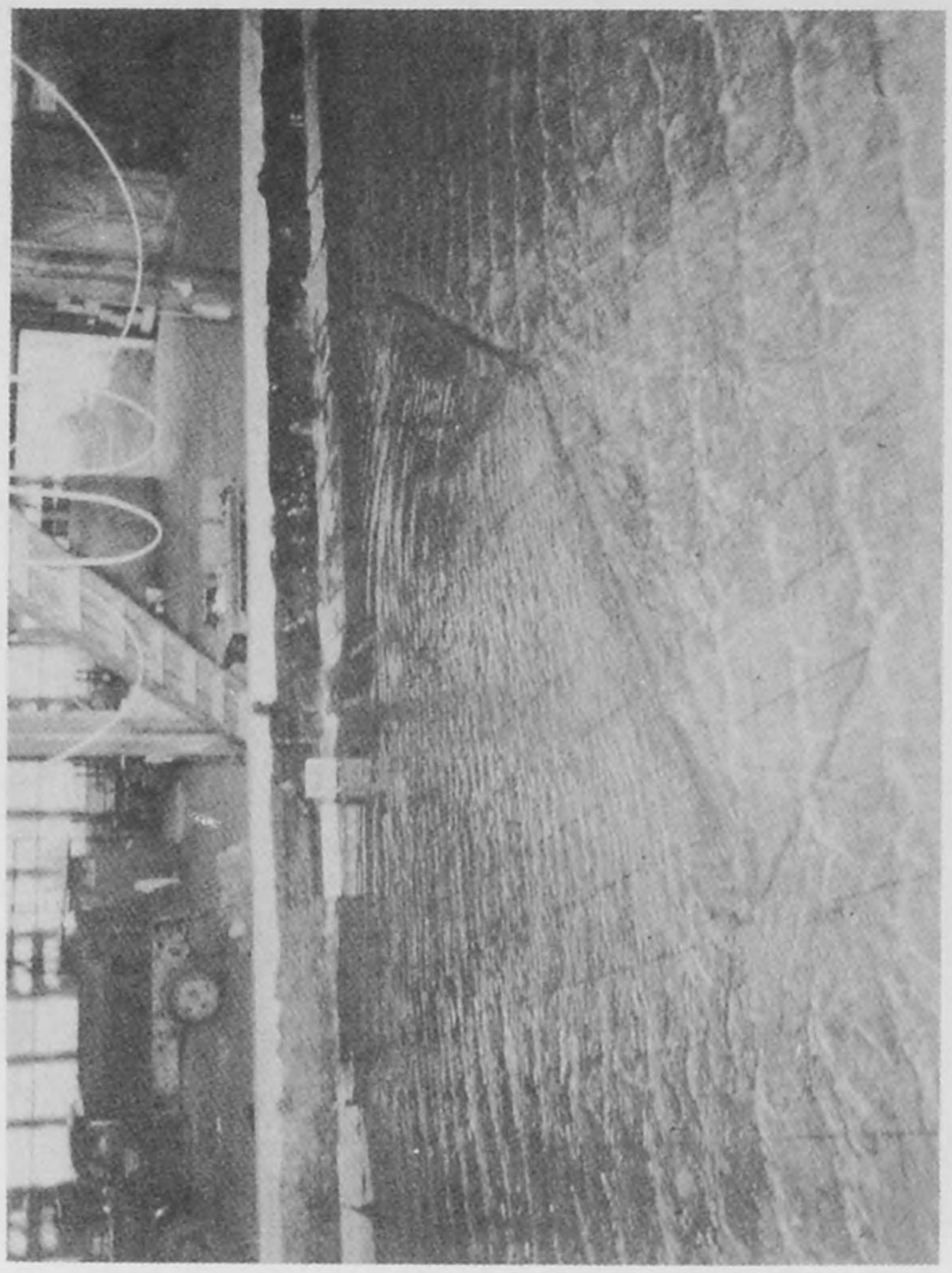


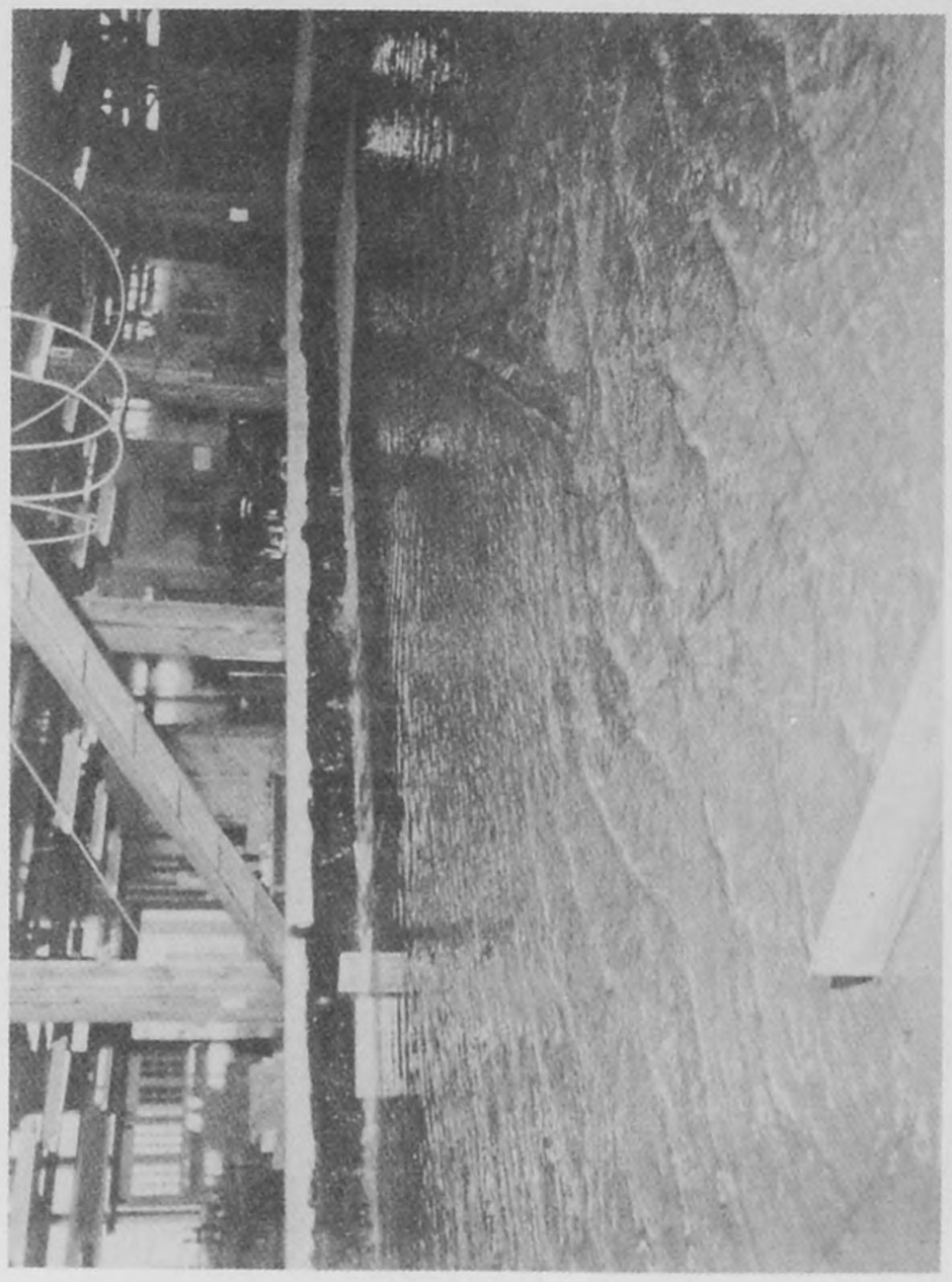
PORT AUSTIN, MICHIGAN
HARBOR MODEL
PLATE 13



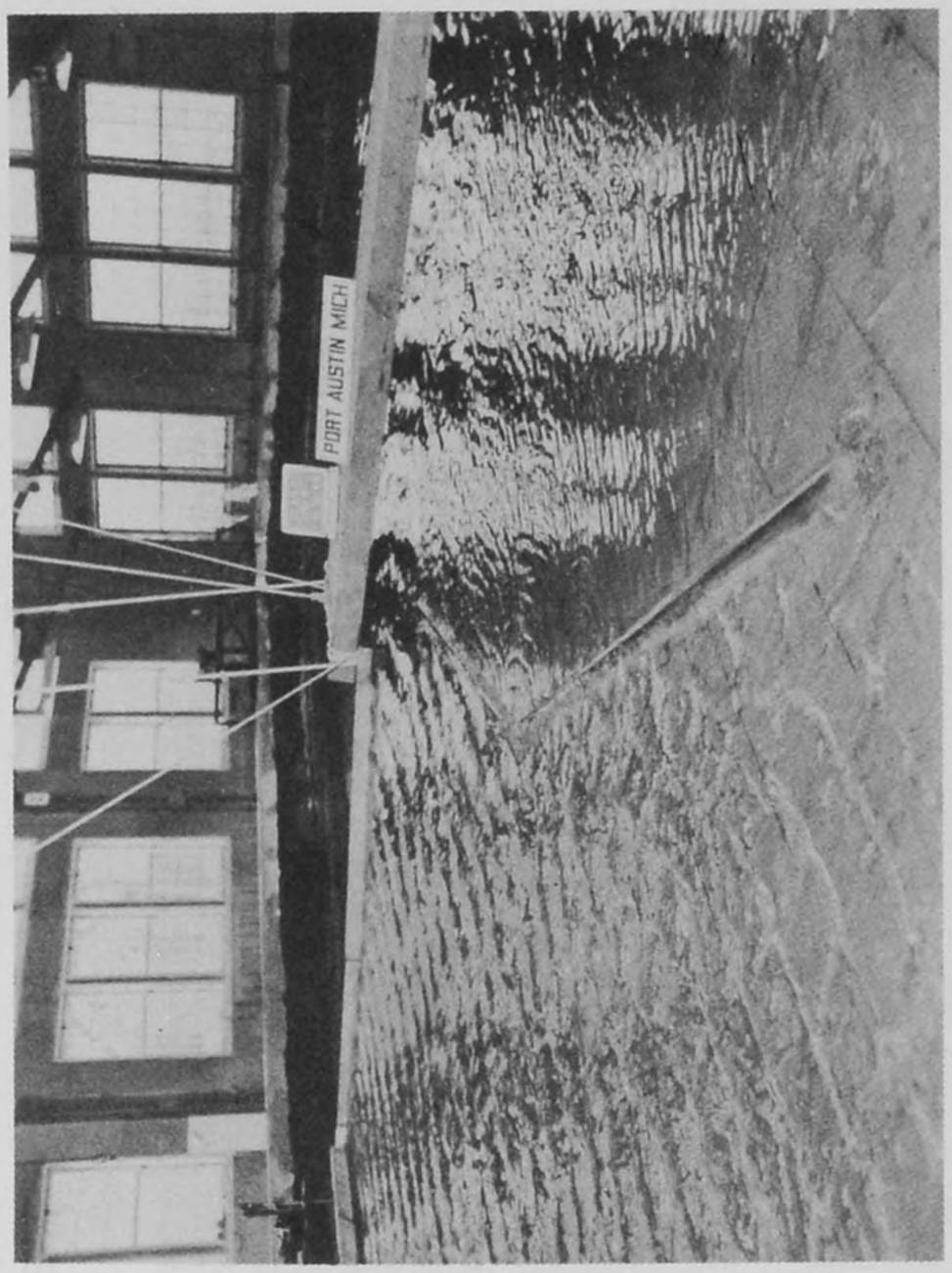


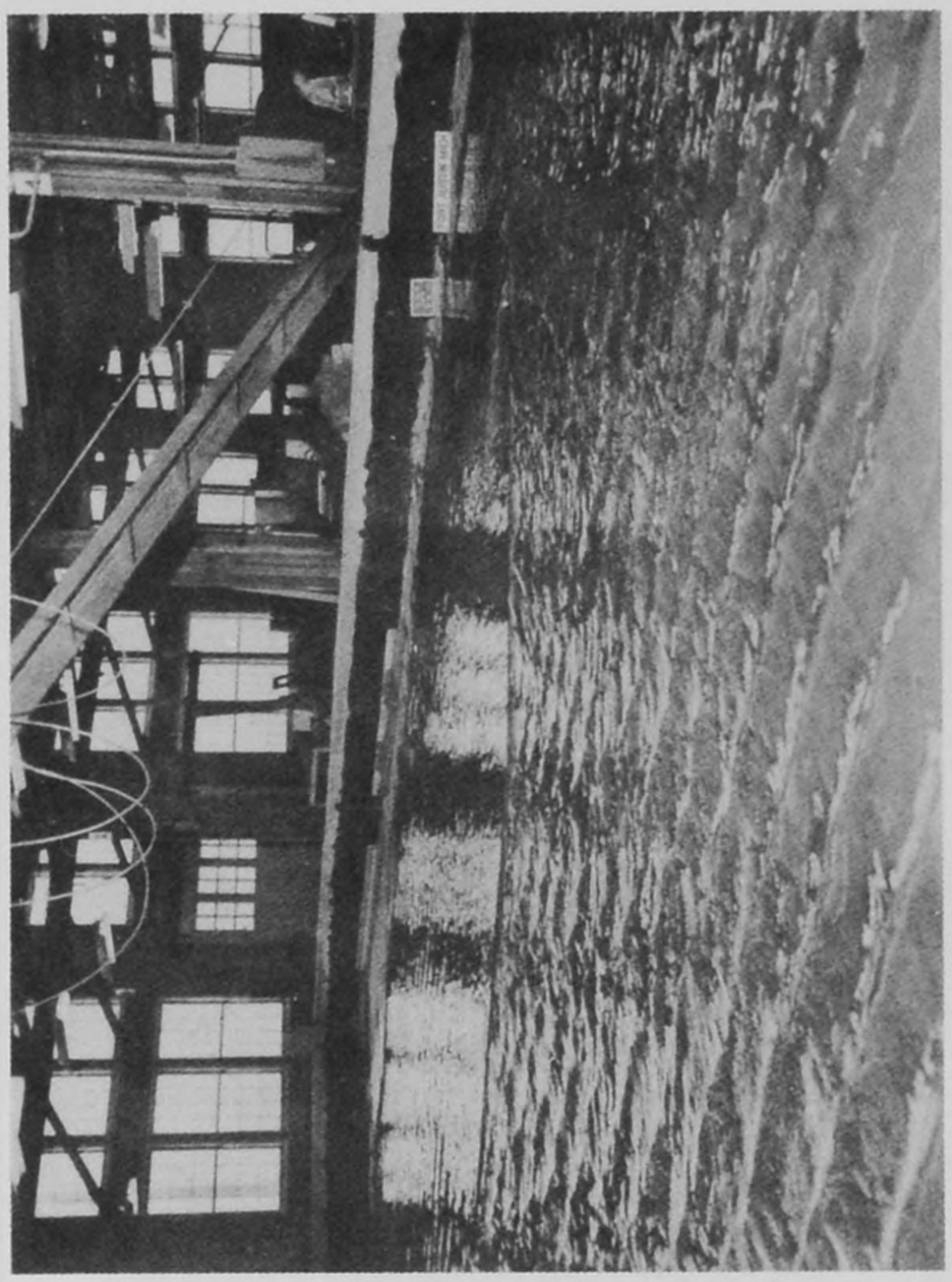
PLAN 5 - NORTH WIND





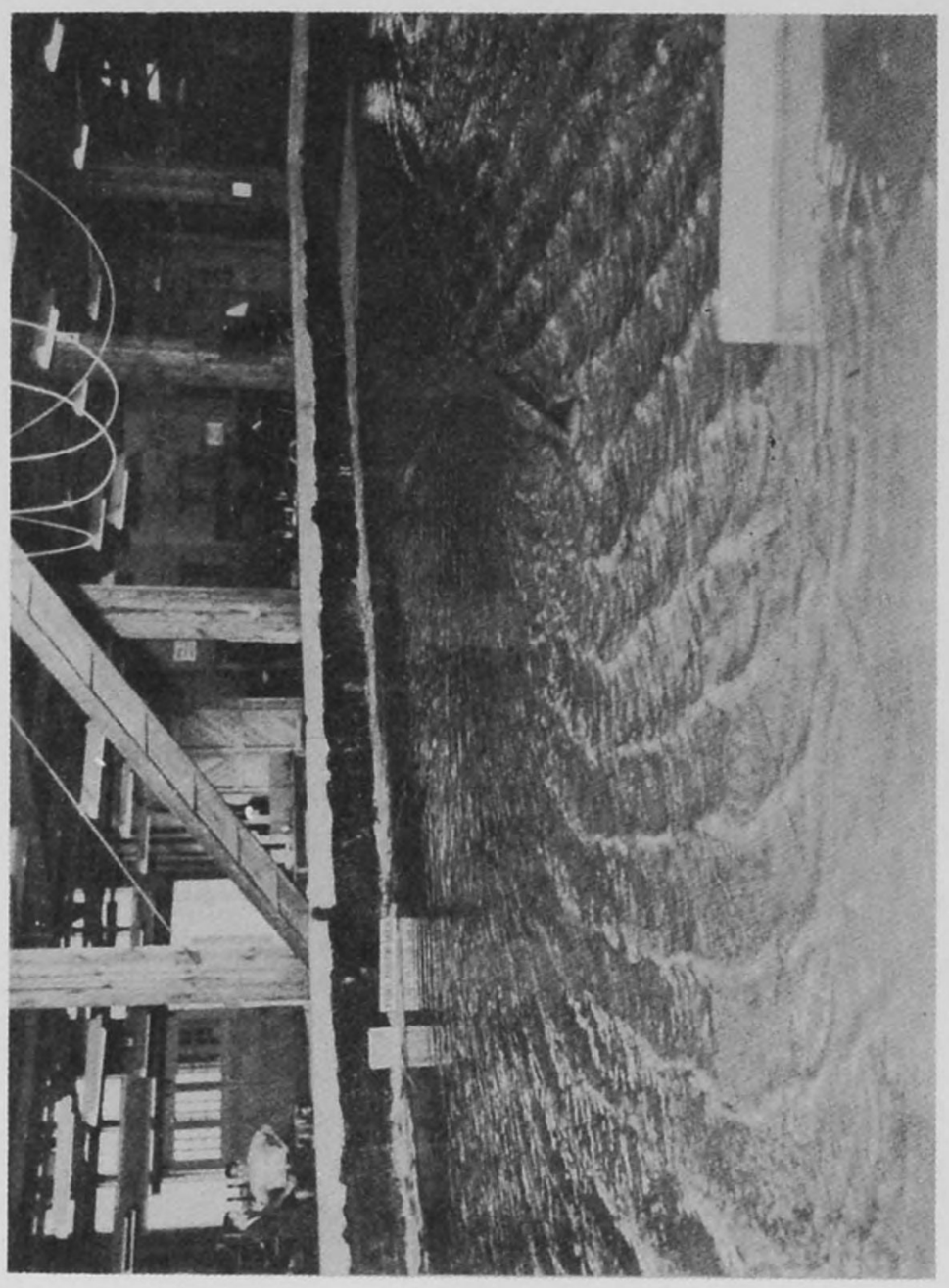
PORT AUSTIN, MICHIGAN
HARBOR MODEL
PLATE 14

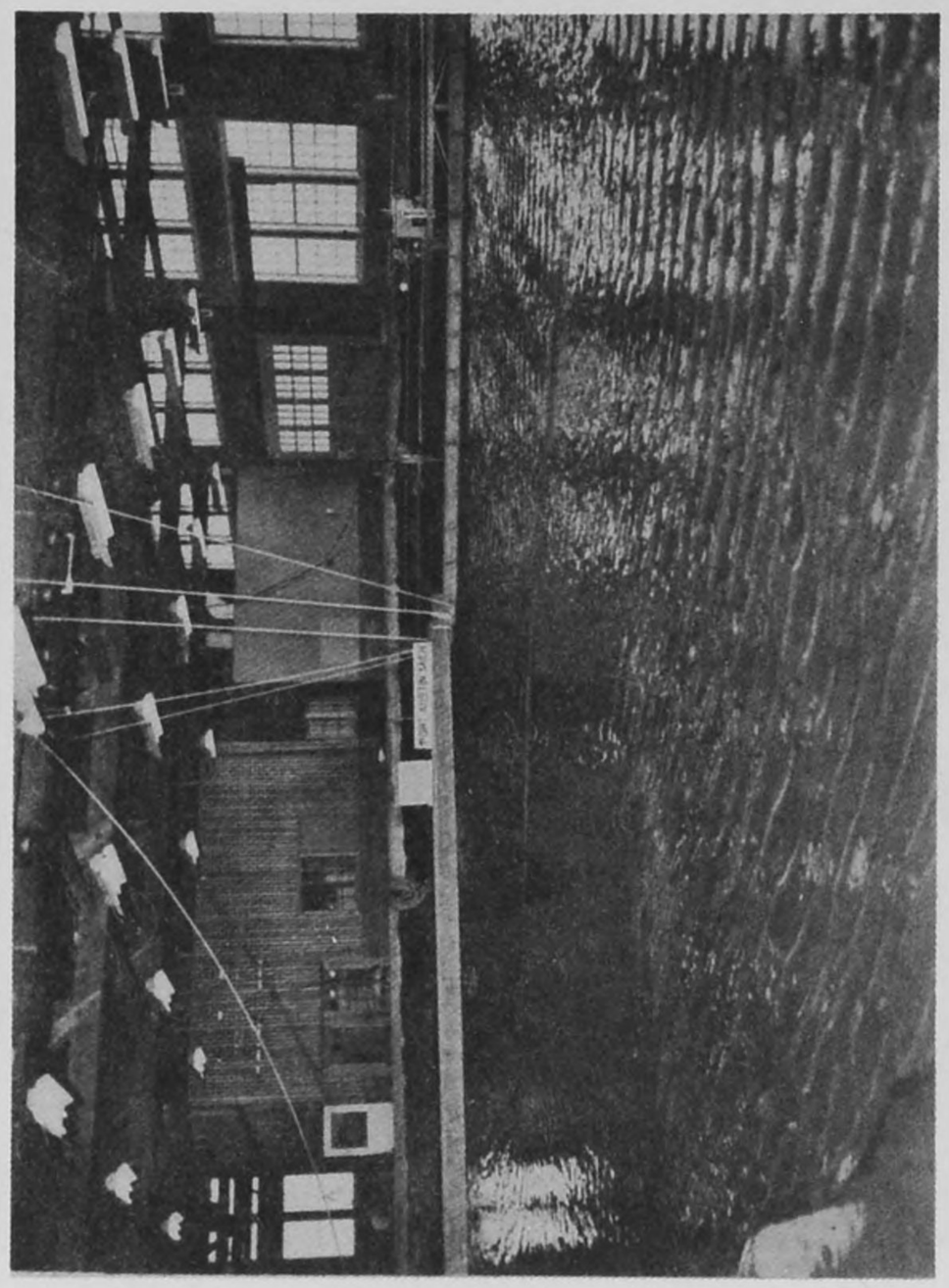




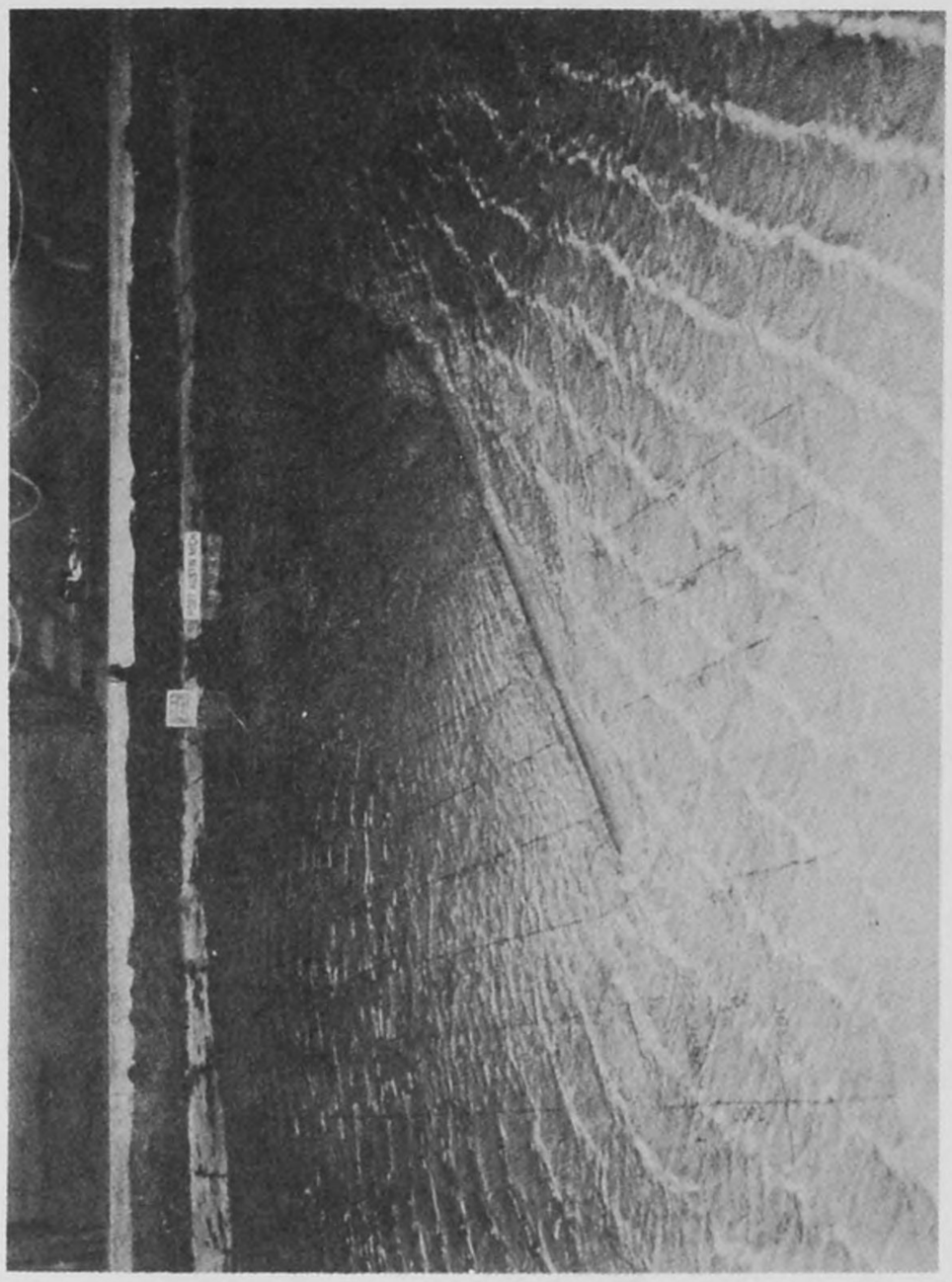
PLAN 5 - NORTHWEST WIND

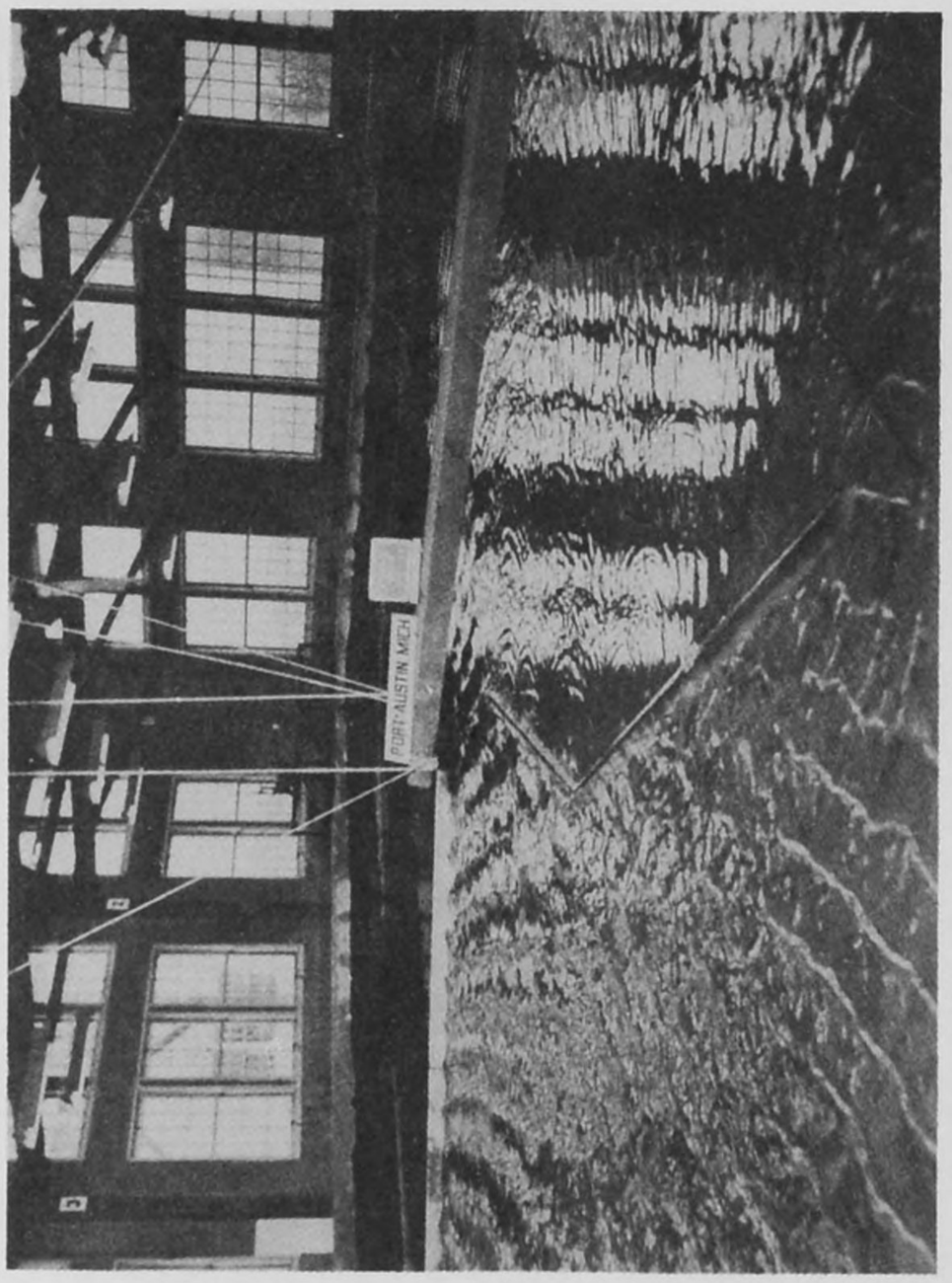
PORT AUSTIN, MICHIGAN
HARBOR MODEL
PLATE 15





PLAN 5 - WEST-NORTHWEST WIND





PORT AUSTIN, MICHIGAN
HARBOR MODEL
PLATE 16

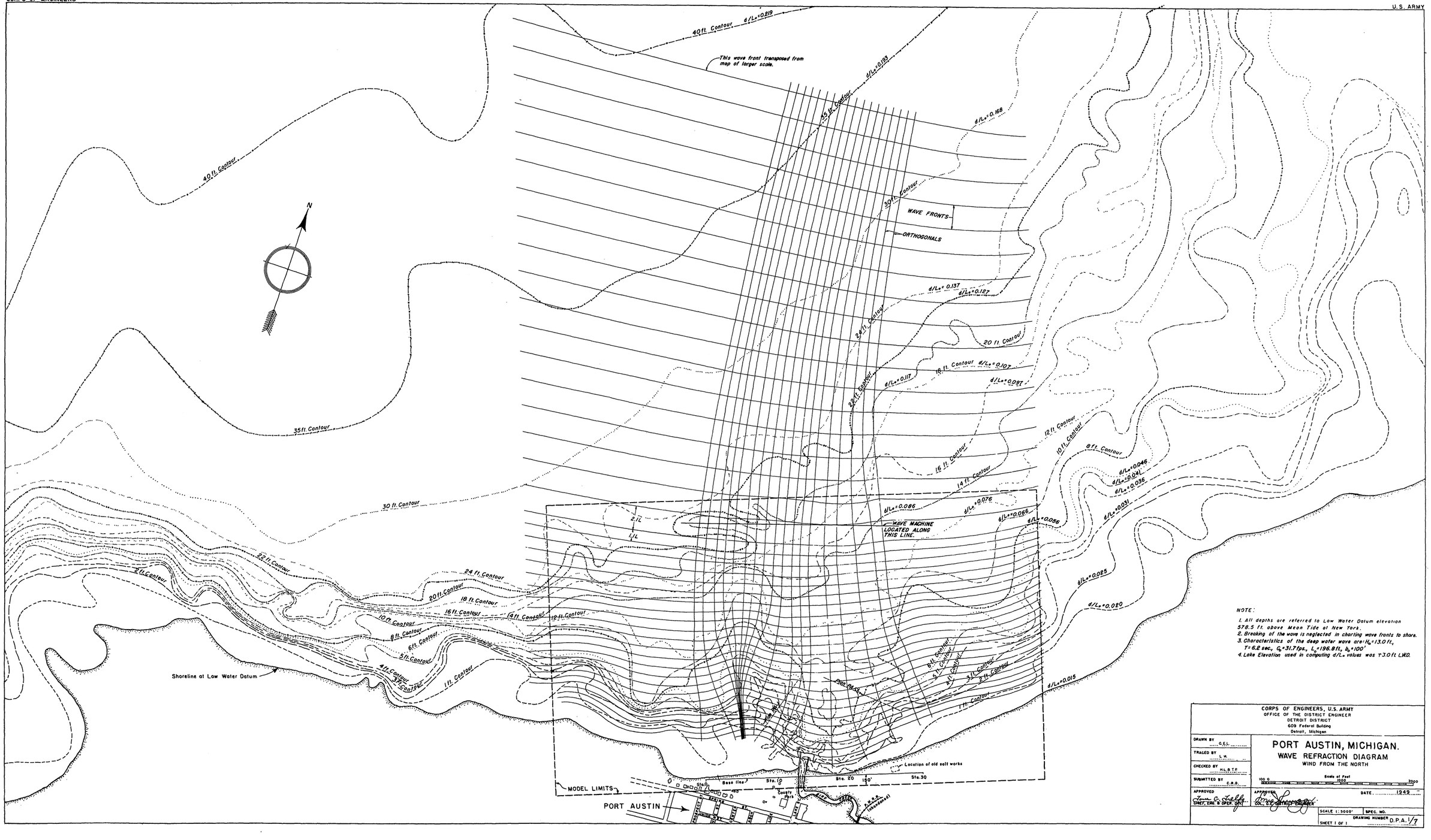
APPENDIX C

DRAWINGS SUPPLIED

BY

THE DETROIT DISTRICT

CORPS OF ENGINEERS, U. S. ARMY



NOTE:

1. All depths are referred to Low Water Datum elevation 578.5 ft. above Mean Tide at New York.
2. Breaking of the wave is neglected in charting wave fronts to shore.
3. Characteristics of the deep water wave are: H_o=13.0 ft., T=6.2 sec., C_o=31.7 fps., L_o=196.8 ft., b_o=100'
4. Lake Elevation used in computing d/L_o values was 573.0 ft LWD.

CORPS OF ENGINEERS, U.S. ARMY
OFFICE OF THE DISTRICT ENGINEER
DETROIT DISTRICT
609 Federal Building
Detroit, Michigan

PORT AUSTIN, MICHIGAN.

WAVE REFRACTION DIAGRAM

WIND FROM THE NORTH

DRAWN BY	O.E.L.
TRACED BY	L.W.
CHECKED BY	H.L.B.T.P.
SUBMITTED BY	C.R.D.
APPROVED	Chief, Eng. & Oper. Div.
APPROVED	Lt. Col. Corps of Engineers, District Engineer
DATE	1949

Scale of Feet: 100 0 1000 2000

SCALE 1:3000' | SPEC. NO.

SHEET 1 OF 1 | DRAWING NUMBER D.P.A. 1/7

NOTE:

1 — All depths are referred to Low Water Datum elevation 578.5 ft. above Mean Tide of New York.

2 — In charting the wave fronts to show the breaking depth is neglected.

3 — The wave characteristics are H_o=10.0 ft., T=3.7 sec., L_o=113.3 ft., C_o=24.1 fps., L_o=100.0 ft

4 — Lake elevation used in computing H/H_o values was +2.0 ft. I.L.D.

CORPS OF ENGINEERS, U.S. ARMY
OFFICE OF THE DISTRICT ENGINEER
DETROIT DISTRICT
609 Federal Building
Detroit, Michigan

PORT AUSTIN, MICHIGAN.

WAVE REFRACTION DIAGRAM

WIND FROM NORTHWEST - NORTH

Scale of Feet 100 0 1000 2000

DRAWN BY	C.E.L.
TRACED BY	L.L.
CHECKED BY	H.L., K.W.
SUBMITTED BY	C.R.D.
APPROVED	Chief, Eng. & Oper. Div.
APPROVED	Col., C.E., District Engineer
DATE	
SCALE	1:5000'
SPEC. NO.	
SHEET	1 OF 1
DRAWING NUMBER	D.P.A. 1/6

NOTE:

1. All depths are referred to Low Water Datum elevation 578.5 ft above Mean Tide at New York.
2. In charting wave front to shore the breaking depth is neglected.
3. Wave characteristics are: $H_o = 9.0$ ft, $T = 4.5$ sec., $L_o = 103.7$ ft, $d_o = 100$ ft.
4. Lake Elevation used in computing d/L_o values was + 3.0 ft. LWD.

CORPS OF ENGINEERS, U.S. ARMY
OFFICE OF THE DISTRICT ENGINEER
DETROIT DISTRICT
609 Federal Building
Detroit, Michigan

DRAWN BY G.R.S.
TRACED BY L.W.
CHECKED BY H.L. & T.P.
SUBMITTED BY C.H.O.

PORT AUSTIN, MICHIGAN.

WAVE REFRACTION DIAGRAM

WIND FROM WEST - NORTHWEST.

Scale of Feet 100 0 100 200

APPROVED
Leon C. Lollis
CHIEF, ENG. & OPER. DIV.

APPROVED
Col. C.C. Comstock
DISTRICT ENGINEER

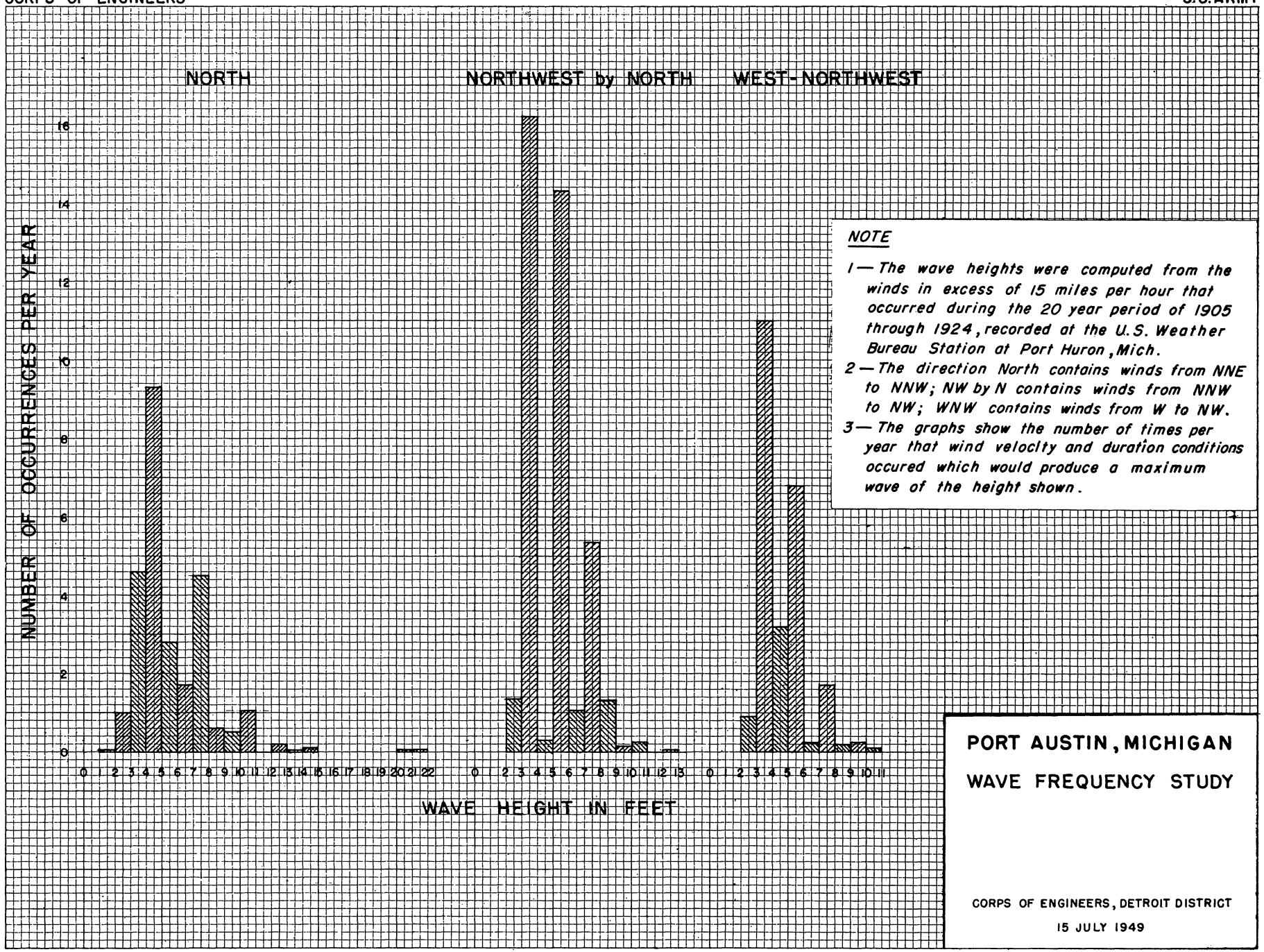
DATE 1949

SCALE 1 : 1000'

SPEC. NO.

DRAWING NUMBER D.P.A. 1/5

SHEET 1 OF 1 -



NOTE

1 — The wave heights were computed from the winds in excess of 15 miles per hour that occurred during the 20 year period of 1905 through 1924, recorded at the U.S. Weather Bureau Station at Port Huron, Mich.

2 — The direction North contains winds from NNE to NNW; NW by N contains winds from NNW to NW; WNW contains winds from W to NW.

3 — The graphs show the number of times per year that wind velocity and duration conditions occured which would produce a maximum wave of the height shown.

PORT AUSTIN, MICHIGAN

WAVE FREQUENCY STUDY

CORPS OF ENGINEERS, DETROIT DISTRICT

15 JULY 1949

AIIM SCANNER TEST CHART # 2

Spectra

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz:'',./?$0123456789

6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

Times Roman

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

Century Schoolbook Bold

4 PT **ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789**

6 PT **ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789**

8 PT **ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789**

10 PT **ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789**

News Gothic Bold Reversed

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6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

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10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

Bodoni Italic

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

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10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:'',./?$0123456789

Greek and Math Symbols

4 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓'',. / ≦±=≠°><⊁⊀⩾⩽≡

6 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓'',. / ≦±=≠°><⊁⊀⩾⩽≡

8 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓'',. / ≦±=≠°><⊁⊀⩾⩽≡

10 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓'',. / ≦±=≠°><⊁⊀⩾⩽≡

White

Black

Isolated Characters

e	m	1	2	3	a
4	5	6	7	o	°
8	9	0	h	I	B

A4 Page 6543210

MESH HALFTONE WEDGES

65

85

100

110

133

150

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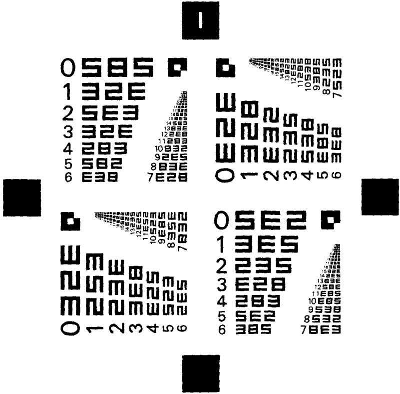
RIT ALPHANUMERIC RESOLUTION TEST OBJECT, RT-1-71



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