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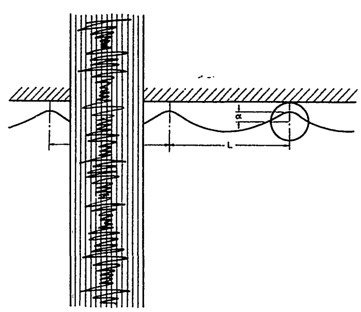
MODEL STUDY FOR HARBOR OF REFUGE FOR LIGHT-DRAFT VESSELS AT HARRISVILLE, MICHIGAN

by

E.F. Brater and L.D.Stair



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Lake Hydraulics Laboratory
Department of Civil Engineering

Project M910 Contract DA-22-079-eng-26
Waterways Experiment Station, Corps of Engineers
United States Army

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and

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WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS, U. S. ARMY
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June 30, 1951

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MODEL STUDY FOR HARBOR OF REFUGE

FOR

LIGHT-DRAFT VESSELS AT HARRISVILLE, MICHIGAN

INTRODUCTION

It is planned to construct a number of harbors on the Michigan shore line which, together with the harbors already available, will provide safe refuge for light-draft vessels at intervals of about 30 or 40 miles. As part of this program, studies have been made in the University of Michigan Lake Hydraulics Laboratory to determine the most effective breakwater arrangements for the harbors of Port Sanilac, Port Austin, and Hammond Bay. Construction of the Port Sanilac harbor is nearly completed. The harbor proposed for construction at Harrisville would provide another link in this chain of harbors of refuge. The model study was made for the purpose of determining the arrangement which would provide the best harbor at minimum cost. The effectiveness of the harbor was determined on the basis of protection from wave action as well as the provision of a navigable entrance.

The Harrisville model study was conducted in accordance with a contract, dated August 16, 1950, between the University of Michigan Engineering Research Institute, Ann Arbor, Michigan, and the Waterways Experiment Station, Corps of Engineers, U. S. Army, Vicksburg, Mississippi.

The University of Michigan Lake Hydraulics Laboratory 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. Dr. Ivan C. Crawford is Dean of Engineering and Professor Earnest Boyce is Chairman of the Department of Civil Engineering. The laboratory is under the direction of Dr. E. F. Brater, Associate Professor of Civil Engineering. Mr. L. D. Stair, Research Associate, was in charge of the construction and operation of the model. He was assisted by Mr. H. R. Bachman. Other members of the staff who took part in the work were Messrs. P. McCallister, J. H. Person, and C. C. Young.

Mr. R. Y. Hudson, Chief of the Wave Action Section, Waterways Experiment Station, and Mr. W. H. Booth, Jr., of the Great Lakes Division, Corps of Engineers, visited the laboratory during the model tests and were kept informed of the results of the tests as various phases were completed. Their suggestions were helpful in planning the testing program. The cooperation of Lt. Colonel John D. Bristor, District Engineer, Detroit District, Corps of Engineers was of vital assistance in the accomplishment of the model study. Mr. H. F. Lawhead, of the Detroit District, Corps of Engineers, and Mr. C. E. Lee, formerly of the Detroit District and later with the Great Lakes Division, Corps of Engineers, visited the laboratory during the different stages of the study and were very helpful in the planning of the various breakwater arrangements tested.

PROTOTYPE CONDITIONS

Harrisville, Michigan, is located on Lake Huron approximately midway between Saginaw Bay and Alpena as shown in Fig. 1. A chart of the

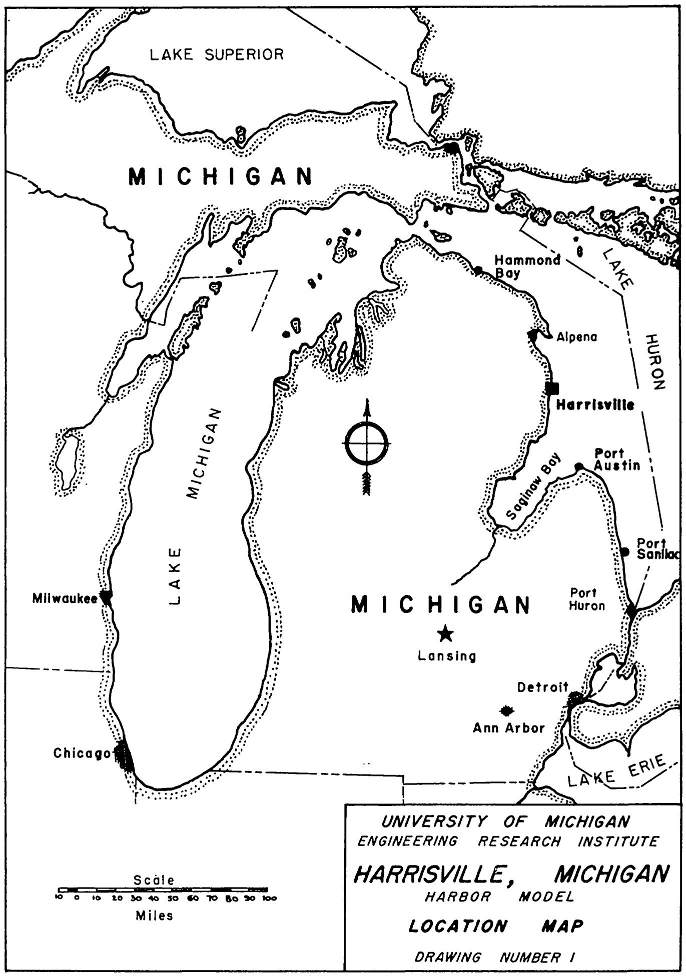

Figure 1.

area, supplied by the Detroit District, Corps of Engineers, is shown in Appendix C, p. 77. The offshore hydrography in the vicinity of the problem area is very irregular. Depths as great as 30 feet occur in the model area. A fairly well defined sand bar rising to within 8 feet of the water surface is located approximately 1000 feet offshore.

The harbor site is exposed to waves approaching from an easterly sector extending from approximately northeast to southeast. Waves generated by winds from a more northerly direction than N 45° E and a more southerly direction than S 33° 45' E should not be an effective menace at the harbor site because of the reduction in wave height and the change in direction due to refraction. Waves from these two limiting directions and from the N 78° 45' E direction were selected as being critical ones for use in the model tests. A limited number of tests were made also with waves from the S 70° E direction.

The test-wave data for this investigation were furnished by representatives of the District Engineer, Detroit District, Corps of Engineers. Deep-water wave characteristics were computed from the fetches and wind records for the three principal directions using the Sverdrop-Munk curves.[1,2*] A chart showing the frequency of occurrence of waves of various sizes is shown in Appendix C. p 83. Two design waves were chosen for each direction. The characteristics of these waves are shown in Table I. The "large" wave for each direction is believed to represent conditions produced by more severe Lake Huron storms when wave action has reached full intensity. The "small" wave for each direction represents storms of more frequent occurrence, and approximates conditions encountered by small boats entering the harbor for protection from severe storms which have not yet reached maximum intensity.

Wave heights and wave-front orientations are affected by bottom configurations at depths less than one-half the deep-water wave length. Because the wave machine positions were located in such depths, it was necessary to compute the correct orientations of the waves at these

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*Numbers refer to the bibliography shown on page 28.

TABLE I

WAVE CHARACTERISTICS

	LARGE WAVES				SMALL WAVES		
	S 33° 45' E	N 78° 45' E	N 45° 00' E	S 70° 00' E	S 33° 45' E	N 78° 45' E	N 45° 00' E
Deep Water Wave Height (Ft)	8.0	9.0	10.0	8.5	4.5	4.5	4.5
Deep Water Wave Length (Ft)	95.0	113.0	138.0	104.0	81.9	81.9	81.9
Wave Period (Seconds)	4.3	4.7	5.2	4.5	4.0	4.0	4.0
Frequency*	1.2	0.8	2.2		23	10	31

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

positions as well as the wave heights at the gage location. Refraction diagrams prepared for this purpose[3,4] are shown in Appendix C, pages 77, 79 and 81. The refraction diagrams were prepared by the staff of the Lake Hydraulics Laboratory with the cooperation and assistance of Messrs. Lawhead and Lee of the Detroit District, Corps of Engineers.

Mean-low-water datum for Lake Huron is at elevation 578.5 feet above mean tide at New York. The lake stages used in the model tests was 581.5, or 3 feet above mean-low-water datum. This stage was determined from a study of the records of the U. S. Lake Survey water-level recorder at Harbor Beach, Michigan, which show that the rise in stage at this locality due to storm conditions is not a very significant factor, as the 581.5-foot stage has been exceeded infrequently during the past sixty years and then only for relatively short periods and to a minor extent. The crests of the breakwaters were placed at elevation 586.5, which is 8 feet above mean-low-water datum and 5 feet above the water surface used in the model tests.

THE MODEL

The model was constructed to an undistorted linear scale of 1 to 75. This scale provided for waves of sufficient size to eliminate the effect of surface tension and to minimize the importance of viscous damping of the waves. The Froude law was used as the basis for determining model wave periods and for converting model velocities to prototype values.

The model was constructed in a tank 90 feet long by 54 feet wide. An area extending approximately one mile along the shore line and one-half mile perpendicular to the shore line was reproduced in the model. A plan of the wave tank showing the model limits is provided in Fig. 2.

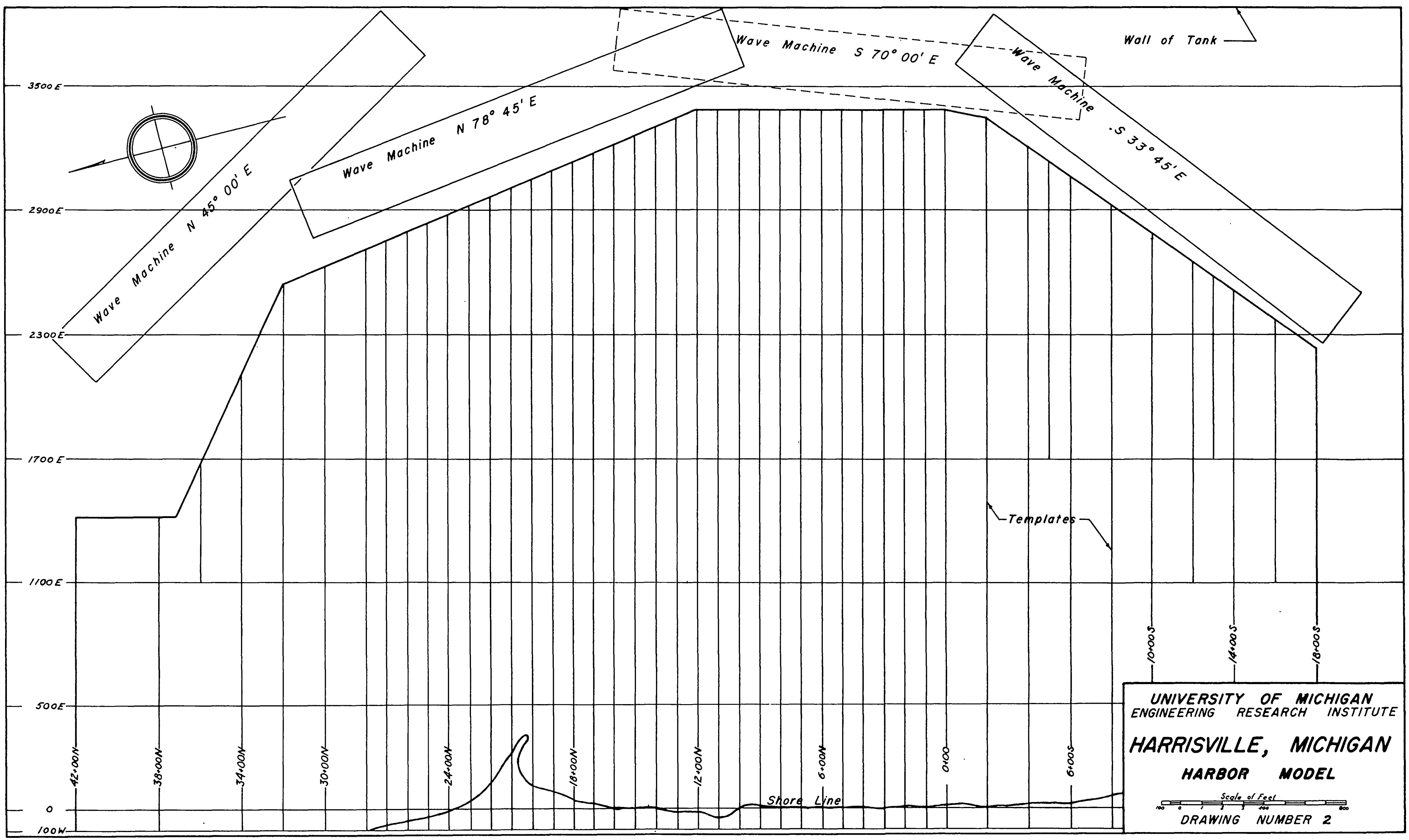

Wave Machine S 70° 00' E
Wall of Tank
Wave Machine N 78° 45' E
Wave Machine N 45° 00' E
Wave Machine S 33° 45' E
3500 E
2900 E
2300 E
1700 E
1100 E
500 E
0
100 W
Templates
42+00N
38+00N
34+00N
30+00N
24+00N
18+00N
12+00N
6+00N
0+00
6+00S
10+00S
14+00S
18+00S
Shore Line
UNIVERSITY OF MICHIGAN
ENGINEERING RESEARCH INSTITUTE
HARRISVILLE, MICHIGAN
HARBOR MODEL
Scale of Feet
DRAWING NUMBER 2

Figure 2

Locations of the tank walls are shown by means of the dashed lines on the topographic charts on pages 77, 79 and 81. Templates were cut from 3/8-inch waterproof plywood in accordance with sounding data supplied by the Detroit District, Corps of Engineers. The templates were spaced at intervals of 1.33 feet in the vicinity of the harbor and at intervals of 2.67 and 5.33 feet in the more remote regions. The template layout is shown in Fig. 2. The templates were cut so that their bottom edges would fall on a single horizontal plane surface, and they were set at the proper elevation by means of an engineer's level. A view of the templates and spacer bars in place is shown in Fig. 3. The space between the templates was filled with well compacted sand to within an inch of their top edges. The upper inch was filled with low-strength cement mortar which was finished by using the top edges of the templates as screeds. Fig. 4 is a photograph of the model with the cement mortar partially in place.

Elevations of the templates were checked before and after the placing of the cement mortar. As a final check on the accuracy of model construction, the tank was filled to a number of water-surface elevations, and the contour lines established by the water's edge were compared with corresponding contour lines on the topographic chart.

TESTING EQUIPMENT AND PROCEDURE

A portable plunger-type wave machine thirty feet long was used to generate waves in the model. Waves of the desired height were produced by selecting the proper eccentricity of the plunger arm. The correct wave period was obtained by setting the wave machine at the desired frequency. A photograph of the wave machine in operation is shown in Fig. 5, p. 10.

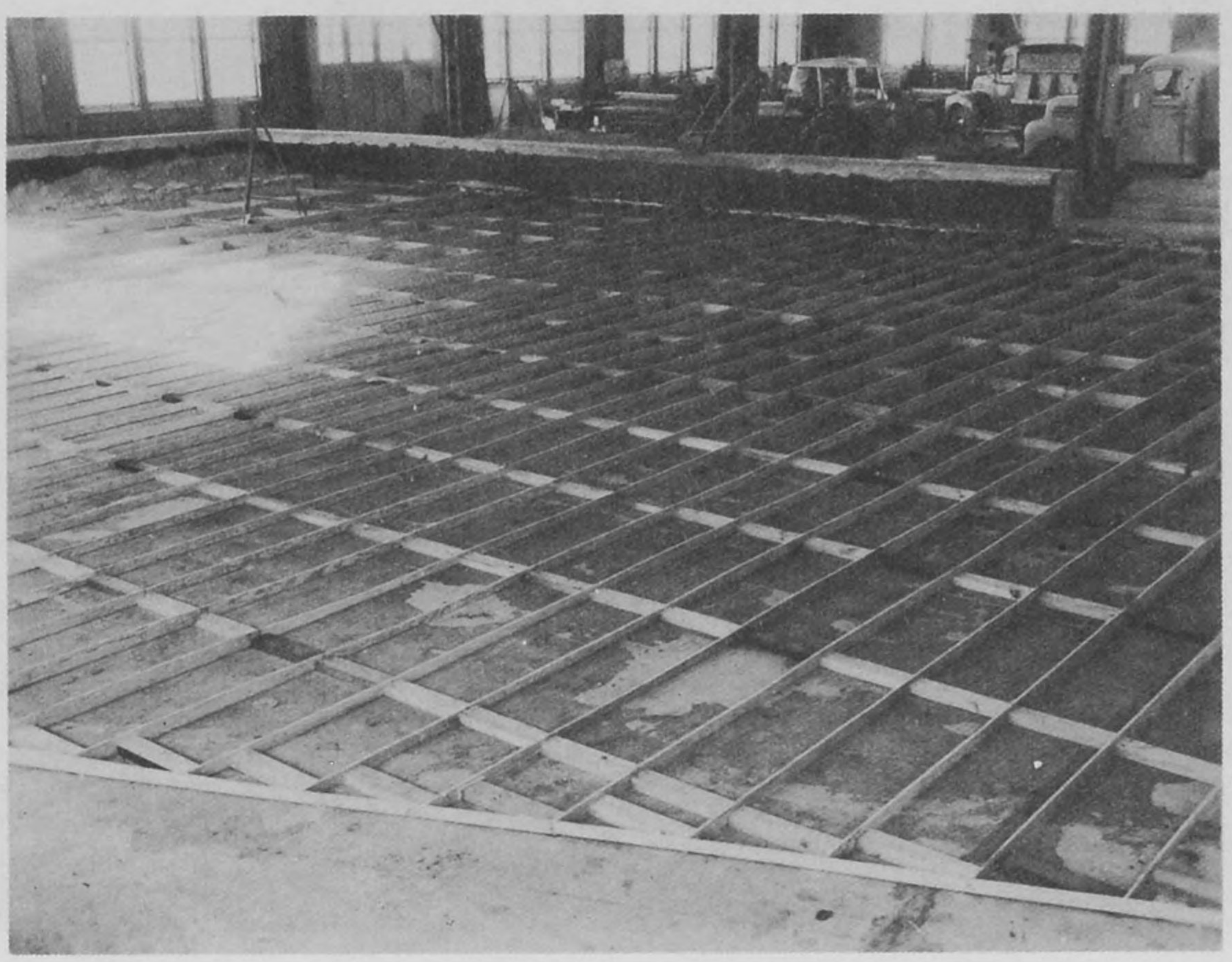


Figure 3. Model under Construction - Templates in Place.

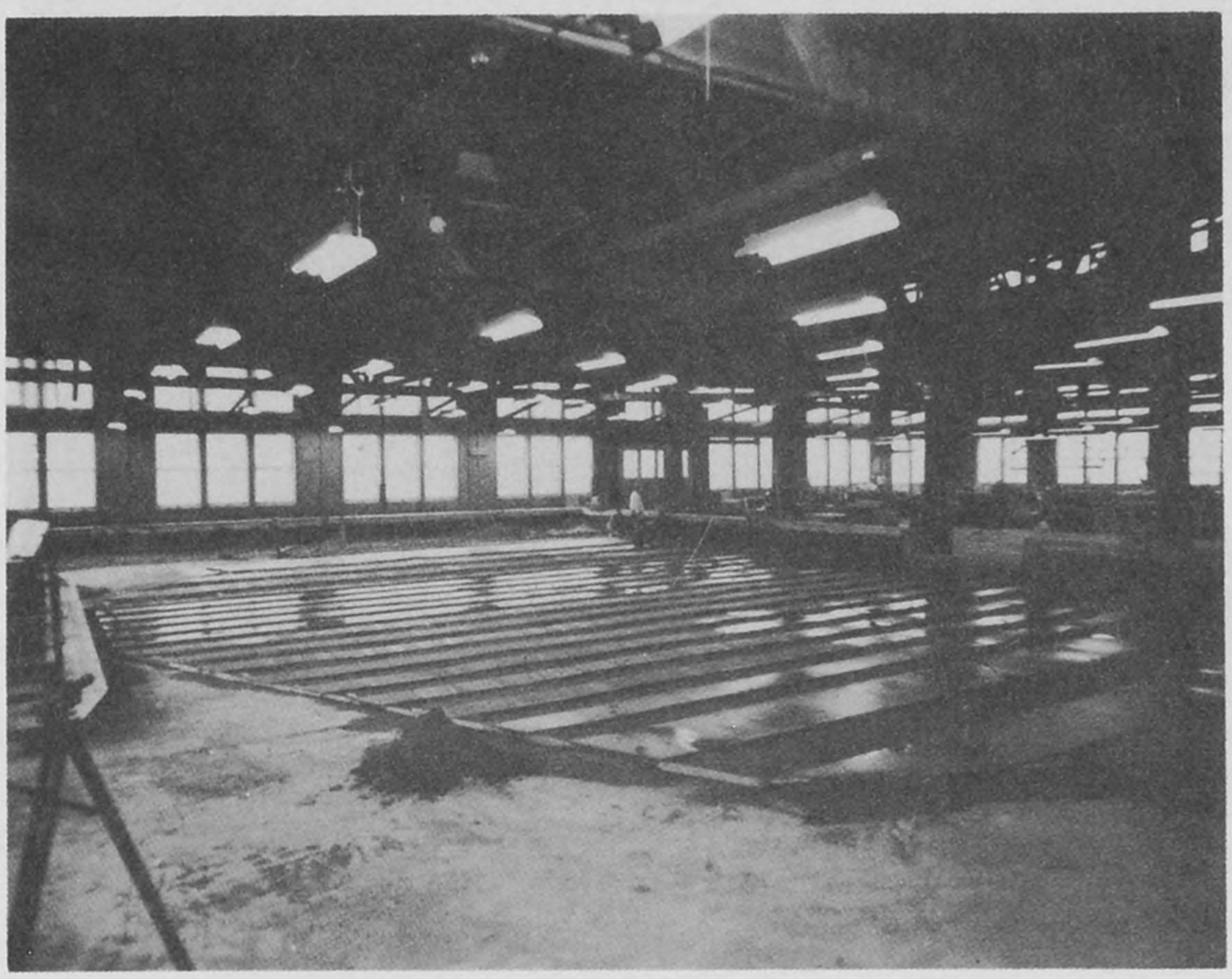


Figure 4. Model under Construction - Cement Mortar Partially in Place.

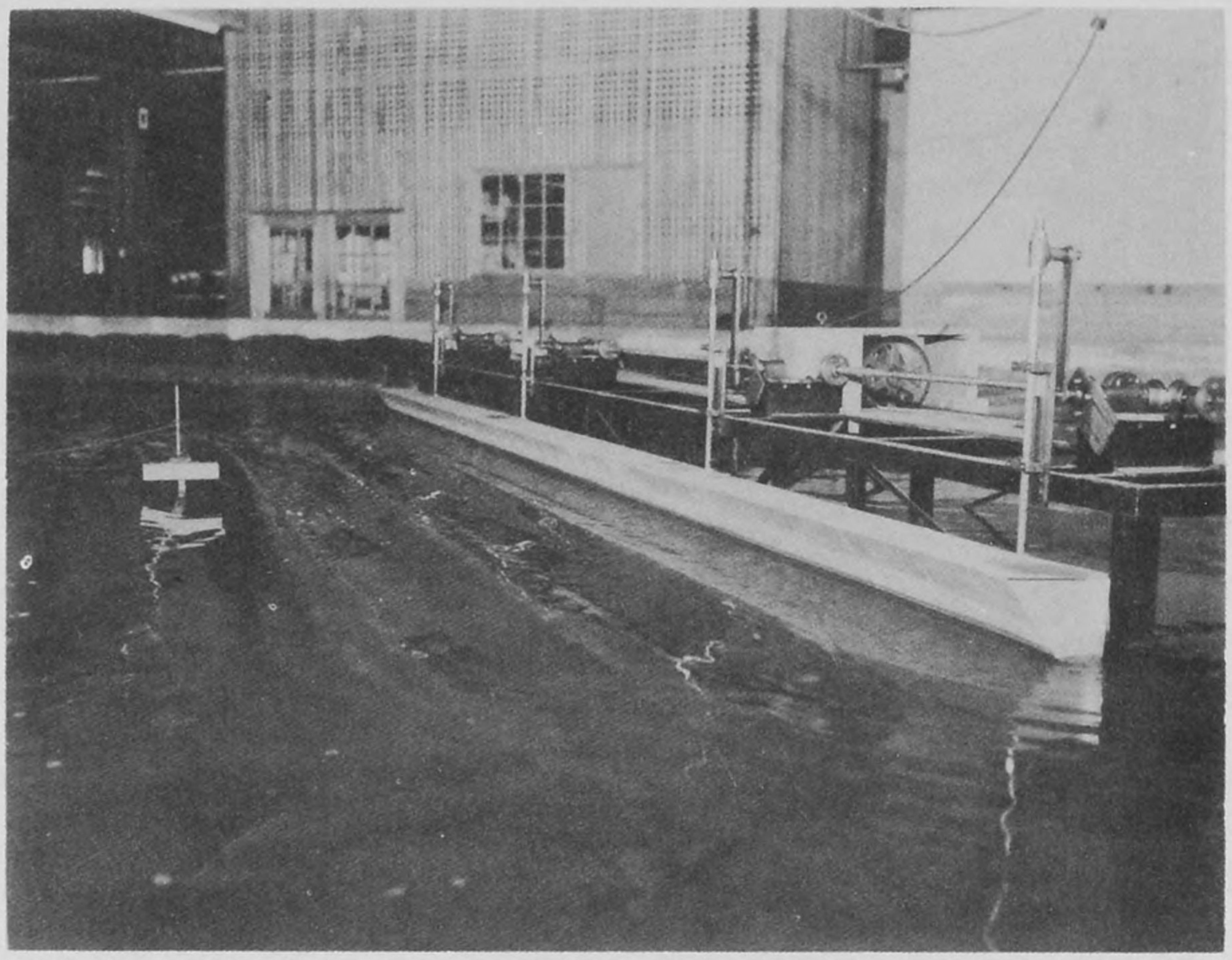


Figure 5. Wave Machine and Gage.

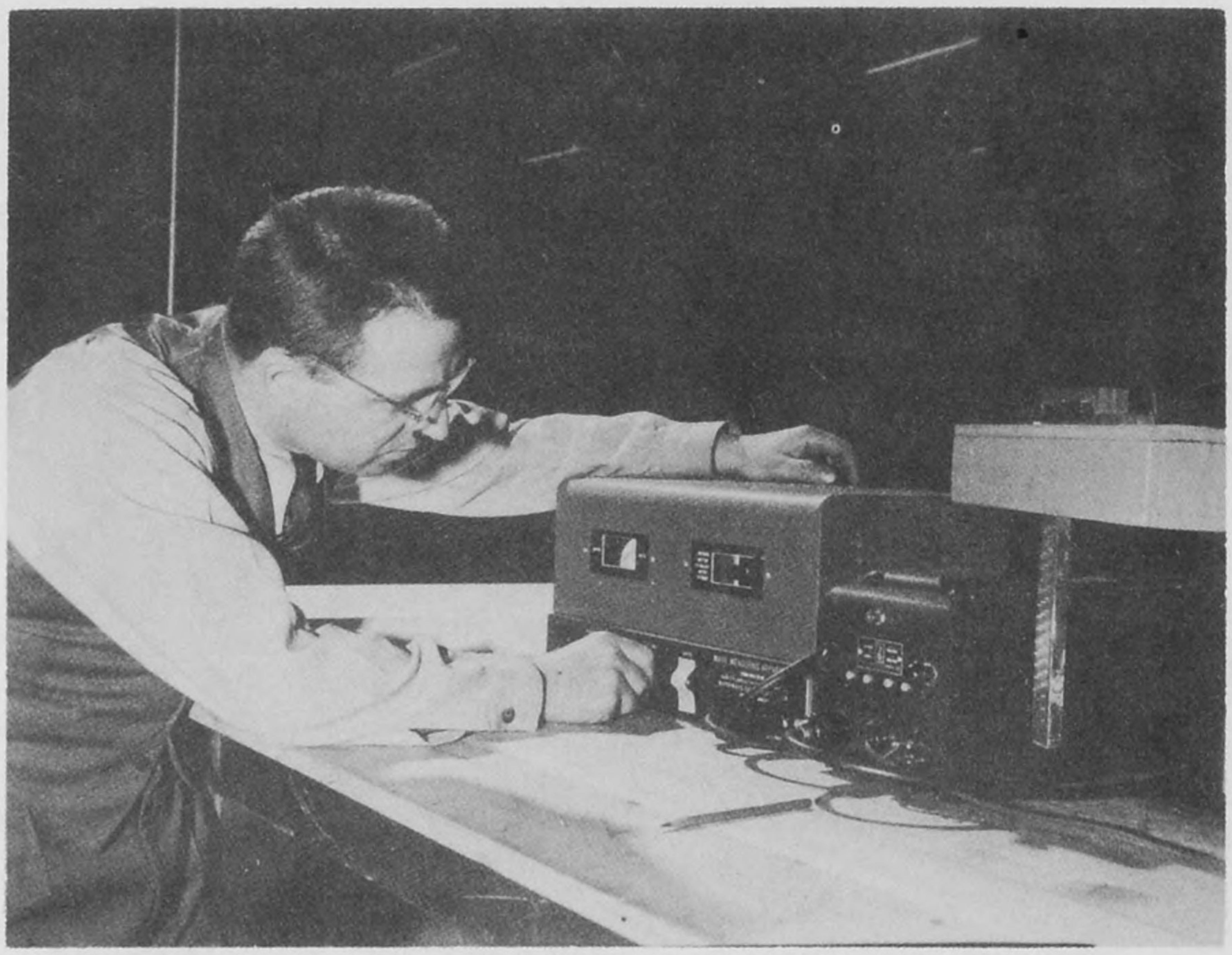


Figure 6. Instruments for Measuring Height of Waves.

Wave heights were measured by means of electrical resistance gages. Variations in submergence due to passing waves caused the voltage across the gage terminals to vary. The voltage variations were amplified and recorded by means of an oscillograph. The instruments were calibrated by raising and lowering the gages specific amounts in still water and recording the corresponding oscillograph fluctuations. Rating curves for the instruments were then constructed. The calibration of the instruments was checked systematically during the tests. One of the resistance gages in a position to determine wave height is shown in Fig. 5. A photograph of all three instruments used is presented in Fig. 6 (from left to right the instruments shown are an amplifier, an oscillograph, and a resistance gage).

Wave heights were measured at 25 to 35 locations for each wind direction. The wave height at any particular point was obtained by averaging the largest one-third of 180 successive waves. During all wave-height measurements, with the following exceptions, the wave machine was operated continuously during the tests. This procedure could not be followed during tests of Plan 2 and its modifications for the wind directions S 33° 45' E. For this direction the southerly breakwaters produced reflections which returned to the wave plunger and were in turn reflected to the harbor, thus causing an unnatural wave condition. To eliminate this condition the wave machine was run intermittently, and the wave heights were measured only in the interval beginning when the waves were first reflected from the south breakwater and ending when the reflections from the wave machine approached the harbor.

Surface currents were measured by timing the movements of small wooden floats between points located from a coordinate system painted on the model bed. The usual distance traveled by a float in a single velocity determination was 20 feet. Additional intermediate points were taken when changes in directions occurred, so that true distances traveled could be determined.

THE MODEL TESTING PROGRAM

Three basic breakwater arrangements, designated as Plans 1, 2, and 3, were studied. Three variations of Plan 2, designated as Plans 2a, 2b, and 2c, and one variation of Plan 3 (Plan 3a) were also tested. These breakwater arrangements are shown in Fig. 7. The harbors were dredged to 12 feet below mean-low-water in the approach channel and navigation entrance and to depths of 10 feet and 6 feet below mean-low-water inside the breakwater, as shown in Fig. 7.

Vertical-walled breakwaters were used in all cases. The model breakwaters were constructed of concrete and simulated prototype breakwaters consisting of cells formed by steel sheet piling. The width of the breakwaters was 25 feet in depths of water less than 6 feet, and 30 feet where the depth exceeded 6 feet. A typical breakwater section is shown in Fig. 8. Riprap was placed only on the lake side of the breakwater, with the exception of the portion extending beyond the harbor opening, where it was placed on both sides.

Plan 1 consisted of two breakwaters with the opening at the south end of the harbor area. The north breakwater was extended lakeward to provide protection at the harbor entrance from waves approaching from a northerly direction. The total length of breakwaters was 2670 feet and the dredged mooring area was 22 acres. The dredged width of the entrance was 150 feet and the distance from toe to toe of the breakwaters was 207 feet.

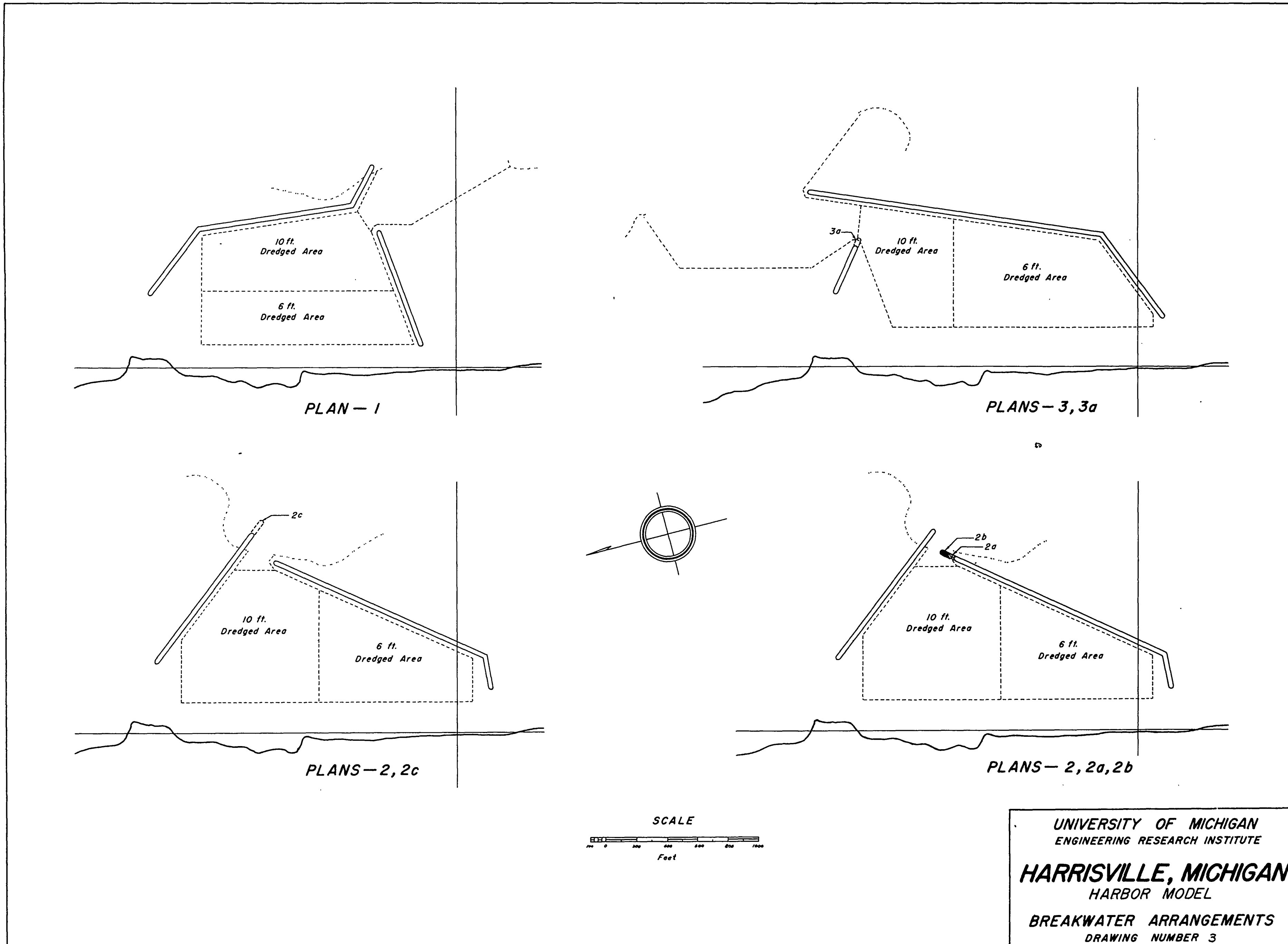

10 ft.
Dredged Area
6 ft.
Dredged Area
PLAN — 1
3a
PLANS — 3, 3a
2c
PLANS — 2, 2c
2b
2a
PLANS — 2, 2a, 2b
SCALE
Feet
UNIVERSITY OF MICHIGAN
ENGINEERING RESEARCH INSTITUTE
HARRISVILLE, MICHIGAN
HARBOR MODEL
BREAKWATER ARRANGEMENTS
DRAWING NUMBER 3

Figure 7

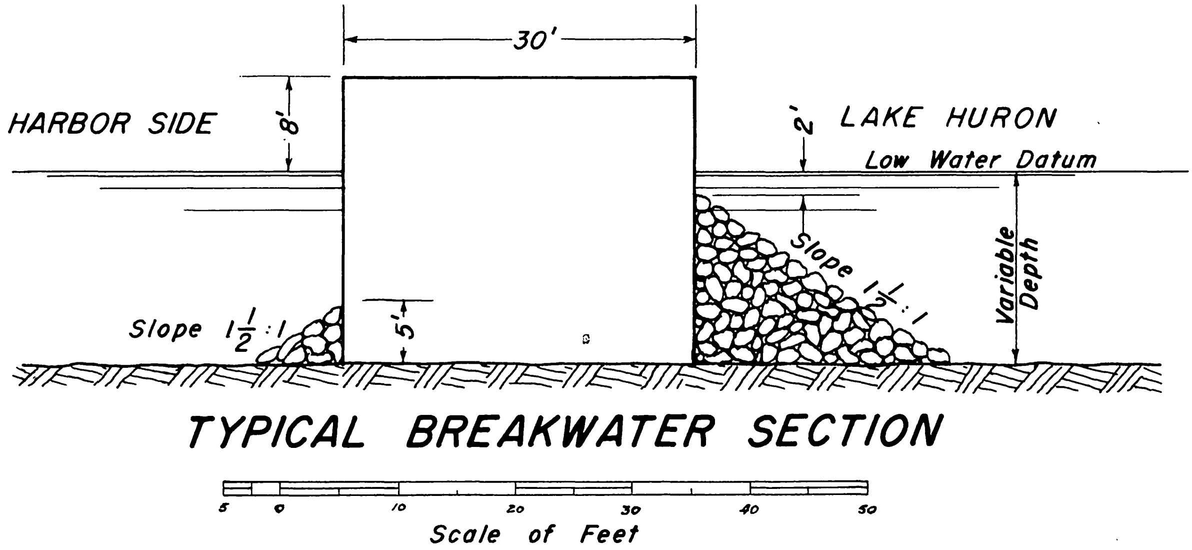


Figure 8.

Plan 2 consisted of two breakwaters, with the opening located somewhat north of the center of the harbor area and facing the southeast. The total length of breakwaters was 2830 feet and the dredged mooring area was 22 acres. The opening of Plan 2 was 177 feet from toe to toe of breakwaters with a dredged channel 150 feet wide.

Plan 2a was identical with Plan 2 except that the south breakwater was extended sufficiently to reduce the entrance width by 50 feet. The dredged entrance width was thus reduced to 100 feet, and the distance from toe to toe of the breakwater was reduced to 127 feet.

Plan 2b consisted of the same breakwater arrangement as for Plan 2a, with the entrance width reduced by another 50 feet due to a further extension of the south breakwater.

Plan 2c was the same as Plan 2 in all respects except that the north breakwater was extended 100 feet lakeward to provide additional protection at the entrance against waves approaching from a northerly direction.

Plan 3 had the opening located at the northerly end of the harbor. The opening faced toward the north, and the south breakwater extended beyond the opening to protect the entrance from wave action. The opening was dredged to a width of 240 feet. The distance from toe to toe of breakwaters was 275 feet. The dredged mooring area covered 27 acres and the total length of breakwaters was 2780 feet.

Plan 3a was the same as Plan 3 except that the northerly breakwater was extended 50 feet, thus making the entrance width 50 feet smaller than that of Plan 3.

In the discussion of the prototype conditions (page 3) it was stated that three principal wind directions and two wave sizes were selected for the tests. It was also pointed out that some tests were made with a fourth wind direction. Table II shows the tests that were made for each plan. It is to be noted that a complete set of tests was not made in all cases, as discussed in the following paragraphs.

Plan 1 was not tested for the direction N 45° E because tests for the direction N 78° 45' E indicated that no significant waves except those resulting from overtopping would be produced in the harbor for more northerly wind directions. Furthermore, the tests for the wind direction S 33° 45' E indicated that Plan 1 would not be a satisfactory arrangement.

Plans 2a and 2b were tested only with the "large" waves for two wind directions. The purpose of the tests of these plans was to determine the variations in wave height inside the harbor which would result from decreasing the size of the harbor opening in successive 50-foot increments from that of Plan 2. Wave action inside the harbor for the direction N 45° E was so mild for Plan 2 that it was not believed that sufficient change would occur to warrant testing Plans 2a and 2b for this wind direction.

TABLE II

SUMMARY OF TESTS MADE ON VARIOUS PLANS*

Plan	S 33° 45' E		N 78° 45' E		N 45° 00' E		S 70° 00' E	
	Large	Small	Large	Small	Large	Small	Large	Small
1	W C	W	W C	W				
2	W C	W	W C	W	W C	W	W C	
2a	W		W					
2b	W		W					
2c	W C		W C		W C		W C	
3	W C	W	W C	W	W C	W		
3a					W			

*W indicates that wave heights were determined.
C indicates that surface currents were determined.

The "small"-wave tests were omitted from Plan 2c because Plan 2 gave satisfactory results during "small"-wave tests, and it was expected that Plan 2c would provide greater protection than Plan 2. An additional wind direction, N 70° E, was tested for Plans 2 and 2c. This direction, which is intermediate between the direction N 78° 45' E, and S 33° 45' E, produces waves which are propagated directly into the harbor entrance. It was believed that waves from any other direction would produce less serious conditions within the harbor.

Plan 3a was tested only for the N 45° E direction because it was only from this direction that waves of appreciable size other than those resulting from overtopping entered the harbor of Plan 3.

TEST RESULTS

The test results are presented in graphical form in Appendix A, p 29. Wave heights are recorded on the drawings at the locations where the measurements were made. Also shown at each gaging point is an arrow which indicates the direction of travel of the predominant waves. Lines of equal wave height are shown on the drawings. The portions of the harbor in which the wave heights were less than 1.5 feet and the areas having wave heights greater than 5 feet were hatched to aid in comparing the effectiveness of the various plans.

The results of wave height tests of Plan 1 are shown on pages 31 to 34. To facilitate the comparison of Plans 2, 2a, 2c, and 3, the drawings for particular wind directions and wave sizes for these four plans are shown on the same sheets on pages 35 to 47. The wave-height drawing for Plan 3a is shown on page 49.

The effects of closing the harbor entrance in successive stages may be seen from a study of the tests on Plans 2, 2a and 2b. To permit the evaluation of these results, the drawings for these three plans are shown together on pages 51 to 53.

The results of the wave-height determinations within the harbor have been summarized in Table III. This table shows, for each plan, the number of acres of harbor area in which the wave heights were less than the indicated values. These data were obtained by planimetering the dredged areas between the lines of equal wave height. The tabulated values are also shown graphically in Figs. 9, 10, 11, and 12. In evaluating the relative merits of the various plans from the drawings and tables it should be kept in mind that the wind directions which produced the most severe harbor conditions were not the same

TABLE III

HARBOR AREA IN ACRES IN WHICH WAVE HEIGHT WAS LESS THAN THE INDICATED VALUES

Wave Height in Feet	S 33° 45' E						N 78° 45' E						M 45° 00' E				S 70° 00' E	
	Plan 1	Plan 2	Plan 2a	Plan 2b	Plan 2c	Plan 3	Plan 1	Plan 2	Plan 2a	Plan 2b	Plan 2c	Plan 3	Plan 2	Plan 2c	Plan 3	Plan 3a	Plan 2	Plan 2c
1.0	6.5	19.6	21.1	23.8	18.9	26.7	19.2	20.4	23.4	25.5	25.3	23.8	22.4	25.1	20.4	24.7	13.4	16.3
1.5	11.8	22.9	24.4	26.5	21.7		21.8	23.8	26.3	26.3	26.1	26.7	26.7	26.7	25.4	26.7	17.8	22.9
2.0	16.3	25.1	25.7	26.7	25.0		22.2	25.6	26.9	26.9	26.7		27.1	27.1	26.5		22.2	25.7
3.0	20.5	25.9	26.9	27.0	26.3			26.9	27.1	27.1	27.1				26.7		25.6	26.6
4.0	21.4	27.1	27.1	27.1	27.0			27.0									26.8	27.1
5.0	21.7				27.1			27.1									27.1	

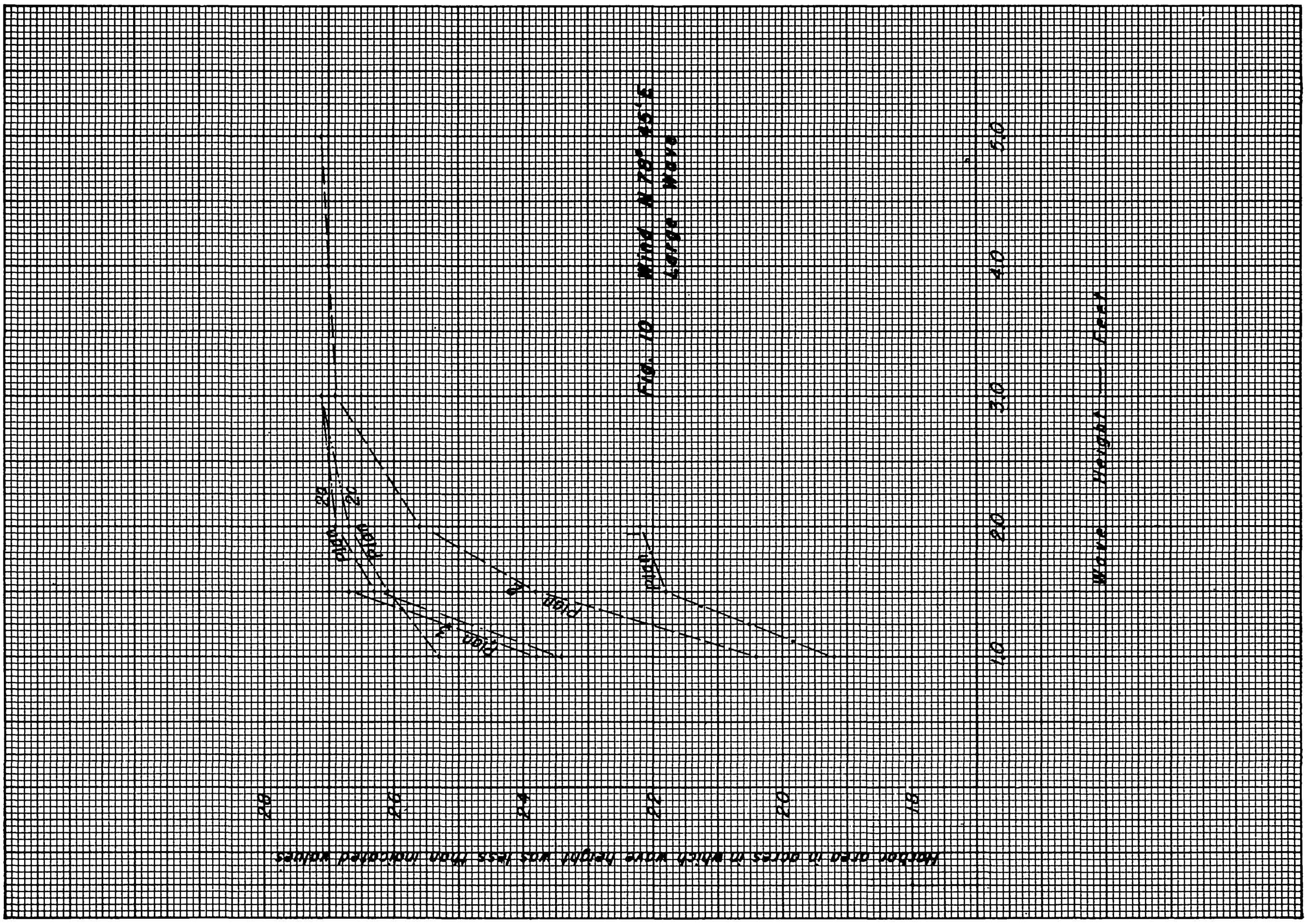


Fig. 10 Wind N 78° 45' E
Large Wave
Plan 22
Plan 21
Plan 8
Plan 2
Plan 1
Harbor area in acres in which wave height was less than indicated values
28
26
24
22
20
18
Wave Height — Feet
1.0
2.0
3.0
4.0
5.0

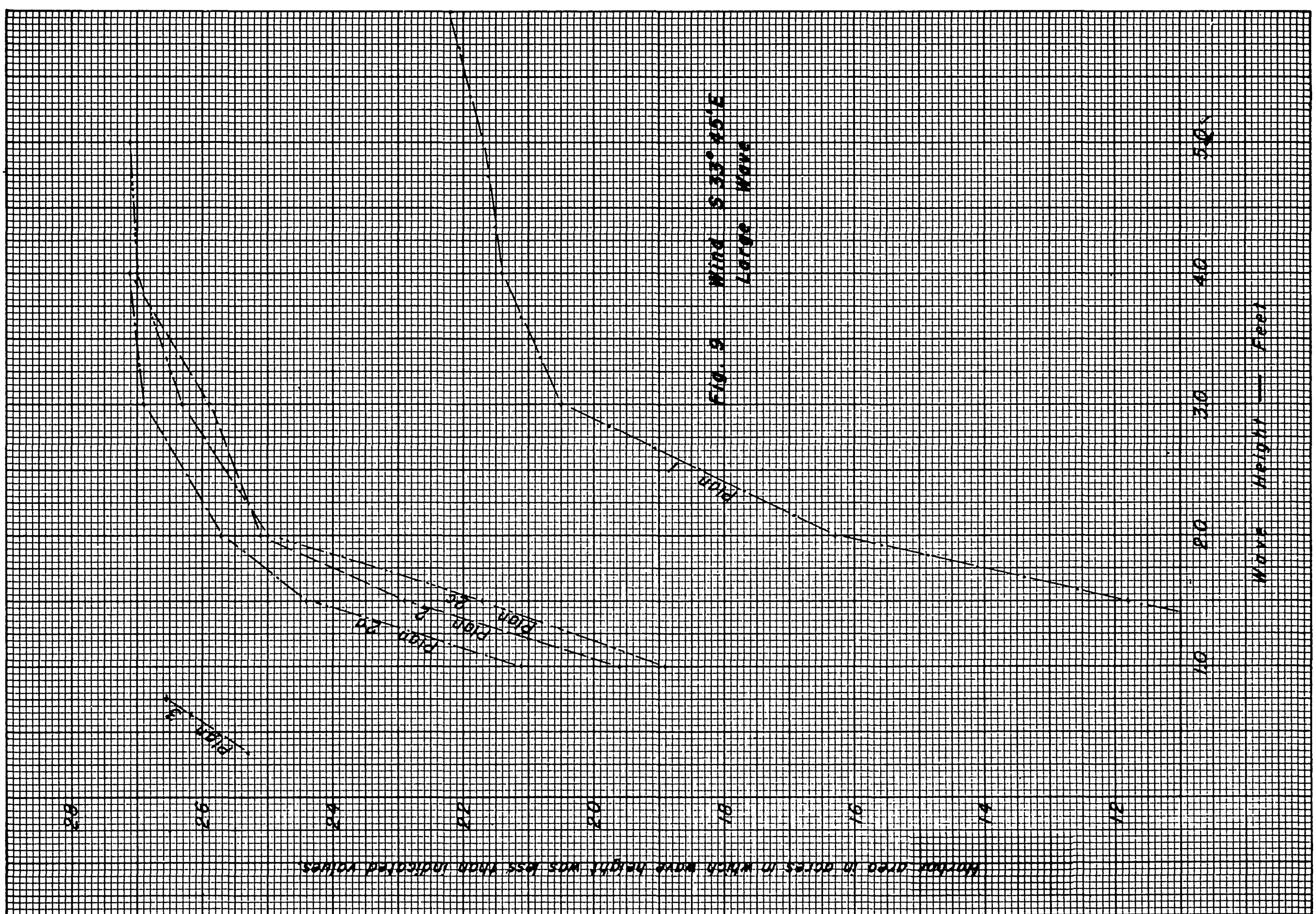


Fig. 9 Wind S 33° 45' E
Large Wave
Plan 1
Plan 30
Plan 2
Plan 24
Plan 31
Harbor area in acres in which wave height was less than indicated values
28
26
24
22
20
18
16
14
12
Wave Height — Feet
1.0
2.0
3.0
4.0
5.0

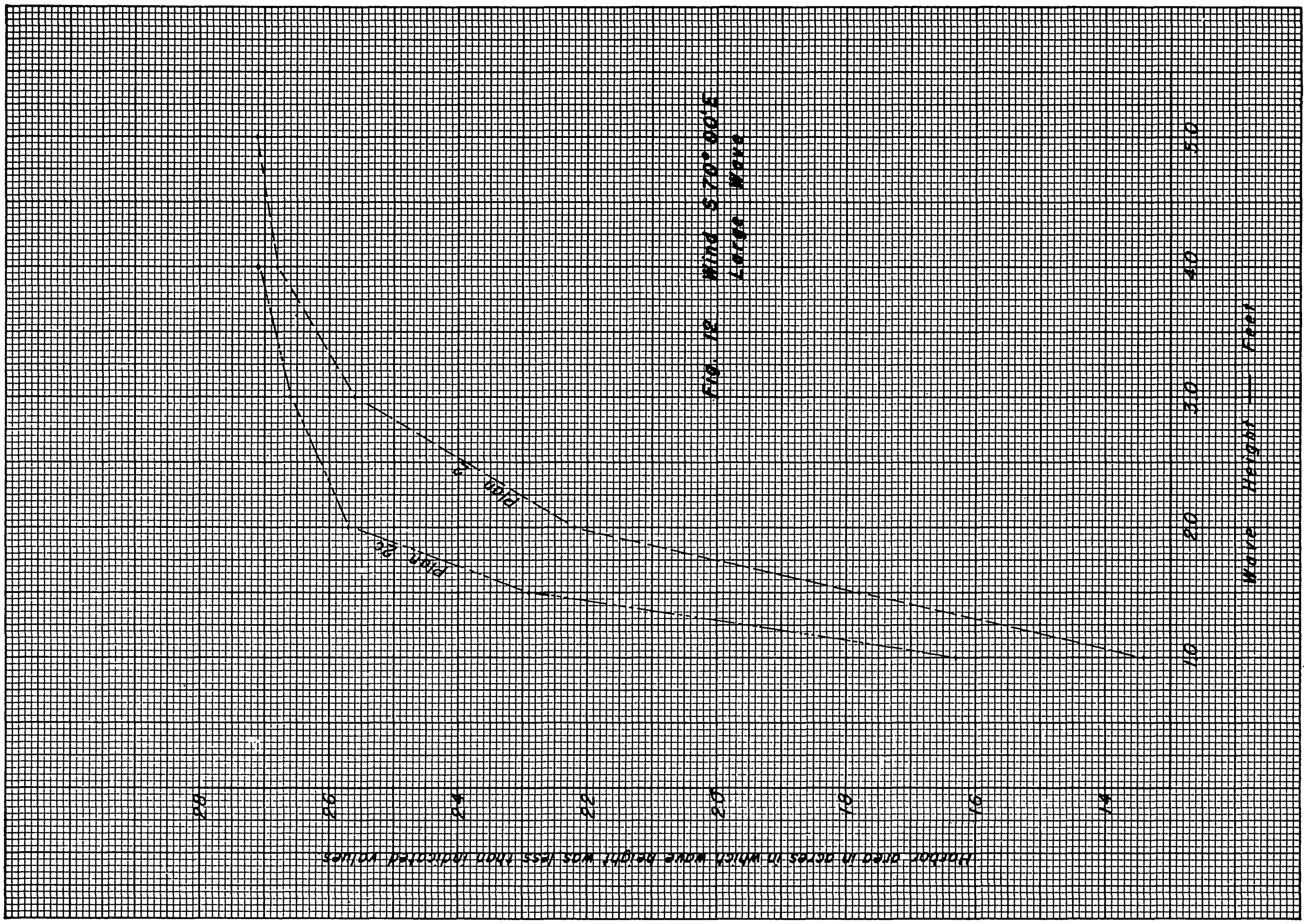


Fig. 12 Wind S 70° 00' E
Large Wave
Plan 3a
Plan 2
Harbor area in acres in which wave height was less than indicated values
28
26
24
22
20
18
16
14
Wave Height — Feet
1.0
2.0
3.0
4.0
5.0

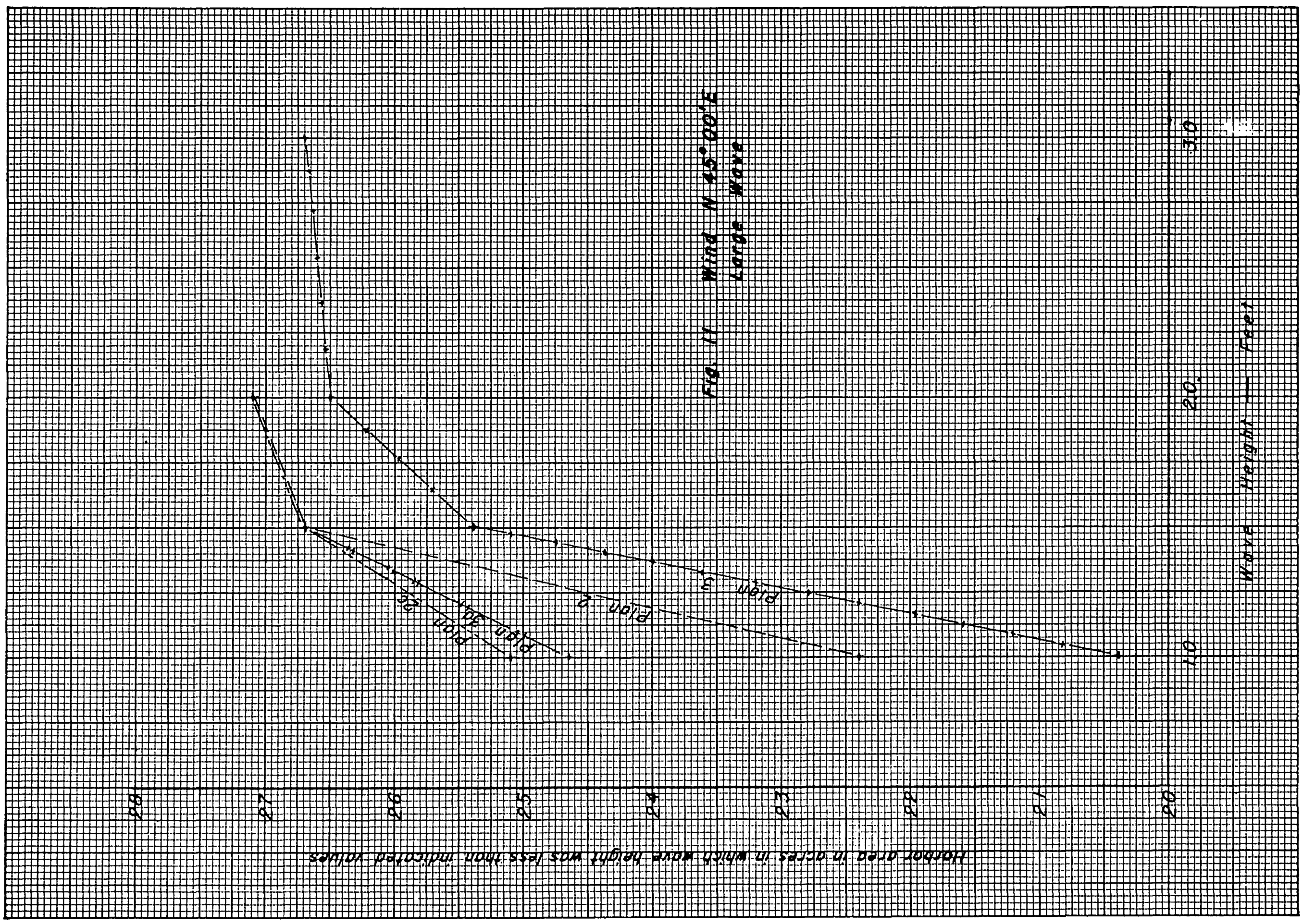


Fig. 11 Wind N 45° 00' E
Large Wave
Plan 3
Plan 2
Plan 3a
Plan 3c
Harbor area in acres in which wave height was less than indicated values
28
27
26
25
24
23
22
21
20
Wave Height — Feet
1.0
2.0
3.0

for each plan. For instance, the harbor entrances for Plans 1 and 2 faced in a southerly direction while that of Plan 3 faced north. Consequently, the relative effectiveness of the various plans can be determined best by comparing the wave conditions produced by the wind direction found to be the most critical in each case. For this reason the wind direction producing the most severe harbor conditions was determined for each plan from Table III, and the corresponding values were plotted in Fig. 13, p. 22. The values for Plan 2b are not shown in Figs. 9 to 13 because it was thought that the harbor entrance for this plan was too small to permit the safe passage of vessels. To permit the evaluation of the effect of changing the size of the opening, the curves for Plans 2, 2a, and 2b are shown separately in Figs. 14 and 15, p. 23.

It should be noted that the relative size of the quiet area alone may not be conclusive in choosing the best harbor arrangement. Because fixed mooring facilities are highly desirable, the best arrangement should include an area where such facilities can be provided which is relatively quiet during storms from all directions. The degree to which such a desired condition was attained can be determined from the drawings showing the test results.

The drawings, tables, and figures described above supply detailed information concerning the sizes of waves to be expected inside the various harbors. The nature of the waves in regard to the presence of reflections or cross waves may be seen from a study of the photographs shown in Appendix B, p 55. During each "large"-wave test, the harbor was photographed from four directions. Each plate in Appendix B contains the four photographs for a particular plan and wind direction.

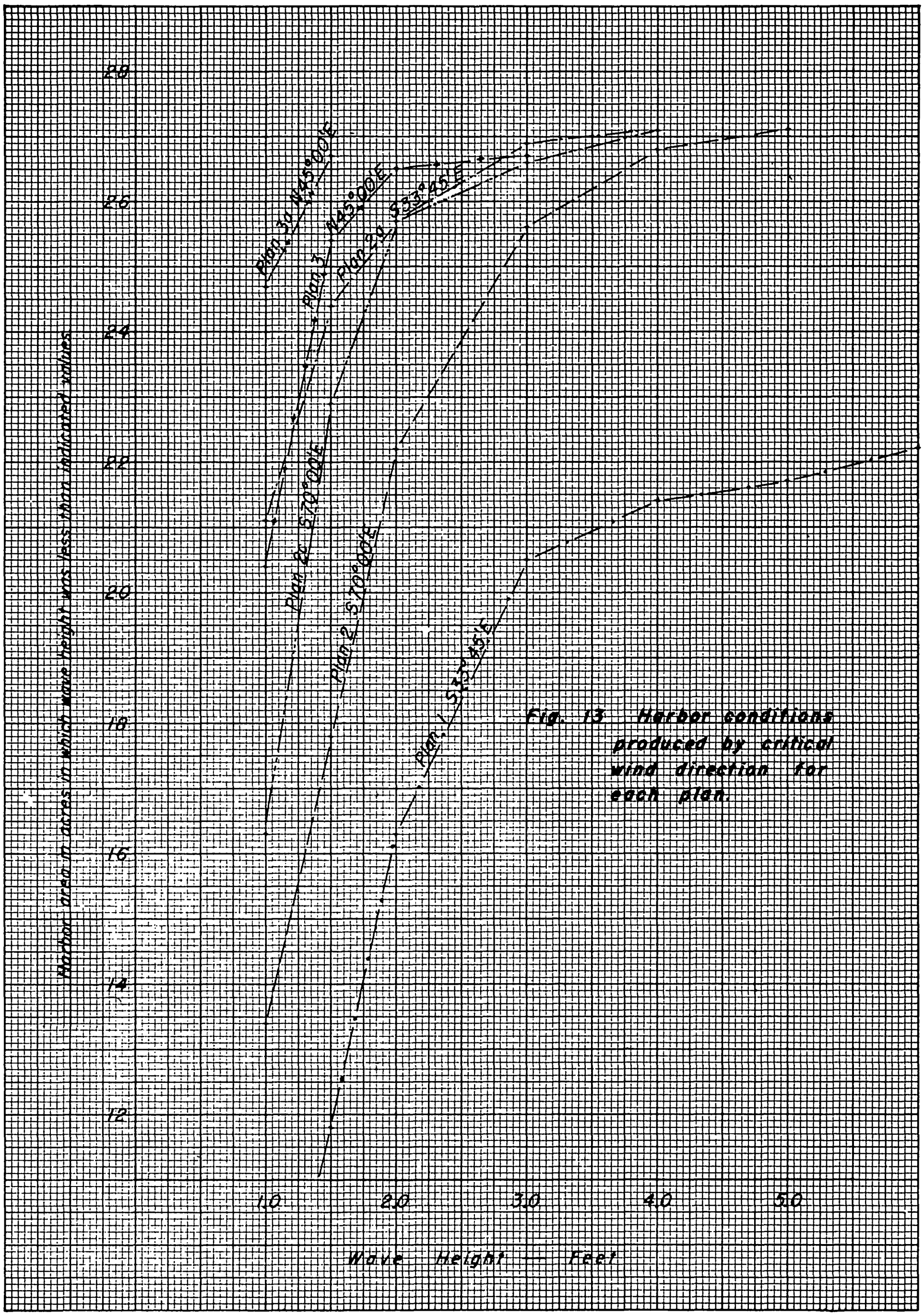


Fig. 13 Harbor conditions produced by critical wind direction for each plan.

A comparison of the various plans in regard to entrance conditions requires consideration of not only the wave height but also such additional factors as width of entrance channel, the presence or absence of reflected waves, and the orientation of approaching waves. These conditions may be determined from a study of the photographs and wave-height

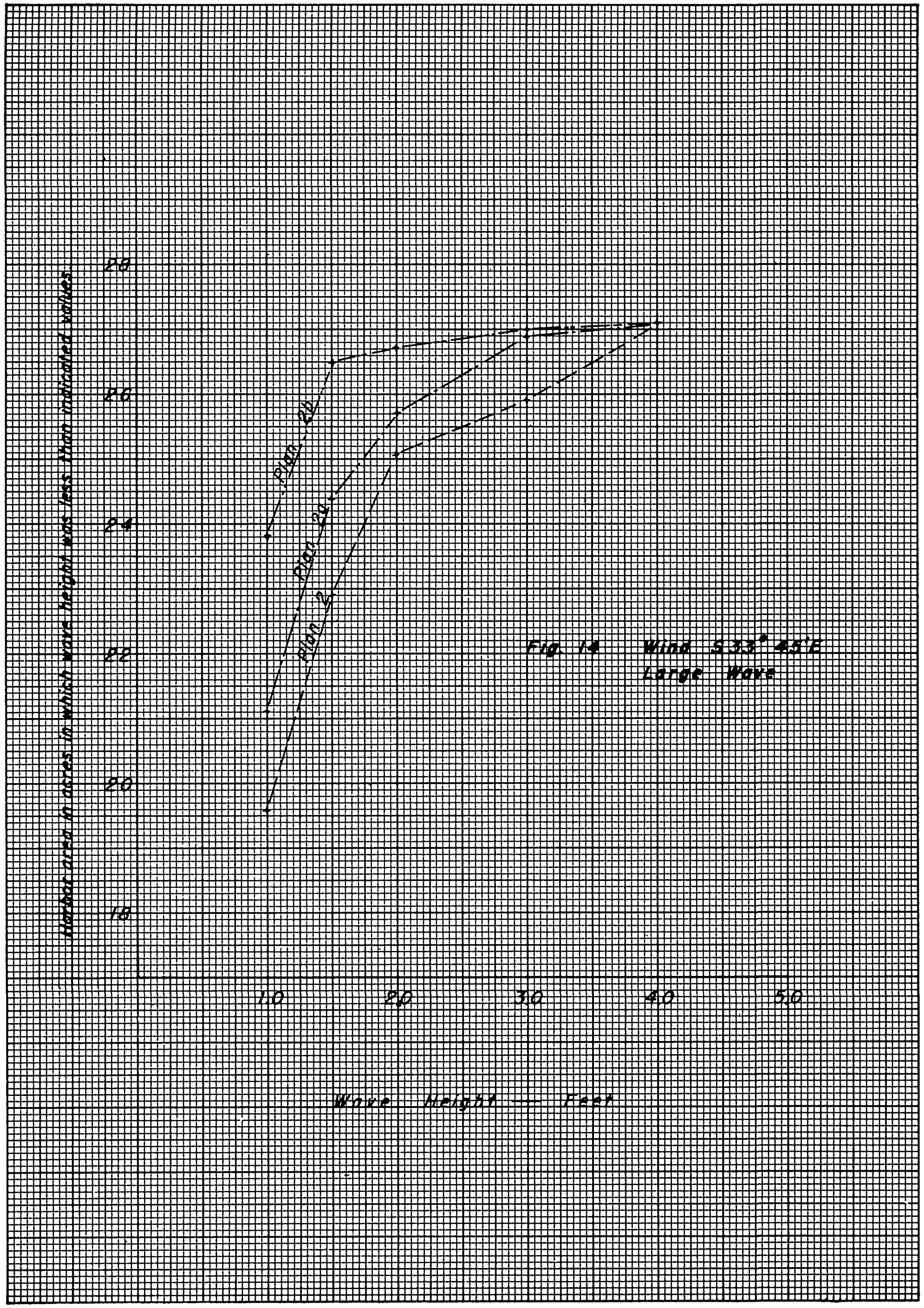


Fig. 14 Wind S 33° 45' E
Large Wave

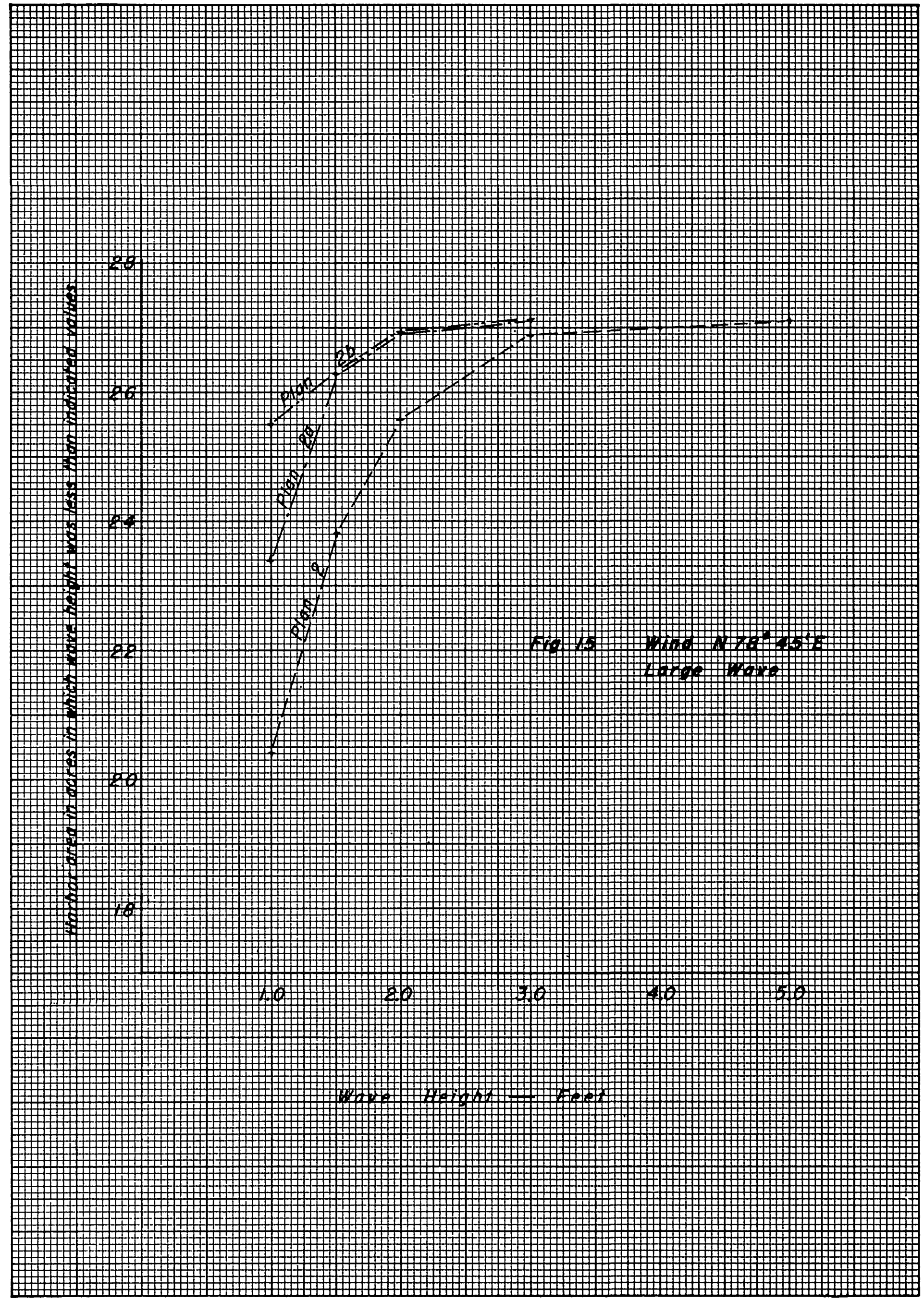


Fig. 15 Wind N 78° 45' E
Large Wave

drawings and from notes made during the tests. By weighting each of these factors equally, a qualitative comparison of the various plans was prepared and presented in Table IV. For the purpose of preparing this table, the plan giving the best results for any condition is numbered 1, the second best 2, etc. Although Table IV aids in evaluating the relative merits of the various plans, it does not indicate the degree to which one plan may be superior or inferior to another. This can be determined only from the original drawings and photographs.

The results of the current measurements were not included in this report for the reason that they were not considered to be a significant factor in determining the relative merits of the various plans for this harbor. Drawings showing the measured currents have been supplied to those offices of the Corps of Engineers which have been directly concerned with these studies.

SUMMARY OF CONCLUSIONS

Plan 1: This plan provided much less protection than any of the other plans against storms approaching from the easterly and southerly directions. This is clearly illustrated in Figs. 9, 10, and 13. For this reason Plan 1 was not considered in further comparisons.

Plan 2: This plan provided good protection from wave action. A large mooring area in the southerly part of the harbor was relatively calm for all the wind directions tested. Conditions at the harbor entrance were fair. A reflected cross-wave occurred at the entrance for the direction S 33° 45' E, as shown in Plate 3, p 59.

Plan 2a: This plan provided better conditions inside the harbor than Plan 2, as shown in Figs. 14 and 15. However, wave heights outside

TABLE IV

COMPARISON OF ENTRANCE CONDITIONS

	S 33° 45' E				N 78° 45' E				N 45° 00' E			
	Plan 2	Plan 2a	Plan 2c	Plan 3	Plan 2	Plan 2a	Plan 2c	Plan 3	Plan 2	Plan 2c	Plan 3	Plan 3a
Width of Entrance	2.5	4	2.5	1	2.5	4	2.5	1	3.5	3.5	1	2
Reflective Disturbance	2	3	4	1	3	4	2	1	3.5	3.5	1.5	1.5
Angle Made by Vessel with Waves	2	2	2	4	2	2	2	4	2.5	2.5	2.5	2.5
Height of Waves in Approach Area	2	3	4	1	3	4	2	1	2.5	2.5	2.5	2.5
Height of Waves in Entrance	2	3	4	1	4	2	3	1	3.5	2	3.5	1
Total Points	10.5	15.0	16.5	8.0	14.5	16.0	11.5	8.0	15.5	14.0	11.0	9.5

the harbor entrance were higher, and more reflected waves occurred. These approach conditions and the fact that the size of the entrance was reduced to 100 feet would make it more difficult for vessels to enter the harbor than in the case of Plan 2.

Plan 2b: This plan provided quieter harbor conditions than Plans 2 and 2a, as shown in Figs. 14 and 15. However, it also produced the highest waves in the approach channel and the most severe reflected waves of any of the plans tested. These latter conditions along with the small entrance width, 50 feet, would make it exceedingly difficult for a vessel to enter the harbor. This plan was not tested with the thought of adopting it for construction but only for the purpose of showing the effect of entrance width on wave size.

Plan 2c: Plan 2c was more effective than Plan 2 in reducing wave heights inside the harbor for winds approaching from the northerly and easterly directions, as shown in Figs. 10, 11, and 12. However, as may be seen from Fig. 9, it was slightly less effective than Plan 2 for waves approaching from the south. In regard to entrance conditions Plan 2c was about the same as Plan 2 for the northerly and easterly directions and inferior for the southerly direction.

Plan 3: This plan provided the best protection of the harbor for the direction S 33° 45' E, while for the direction N 78° 45' E it was one of the three most effective plans. For the direction N 45° E it was less effective in reducing wave heights than Plans 2 and 2c. However, it may be seen from Fig. 13 that this plan provided better harbor conditions for its critical wind direction than any of the other plans except Plan 3a. As shown by Table IV, it gave the best over-all entrance conditions of any of the plans tested. Only in one respect, namely, the orientation of the waves as they approached the entrance, did this plan appear to be inferior to Plan 2 and its modifications. The good entrance conditions in regard to wave heights and reflections were due in some degree to the fact that this arrangement permitted the use of an entrance width which was 90 feet greater than that of Plans 2 and 2c and 140 feet greater than that of Plan 2a.

Plan 3a: This plan provided more complete protection against waves approaching from a northerly direction than Plan 3. It may be seen from Fig. 11 that it gave results for the directions N 45° E which were nearly as good as those of Plan 2c. The entrance conditions were as good as those of Plan 3. However, a vessel approaching the harbor would have less space in which to make the turn into the entrance than in the case of Plan 3.

RECOMMENDATIONS

Plans 3 or 3a would provide better harbors both from the standpoint of mooring conditions and entrance conditions than any of the other plans tested. It is also expected that the cost of Plans 3 or 3a would be somewhat less than that of Plan 2 or its modifications. For these reasons either Plan 3 or 3a would be considered as first choice. However, it is understood that the predominant direction of littoral drift at Harrisville is from the north to the south. If this drift is severe, it may cause the entrance and mooring areas of Plans 3 and 3a to fill in faster than would be the case for Plan 2 or its modifications. A field study would indicate whether or not littoral drift is a significant factor.

It is recommended that Plan 3 be chosen rather than Plan 3a because of greater ease with which vessels could enter the harbor.

Plans 2, 2a, or 2c would make effective harbors. It is believed that Plan 2c would be the most satisfactory of these three because it provided greater protection than Plan 2 and better entrance conditions than Plan 2a.

BIBLIOGRAPHY

1. WIND WAVES AND SWELL, PRINCIPLES IN FORECASTING, U. S. Hydrographic Office Publ., Misc. 11, 275, 61 pp., 1943.

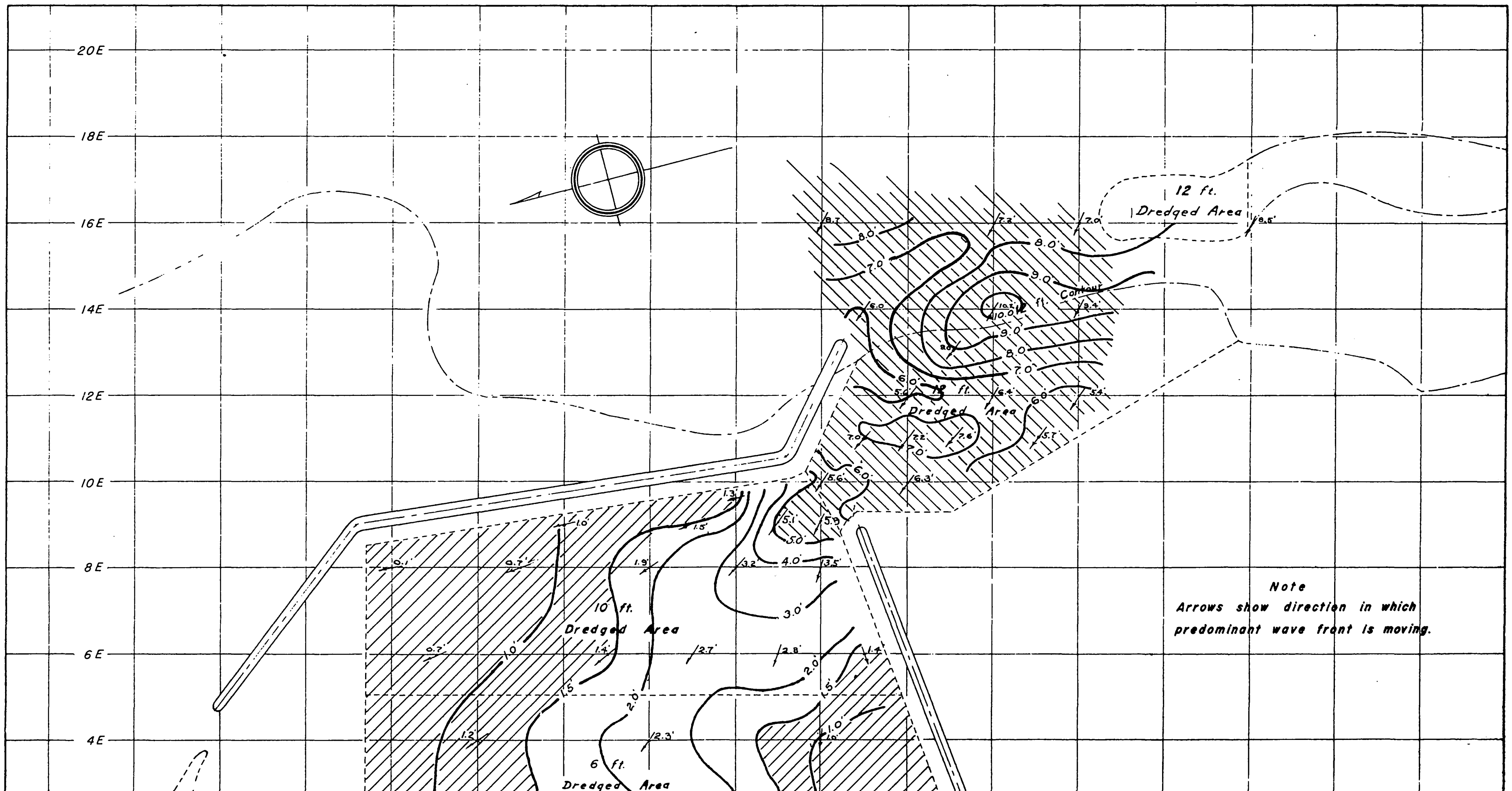
2. BEACH EROSION BOARD SPECIAL ISSUE NO. 1, Wiegel, R. L., 50 pp., 1948.

3. BREAKERS AND SURF, U. S. Hydrographic Office Publ., no. 234, 52 pp., 1944.

4. GRAPHICAL CONSTRUCTION OF WAVE REFRACTION DIAGRAMS, Johnson, O'Brien, and Isaacs, U. S. Hydrographic Office Publ., no. 605, 45 pp., 1948.

APPENDIX A

DRAWINGS SHOWING TEST DATA



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HARRISVILLE, MICHIGAN

HARBOR MODEL — PLAN I

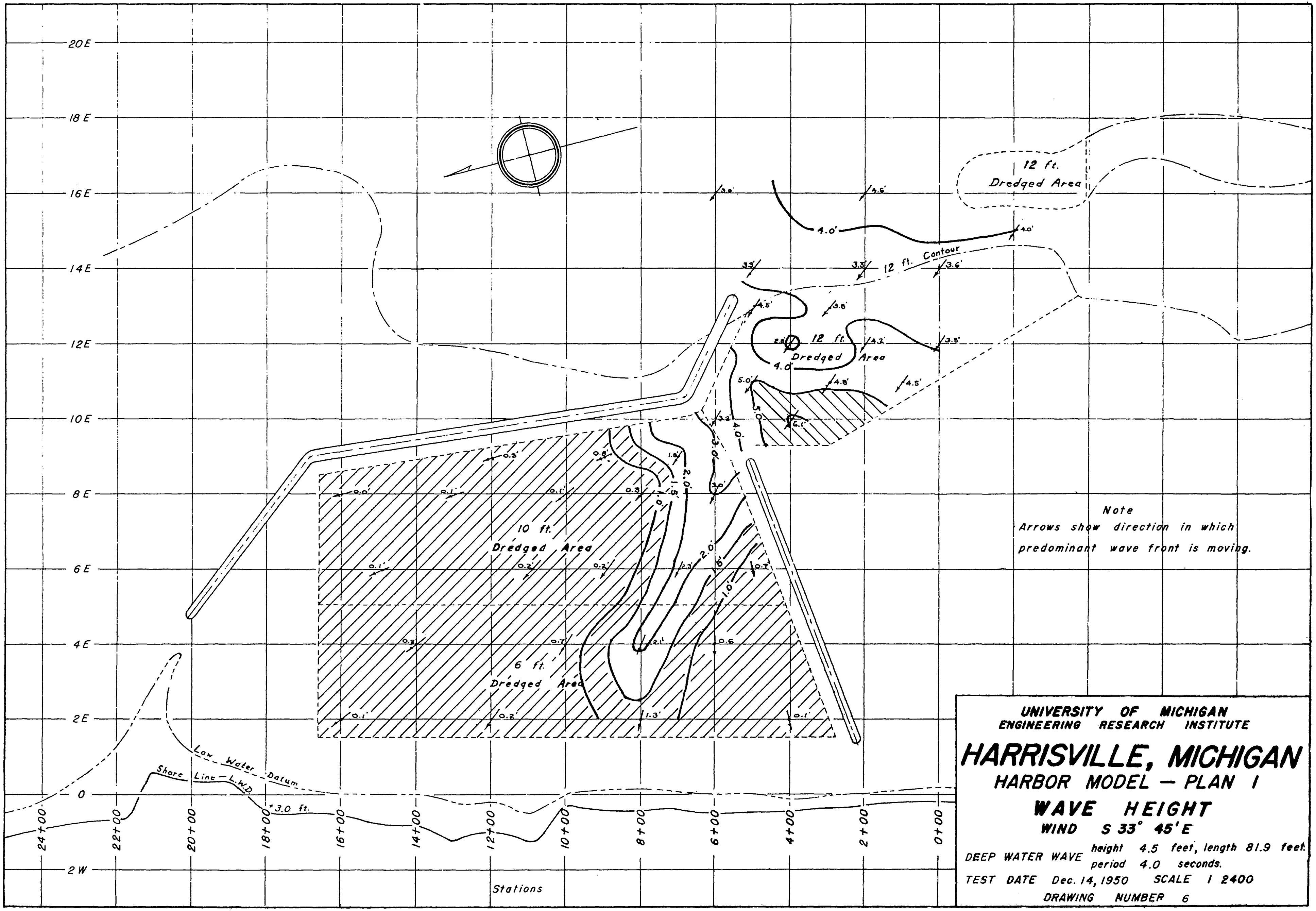
WAVE HEIGHT

WIND S 33° 45' E

DEEP WATER WAVE height 8.0 feet, length 95.0 feet. period 4.3 seconds.

TEST DATE Dec. 8, 1950 SCALE 1:2400

DRAWING NUMBER 5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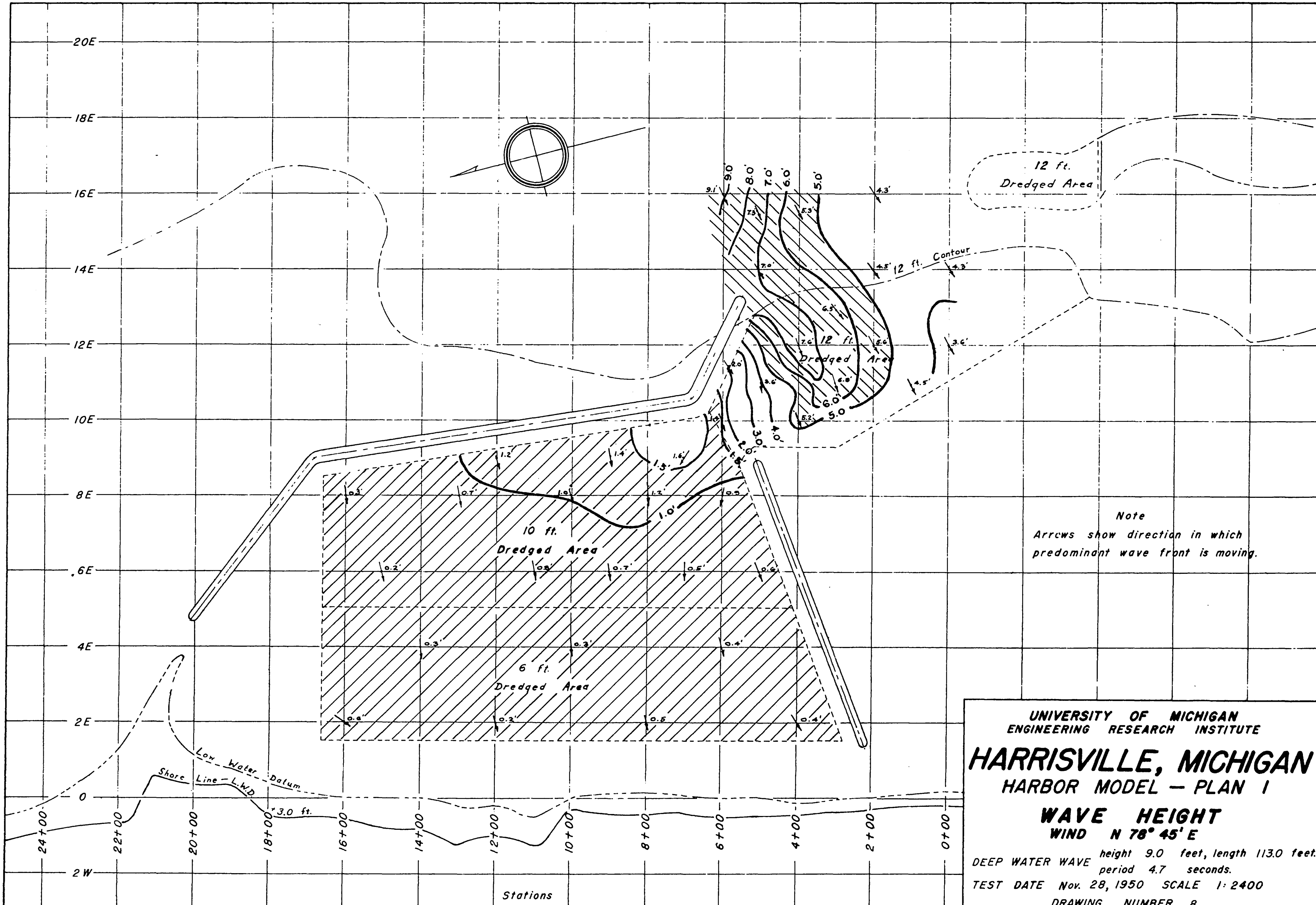
HARRISVILLE, MICHIGAN
HARBOR MODEL — PLAN I
WAVE HEIGHT
WIND S 33° 45' E
DEEP WATER WAVE height 4.5 feet, length 81.9 feet. period 4.0 seconds.
TEST DATE Dec. 14, 1950 SCALE 1 2400
DRAWING NUMBER 6
Note
Arrows show direction in which predominant wave front is moving.
12 ft. Dredged Area
12 ft. Contour
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Low Water Datum
Shore Line - L.W.D. +3.0 ft.
Stations
20E
18E
16E
14E
12E
10E
8E
6E
4E
2E
0
2W
24+00
22+00
20+00
18+00
16+00
14+00
12+00
10+00
8+00
6+00
4+00
2+00
0+00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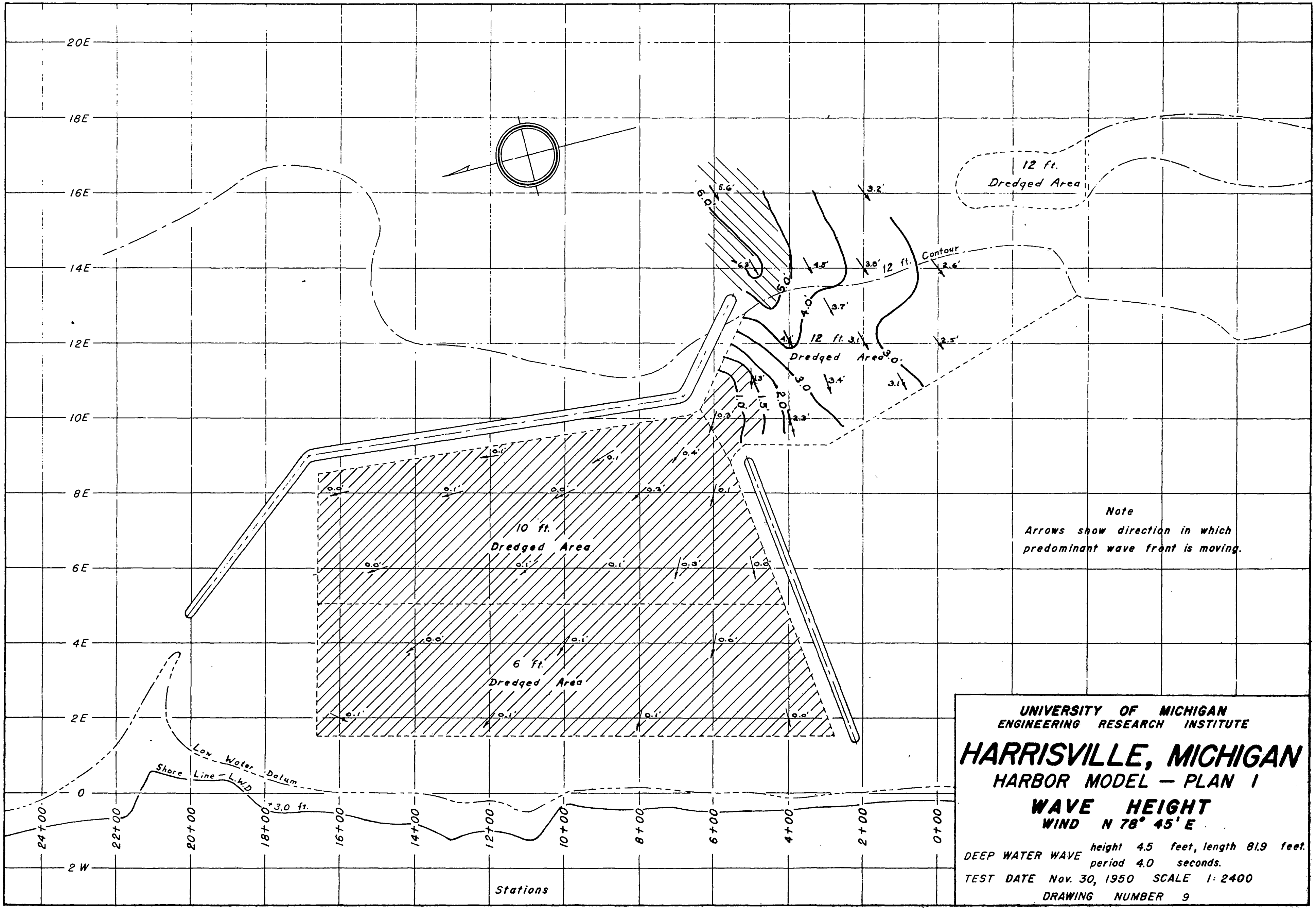
HARRISVILLE, MICHIGAN
HARBOR MODEL — PLAN I
WAVE HEIGHT
WIND N 78° 45' E
DEEP WATER WAVE height 9.0 feet, length 113.0 feet. period 4.7 seconds.
TEST DATE Nov. 28, 1950 SCALE 1:2400
DRAWING NUMBER 8
Note
Arrows show direction in which predominant wave front is moving.
12 ft. Dredged Area
12 ft. Contour
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Low Water Datum
Shore Line - L.W.D.
+3.0 ft.
Stations
20E
18E
16E
14E
12E
10E
8E
6E
4E
2E
0
2W
24+00
22+00
20+00
18+00
16+00
14+00
12+00
10+00
8+00
6+00
4+00
2+00
0+00



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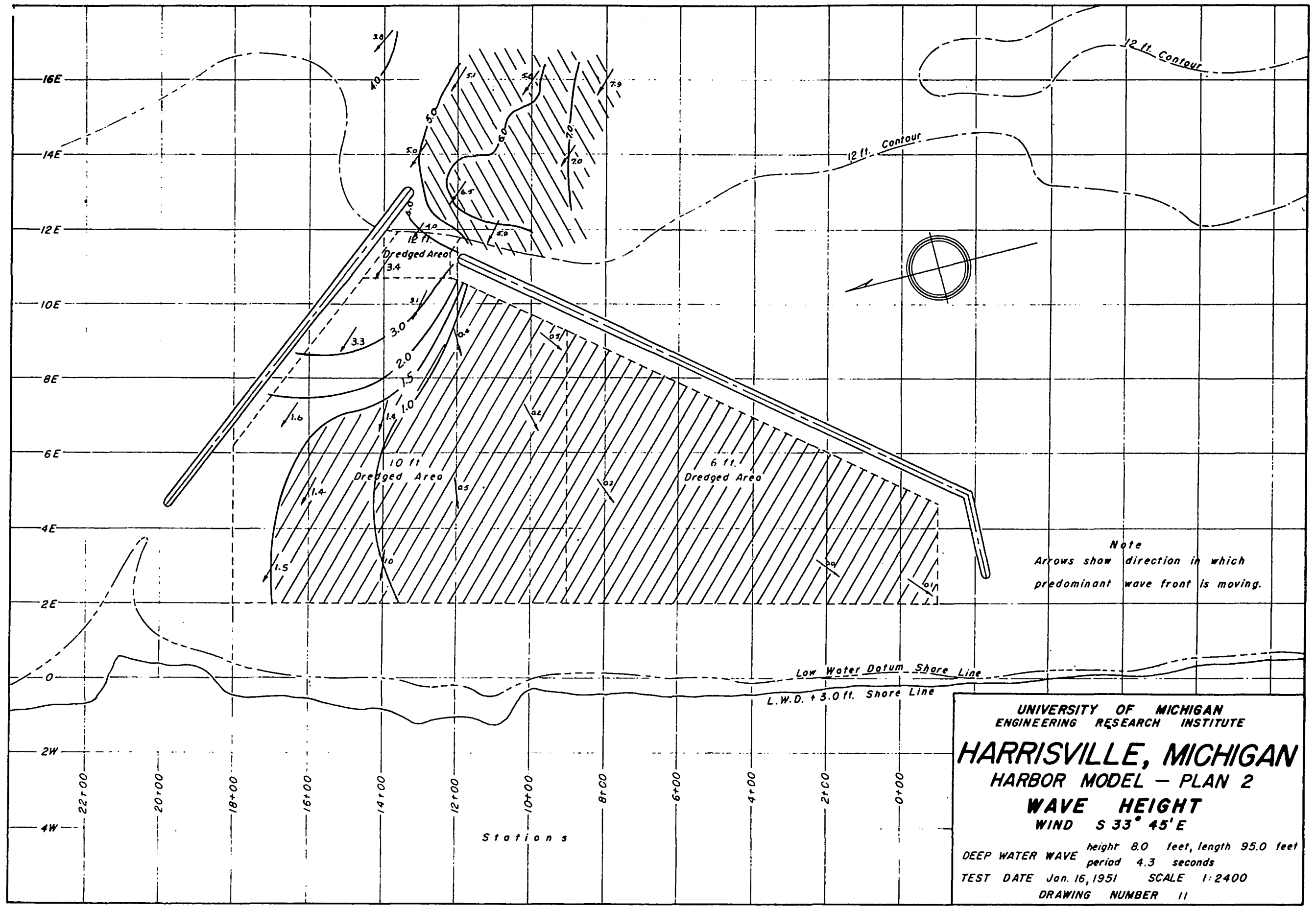
HARRISVILLE, MICHIGAN
HARBOR MODEL — PLAN I
WAVE HEIGHT
WIND N 78° 45' E
DEEP WATER WAVE height 4.5 feet, length 81.9 feet. period 4.0 seconds.
TEST DATE Nov. 30, 1950 SCALE 1:2400
DRAWING NUMBER 9
Note
Arrows show direction in which predominant wave front is moving.
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
12 ft. Contour
Low Water Datum
Shore Line — L.W.D.
+3.0 ft.
Stations
20E
18E
16E
14E
12E
10E
8E
6E
4E
2E
0
2 W
24+00
22+00
20+00
18+00
16+00
14+00
12+00
10+00
8+00
6+00
4+00
2+00
0+00


12 ft. Contour
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Note
Arrows show direction in which predominant wave front is moving.
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
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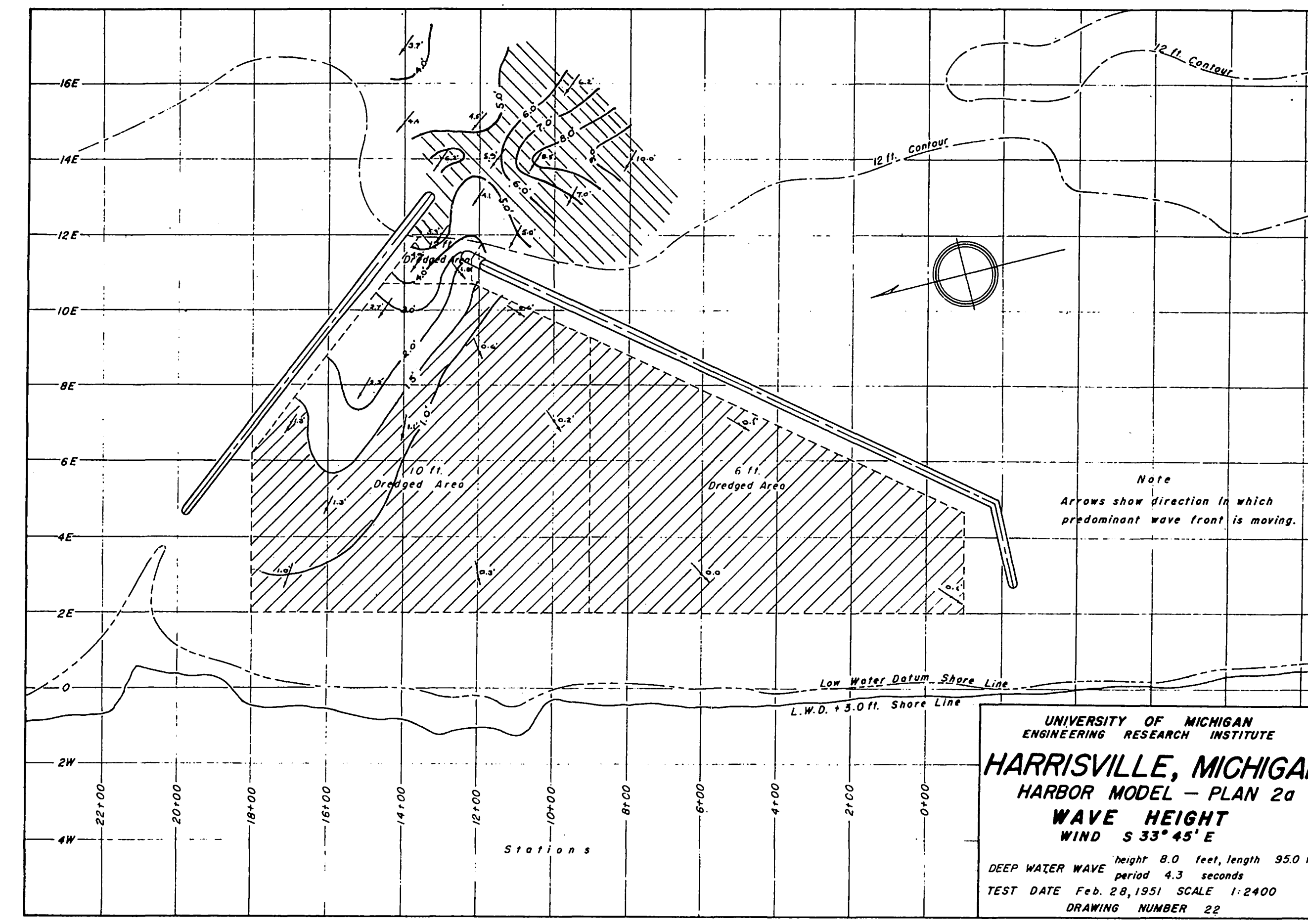
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2
WAVE HEIGHT
WIND S 33° 45' E
DEEP WATER WAVE height 8.0 feet, length 95.0 feet period 4.3 seconds
TEST DATE Jan. 16, 1951 SCALE 1:2400
DRAWING NUMBER 11


12 ft. Contour
Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Note
Arrows show direction in which predominant wave front is moving.
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
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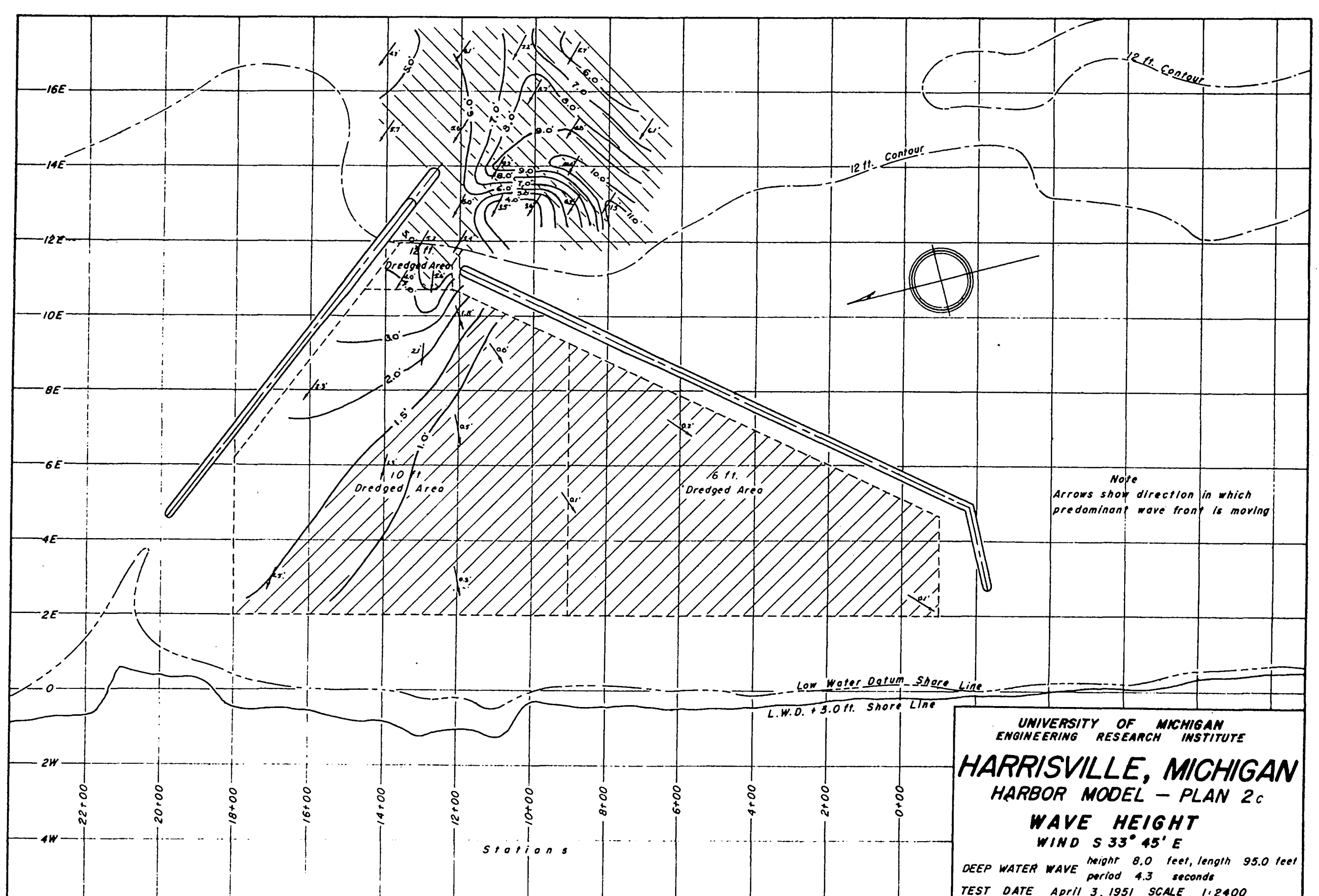
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2a
WAVE HEIGHT
WIND S 33° 45' E
DEEP WATER WAVE height 8.0 feet, length 95.0 feet period 4.3 seconds
TEST DATE Feb. 28, 1951 SCALE 1:2400
DRAWING NUMBER 22


12 ft. Contour
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Note
Arrows show direction in which predominant wave front is moving
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
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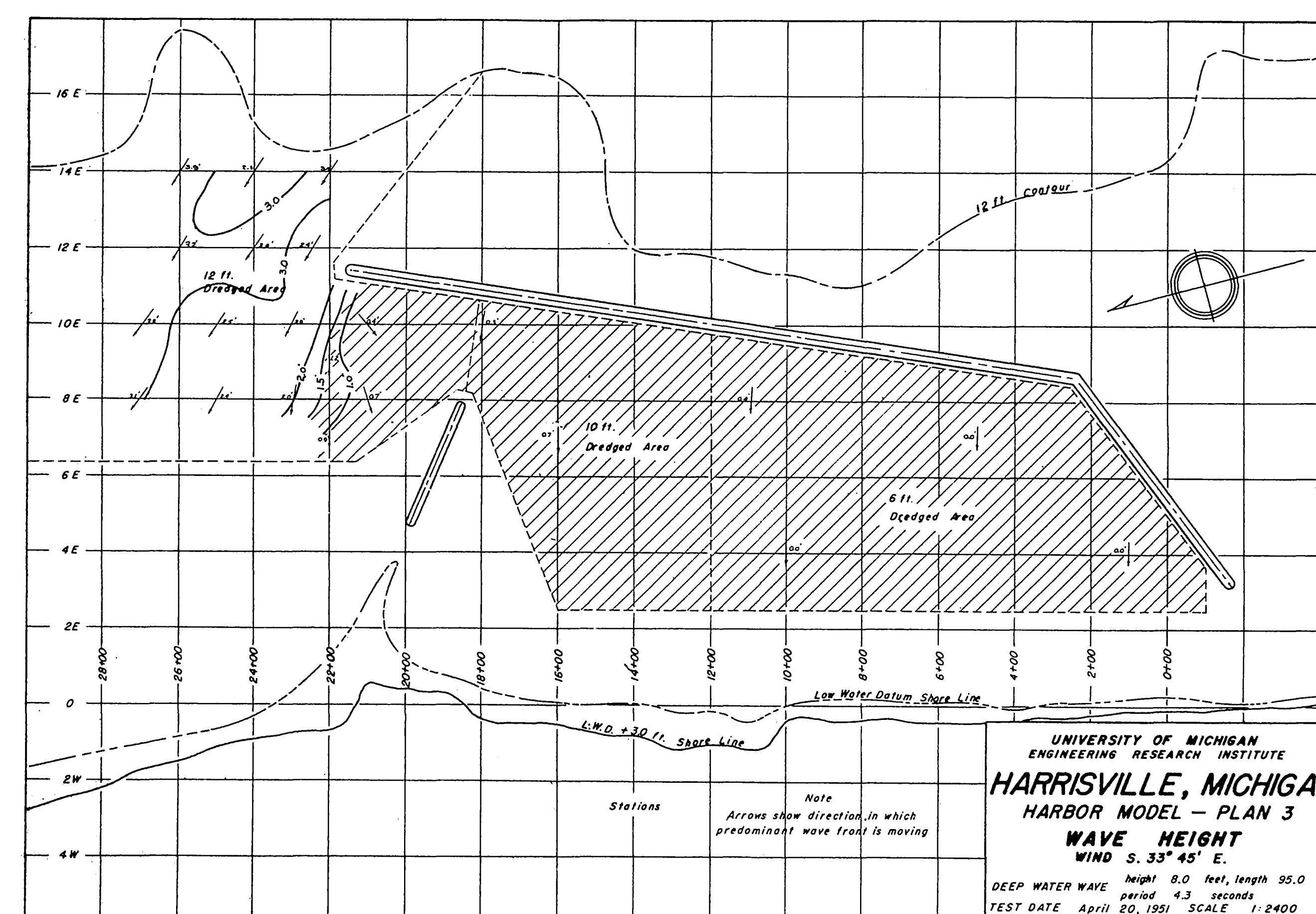
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2c
WAVE HEIGHT
WIND S 33° 45' E
DEEP WATER WAVE height 8.0 feet, length 95.0 feet period 4.3 seconds
TEST DATE April 3, 1951 SCALE 1:2400
DRAWING NUMBER 26


12 ft. Contour
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
Note
Arrows show direction in which predominant wave front is moving
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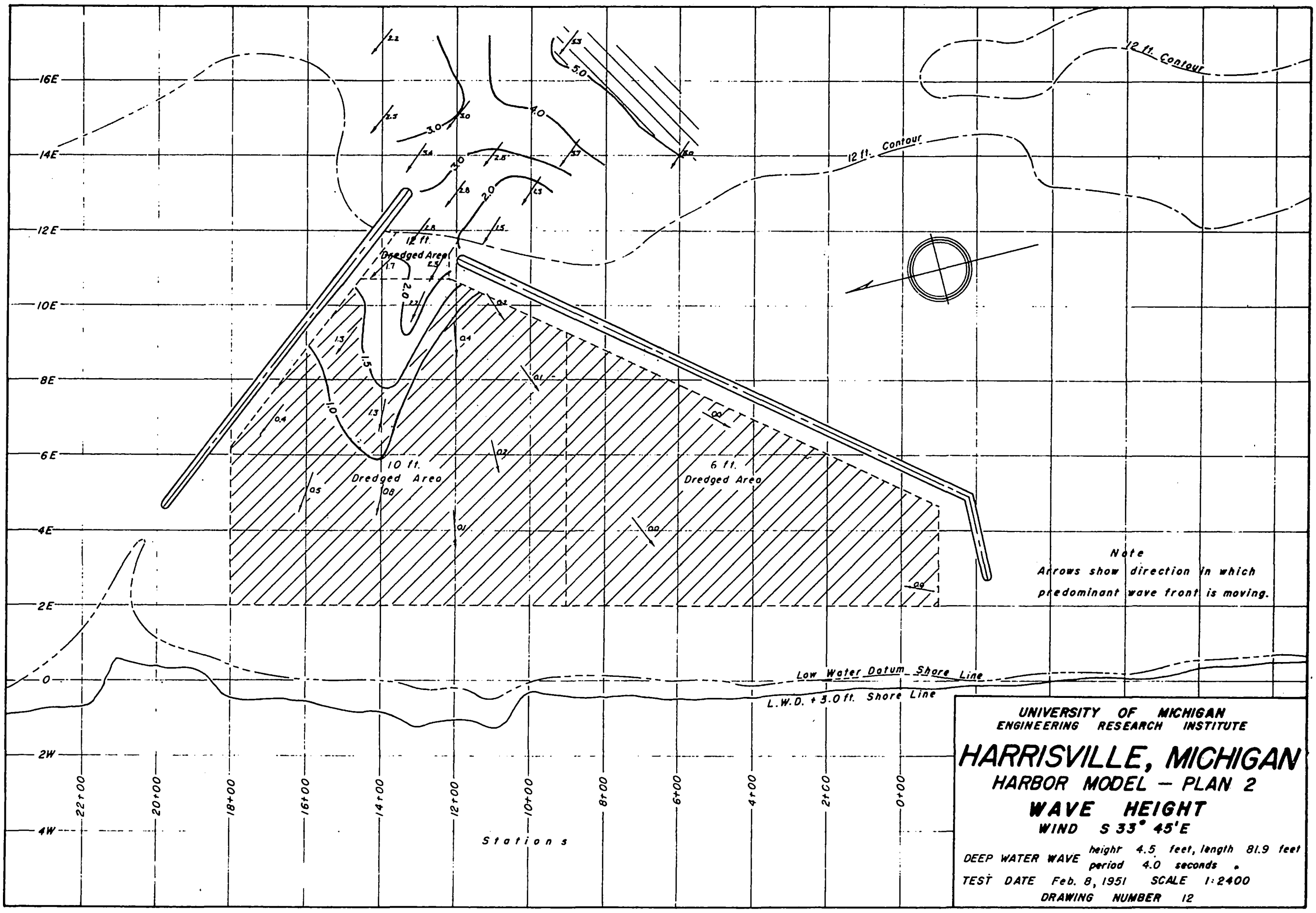
HARBOR MODEL – PLAN 3
WAVE HEIGHT
WIND S. 33° 45' E.
DEEP WATER WAVE height 8.0 feet, length 95.0 feet period 4.3 seconds
TEST DATE April 20, 1951 SCALE 1:2400
DRAWING NUMBER 34


12 ft. Contour
12 ft. Contour
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Note
Arrows show direction in which predominant wave front is moving.
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
16E
14E
12E
10E
8E
6E
4E
2E
0
2W
4W
22+00
20+00
18+00
16+00
14+00
12+00
10+00
8+00
6+00
4+00
2+00
0+00
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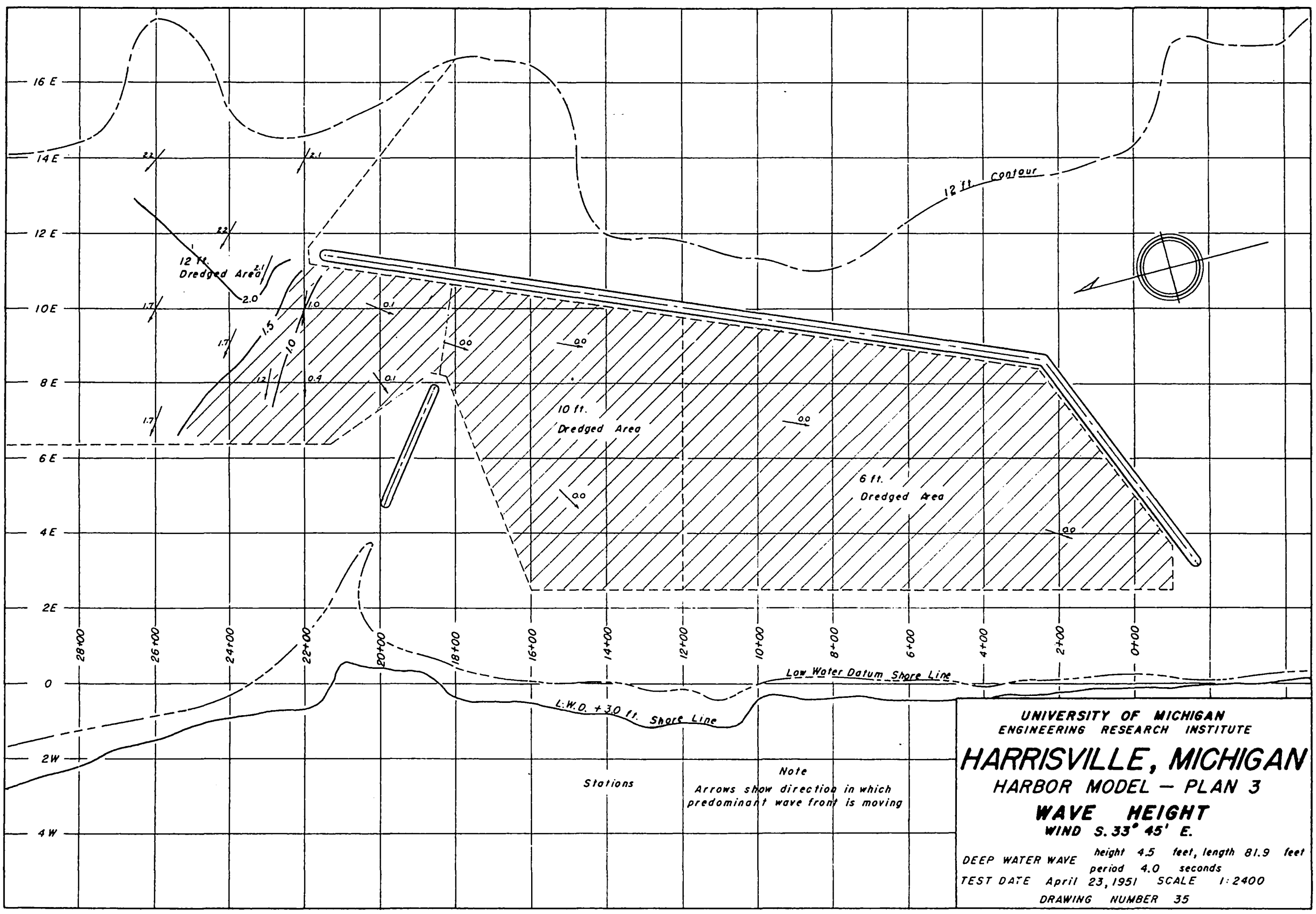
HARBOR MODEL — PLAN 2
WAVE HEIGHT
WIND S 33° 45'E
DEEP WATER WAVE height 4.5 feet, length 81.9 feet period 4.0 seconds
TEST DATE Feb. 8, 1951 SCALE 1:2400
DRAWING NUMBER 12


12 ft. Contour
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
Note
Arrows show direction in which predominant wave front is moving
16 E
14 E
12 E
10 E
8 E
6 E
4 E
2E
0
2W
4 W
28+00
26+00
24+00
22+00
20+00
18+00
16+00
14+00
12+00
10+00
8+00
6+00
4+00
2+00
0+00
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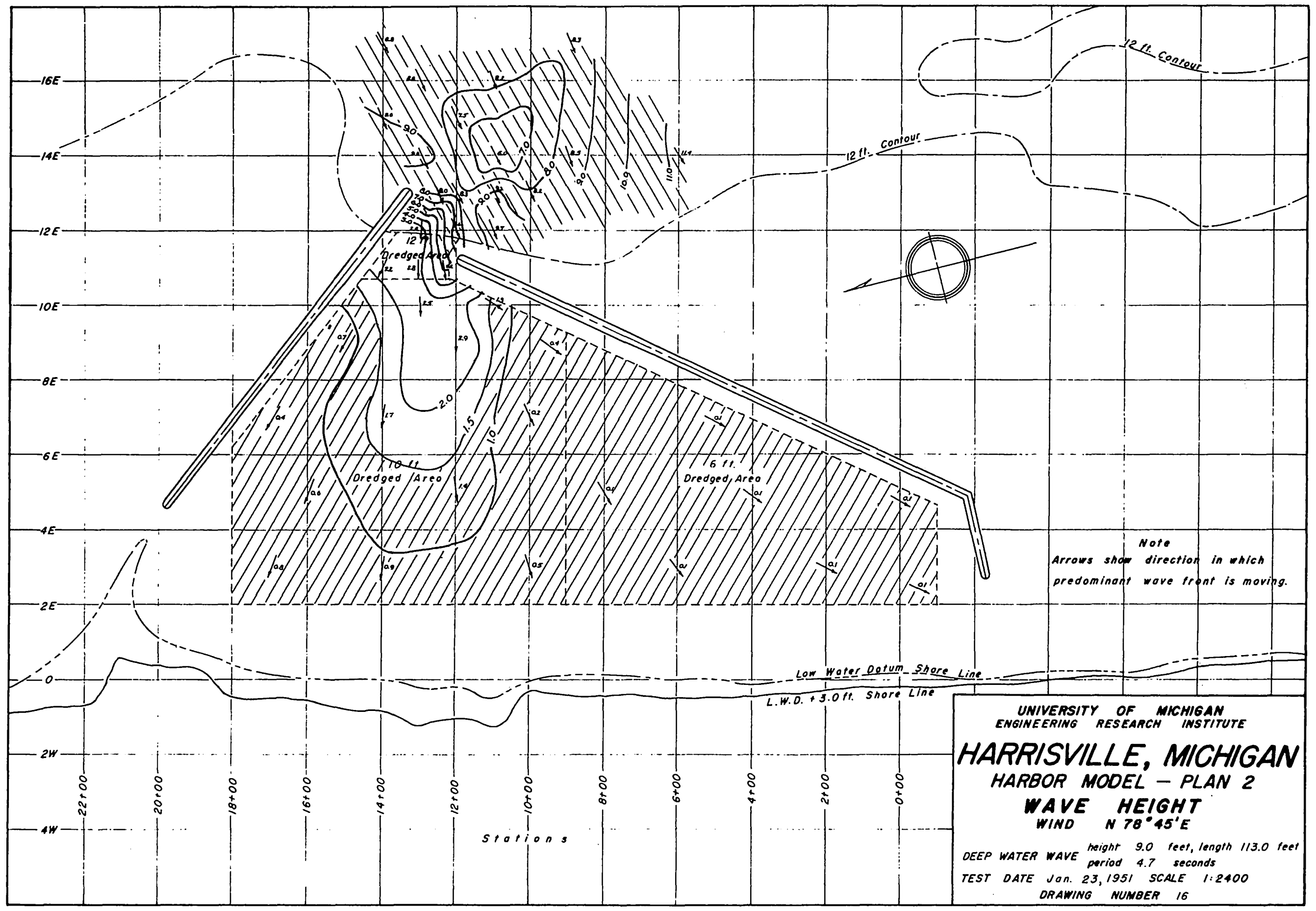
HARRISVILLE, MICHIGAN
HARBOR MODEL — PLAN 3
WAVE HEIGHT
WIND S. 33° 45' E.
DEEP WATER WAVE height 4.5 feet, length 81.9 feet period 4.0 seconds
TEST DATE April 23, 1951 SCALE 1:2400
DRAWING NUMBER 35


12 ft. Contour
12 ft. Contour
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Note
Arrows show direction in which predominant wave front is moving.
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
UNIVERSITY OF MICHIGAN
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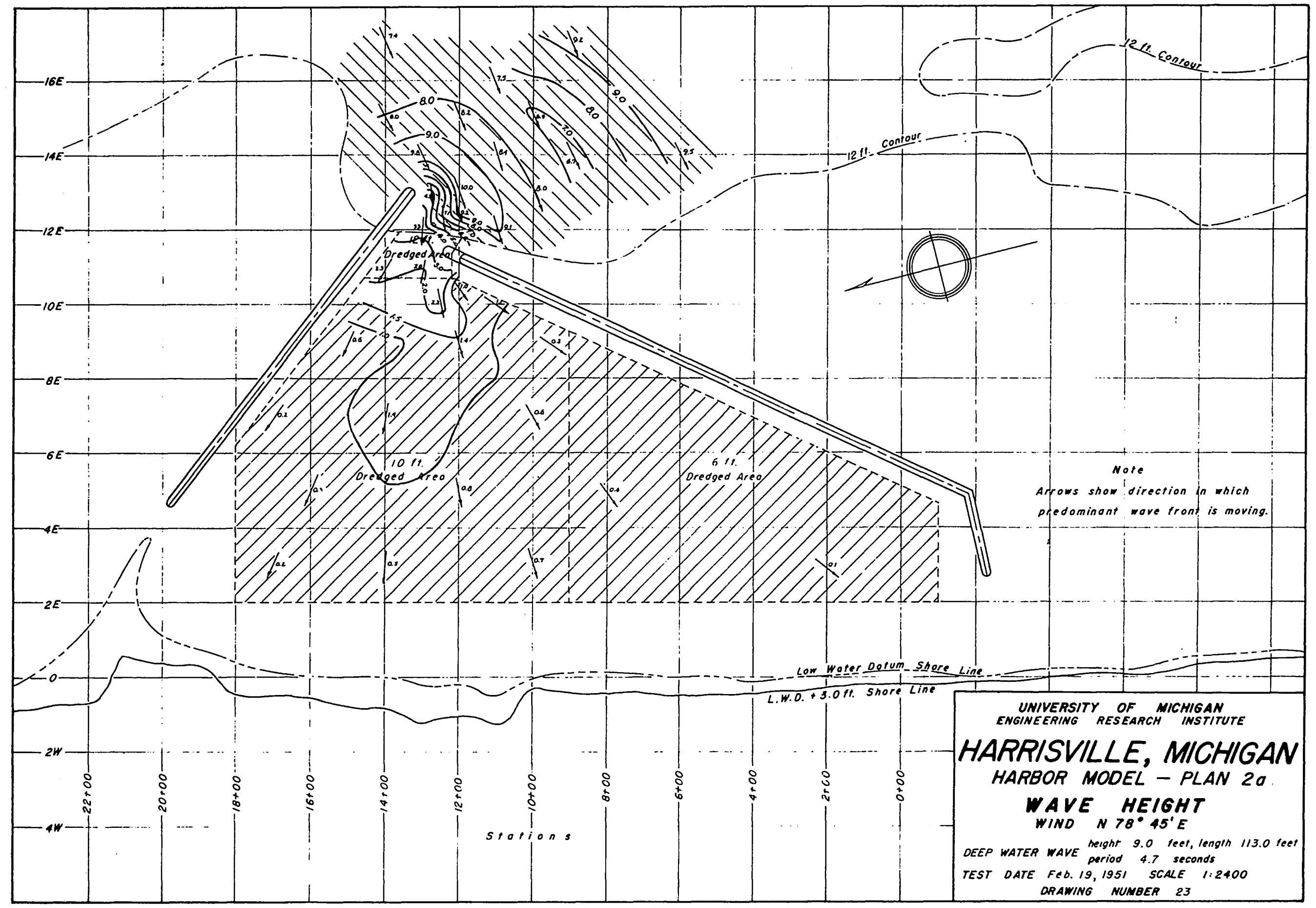
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2
WAVE HEIGHT
WIND N 78° 45' E
DEEP WATER WAVE height 9.0 feet, length 113.0 feet period 4.7 seconds
TEST DATE Jan. 23, 1951 SCALE 1:2400
DRAWING NUMBER 16


12 ft. Contour
12 ft. Contour
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Note
Arrows show direction in which predominant wave front is moving.
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
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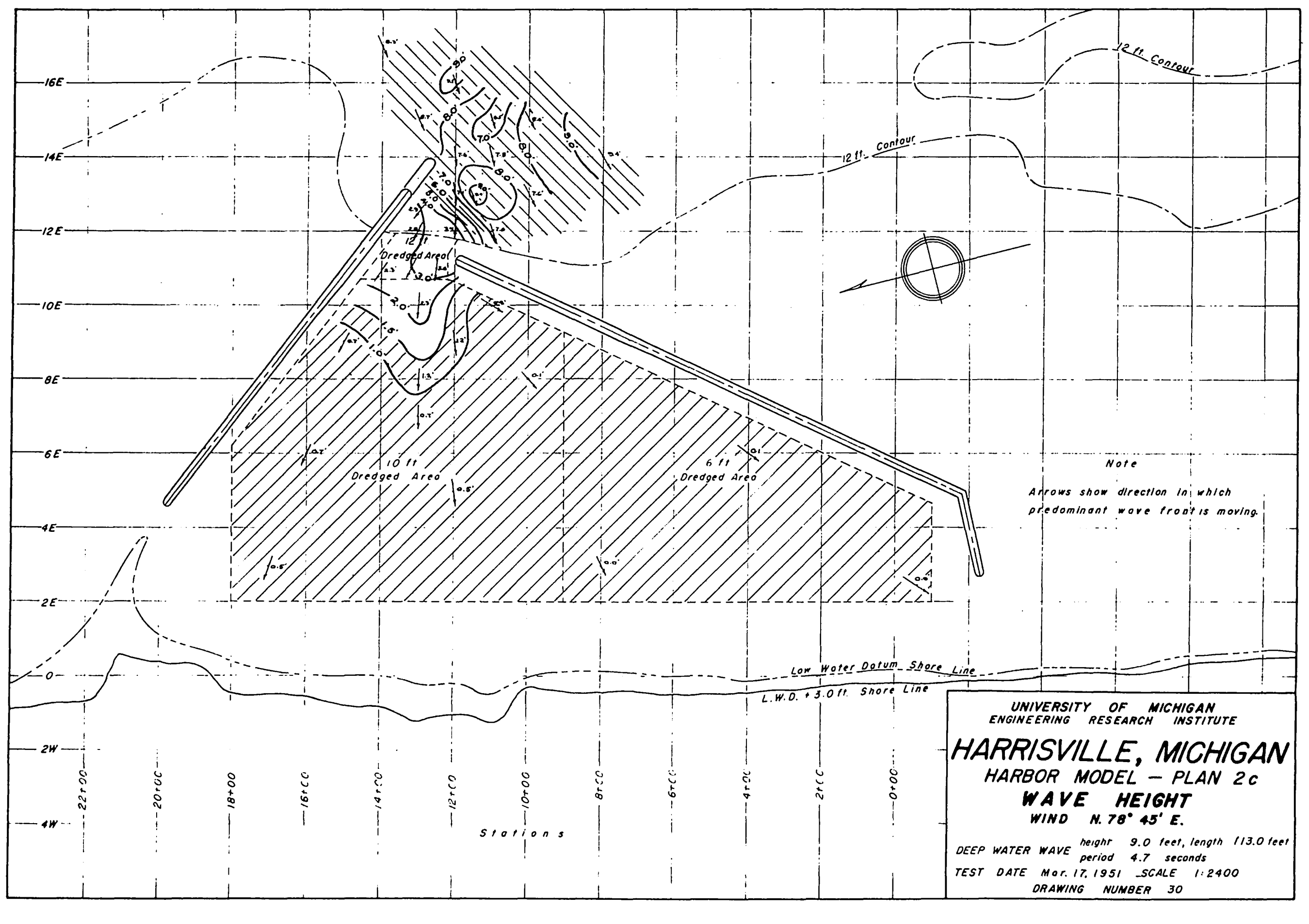
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2a
WAVE HEIGHT
WIND N 78° 45' E
DEEP WATER WAVE height 9.0 feet, length 113.0 feet period 4.7 seconds
TEST DATE Feb. 19, 1951 SCALE 1:2400
DRAWING NUMBER 23


12 ft. Contour
12 ft. Contour
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Note
Arrows show direction in which predominant wave front is moving.
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
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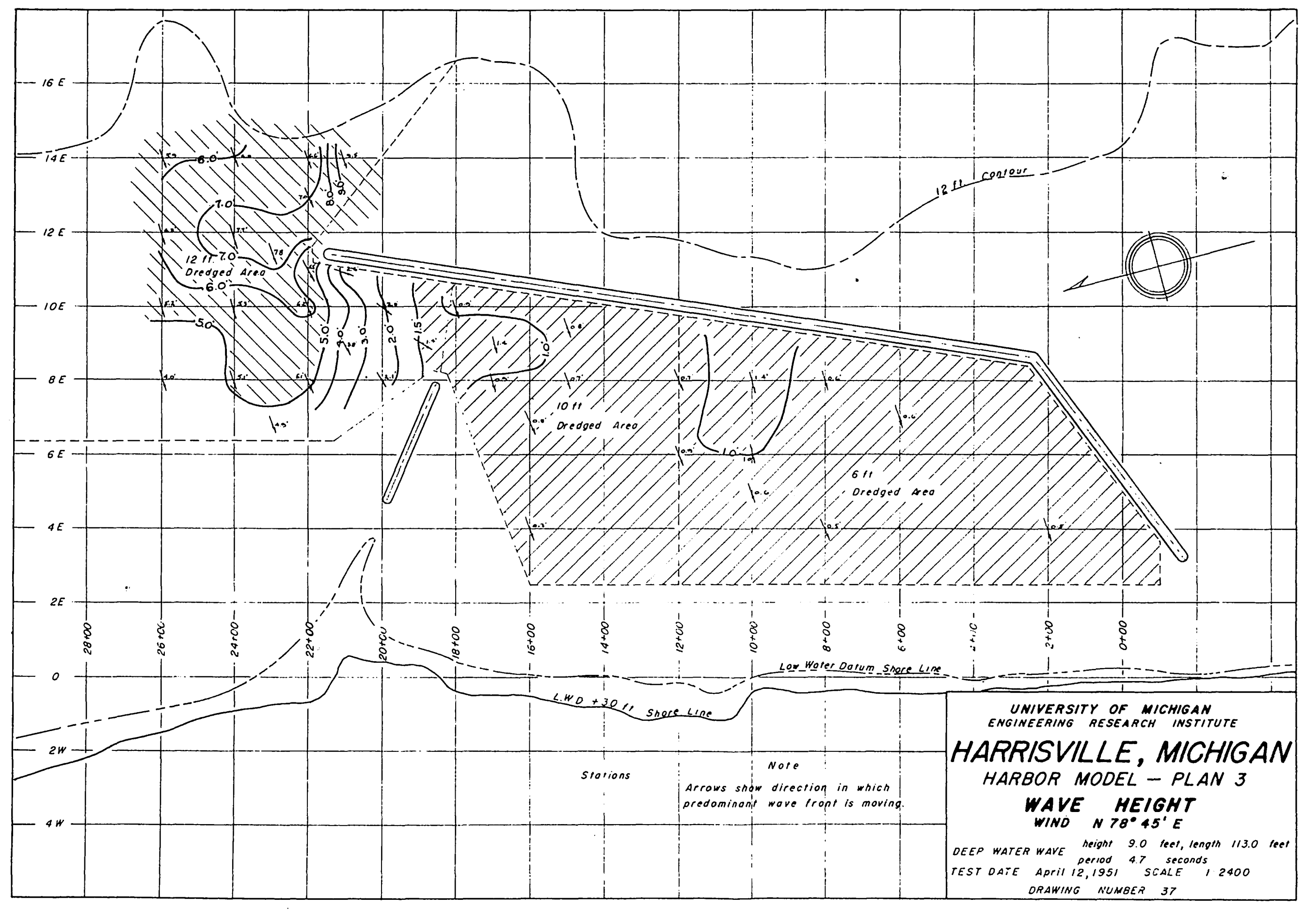
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2c
WAVE HEIGHT
WIND N. 78° 45' E.
DEEP WATER WAVE height 9.0 feet, length 113.0 feet period 4.7 seconds
TEST DATE Mar. 17, 1951 SCALE 1:2400
DRAWING NUMBER 30


12 ft. Contour
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
Note
Arrows show direction in which predominant wave front is moving.
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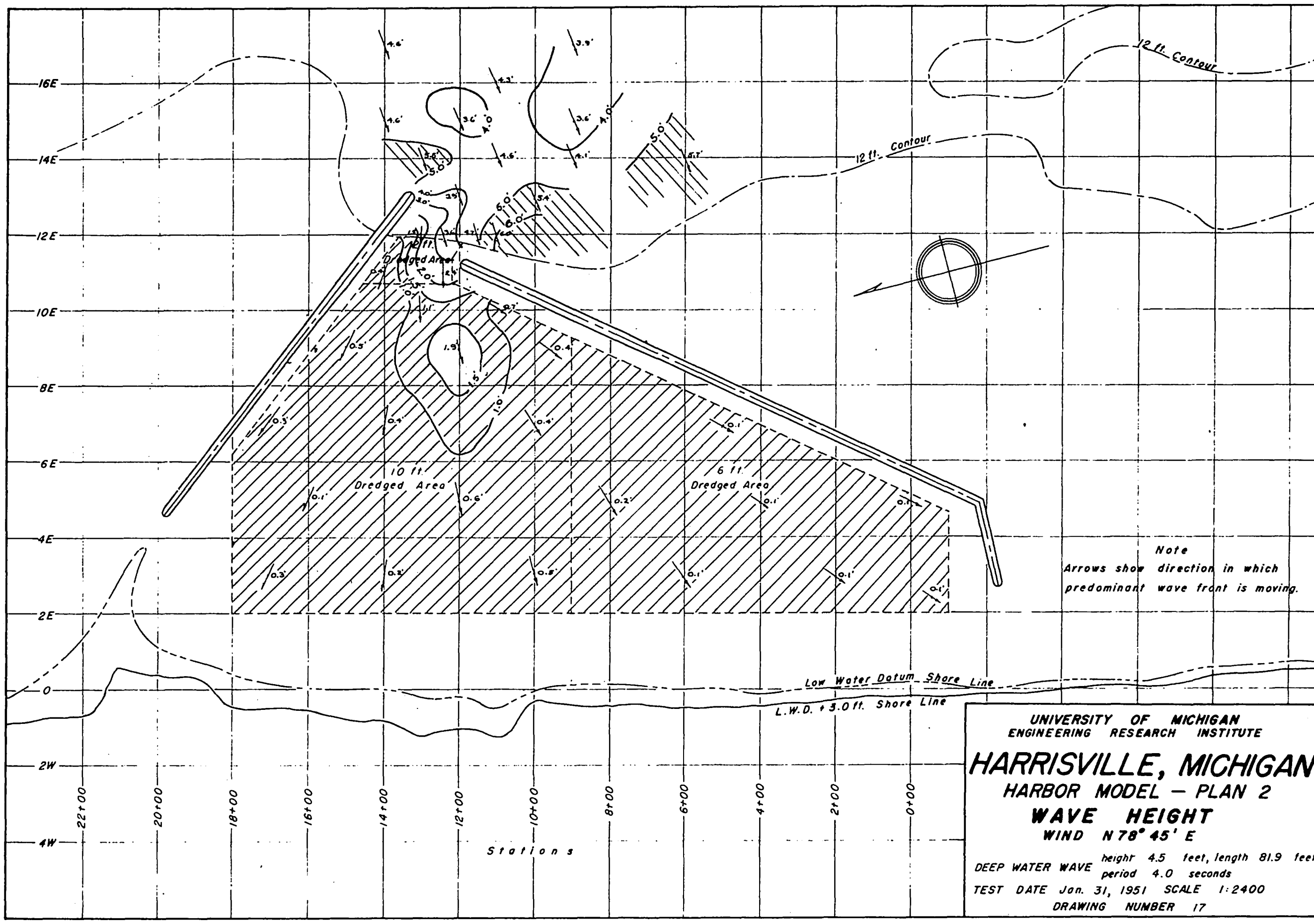
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 3
WAVE HEIGHT
WIND N 78° 45' E
DEEP WATER WAVE height 9.0 feet, length 113.0 feet period 4.7 seconds
TEST DATE April 12, 1951 SCALE 1:2400
DRAWING NUMBER 37


12 ft. Contour
12 ft. Contour
10 ft.
Dredged Area
6 ft.
Dredged Area
Note
Arrows show direction in which predominant wave front is moving.
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
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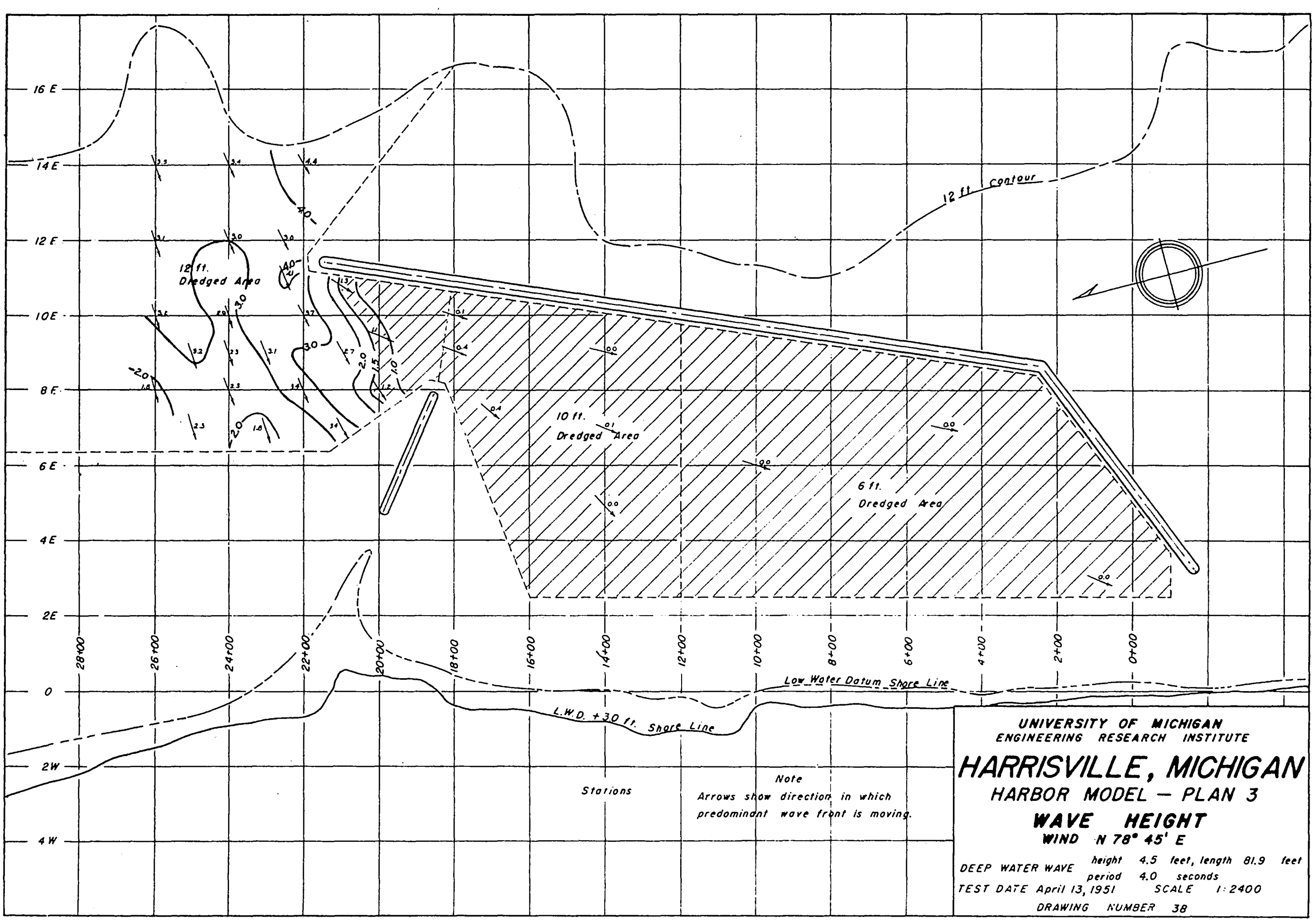
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2
WAVE HEIGHT
WIND N 78° 45' E
DEEP WATER WAVE height 4.5 feet, length 81.9 feet period 4.0 seconds
TEST DATE Jan. 31, 1951 SCALE 1:2400
DRAWING NUMBER 17


12 ft. Contour
12 ft.
Dredged Area
10 ft.
Dredged Area
6 ft.
Dredged Area
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
Note
Arrows show direction in which predominant wave front is moving.
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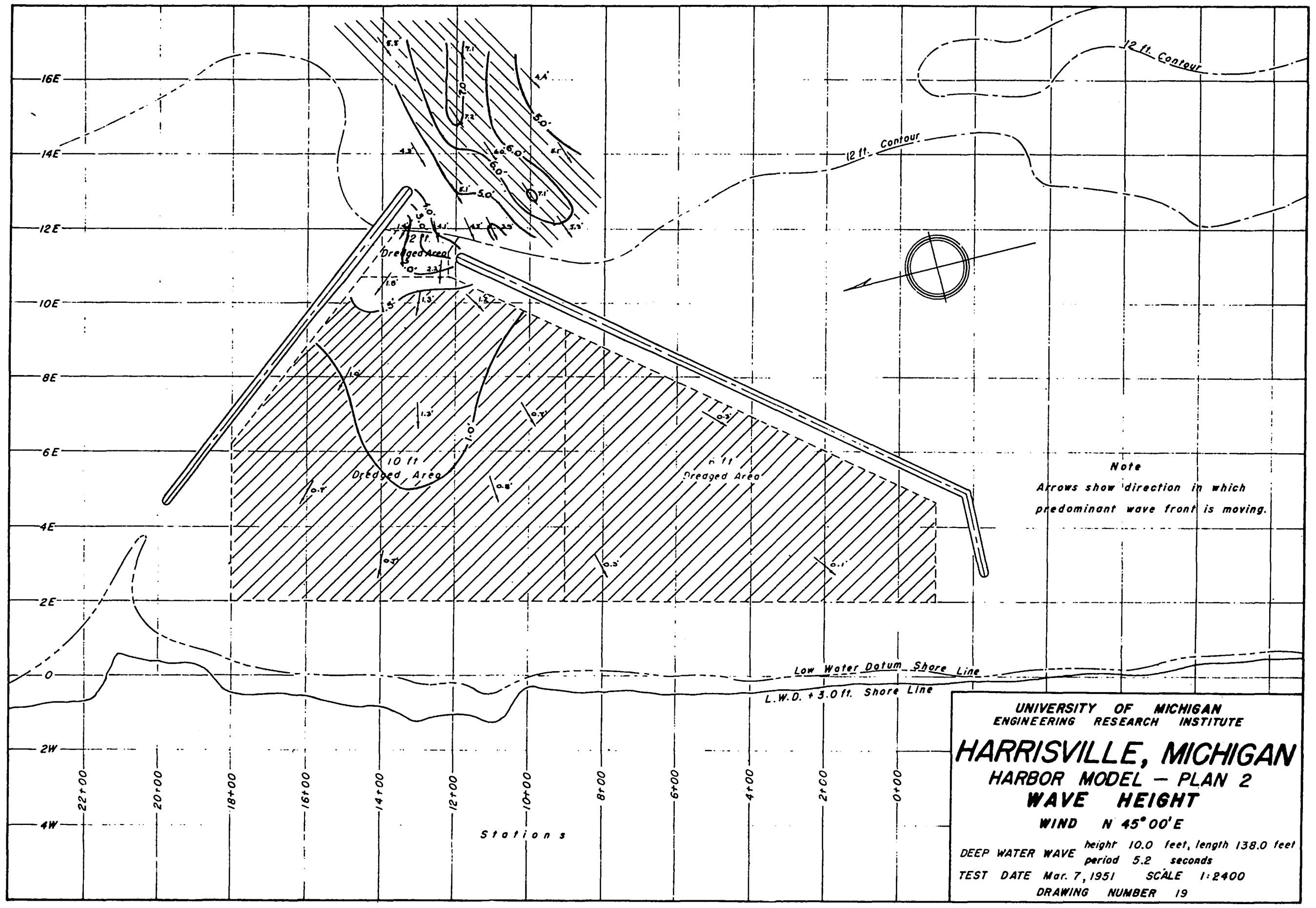
HARBOR MODEL – PLAN 3
WAVE HEIGHT
WIND N 78° 45' E
DEEP WATER WAVE height 4.5 feet, length 81.9 feet period 4.0 seconds
TEST DATE April 13, 1951 SCALE 1:2400
DRAWING NUMBER 38


12 ft. Contour
16E
14E
12E
10E
8E
6E
4E
2E
0
2W
4W
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Note
Arrows show direction in which predominant wave front is moving.
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
22+00
20+00
18+00
16+00
14+00
12+00
10+00
8+00
6+00
4+00
2+00
0+00
Stations
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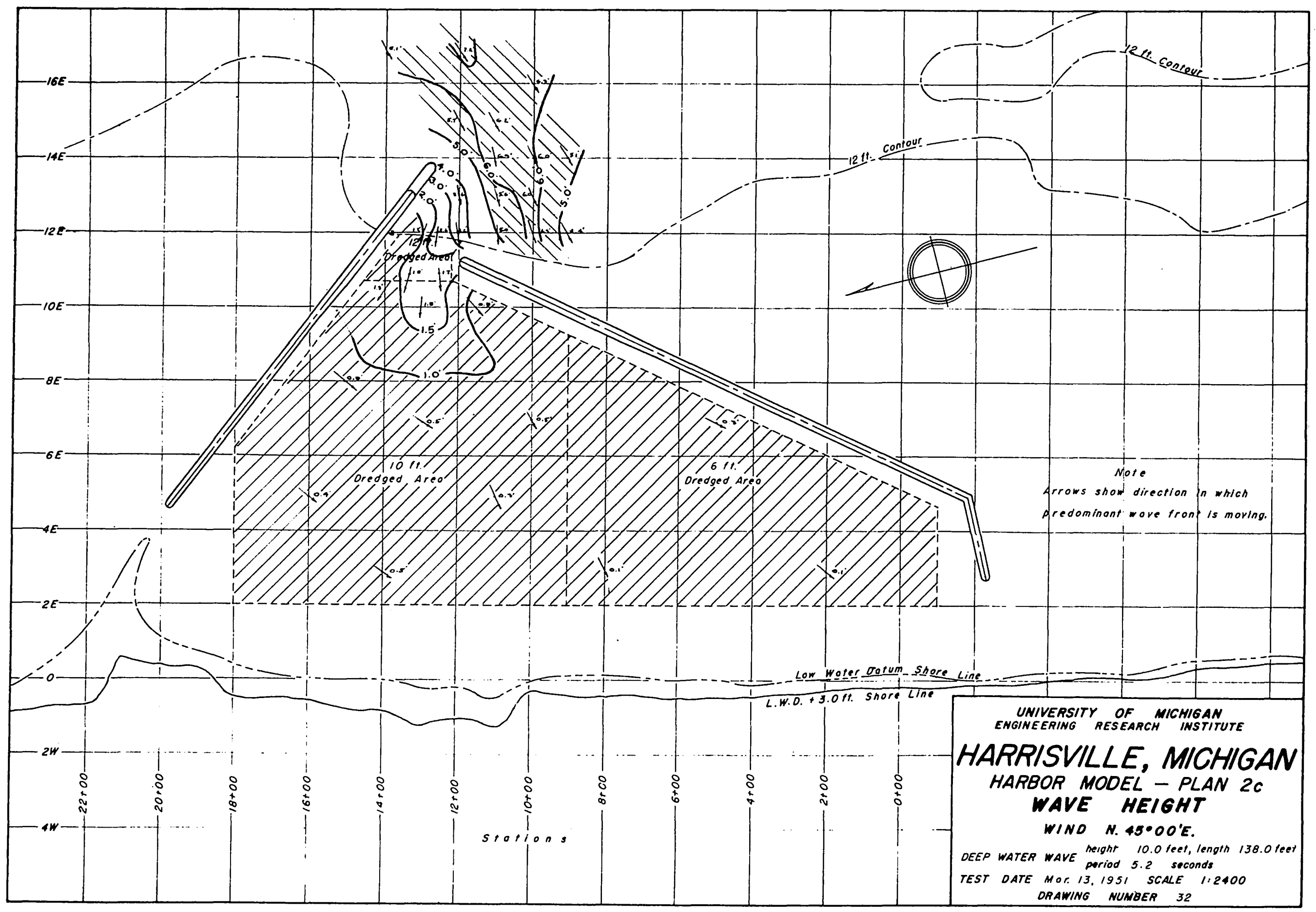
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2
WAVE HEIGHT
WIND N 45°00'E
DEEP WATER WAVE height 10.0 feet, length 138.0 feet period 5.2 seconds
TEST DATE Mar. 7, 1951 SCALE 1:2400
DRAWING NUMBER 19


12 ft. Contour
16E
14E
12E
10E
8E
6E
4E
2E
0
2W
4W
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Note
Arrows show direction in which predominant wave front is moving.
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
22+00
20+00
18+00
16+00
14+00
12+00
10+00
8+00
6+00
4+00
2+00
0+00
Stations
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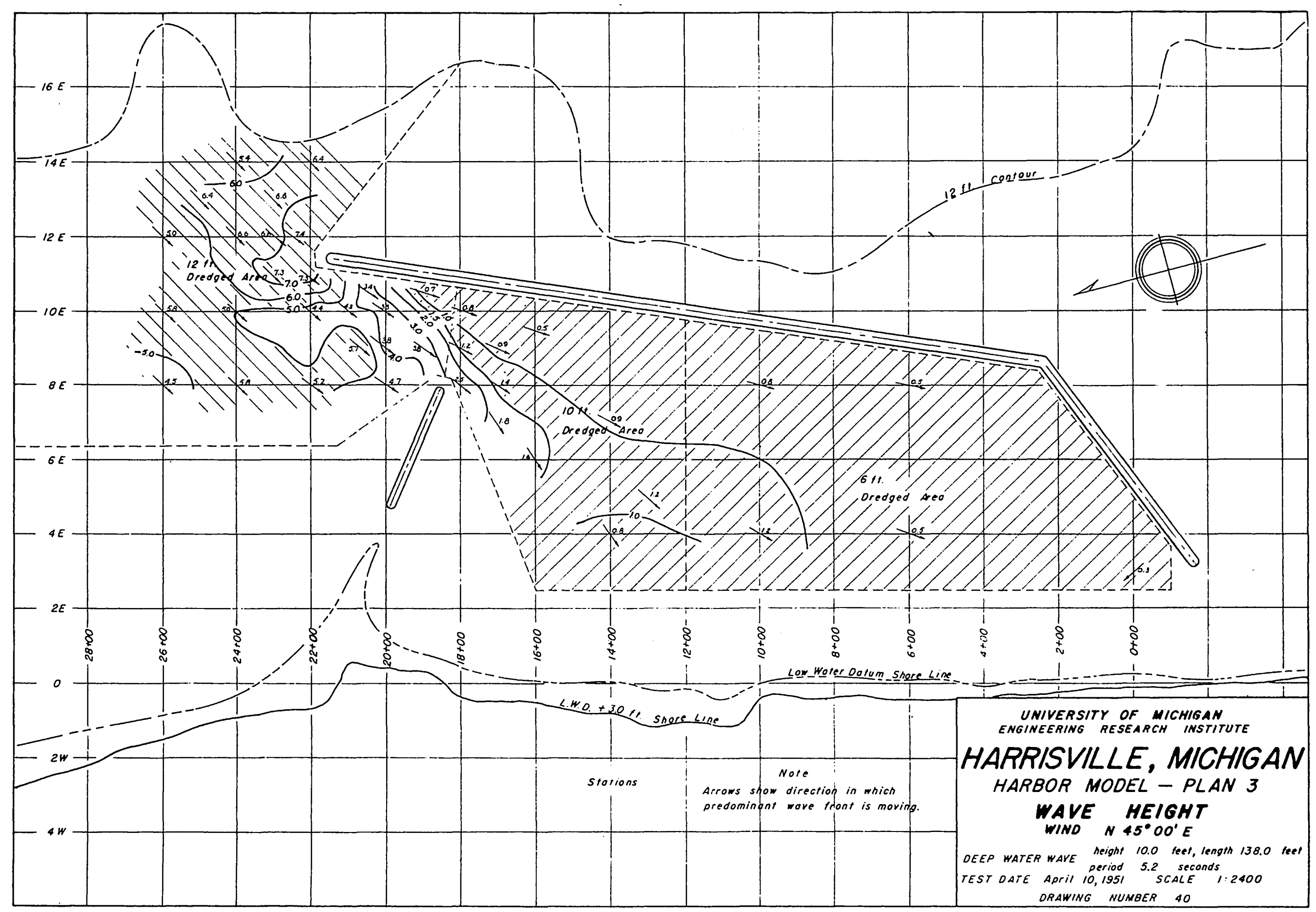
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2c
WAVE HEIGHT
WIND N. 45°00'E.
DEEP WATER WAVE height 10.0 feet, length 138.0 feet period 5.2 seconds
TEST DATE Mar. 13, 1951 SCALE 1:2400
DRAWING NUMBER 32


12 ft. Contour
16 E
14 E
12 E
10 E
8 E
6 E
4 E
2 E
0
2 W
4 W
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
28+00
26+00
24+00
22+00
20+00
18+00
16+00
14+00
12+00
10+00
8+00
6+00
4+00
2+00
0+00
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
Note
Arrows show direction in which predominant wave front is moving.
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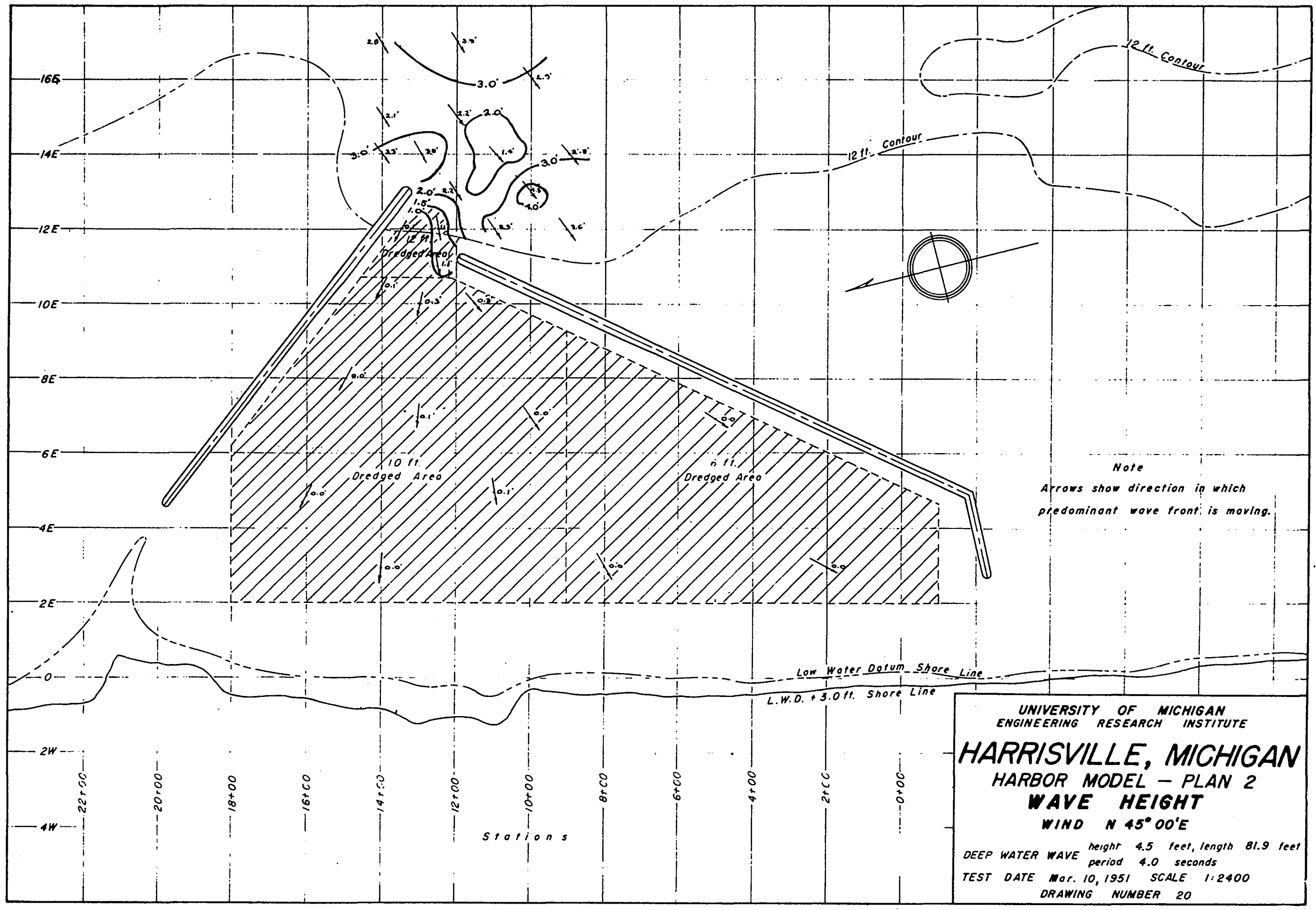
HARBOR MODEL – PLAN 3
WAVE HEIGHT
WIND N 45°00' E
DEEP WATER WAVE height 10.0 feet, length 138.0 feet period 5.2 seconds
TEST DATE April 10, 1951 SCALE 1:2400
DRAWING NUMBER 40


12 ft. Contour
12 ft. Contour
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Note
Arrows show direction in which predominant wave front is moving.
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
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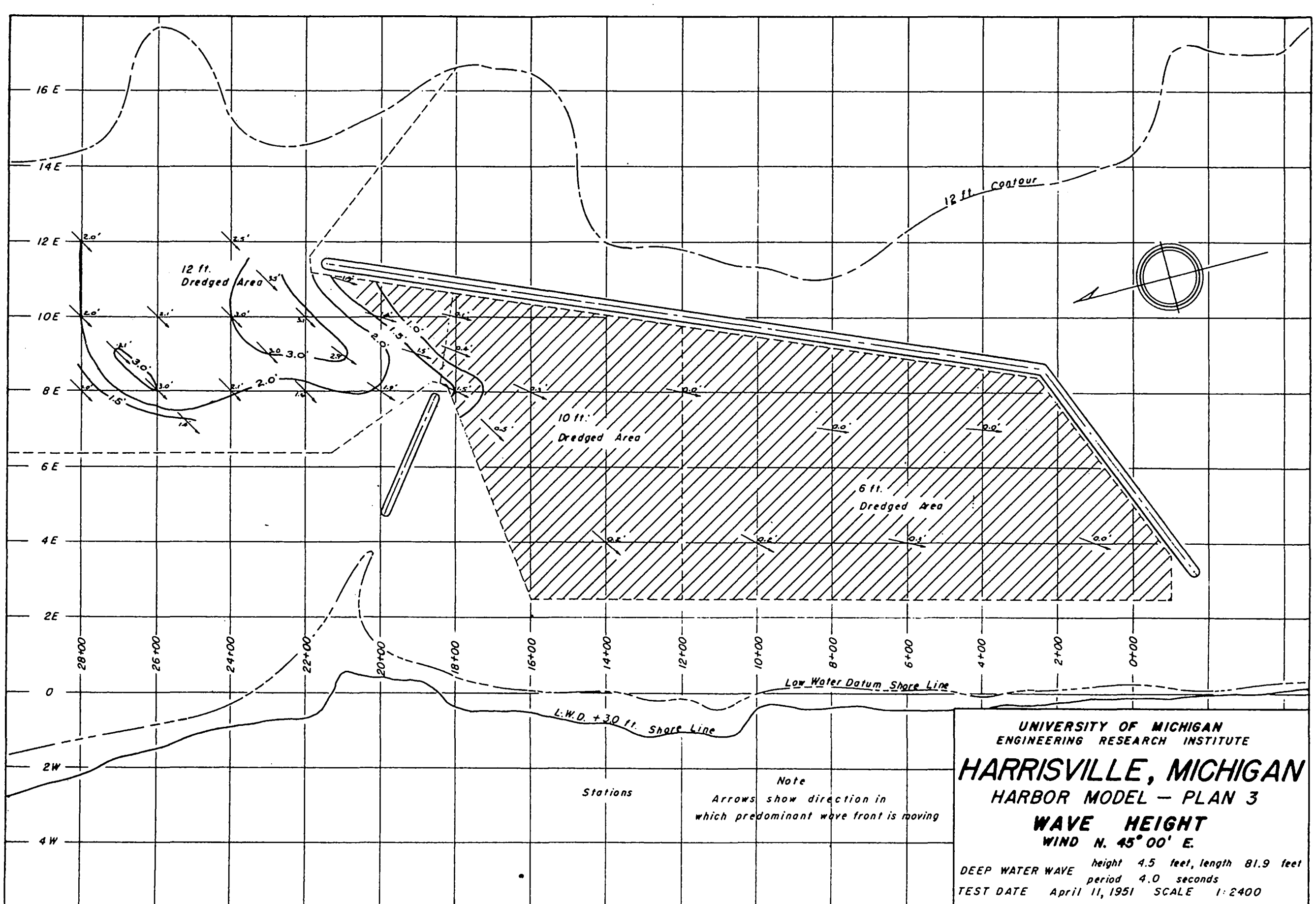
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2
WAVE HEIGHT
WIND N 45° 00'E
DEEP WATER WAVE height 4.5 feet, length 81.9 feet period 4.0 seconds
TEST DATE Mar. 10, 1951 SCALE 1:2400
DRAWING NUMBER 20


12 ft. Contour
12 ft. Dredged Area
10 ft. Dredged Area
6 ft. Dredged Area
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
Note
Arrows show direction in which predominant wave front is moving
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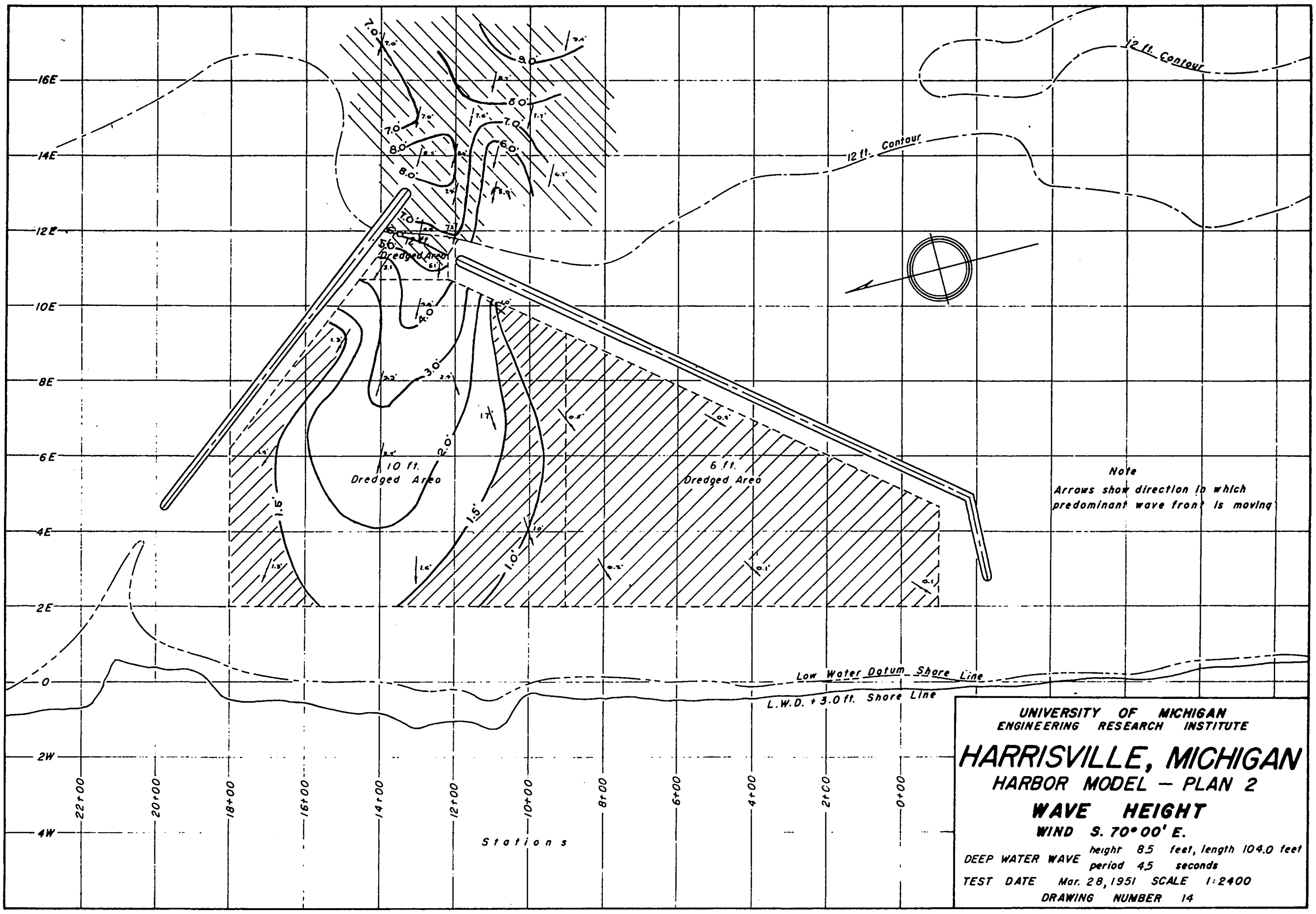
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 3
WAVE HEIGHT
WIND N. 45° 00' E.
DEEP WATER WAVE height 4.5 feet, length 81.9 feet period 4.0 seconds
TEST DATE April 11, 1951 SCALE 1:2400
DRAWING NUMBER 41


12 ft. Contour
12 ft. Contour
10 ft. Dredged Area
6 ft. Dredged Area
12 ft. Dredged Area
Note
Arrows show direction in which predominant wave front is moving
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
UNIVERSITY OF MICHIGAN
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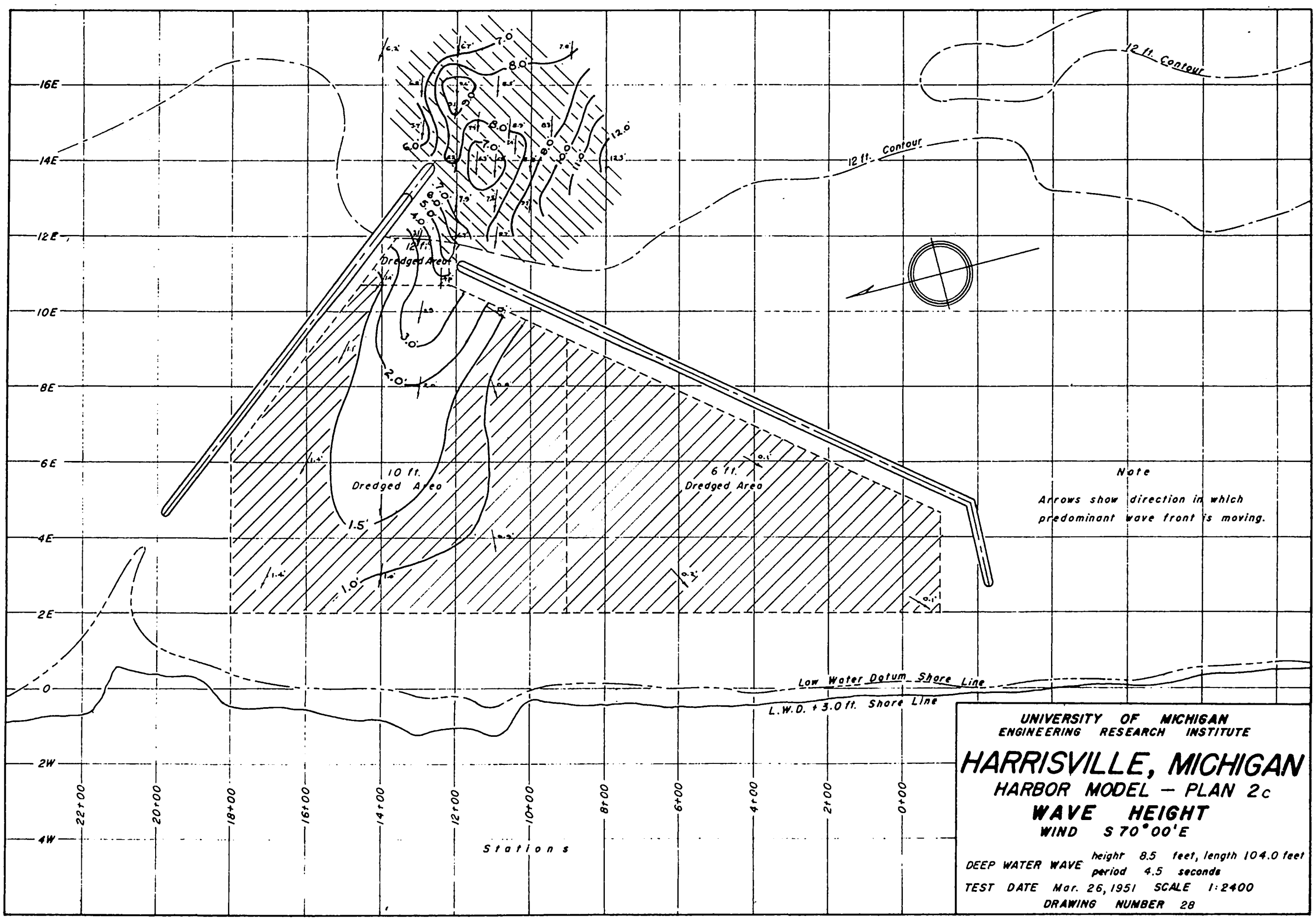
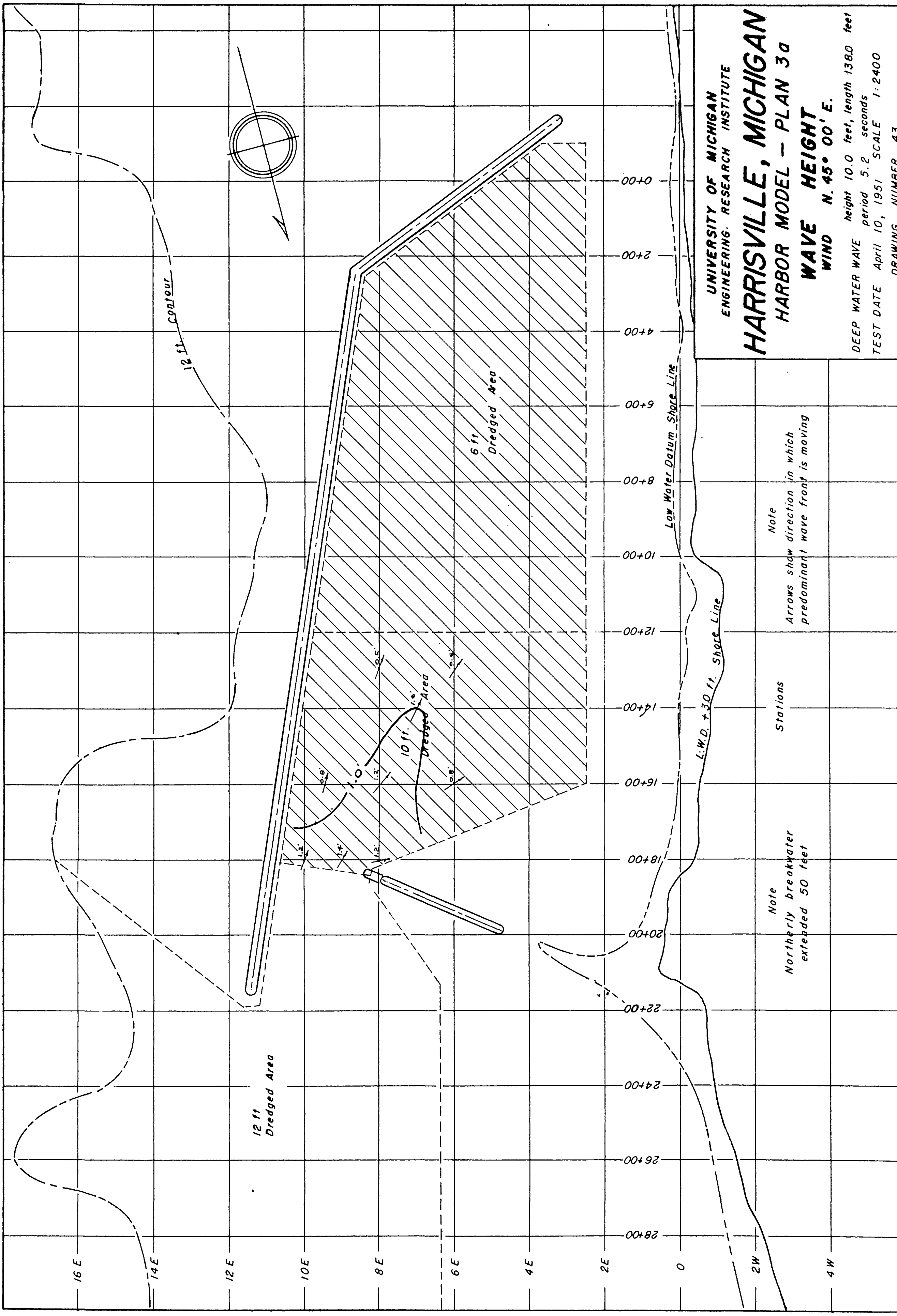
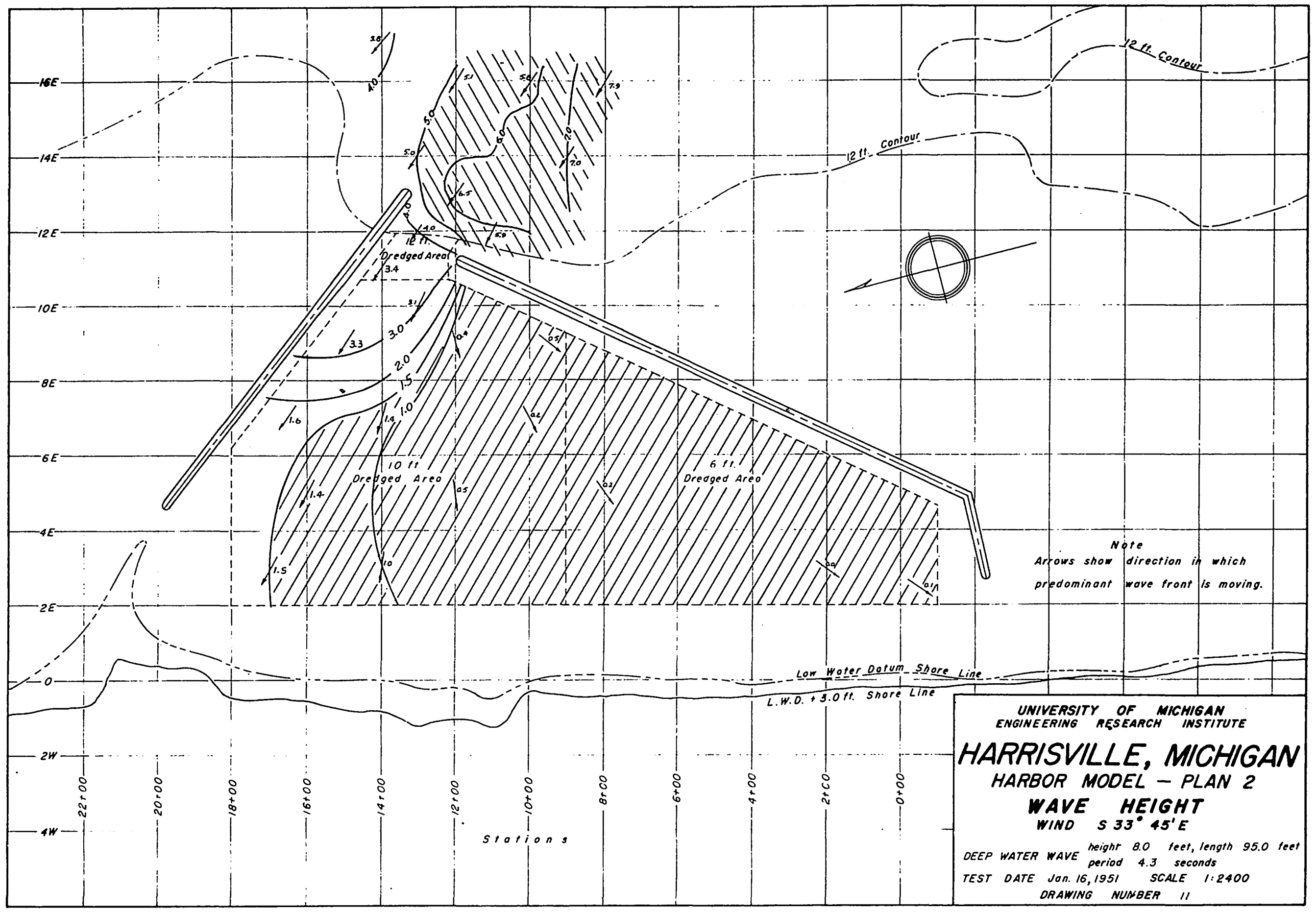
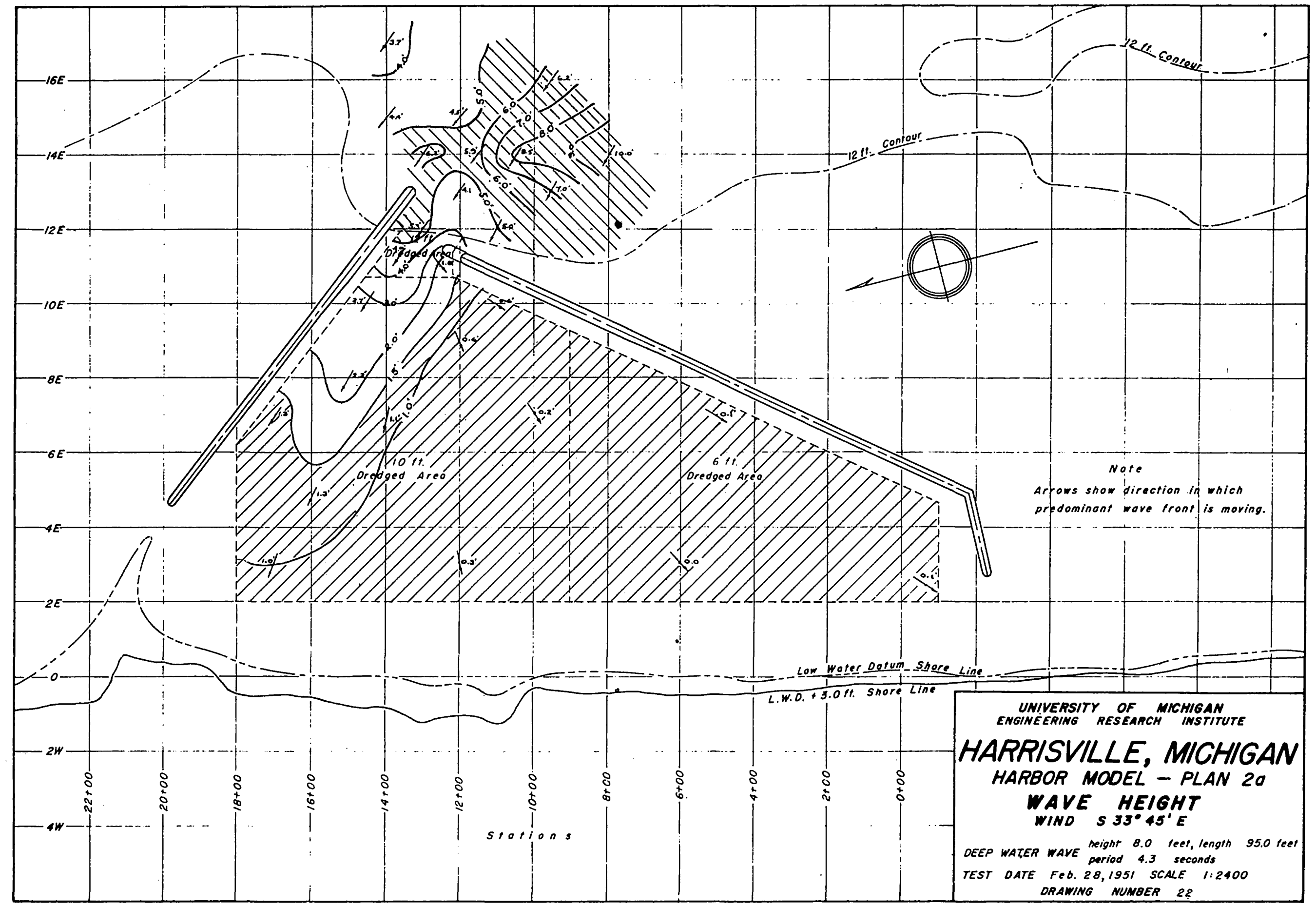
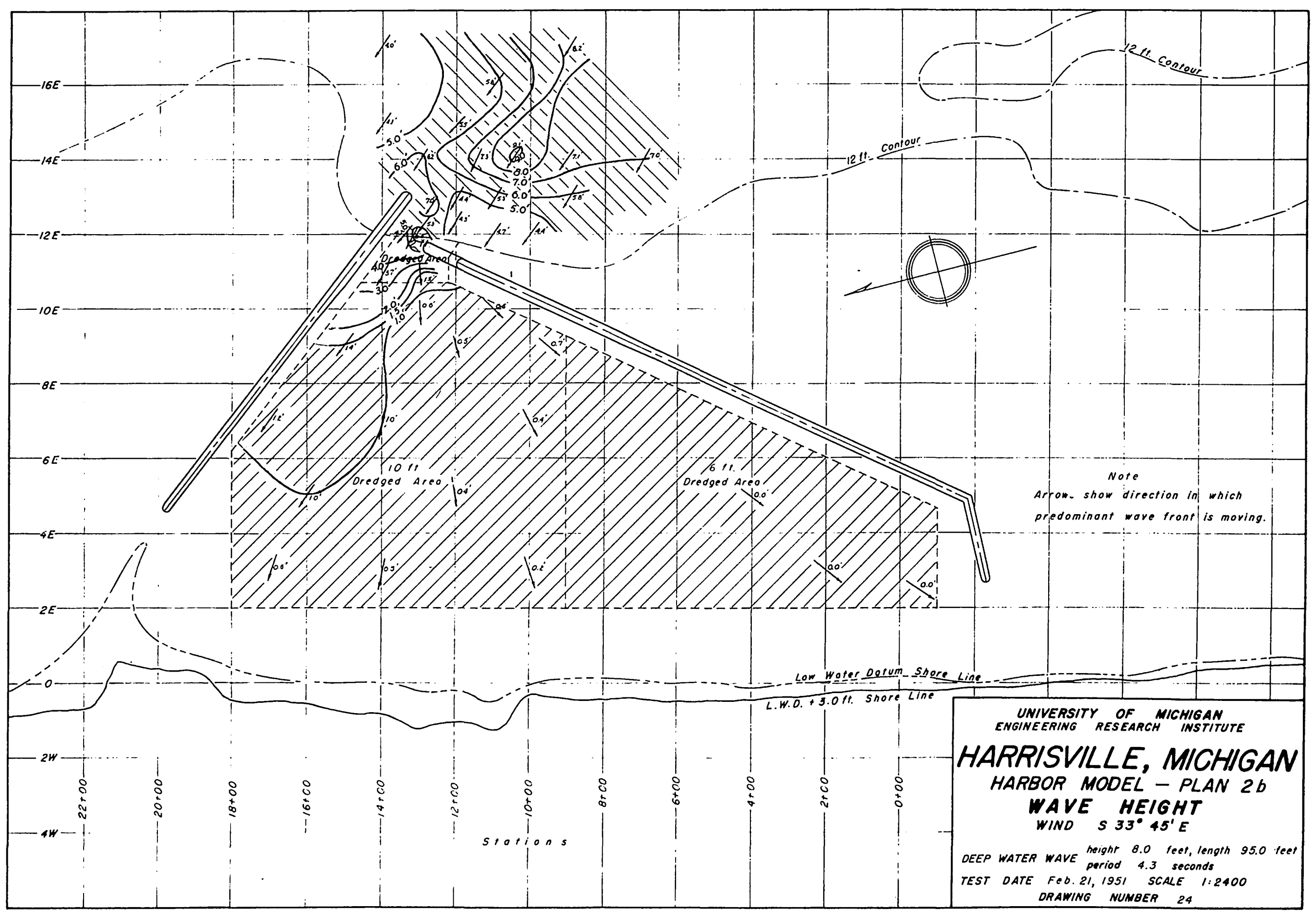
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2
WAVE HEIGHT
WIND S. 70° 00' E.
DEEP WATER WAVE height 8.5 feet, length 104.0 feet period 4.5 seconds
TEST DATE Mar. 28, 1951 SCALE 1:2400
DRAWING NUMBER 14

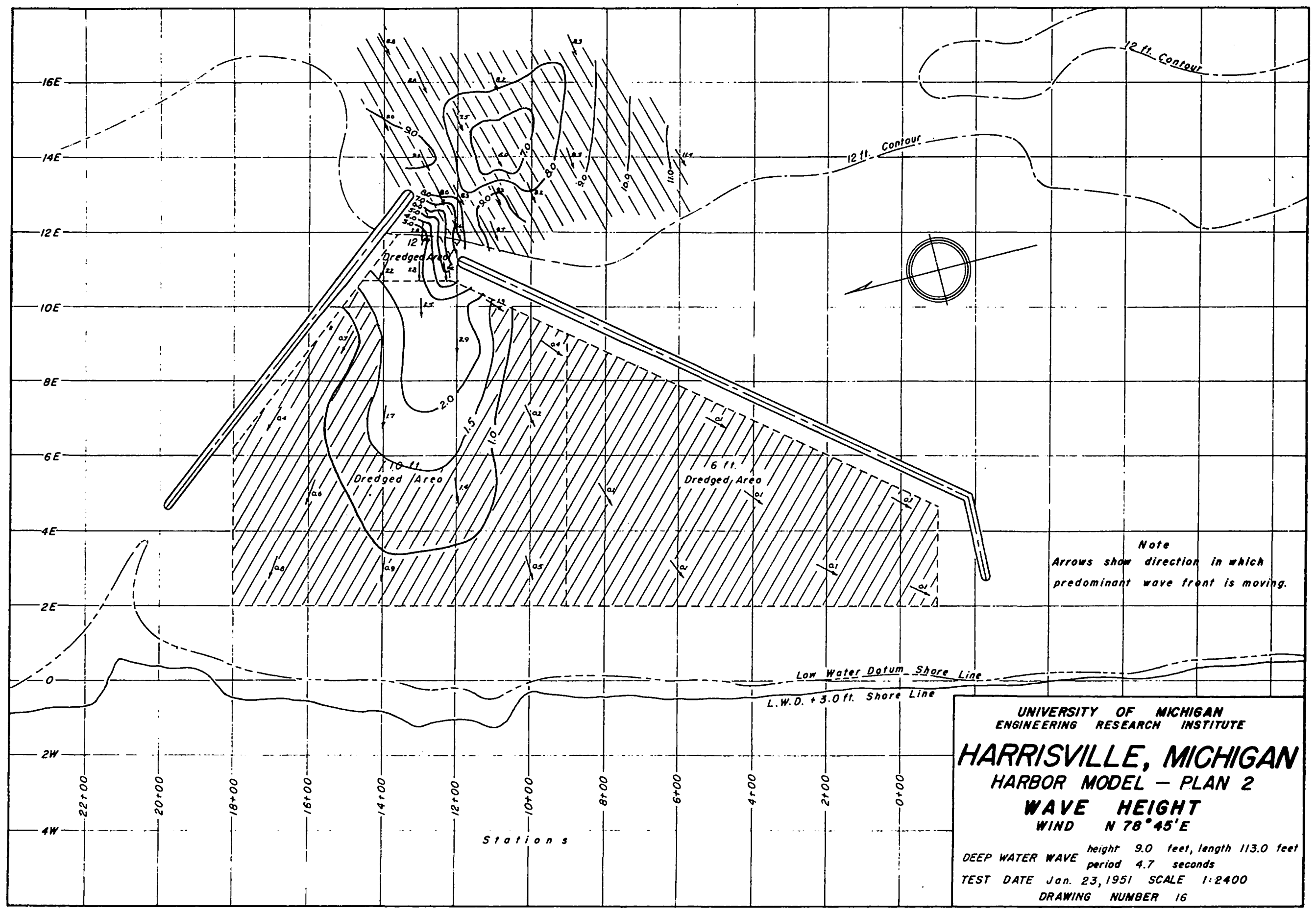

12 ft. Contour
12 ft. Contour
10 ft. Dredged Area
6 ft. Dredged Area
Dredged Area
Note
Arrows show direction in which predominant wave front is moving.
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
Stations
UNIVERSITY OF MICHIGAN
ENGINEERING RESEARCH INSTITUTE
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2c
WAVE HEIGHT
WIND S 70° 00' E
DEEP WATER WAVE height 8.5 feet, length 104.0 feet period 4.5 seconds
TEST DATE Mar. 26, 1951 SCALE 1:2400
DRAWING NUMBER 28

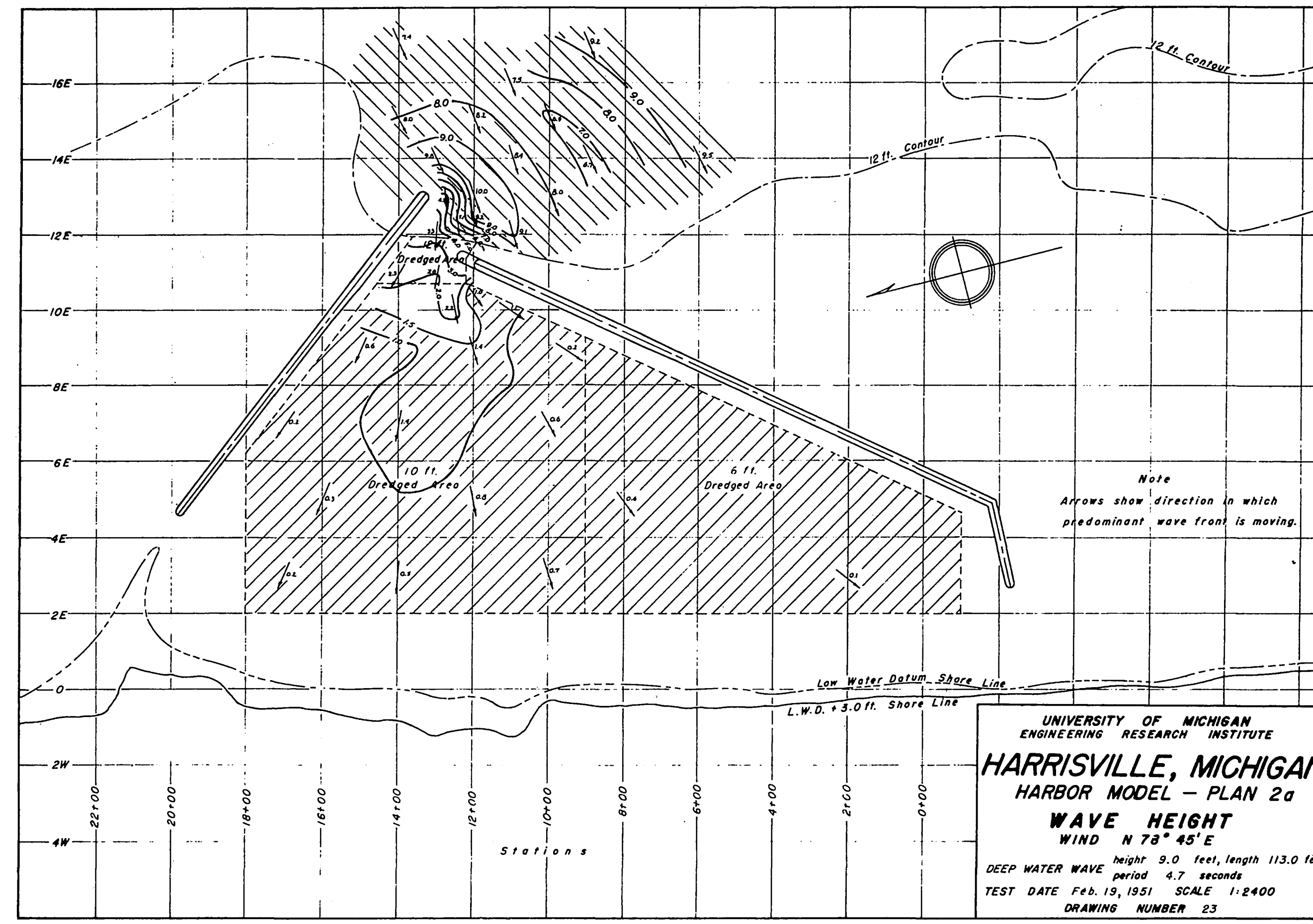

UNIVERSITY OF MICHIGAN
ENGINEERING RESEARCH INSTITUTE
HARRISVILLE, MICHIGAN
HARBOR MODEL — PLAN 3a
WAVE HEIGHT
WIND N. 45° 00' E.
DEEP WATER WAVE height 10.0 feet, length 138.0 feet
period 5.2 seconds
TEST DATE April 10, 1951 SCALE 1:2400
DRAWING NUMBER 43
12 ft. contour
6 ft Dredged Area
10 ft. Dredged Area
12 ft Dredged Area
Low Water Datum Shore Line
L.W.D. +3.0 ft. Shore Line
Note
Arrows show direction in which predominant wave front is moving
Stations
Note
Northerly breakwater extended 50 feet
0+00
2+00
4+00
6+00
8+00
10+00
12+00
14+00
16+00
18+00
20+00
22+00
24+00
26+00
28+00
16 E
14 E
12 E
10 E
8 E
6 E
4 E
2 E
0
2 W
4 W

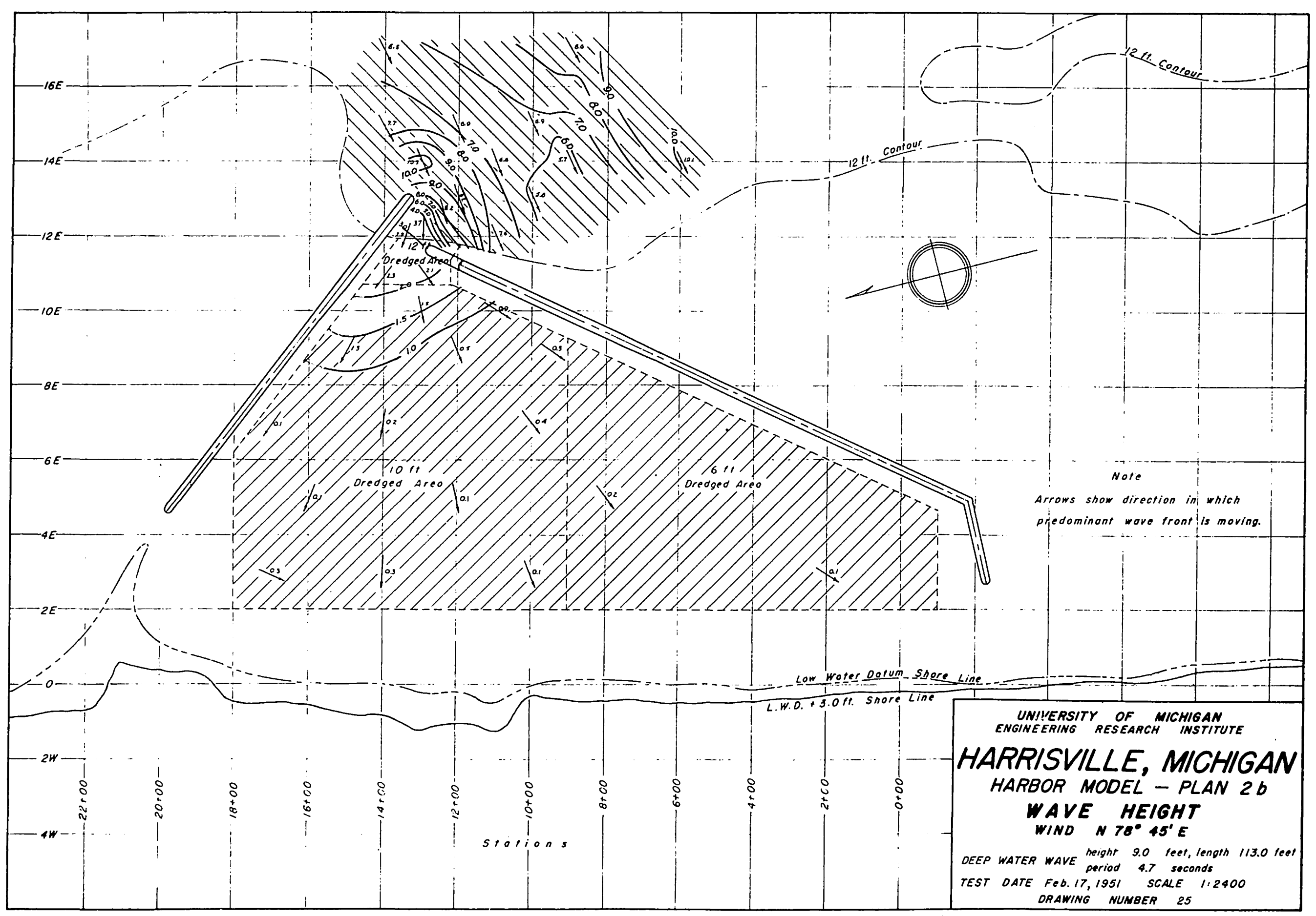

12 ft. Contour
12 ft. Contour
12 ft.
Dredged Area
10 ft.
Dredged Area
6 ft.
Dredged Area
Note
Arrows show direction in which
predominant wave front is moving.
Low Water Datum Shore Line
L.W.D. + 5.0 ft. Shore Line
16E
14E
12E
10E
8E
6E
4E
2E
0
2W
4W
22+00
20+00
18+00
16+00
14+00
12+00
10+00
8+00
6+00
4+00
2+00
0+00
Stations
UNIVERSITY OF MICHIGAN
ENGINEERING RESEARCH INSTITUTE
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2
WAVE HEIGHT
WIND S 33° 45' E
DEEP WATER WAVE height 8.0 feet, length 95.0 feet
period 4.3 seconds
TEST DATE Jan. 16, 1951 SCALE 1:2400
DRAWING NUMBER 11


12 ft. Contour
12 ft. Contour
12 ft.
Dredged Area
10 ft.
Dredged Area
6 ft.
Dredged Area
Note
Arrows show direction in which
predominant wave front is moving.
Low Water Datum Shore Line
L.W.D. + 5.0 ft. Shore Line
16E
14E
12E
10E
8E
6E
4E
2E
0
2W
4W
22+00
20+00
18+00
16+00
14+00
12+00
10+00
8+00
6+00
4+00
2+00
0+00
Stations
UNIVERSITY OF MICHIGAN
ENGINEERING RESEARCH INSTITUTE
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2a
WAVE HEIGHT
WIND S 33° 45' E
DEEP WATER WAVE height 8.0 feet, length 95.0 feet
period 4.3 seconds
TEST DATE Feb. 28, 1951 SCALE 1:2400
DRAWING NUMBER 22


12 ft. Contour
12 ft. Contour
Dredged Area
10 ft.
Dredged Area
6 ft.
Dredged Area
Note
Arrows show direction in which
predominant wave front is moving.
Low Water Datum Shore Line
L.W.D. + 5.0 ft. Shore Line
16E
14E
12E
10E
8E
6E
4E
2E
0
2W
4W
22+00
20+00
18+00
16+00
14+00
12+00
10+00
8+00
6+00
4+00
2+00
0+00
Stations
UNIVERSITY OF MICHIGAN
ENGINEERING RESEARCH INSTITUTE
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2b
WAVE HEIGHT
WIND S 33° 45' E
DEEP WATER WAVE height 8.0 feet, length 95.0 feet
period 4.3 seconds
TEST DATE Feb. 21, 1951 SCALE 1:2400
DRAWING NUMBER 24

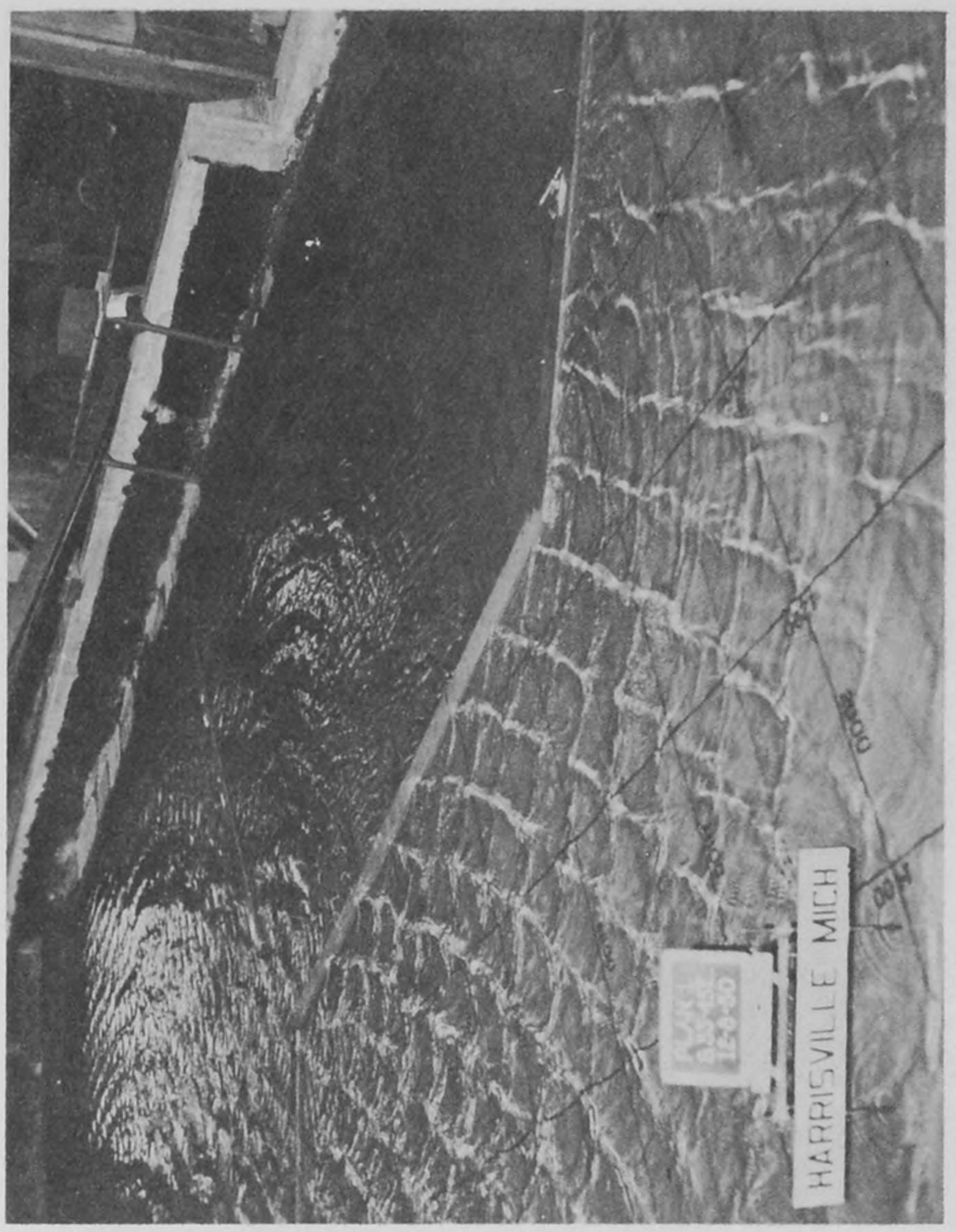

UNIVERSITY OF MICHIGAN
ENGINEERING RESEARCH INSTITUTE
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2
WAVE HEIGHT
WIND N 78° 45' E
DEEP WATER WAVE height 9.0 feet, length 113.0 feet period 4.7 seconds
TEST DATE Jan. 23, 1951 SCALE 1:2400
DRAWING NUMBER 16
Note
Arrows show direction in which predominant wave front is moving.
12 ft. Contour
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
10 ft. Dredged Area
6 ft. Dredged Area
Stations

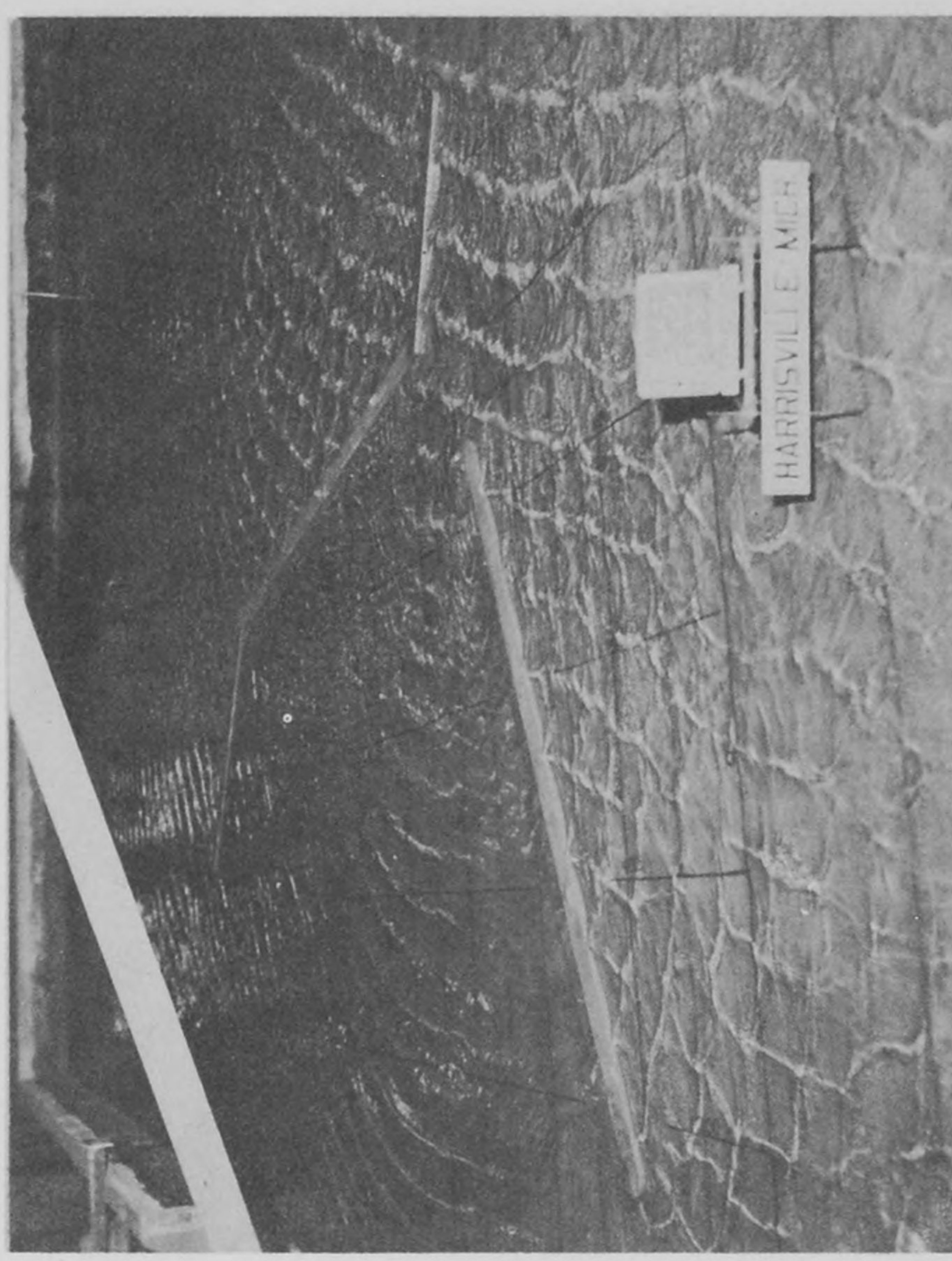

UNIVERSITY OF MICHIGAN
ENGINEERING RESEARCH INSTITUTE
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2a
WAVE HEIGHT
WIND N 78° 45' E
DEEP WATER WAVE height 9.0 feet, length 113.0 feet period 4.7 seconds
TEST DATE Feb. 19, 1951 SCALE 1:2400
DRAWING NUMBER 23
Note
Arrows show direction in which predominant wave front is moving.
12 ft. Contour
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
10 ft. Dredged Area
6 ft. Dredged Area
Stations

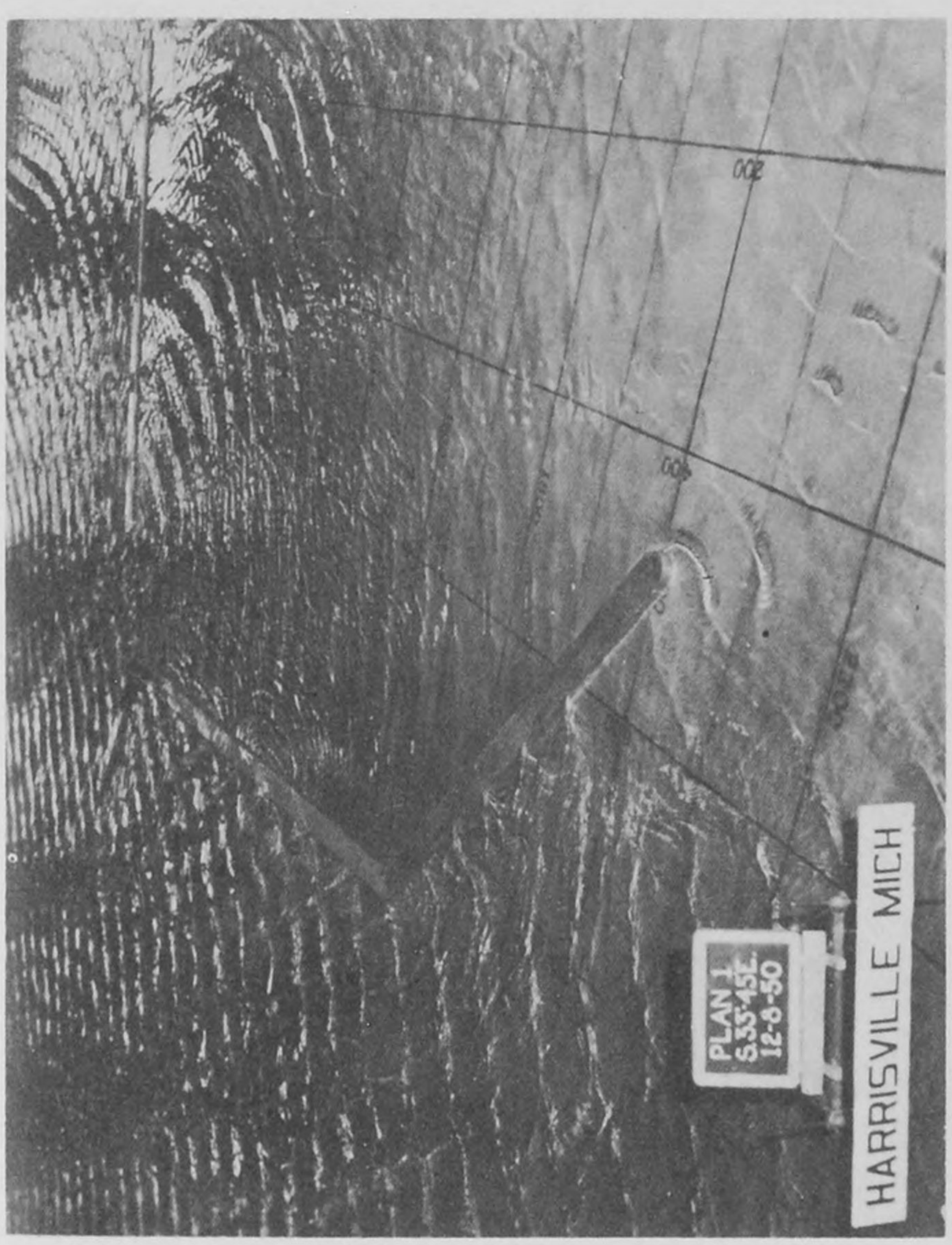

UNIVERSITY OF MICHIGAN
ENGINEERING RESEARCH INSTITUTE
HARRISVILLE, MICHIGAN
HARBOR MODEL – PLAN 2b
WAVE HEIGHT
WIND N 78° 45' E
DEEP WATER WAVE height 9.0 feet, length 113.0 feet period 4.7 seconds
TEST DATE Feb. 17, 1951 SCALE 1:2400
DRAWING NUMBER 25
Note
Arrows show direction in which predominant wave front is moving.
12 ft. Contour
Low Water Datum Shore Line
L.W.D. + 3.0 ft. Shore Line
10 ft. Dredged Area
6 ft. Dredged Area
Stations

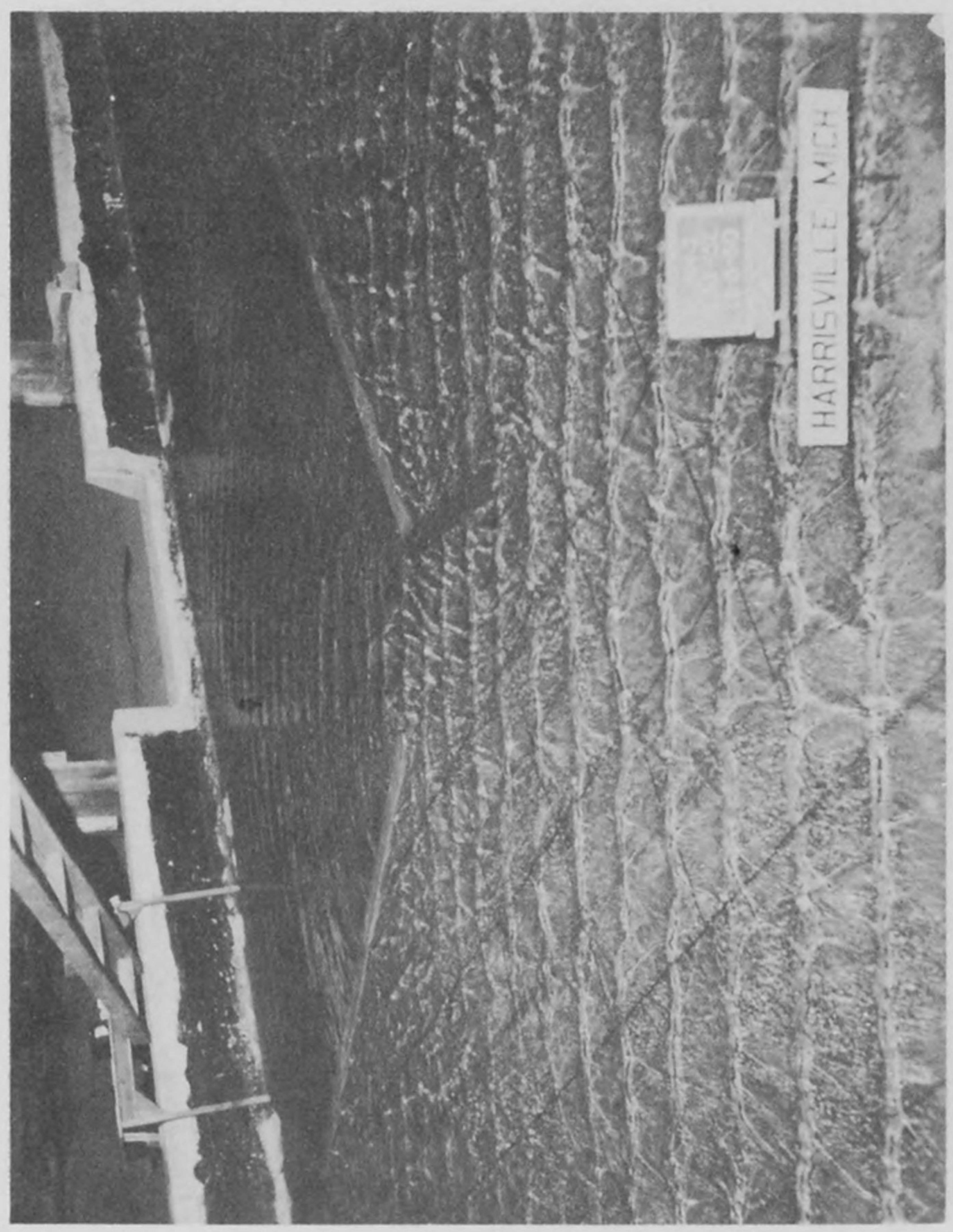
APPENDIX B

PHOTOGRAPHS SHOWING WAVE CONDITIONS DURING TESTS

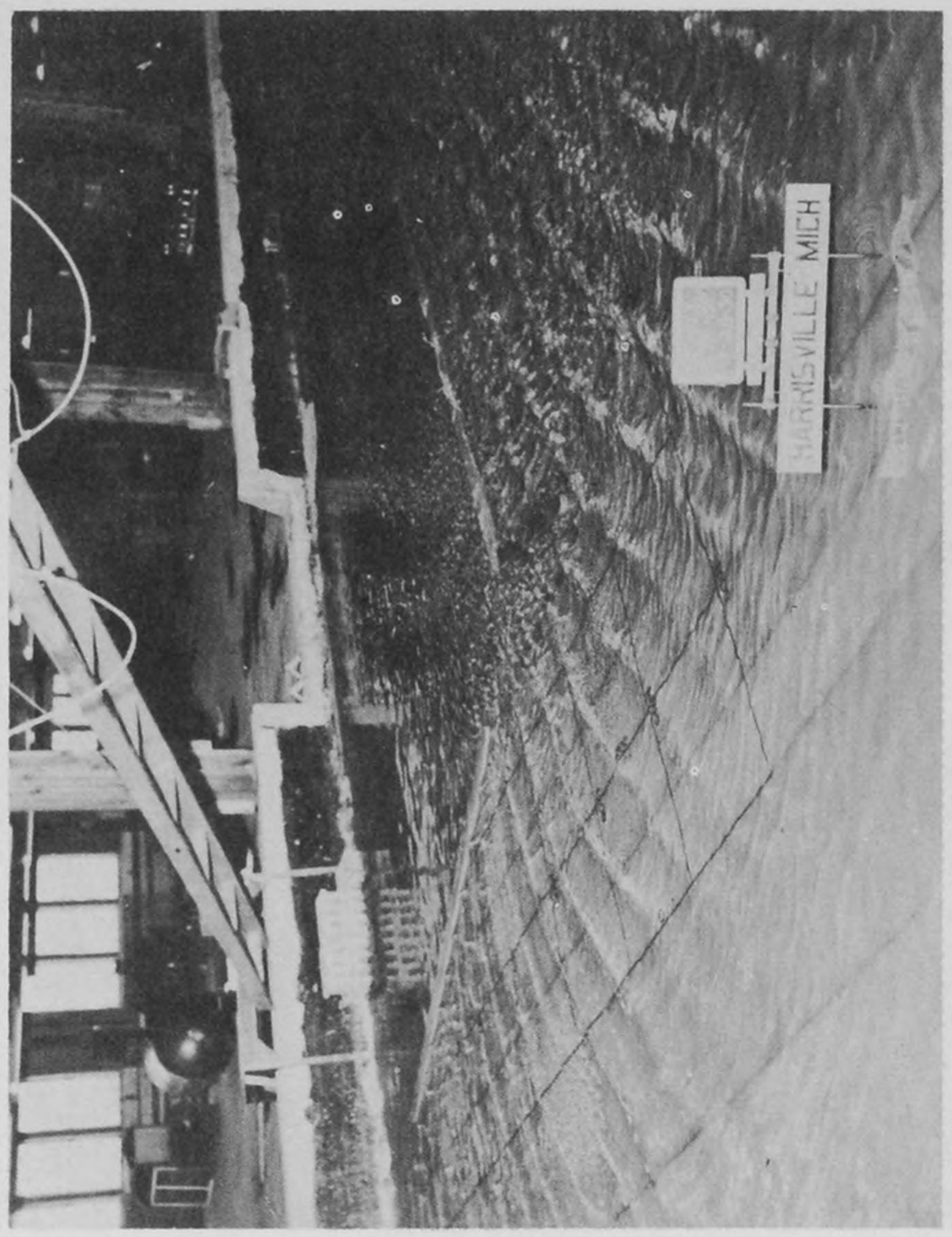


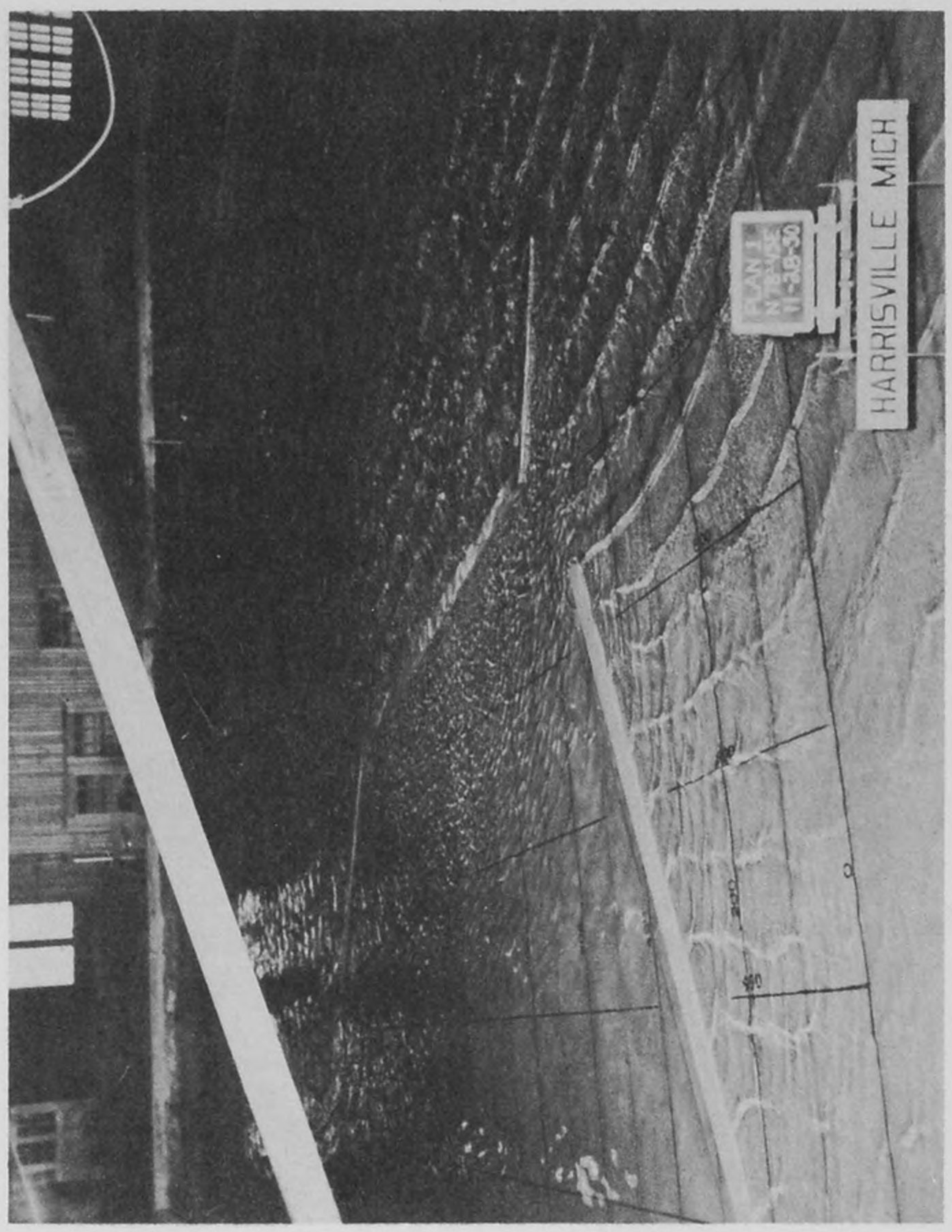


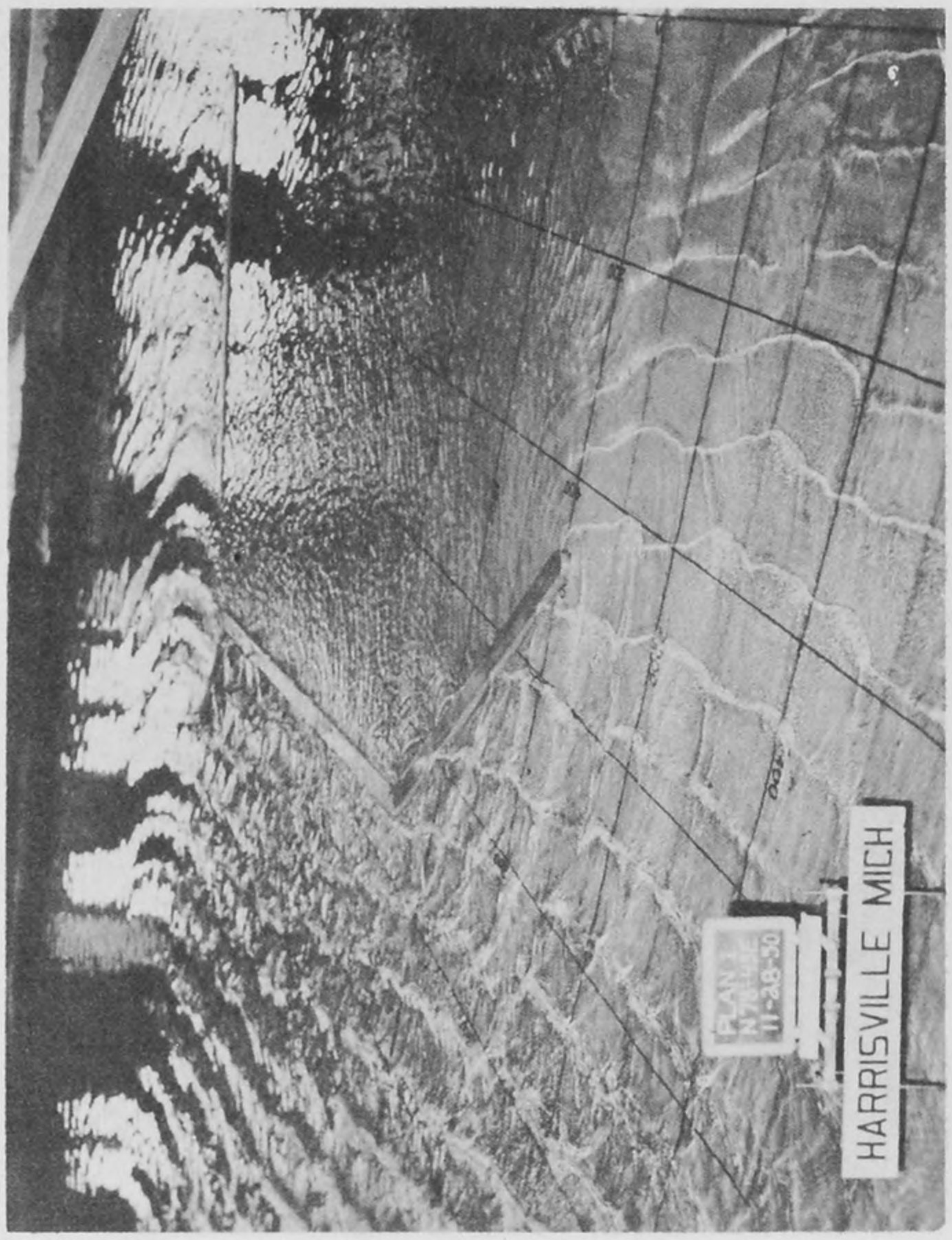


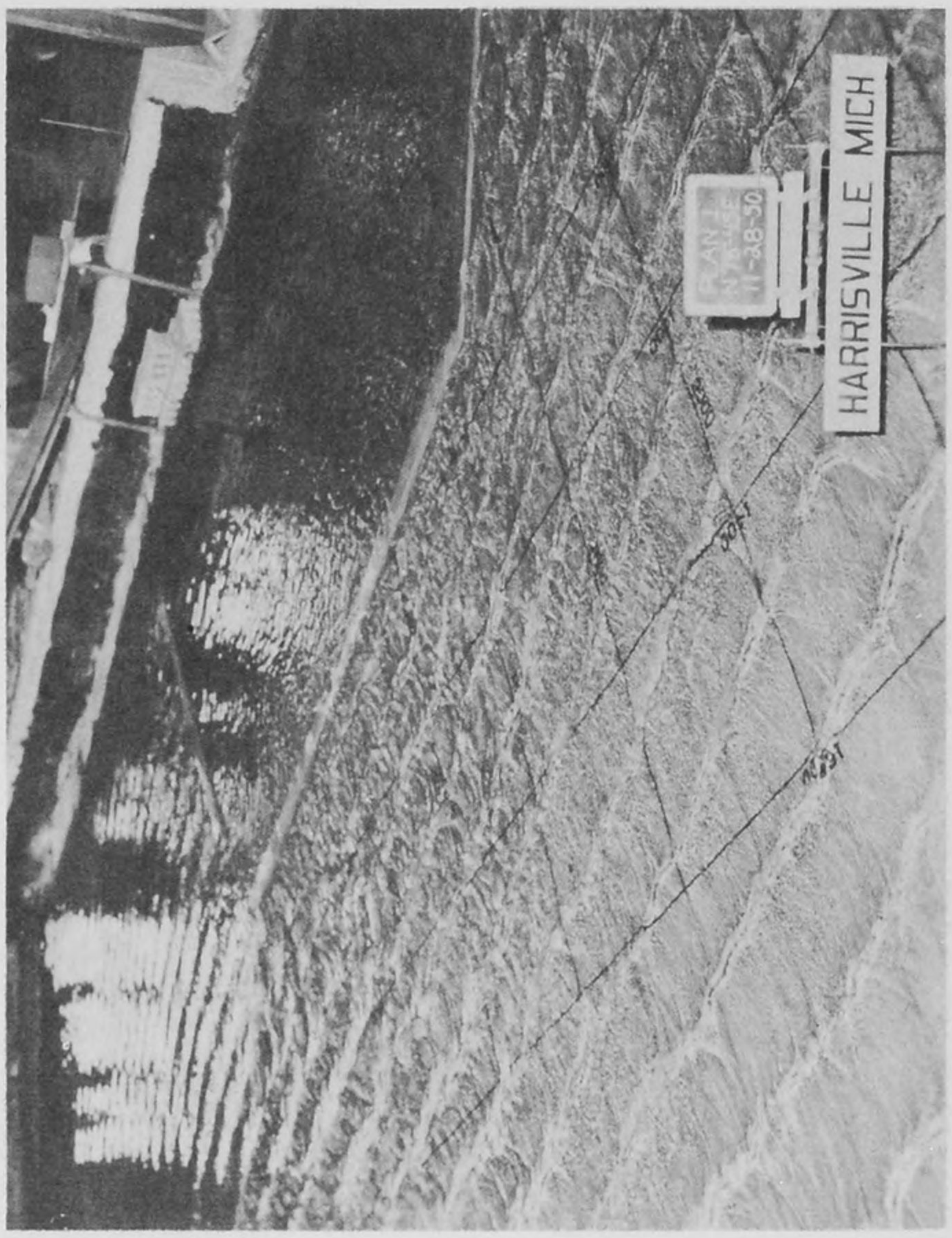


HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 1

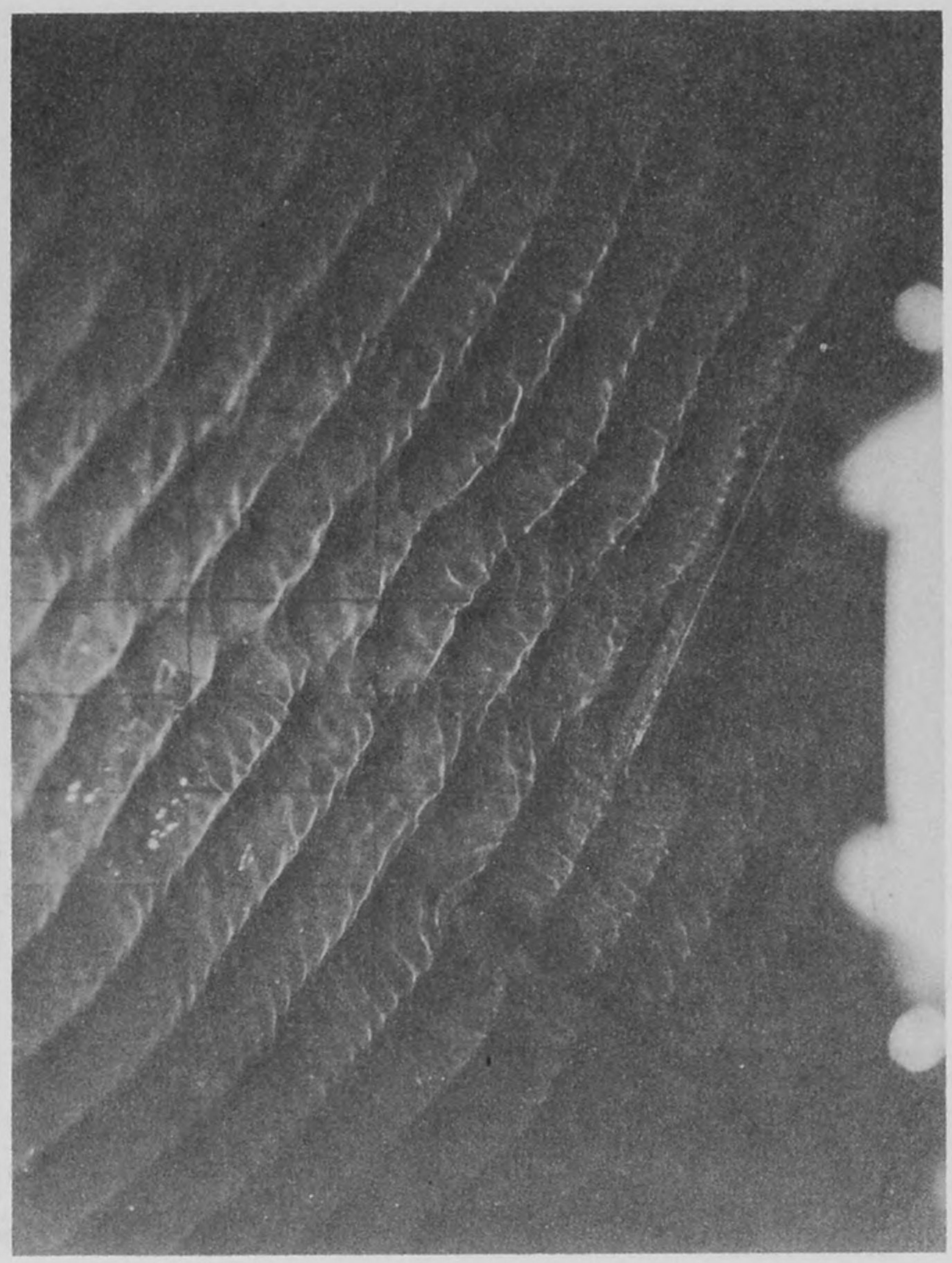


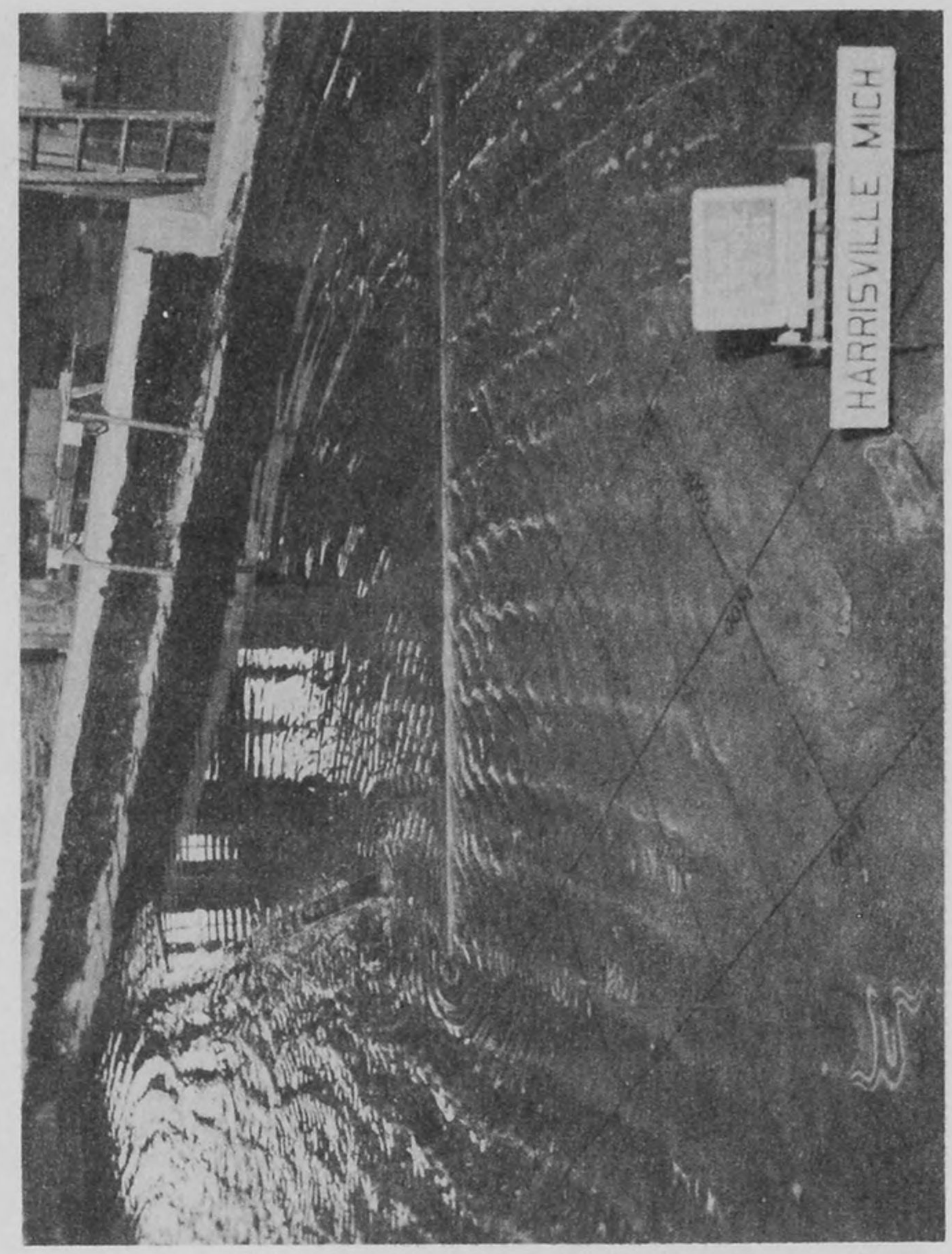


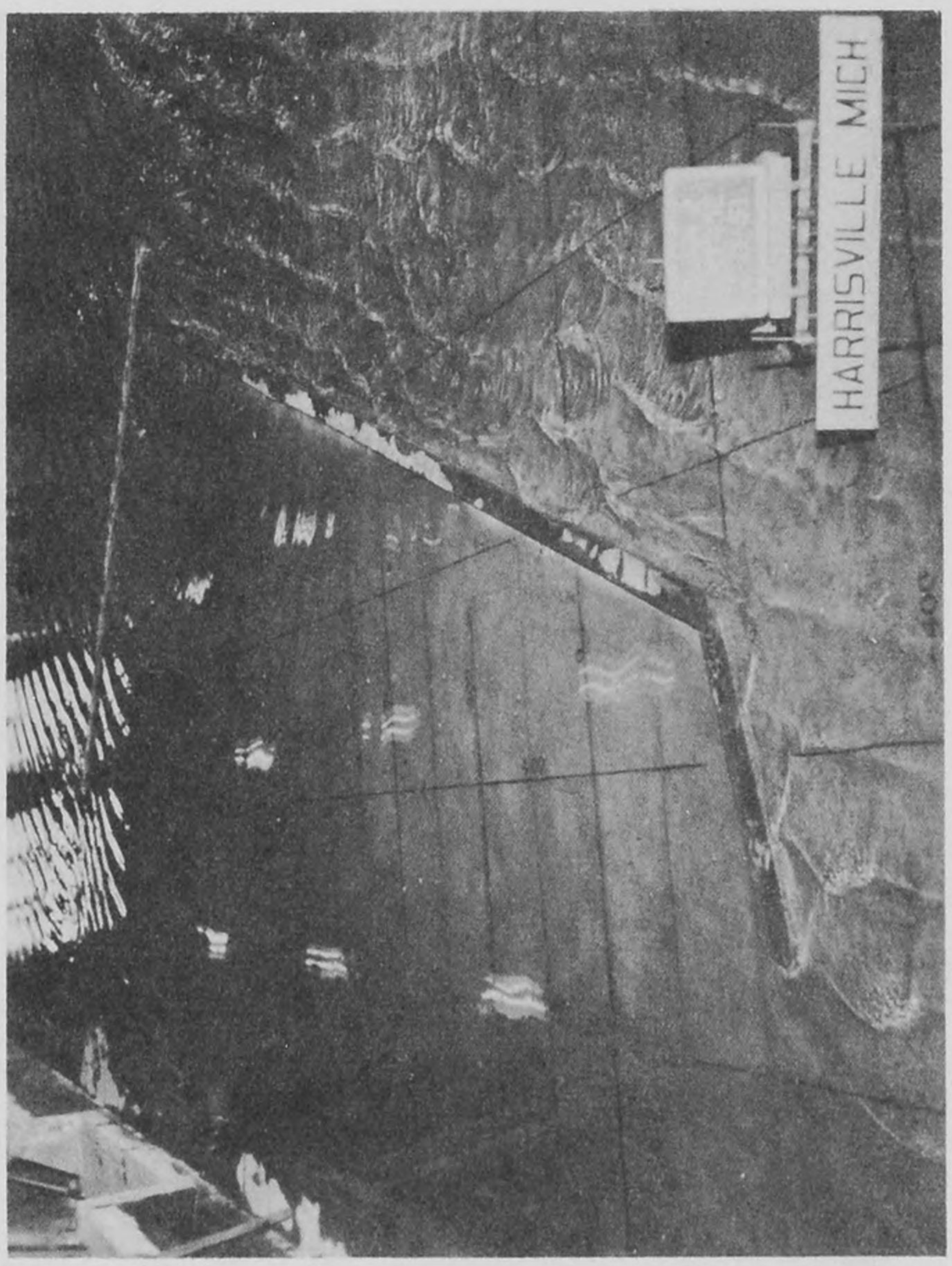


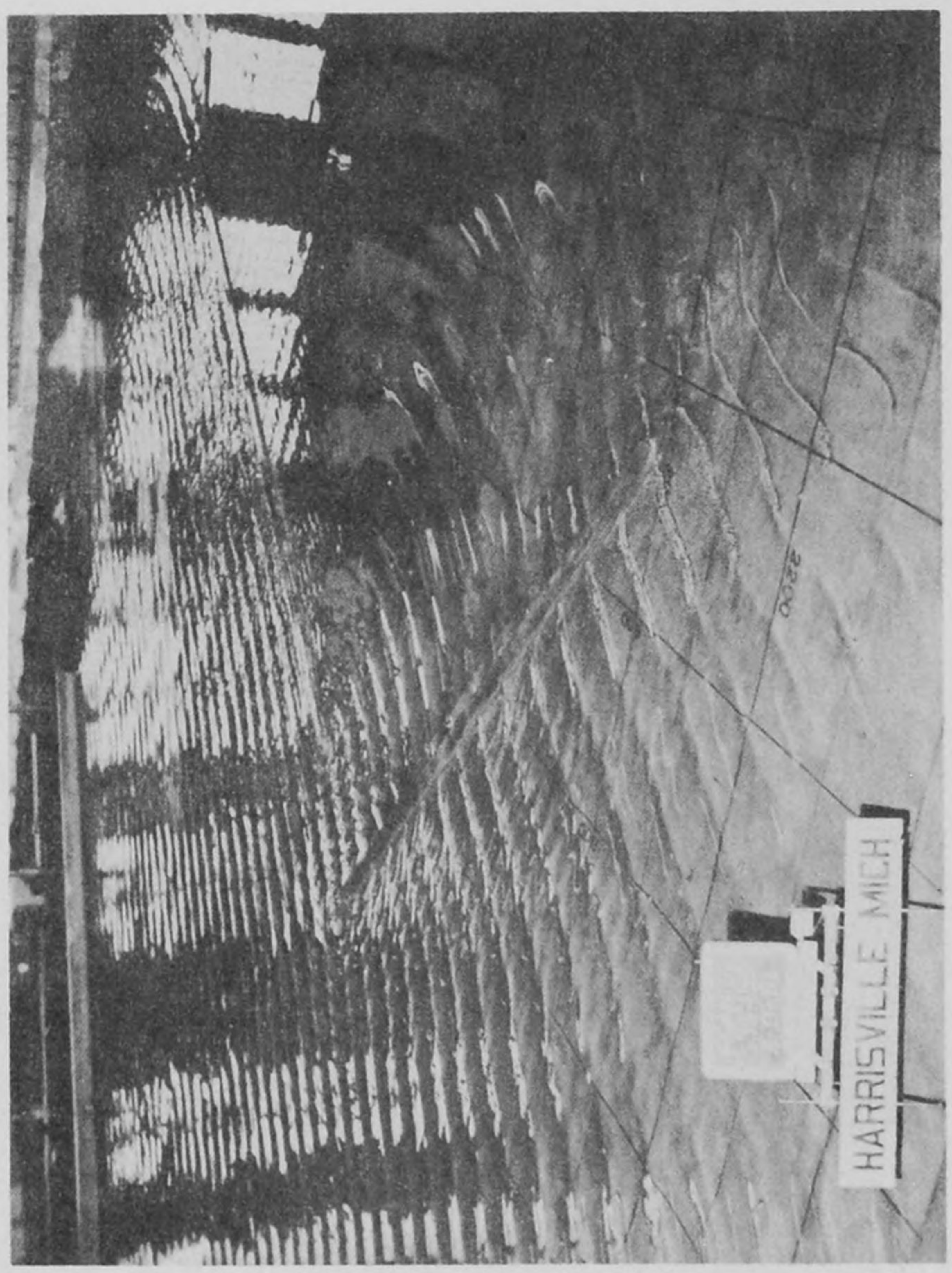


HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 2

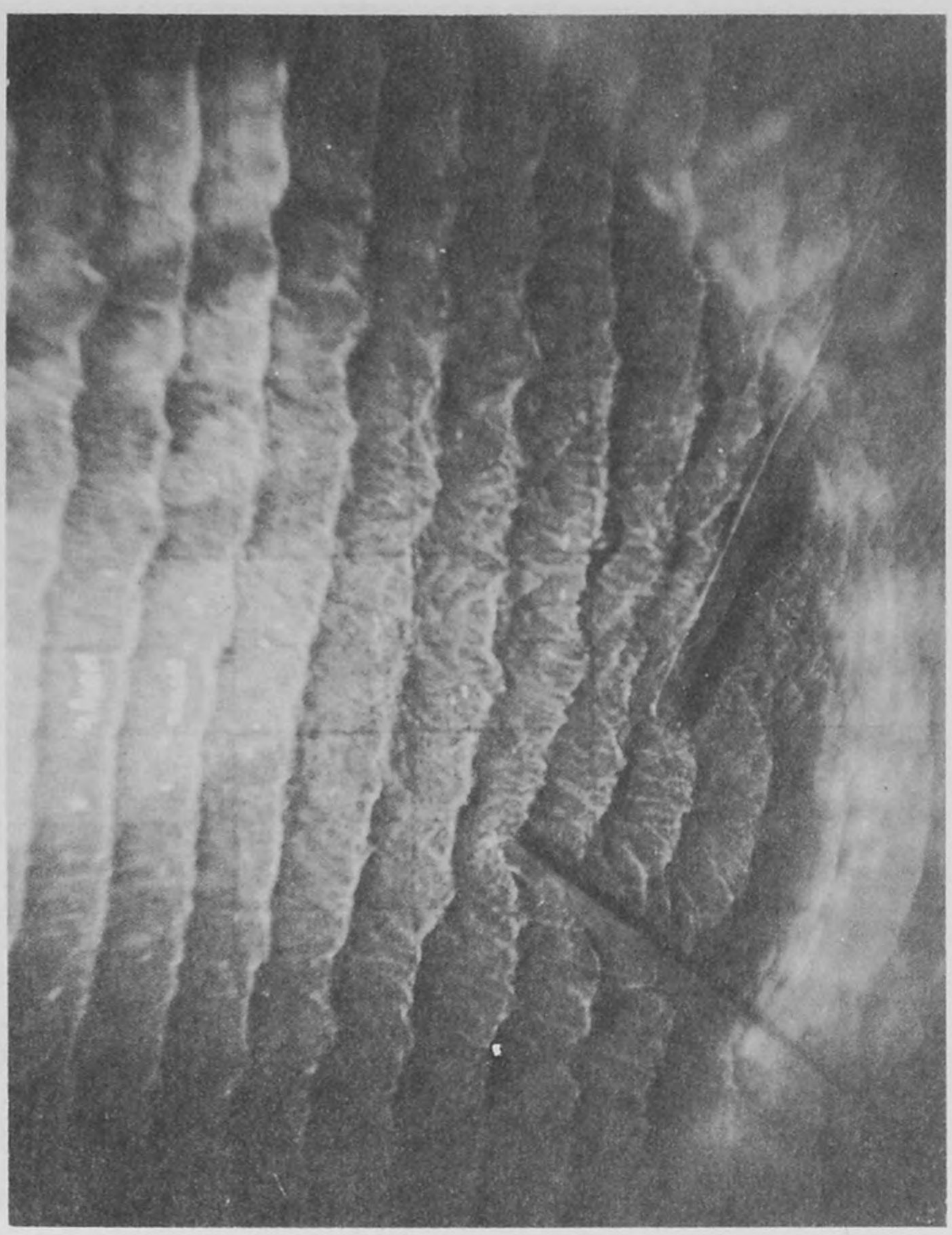


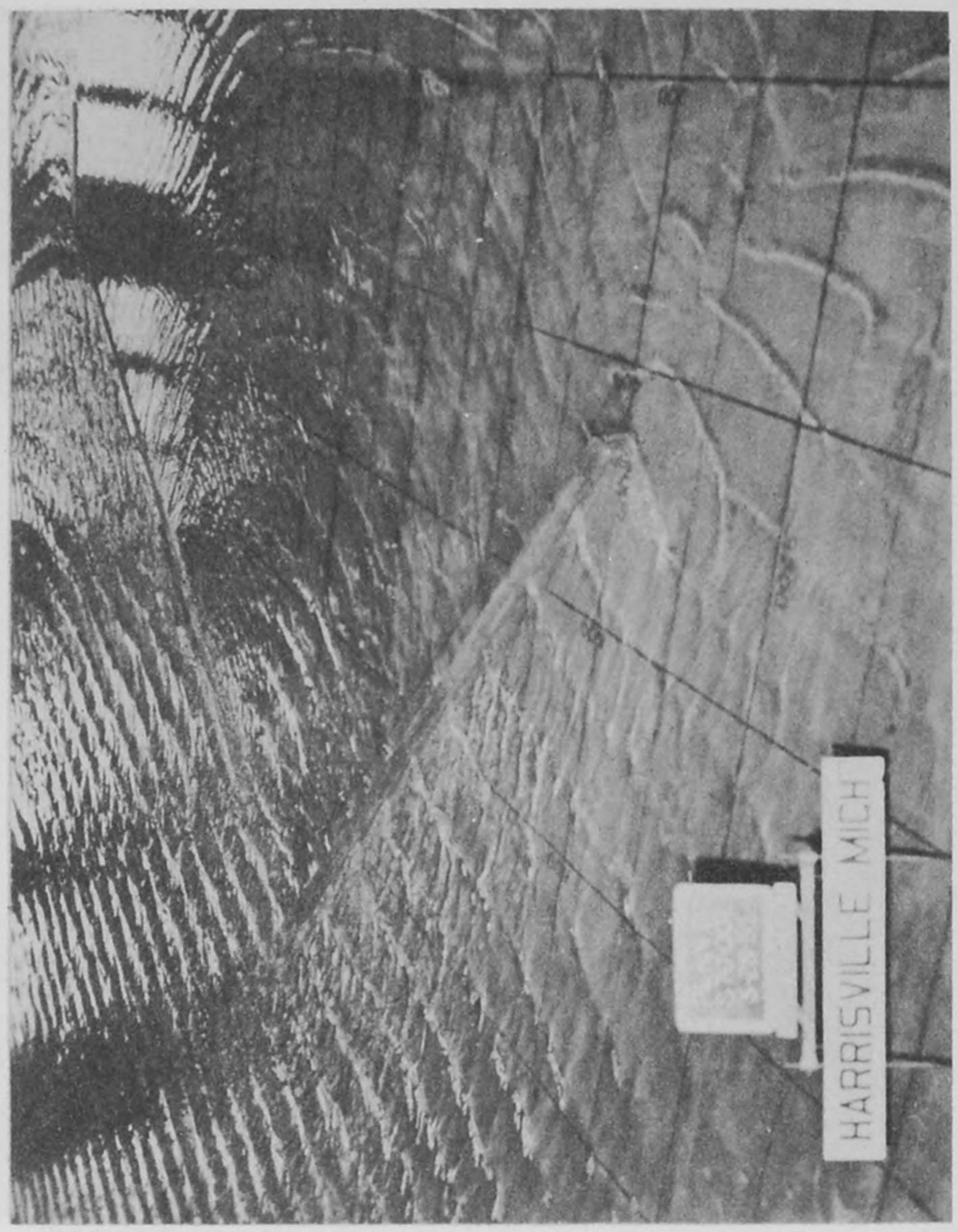


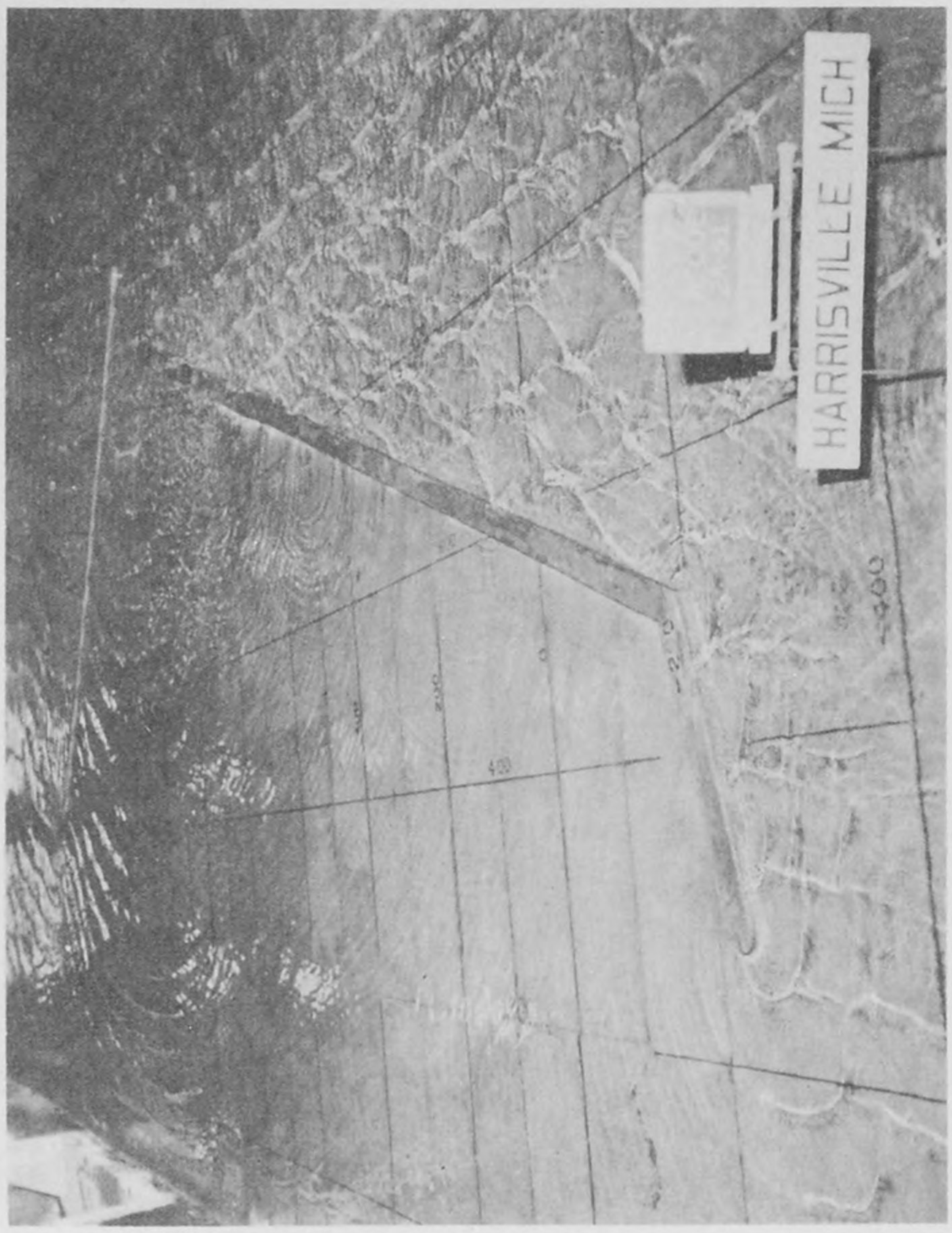


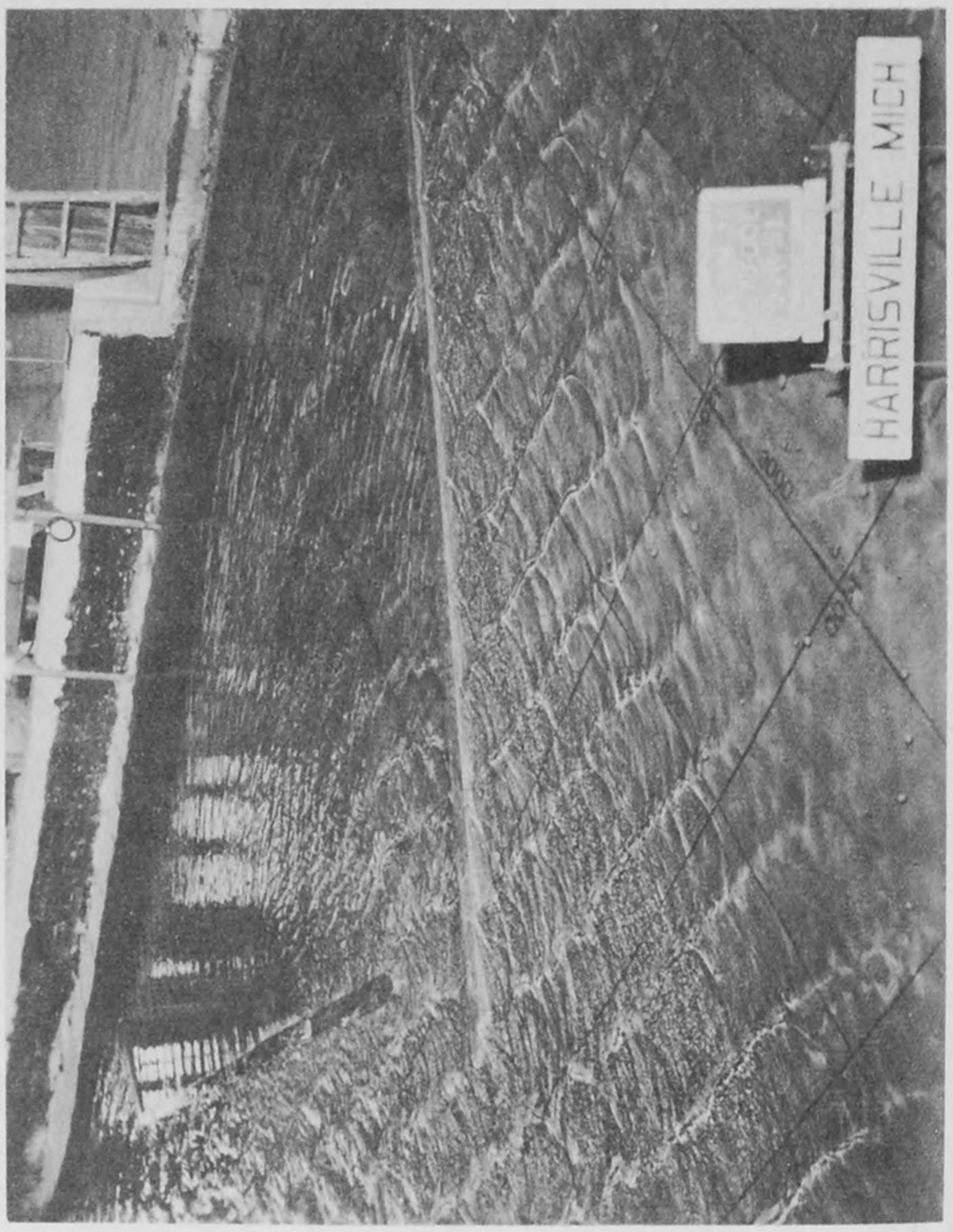


HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 3

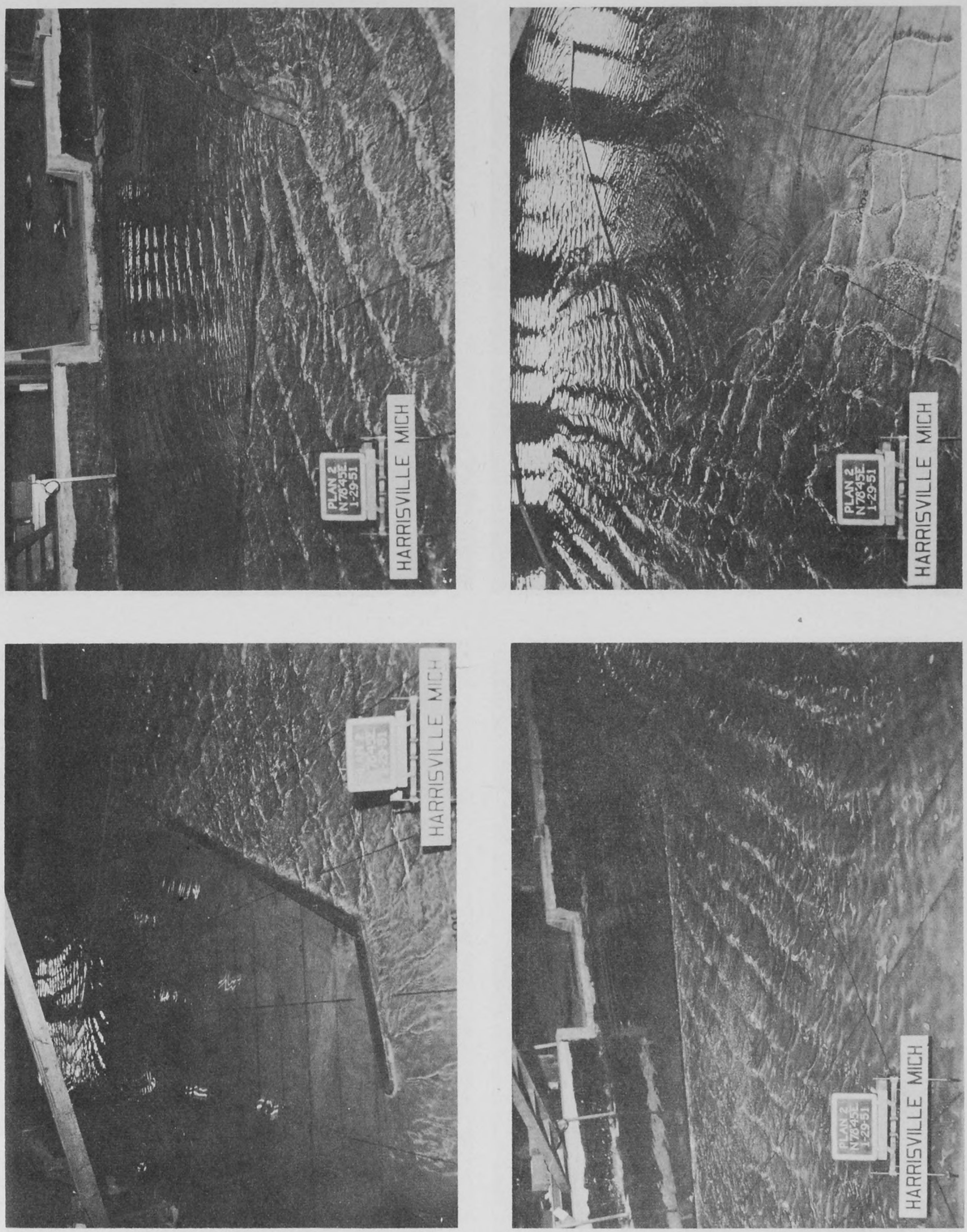




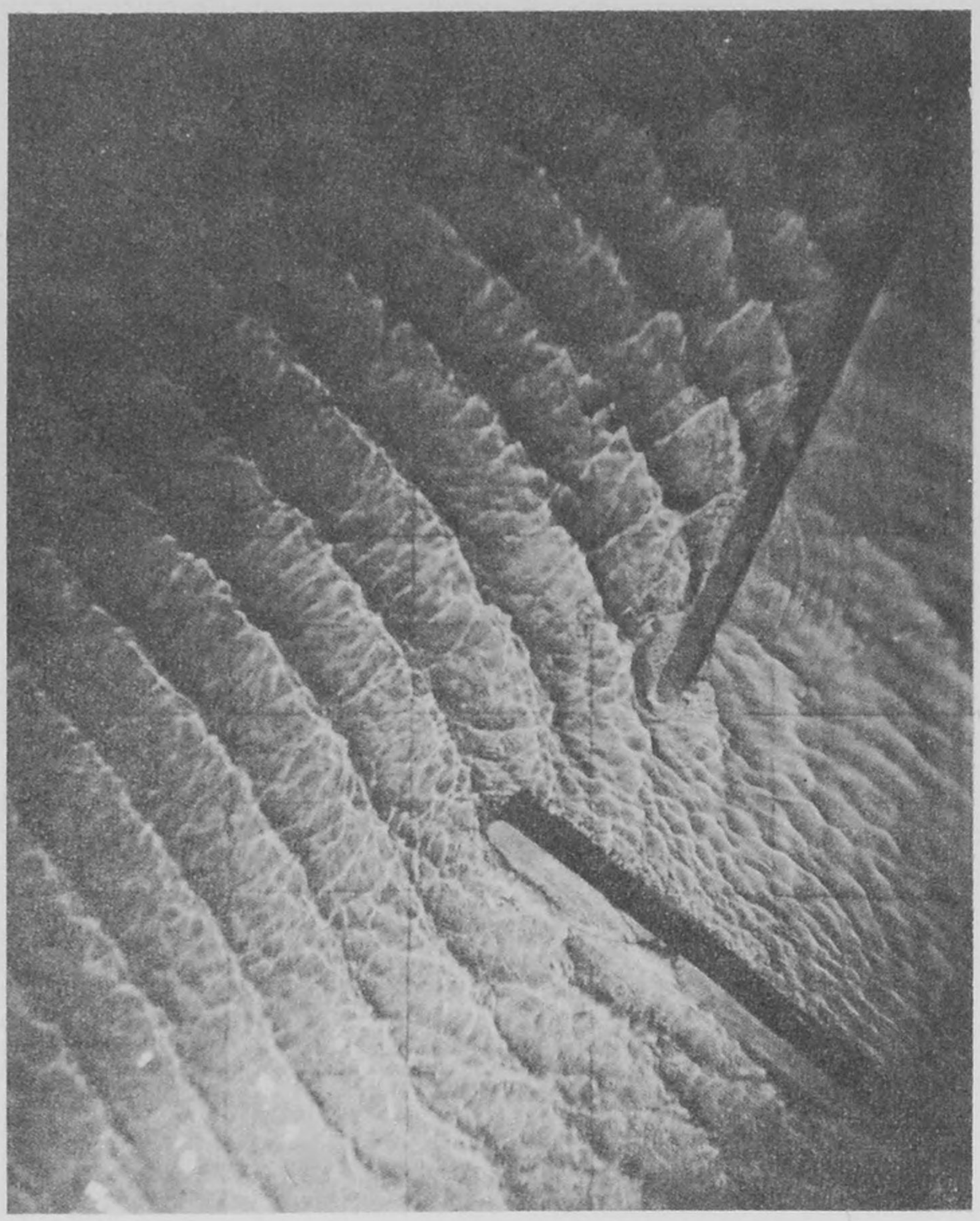


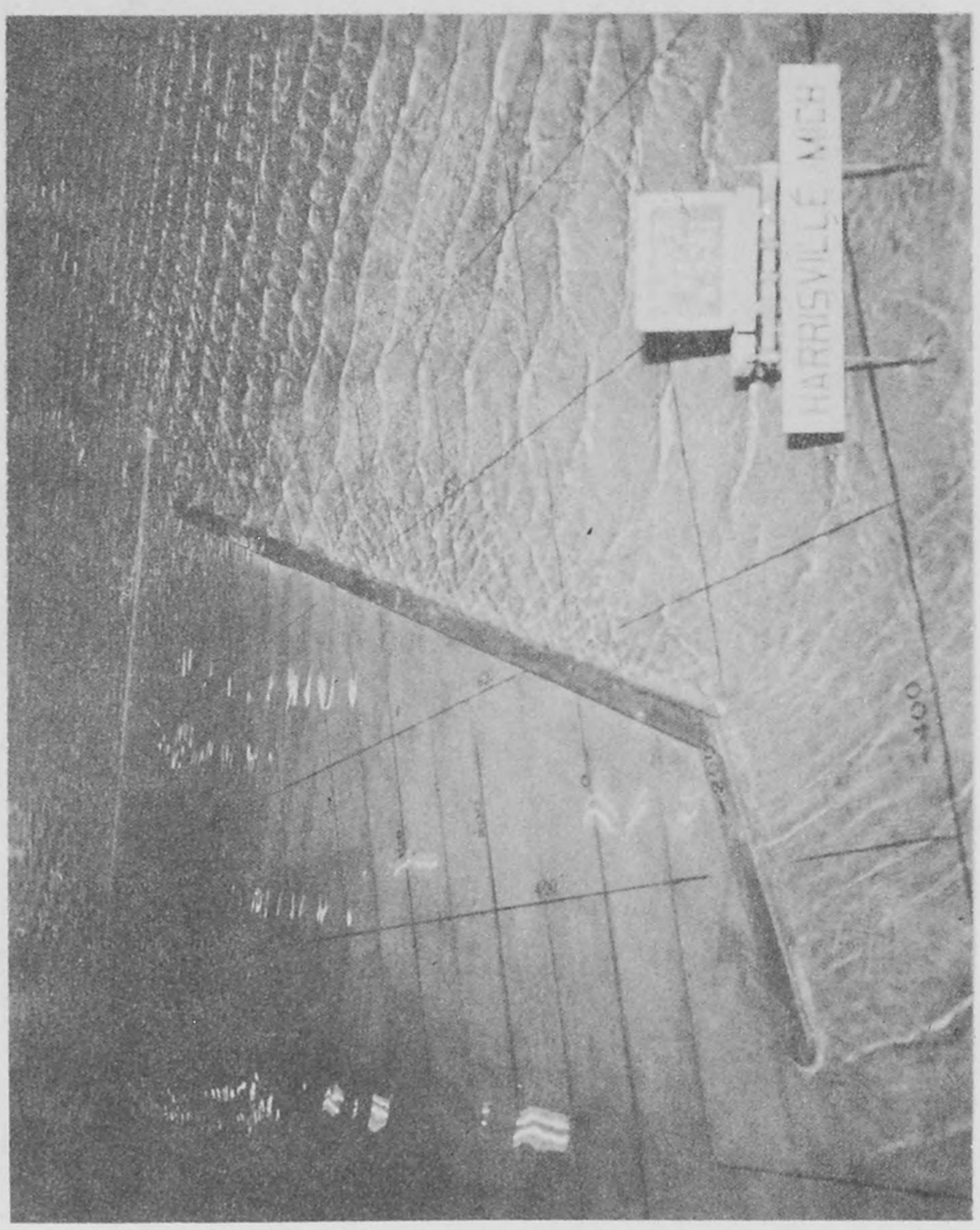


HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 4

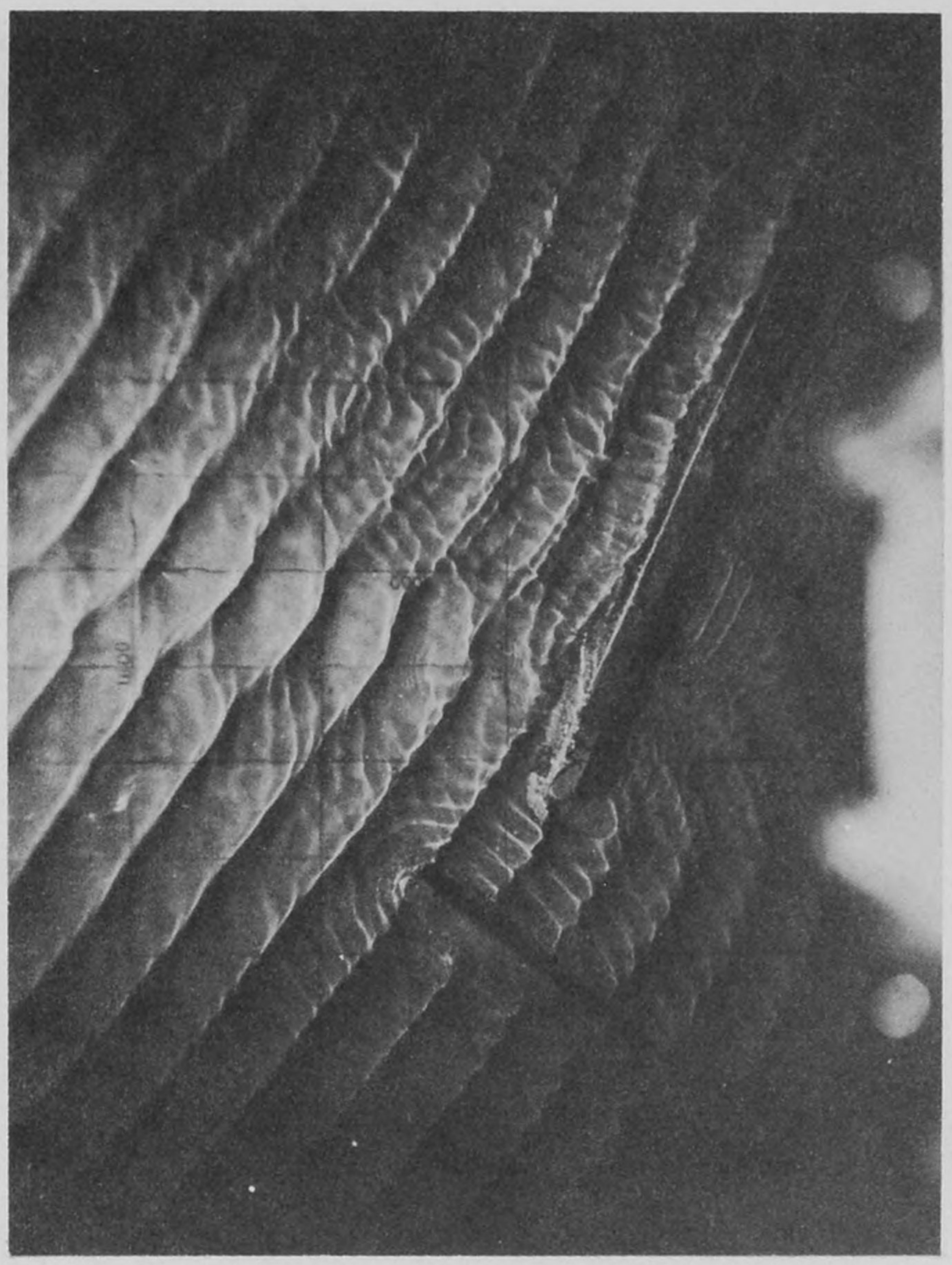


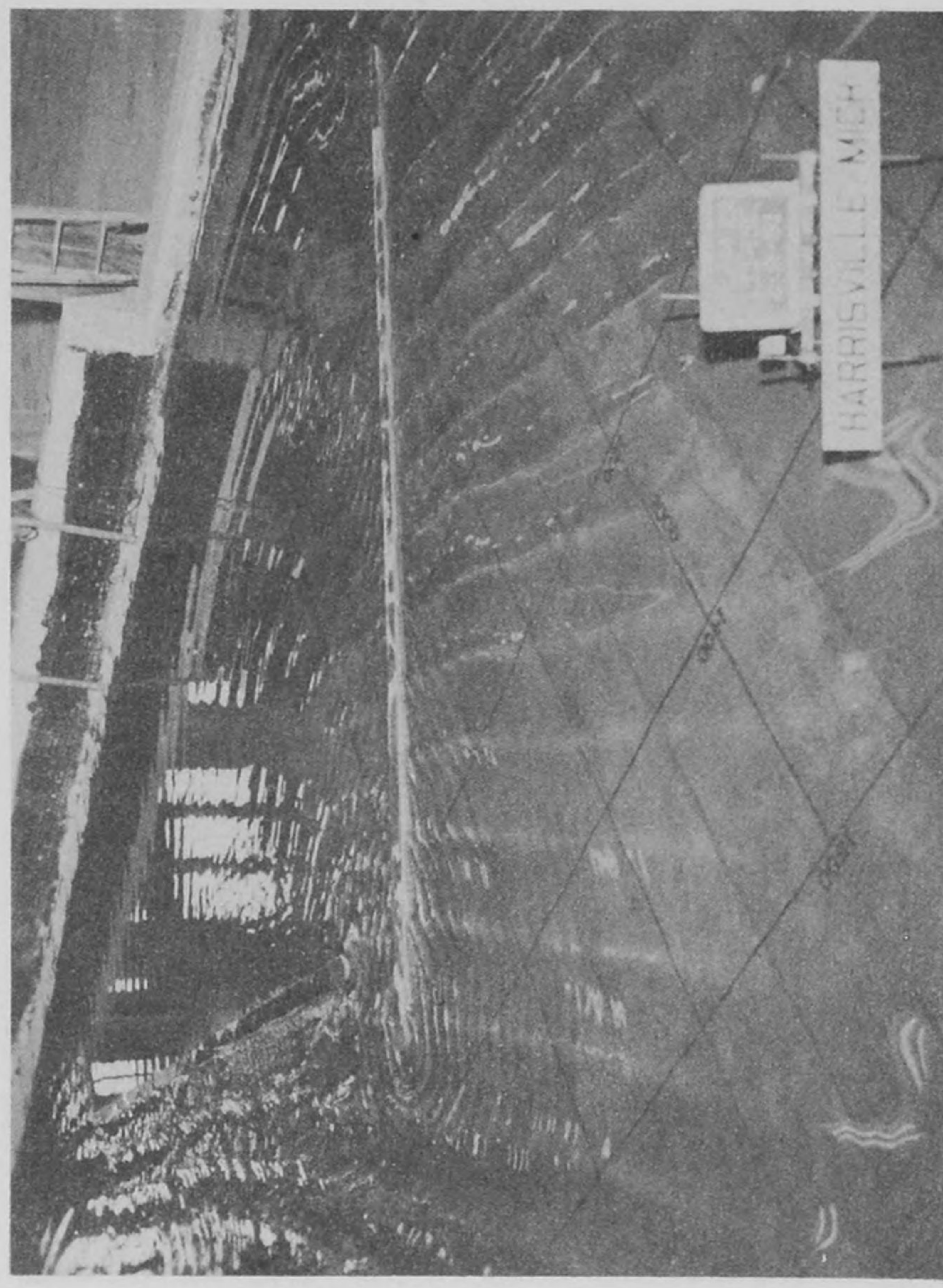
HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 5

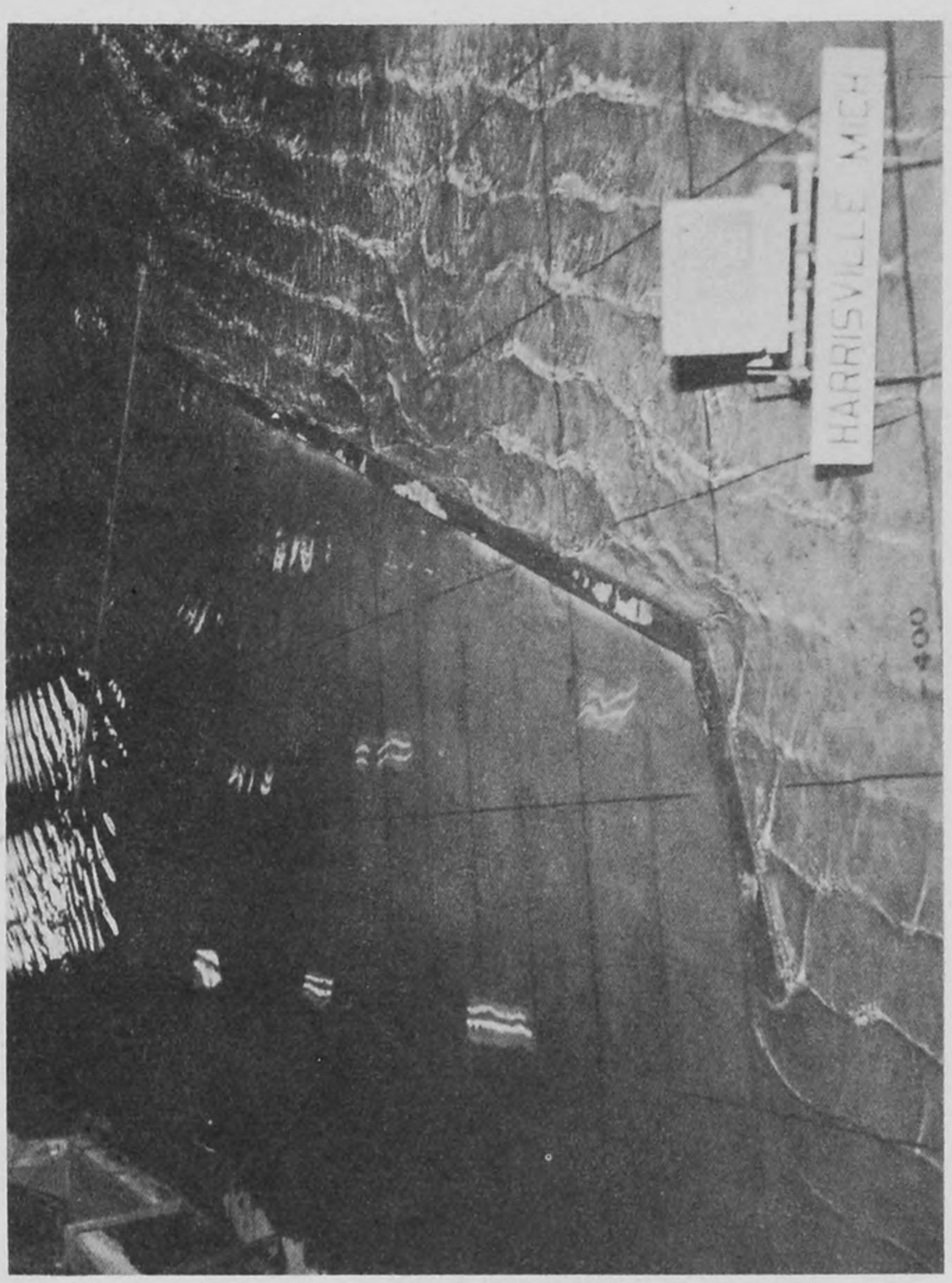


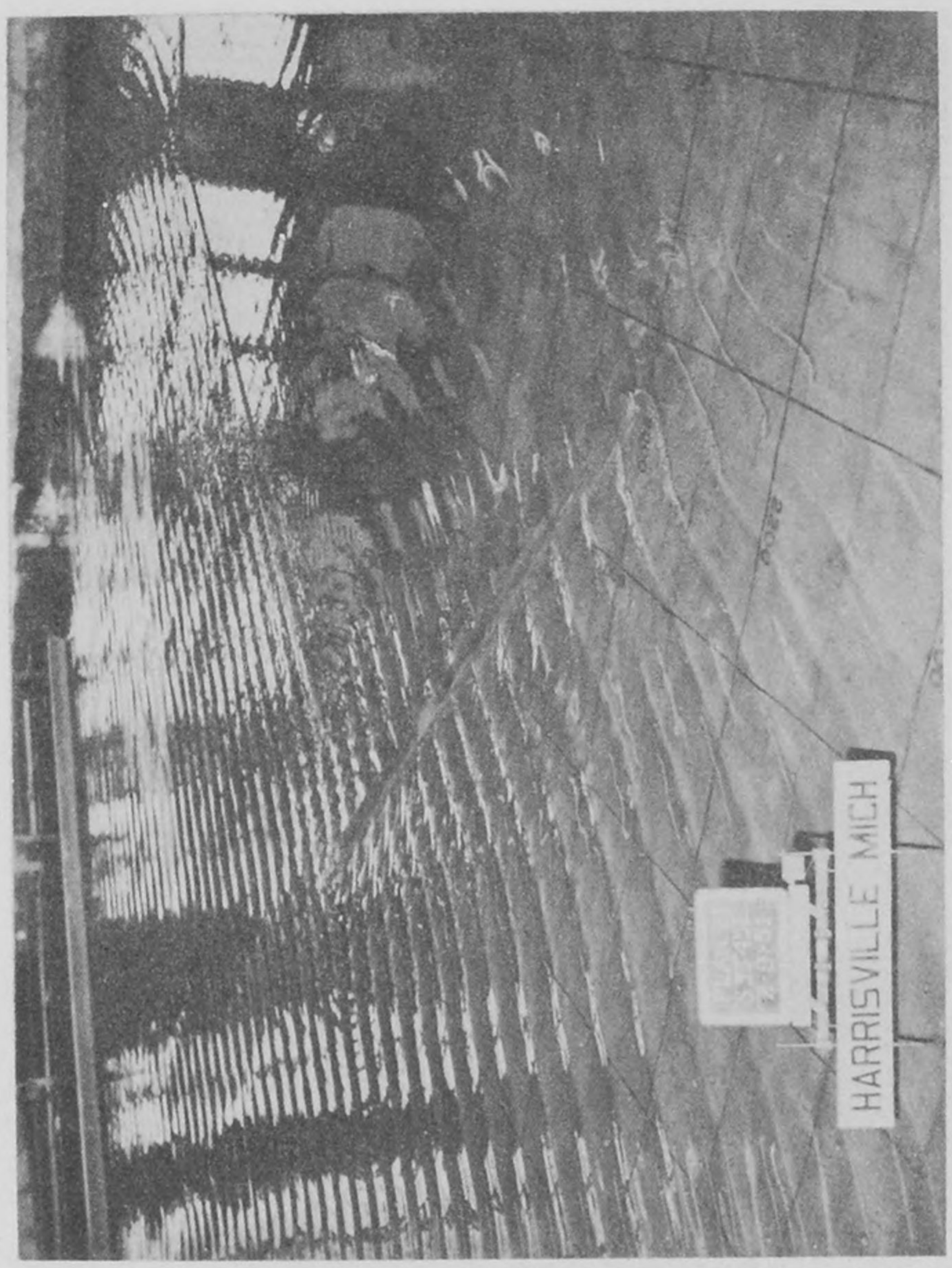


HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 6

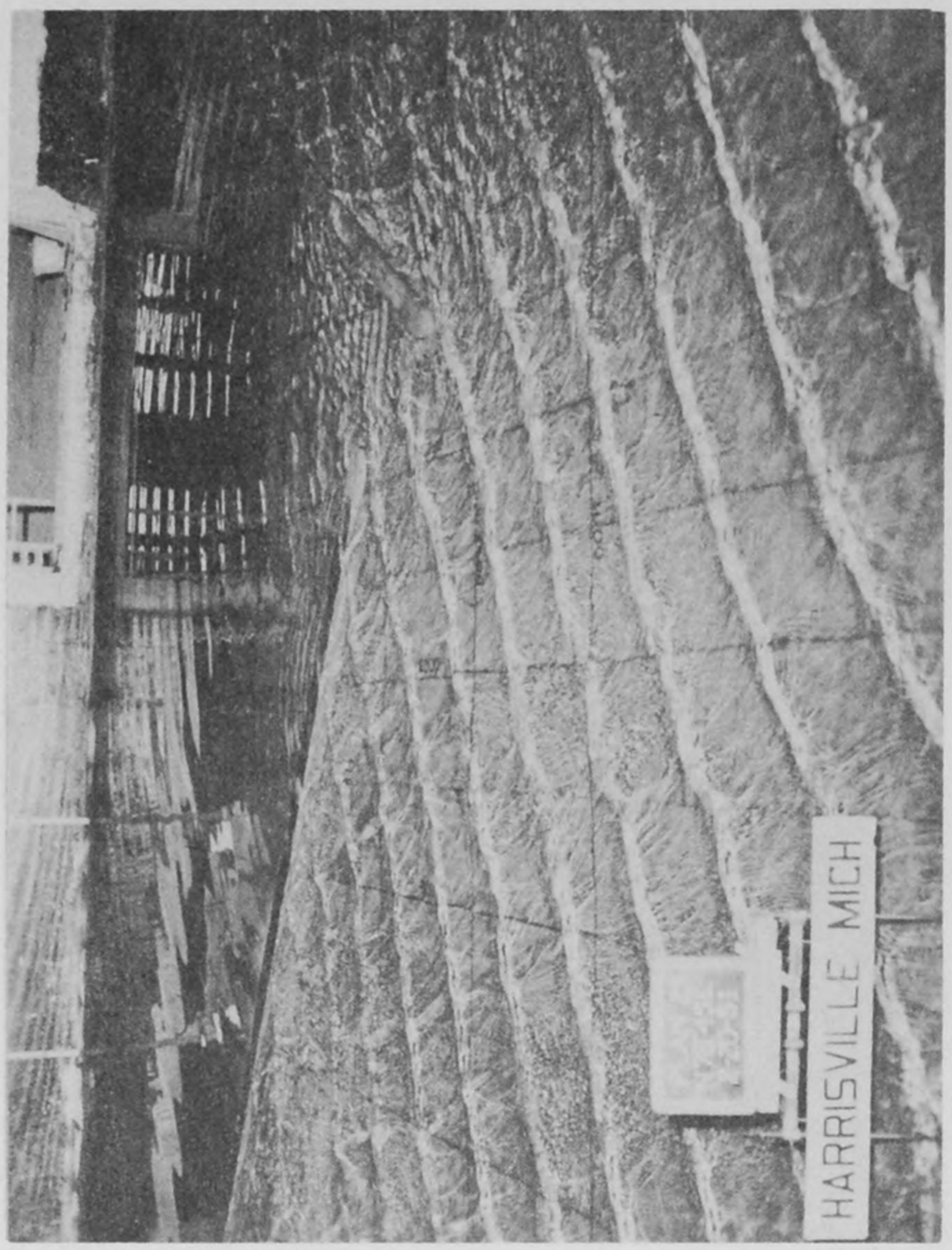


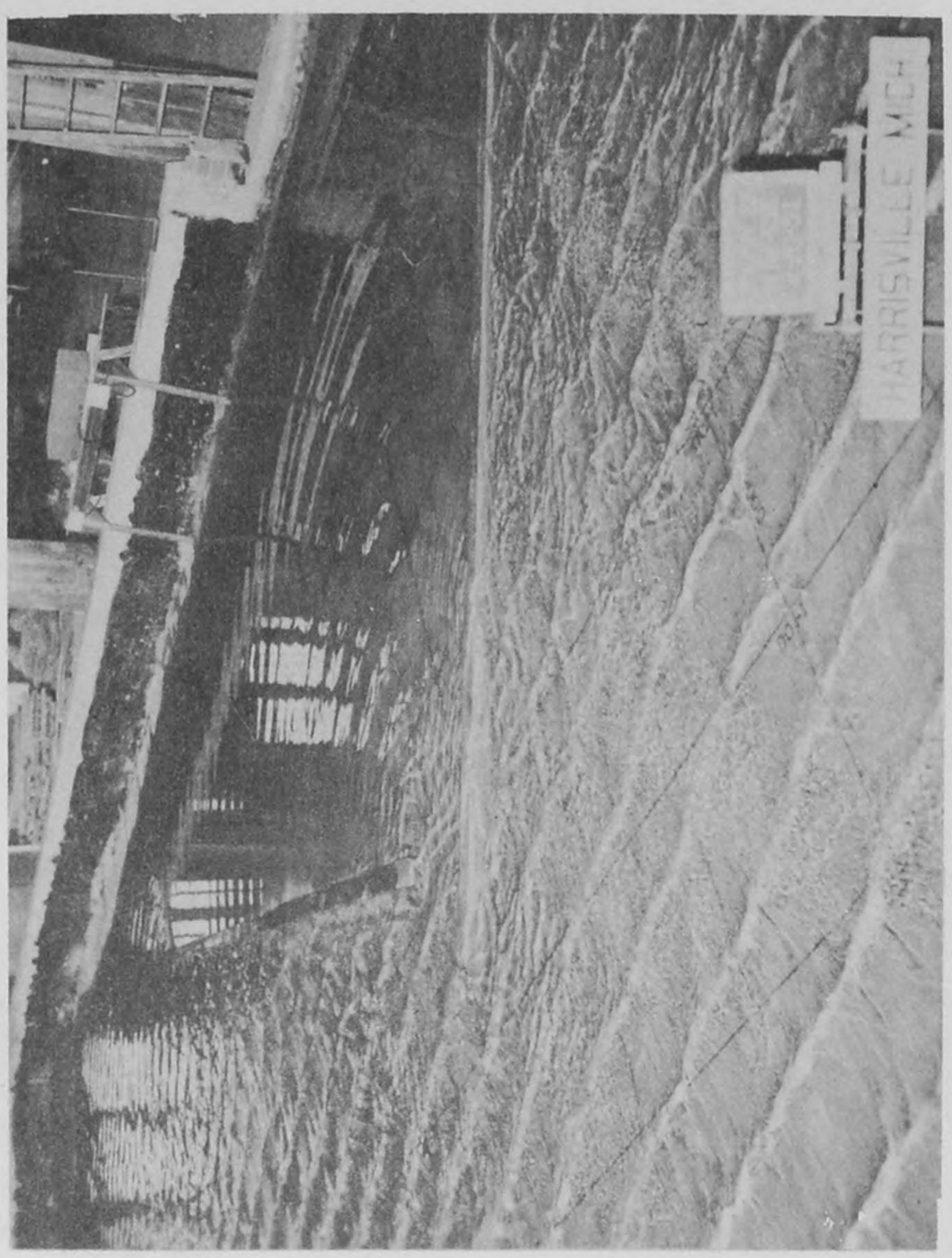


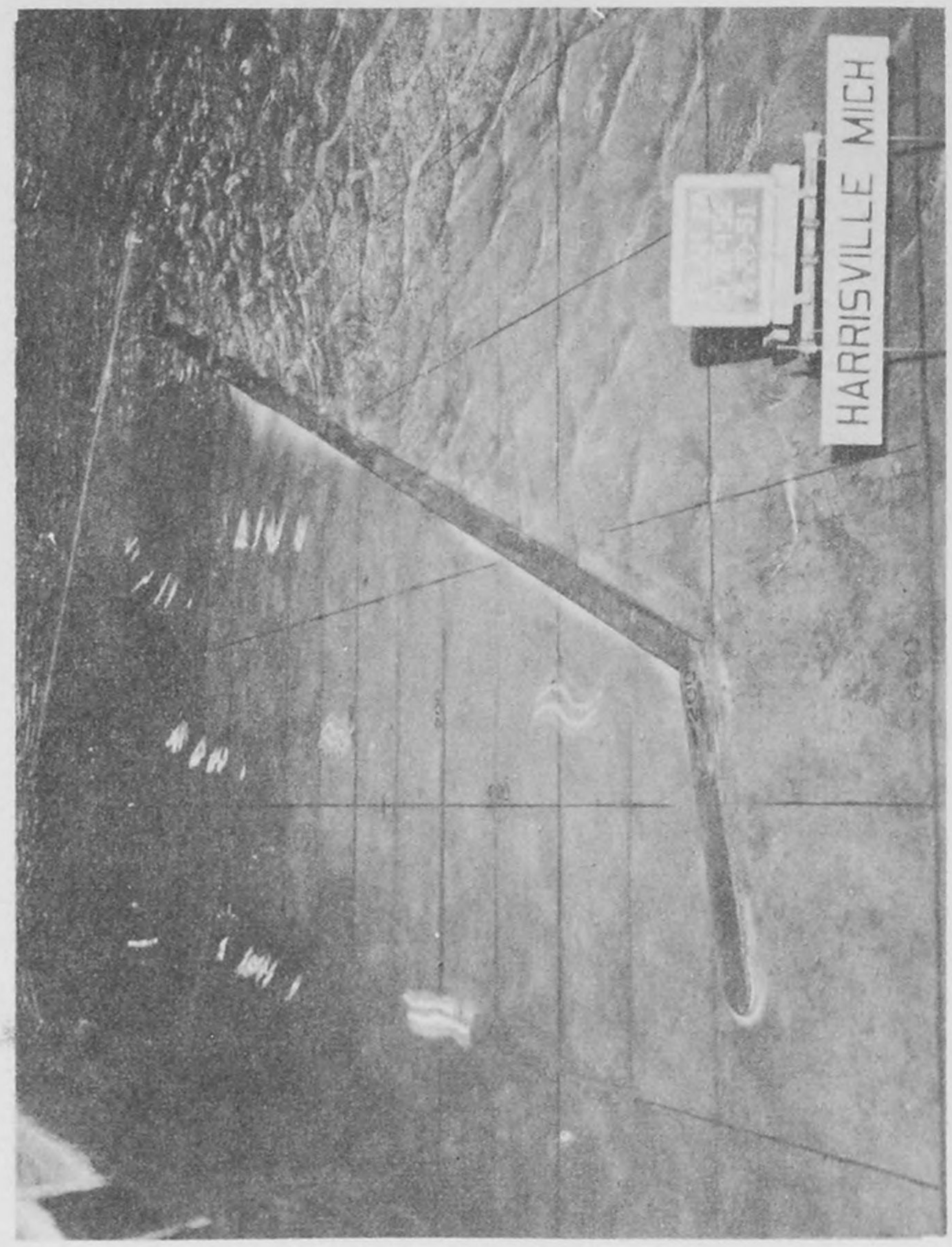


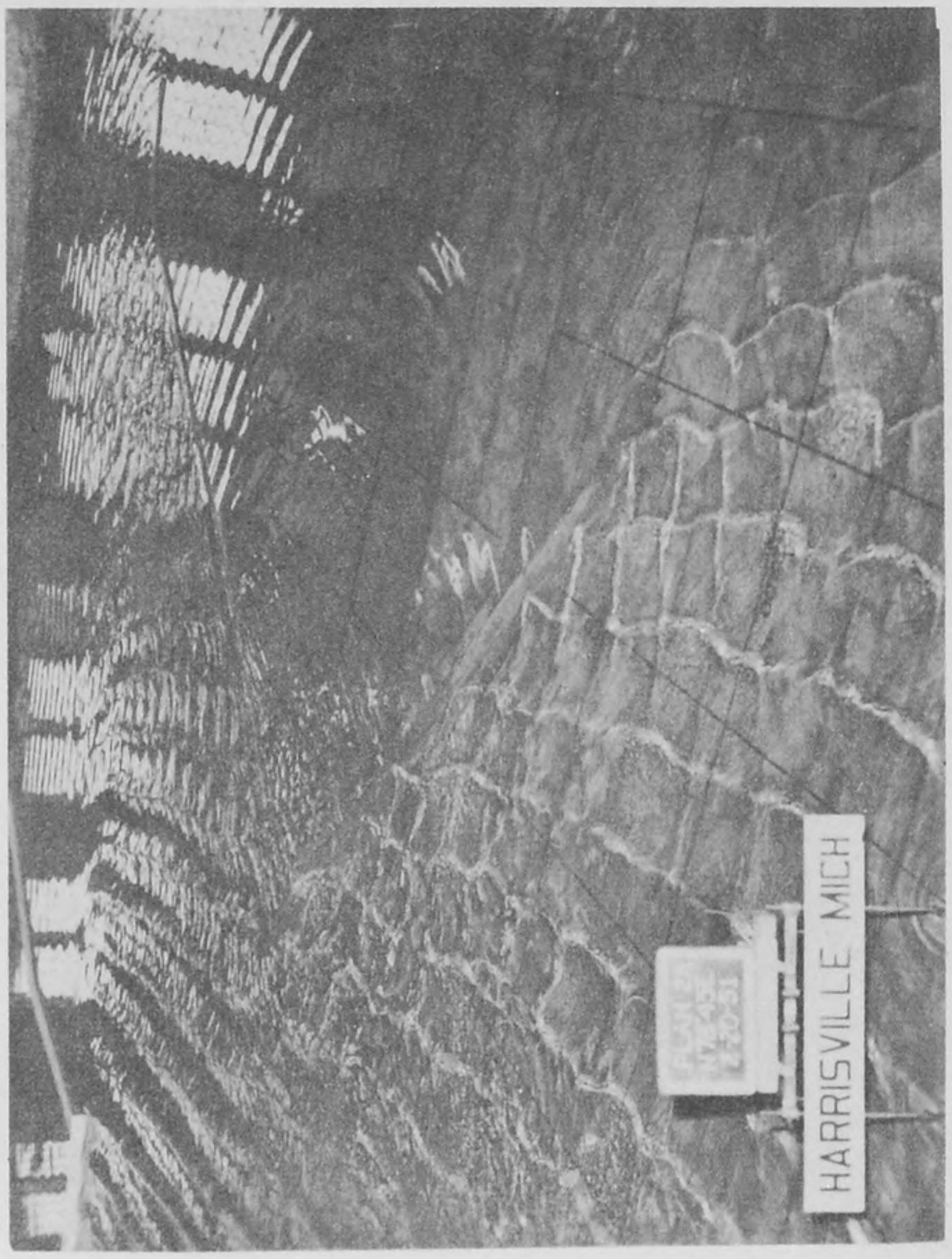


HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 7

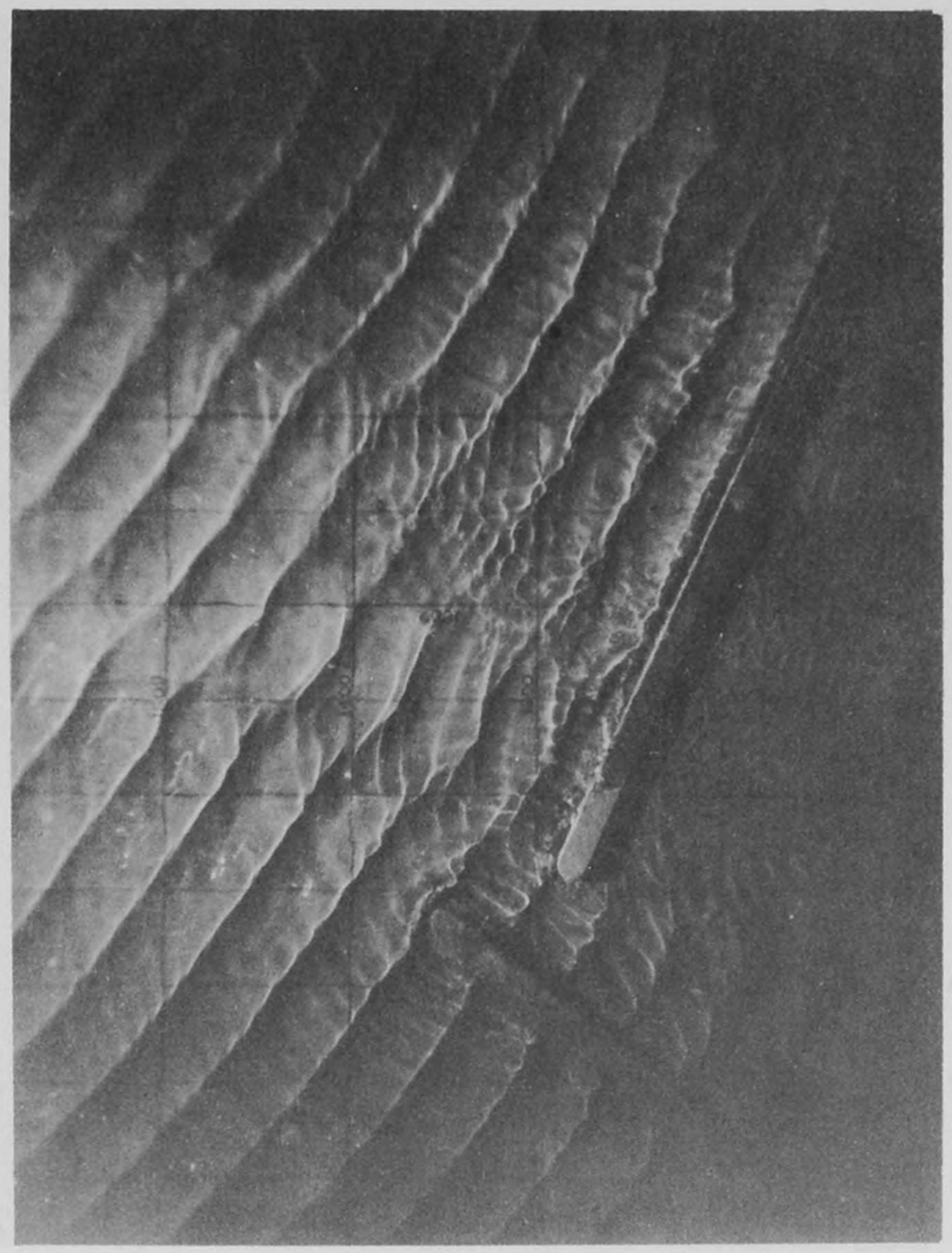


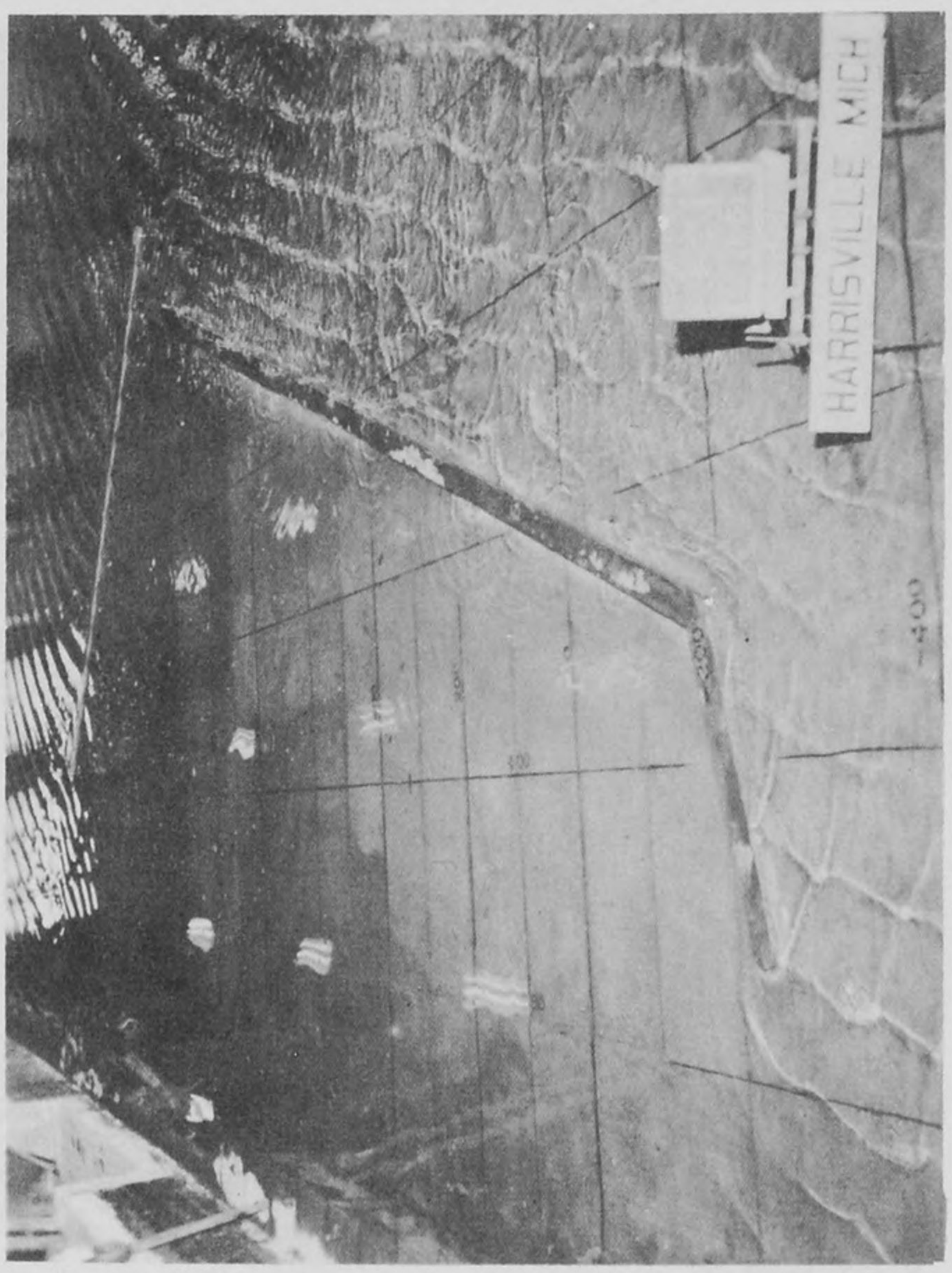




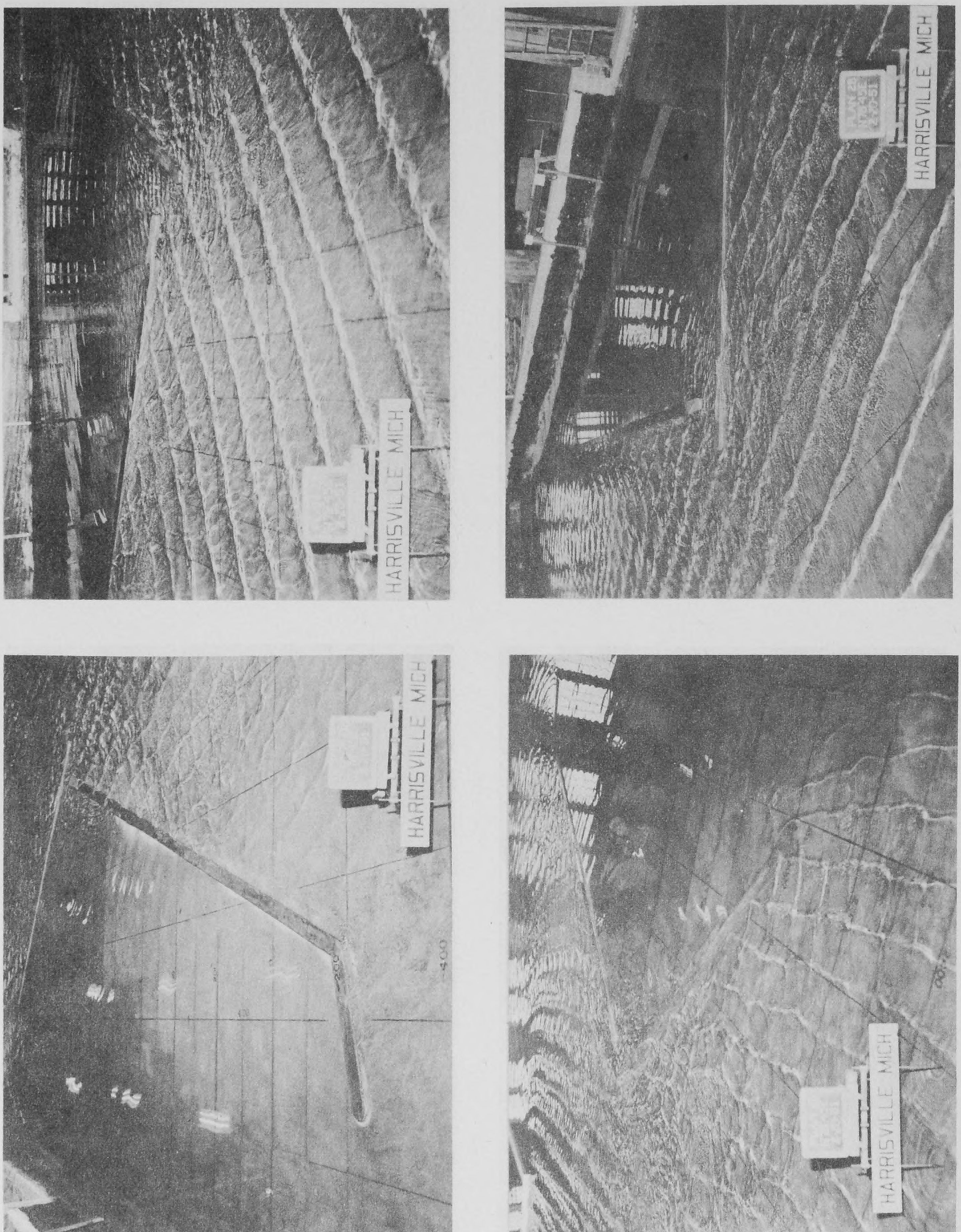


HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 8

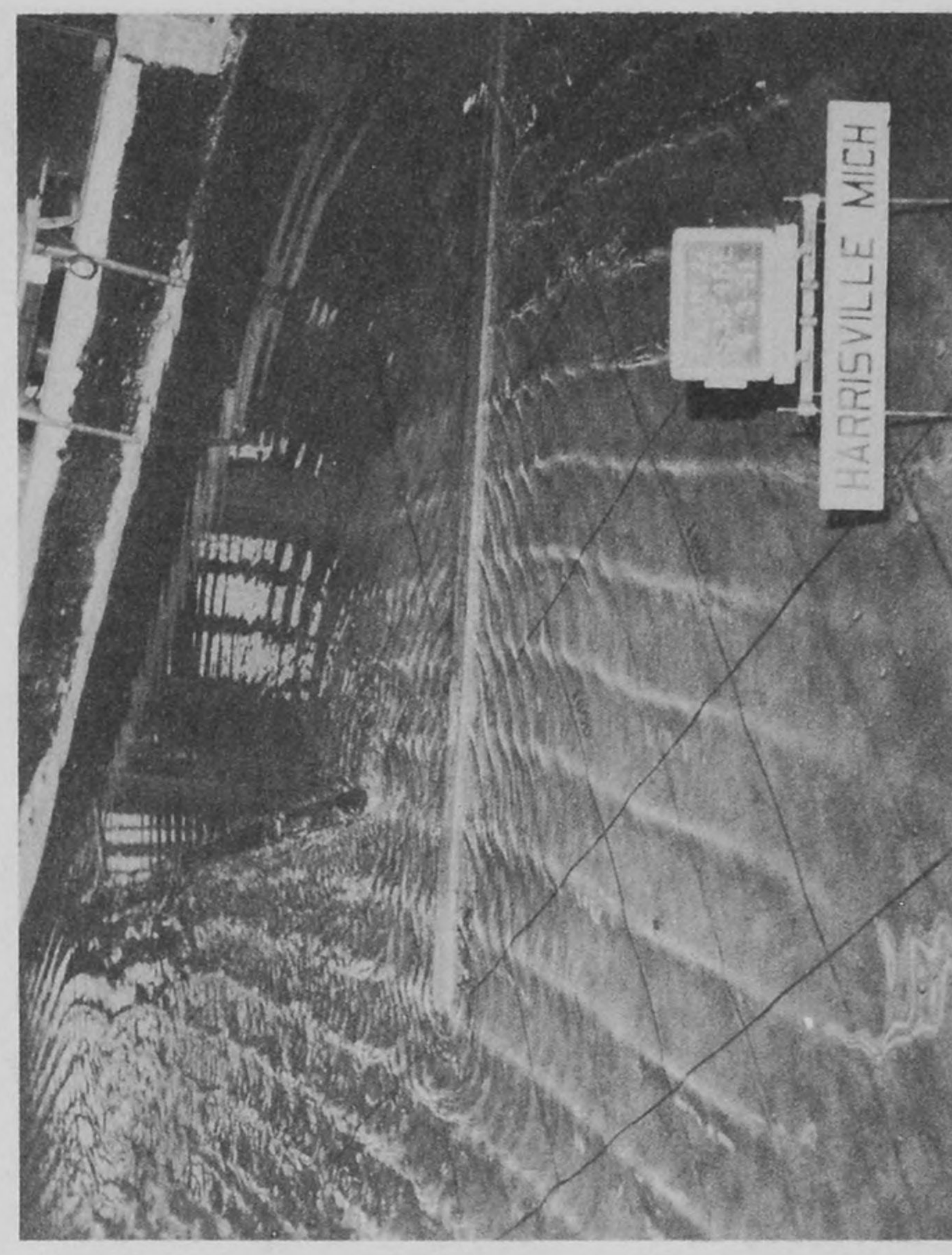


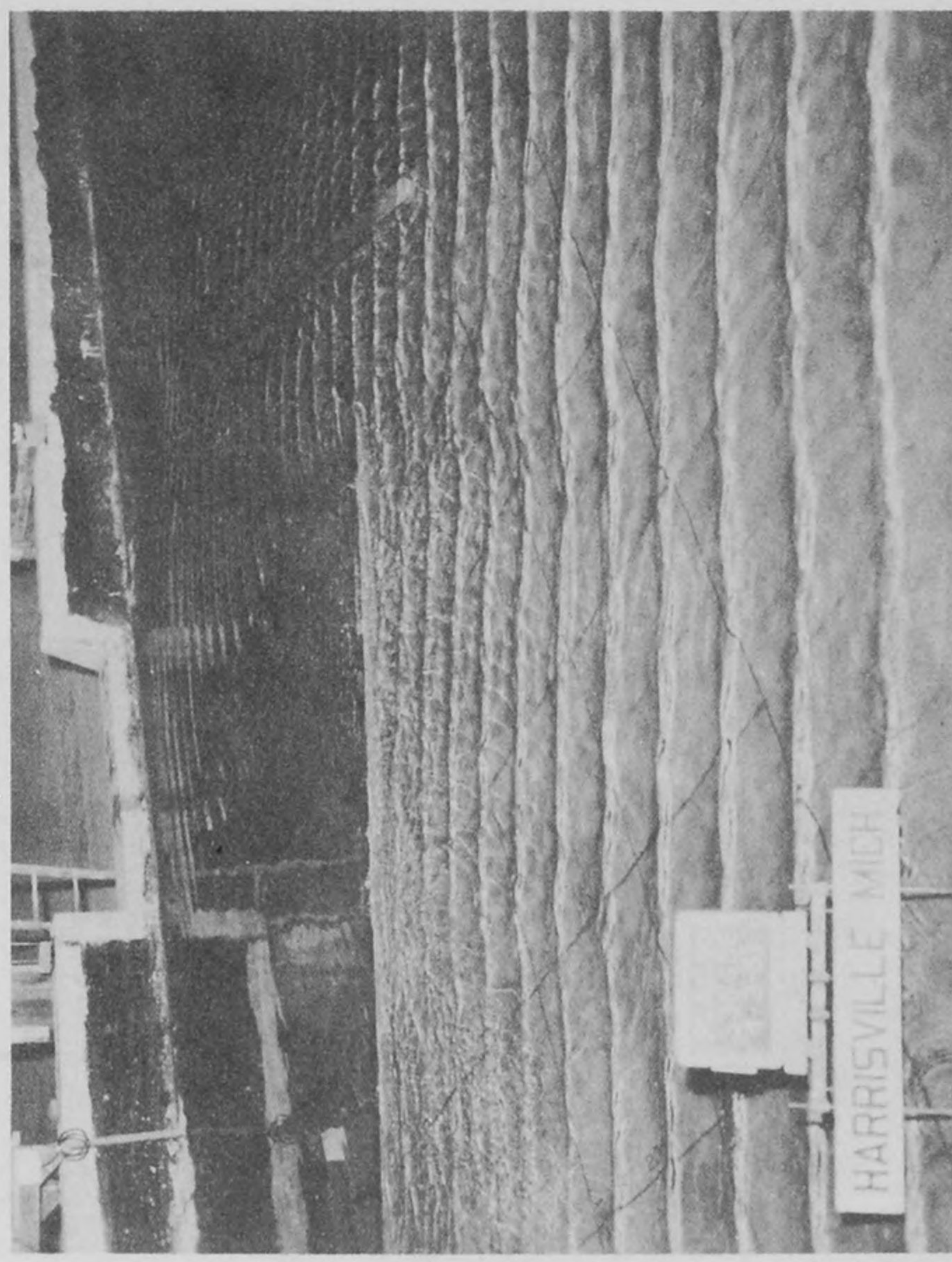


HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 9

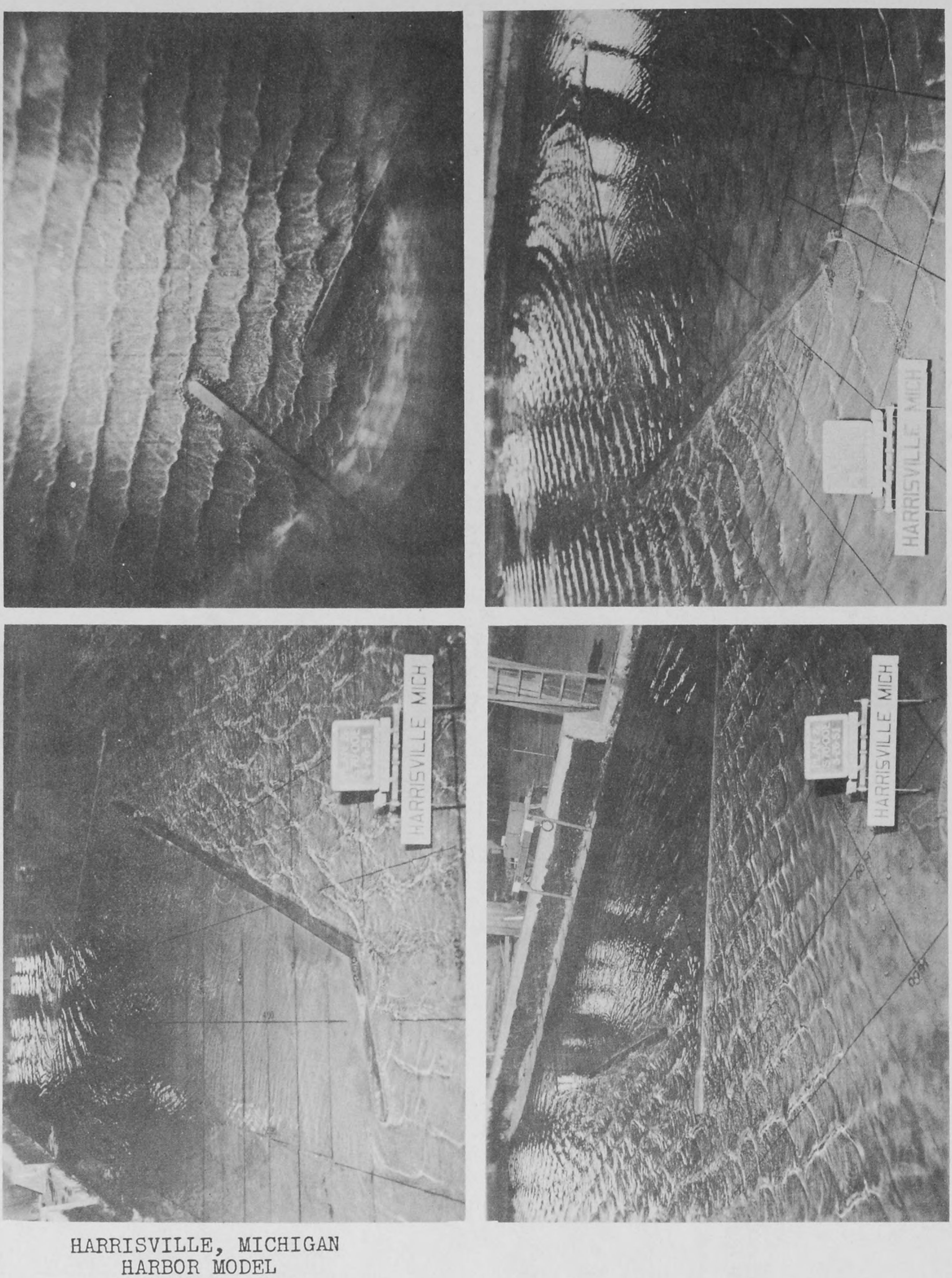


HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 10

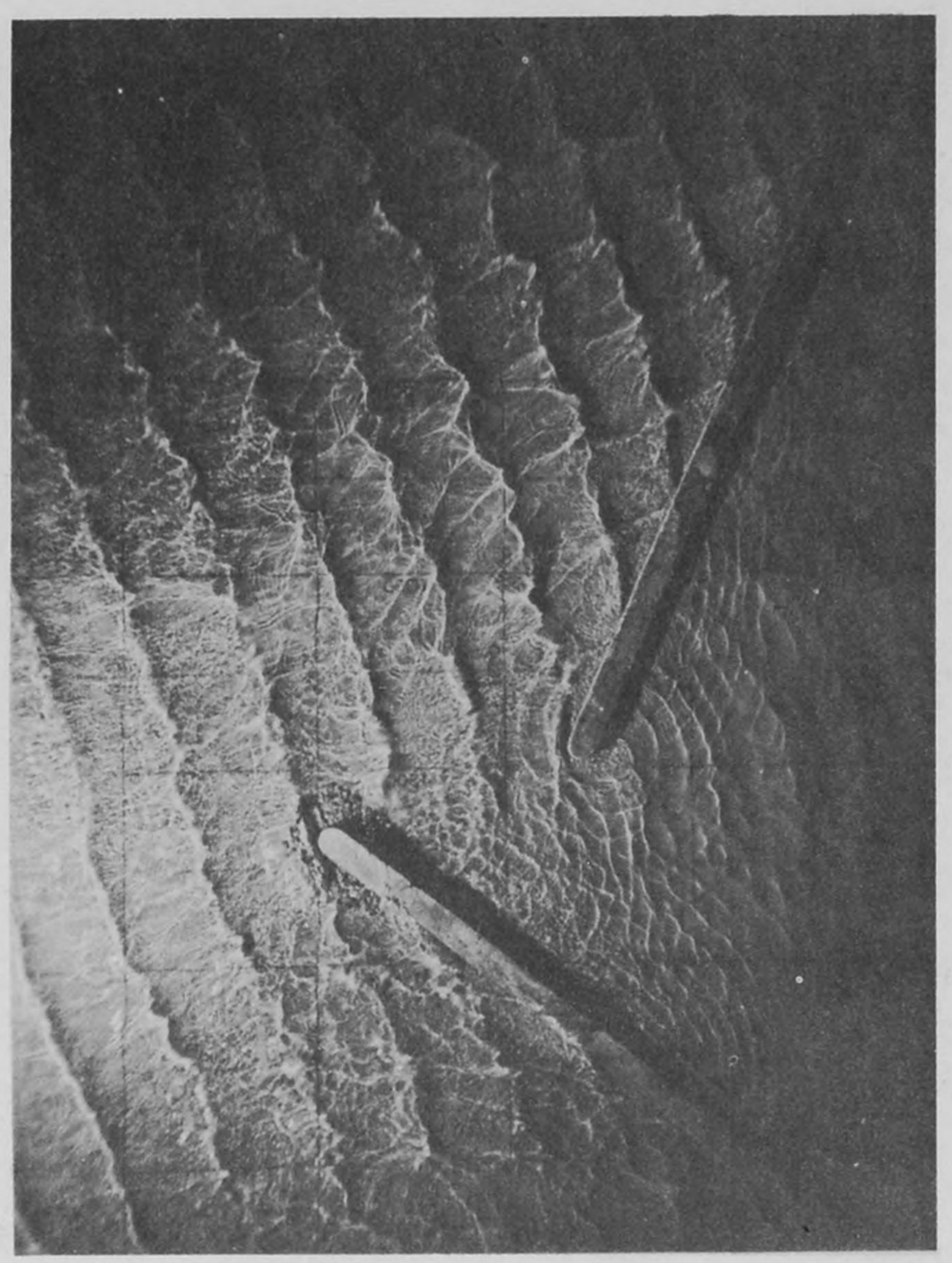


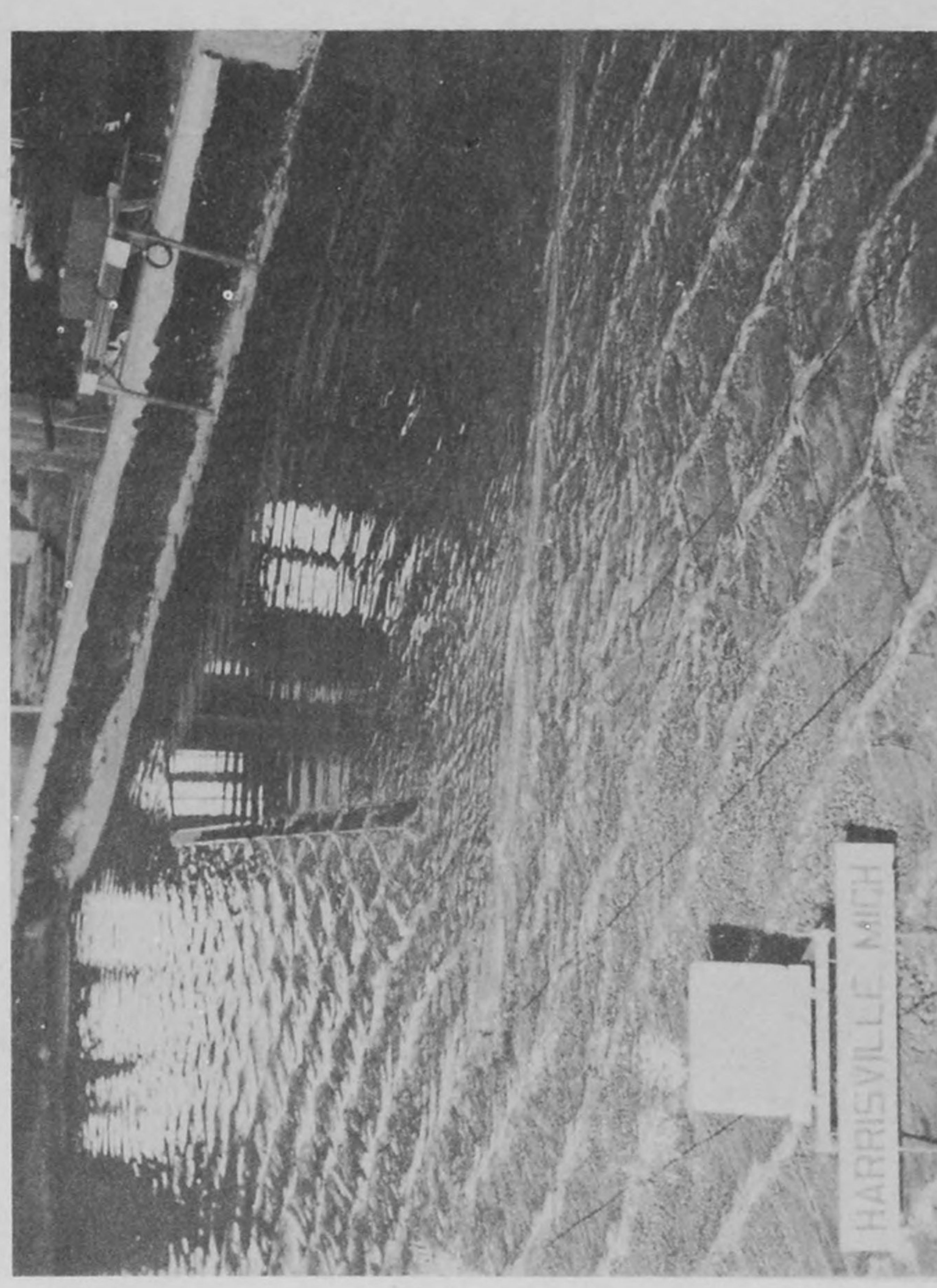


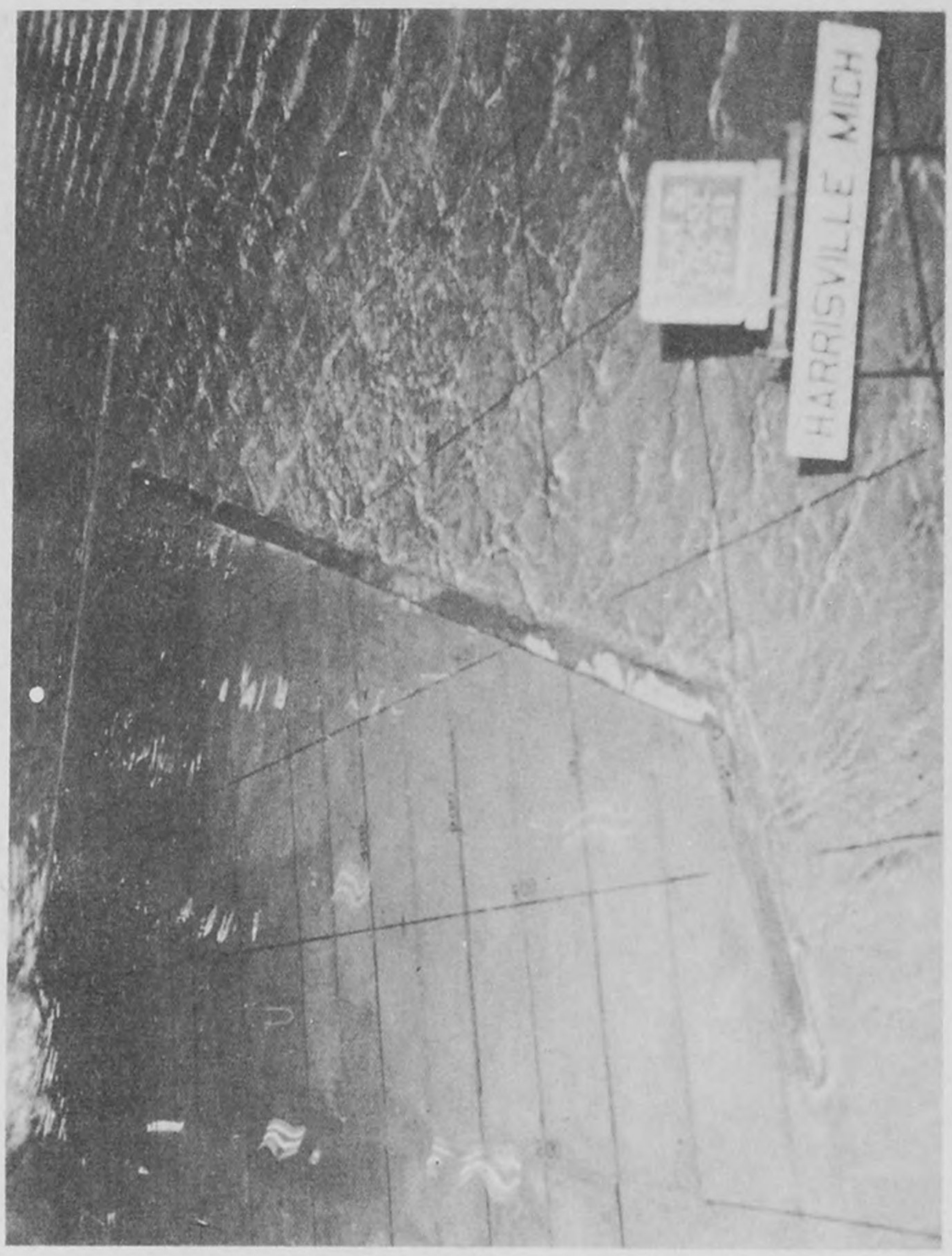
HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 11

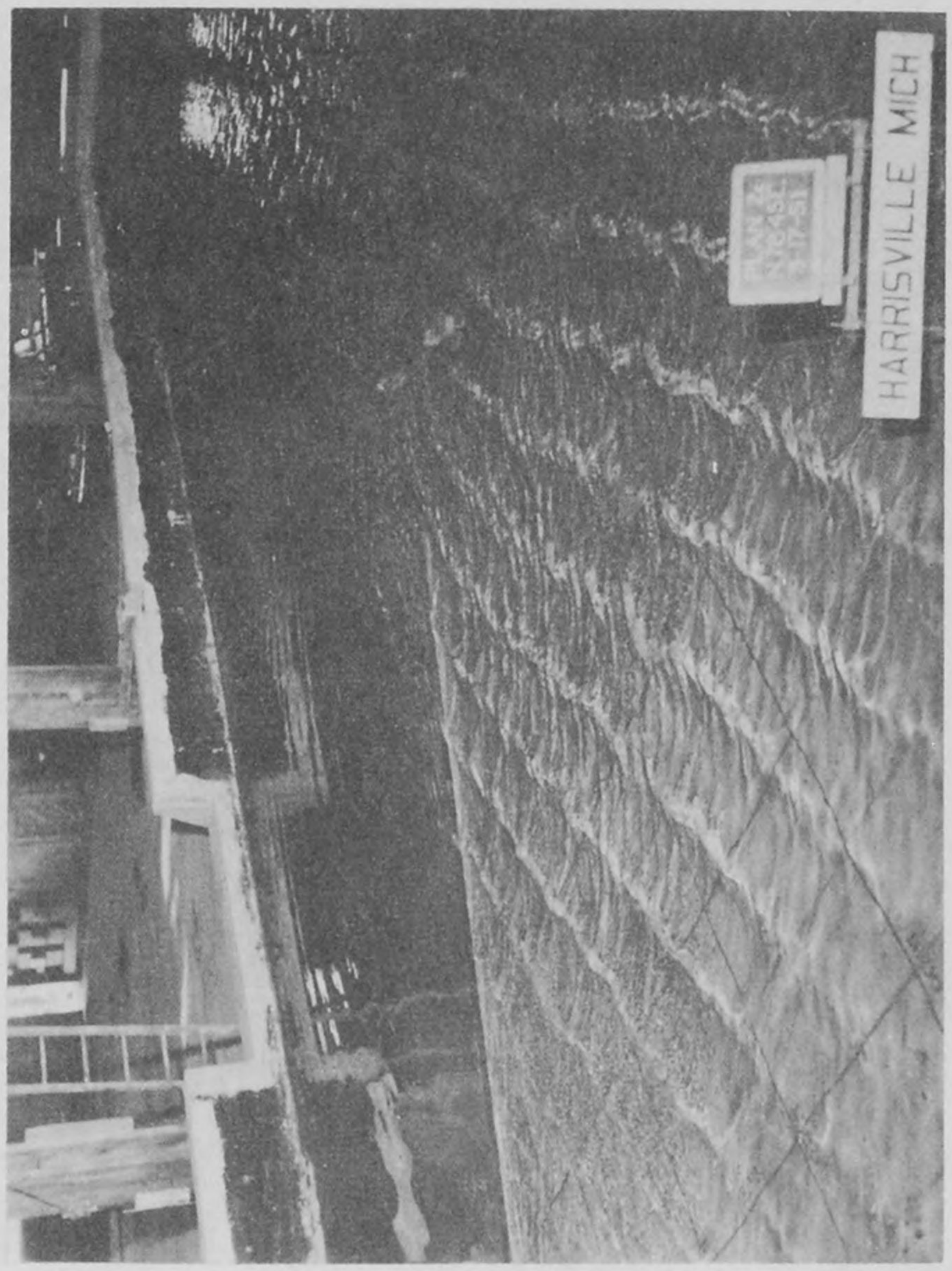


HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 12

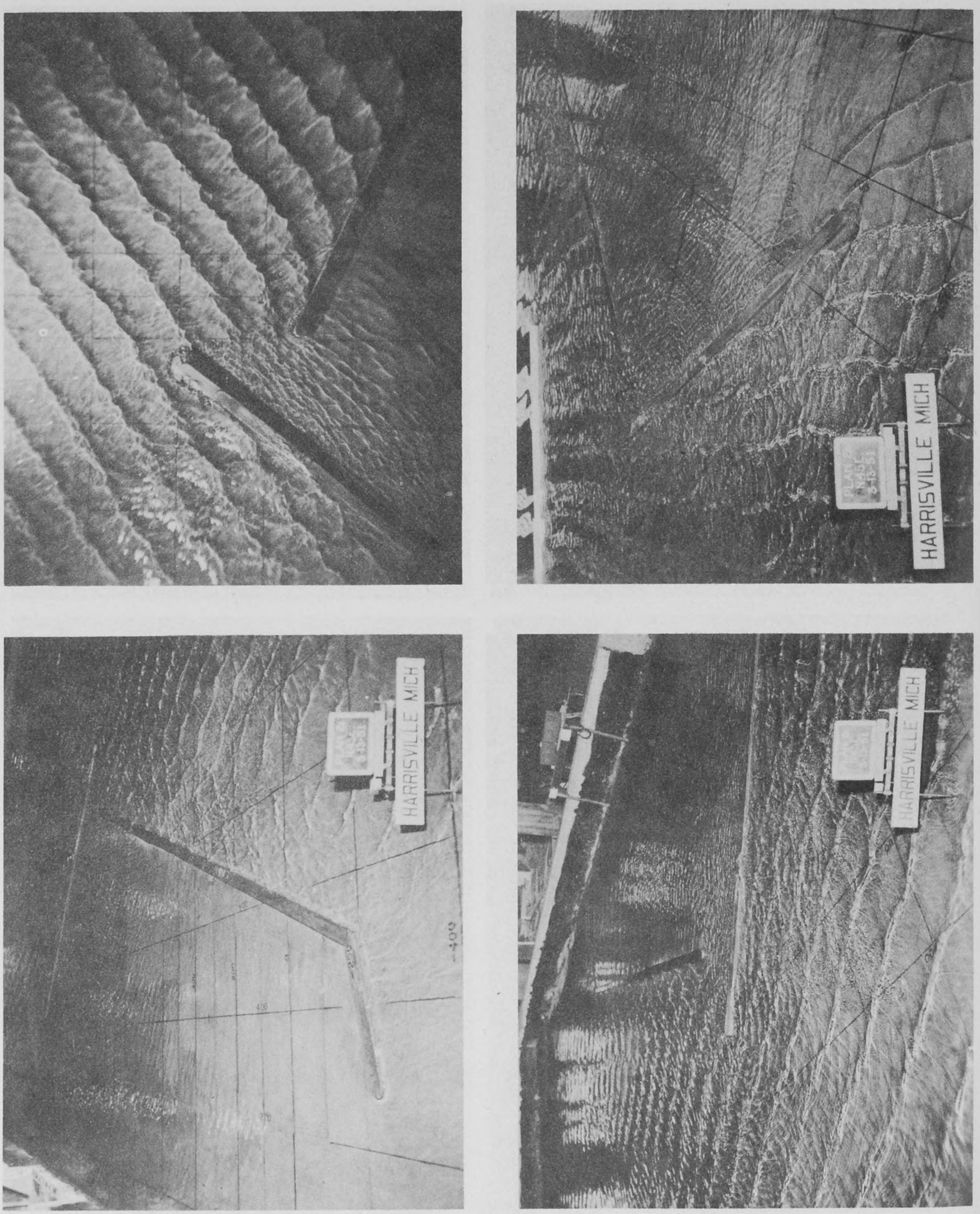




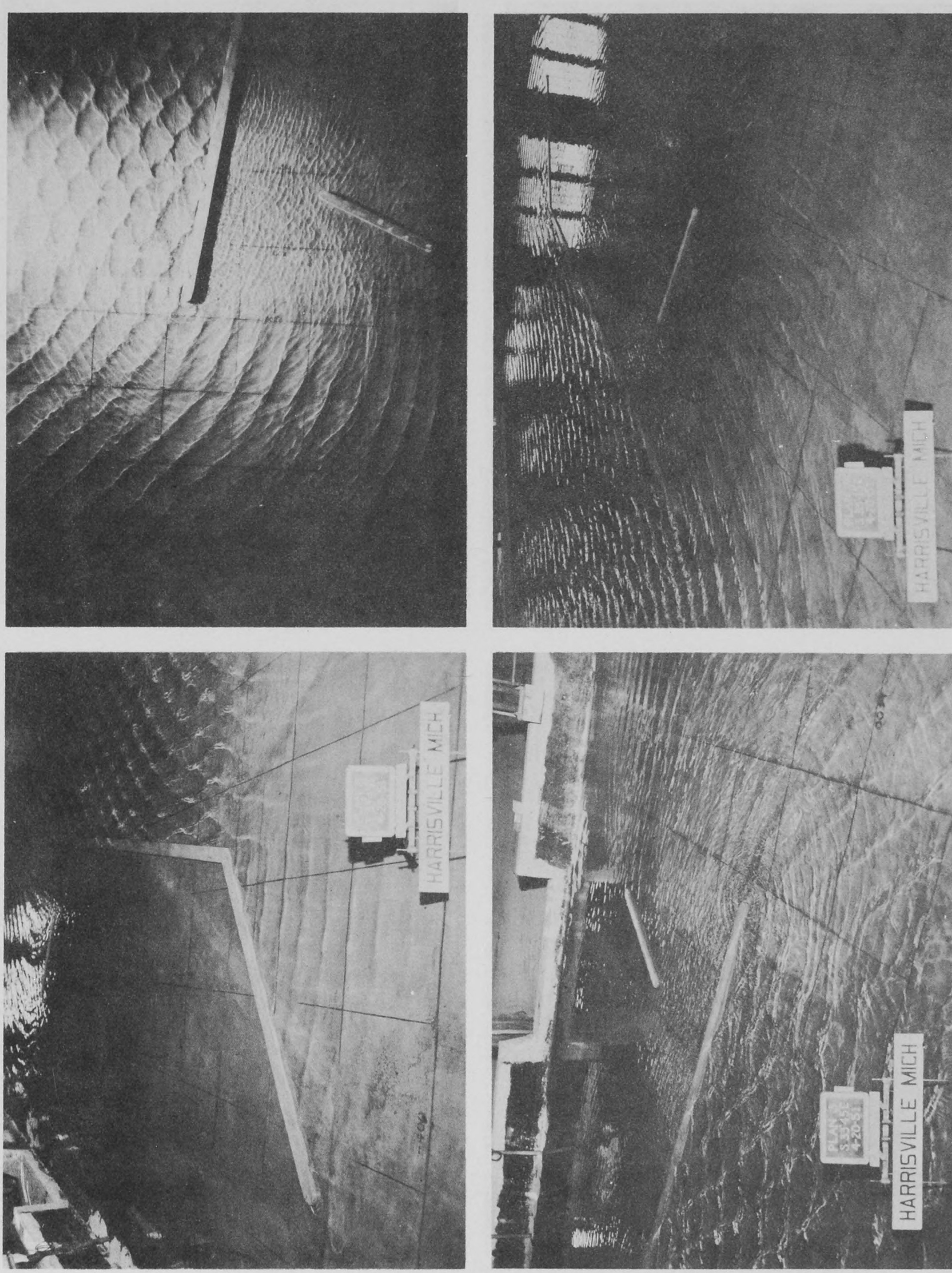




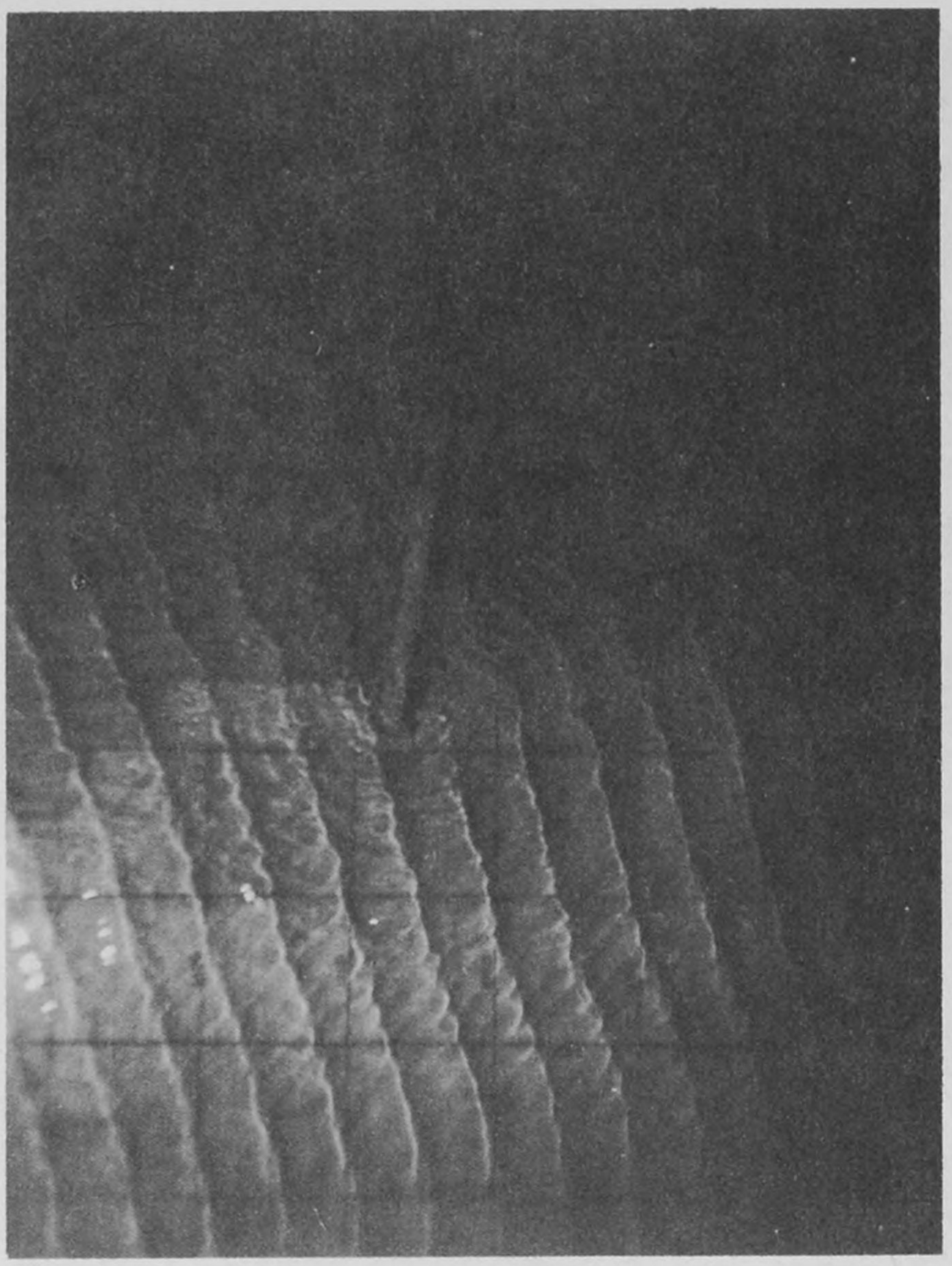
HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 13

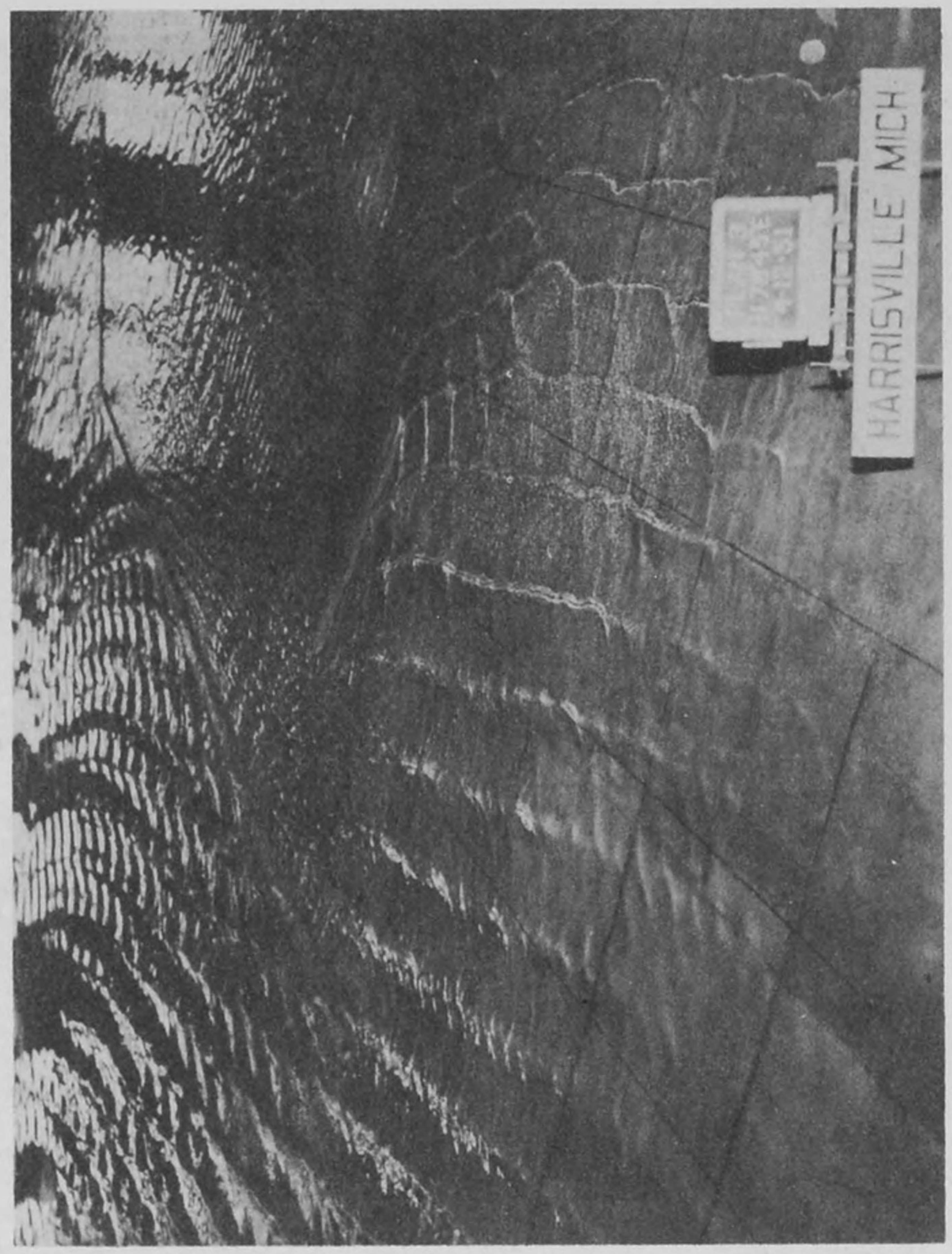


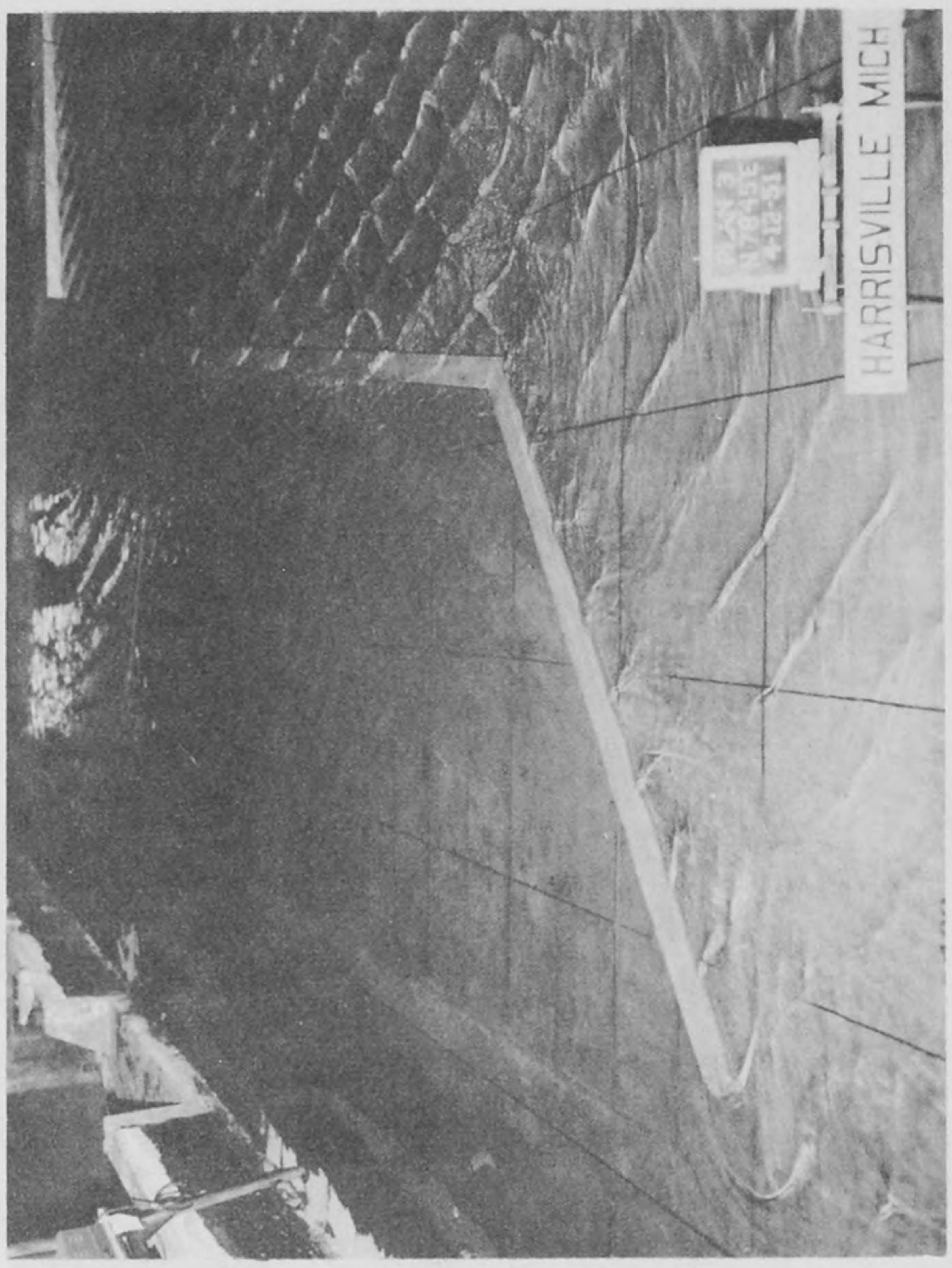
HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 14

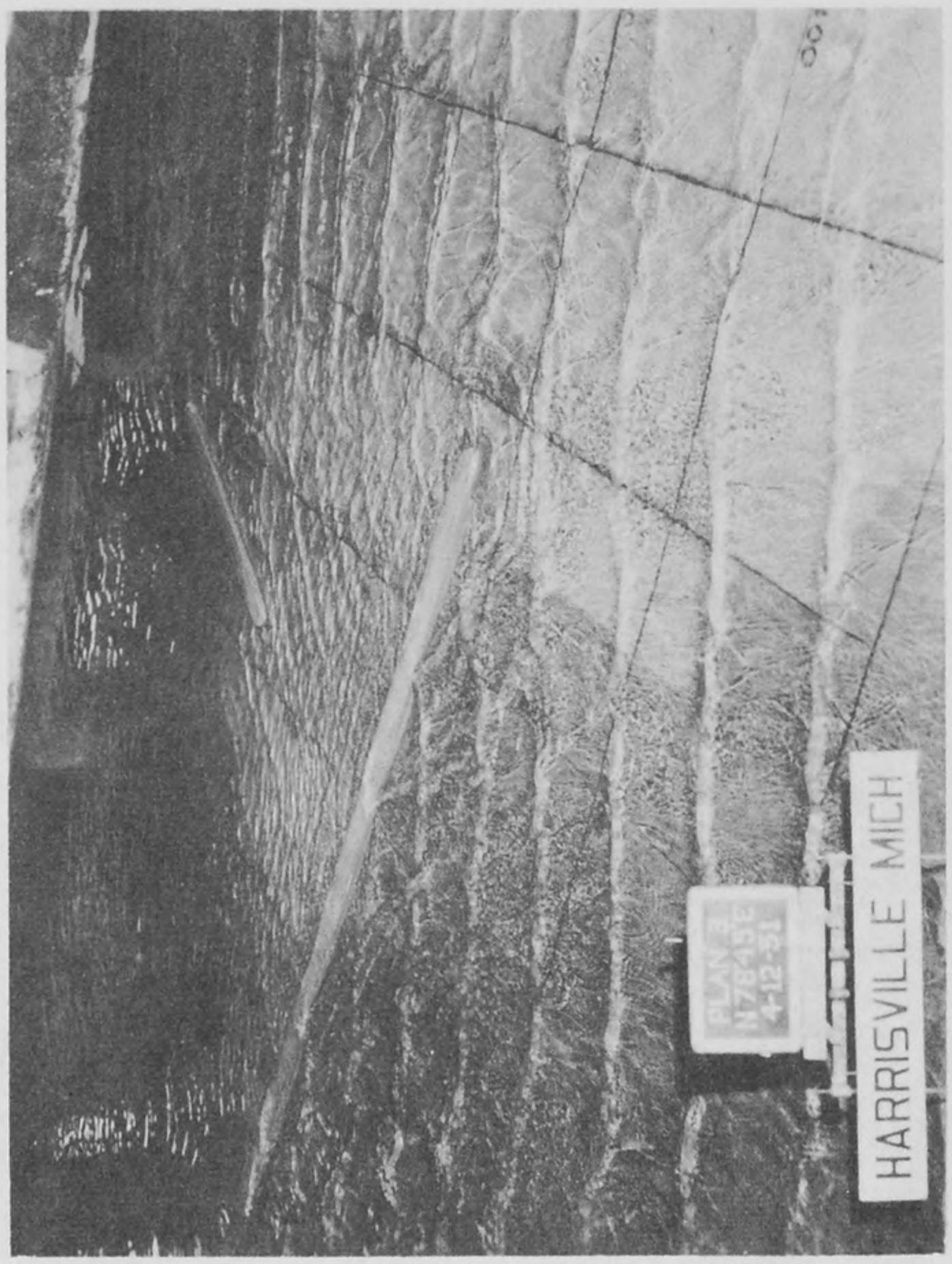


HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 15

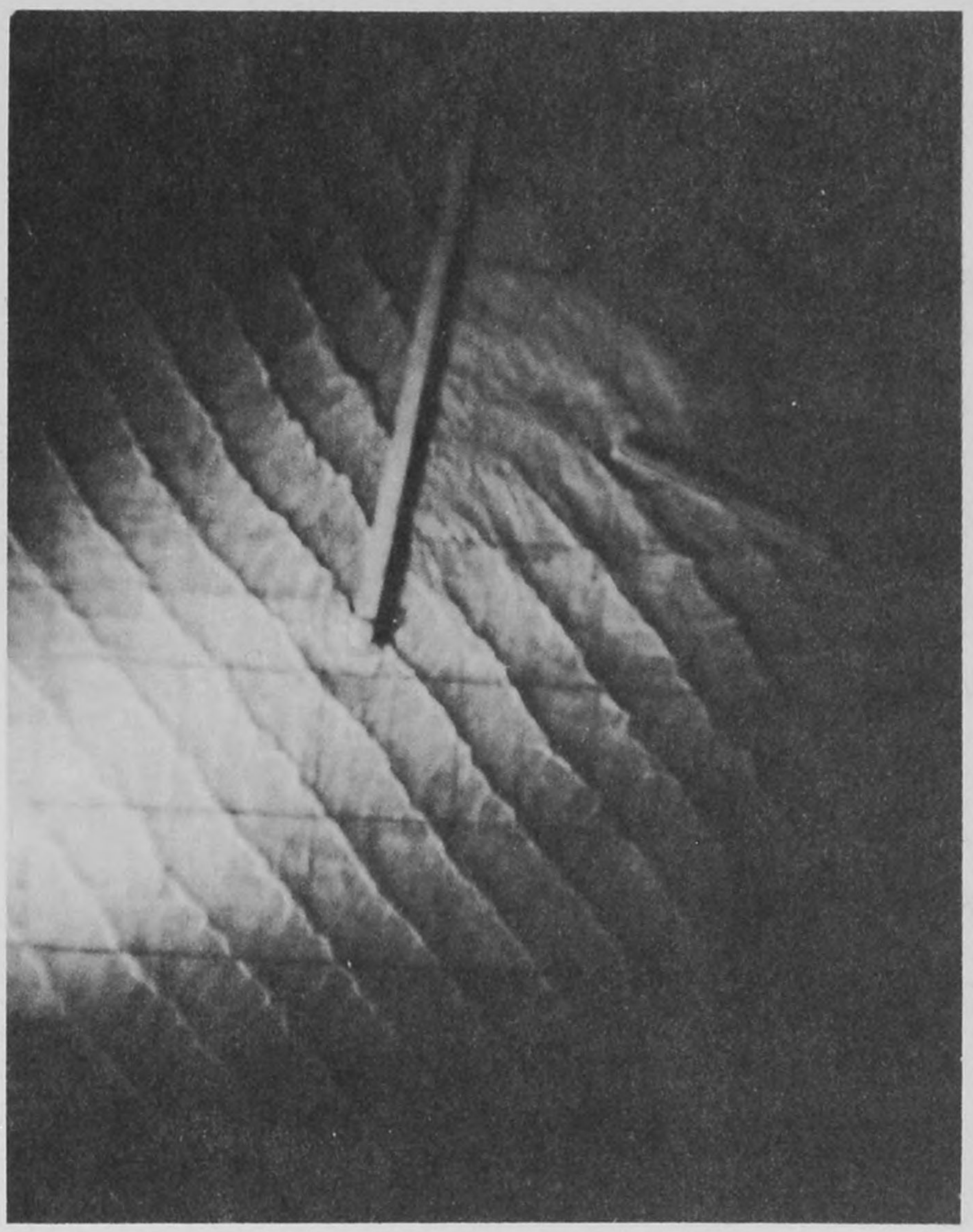


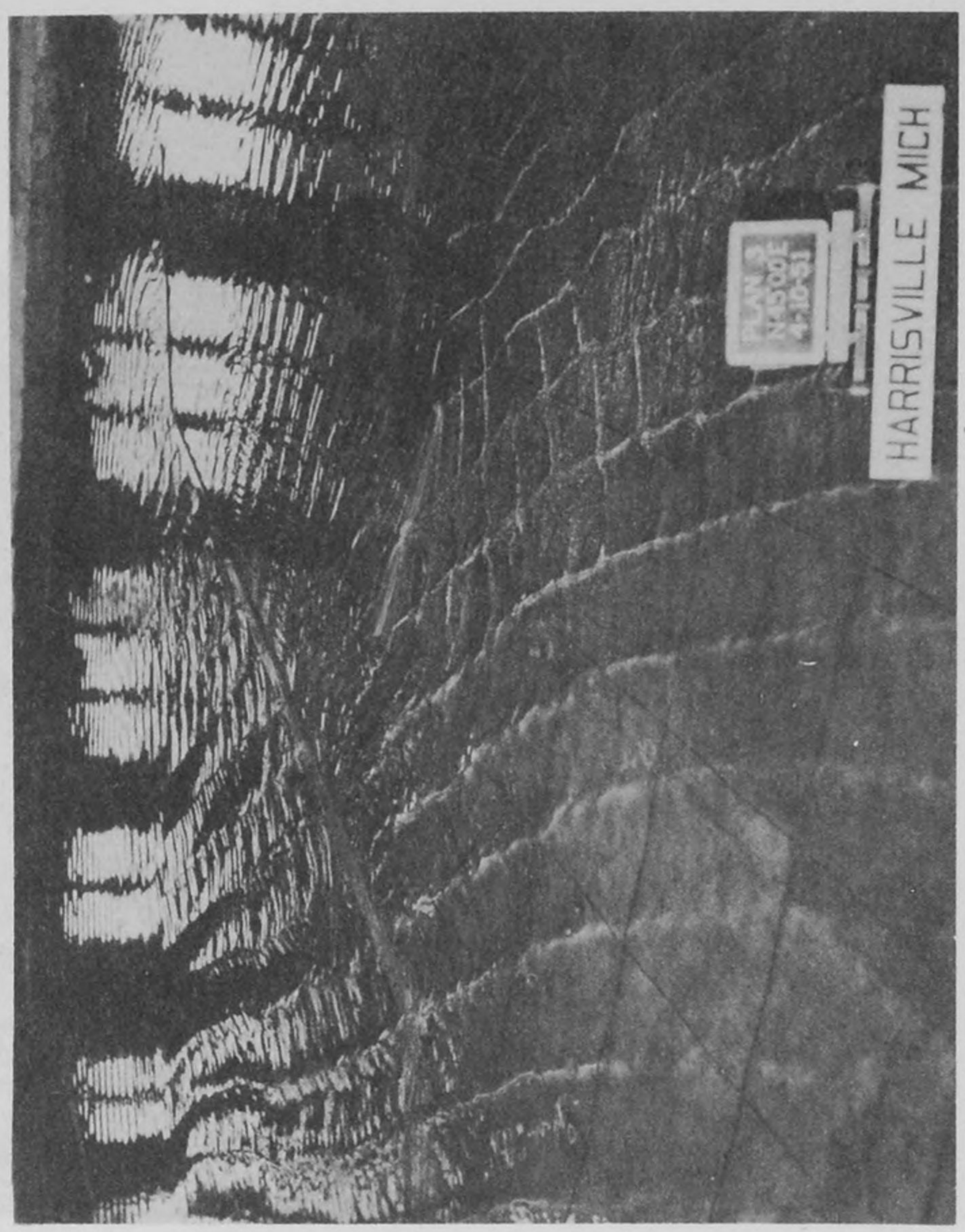


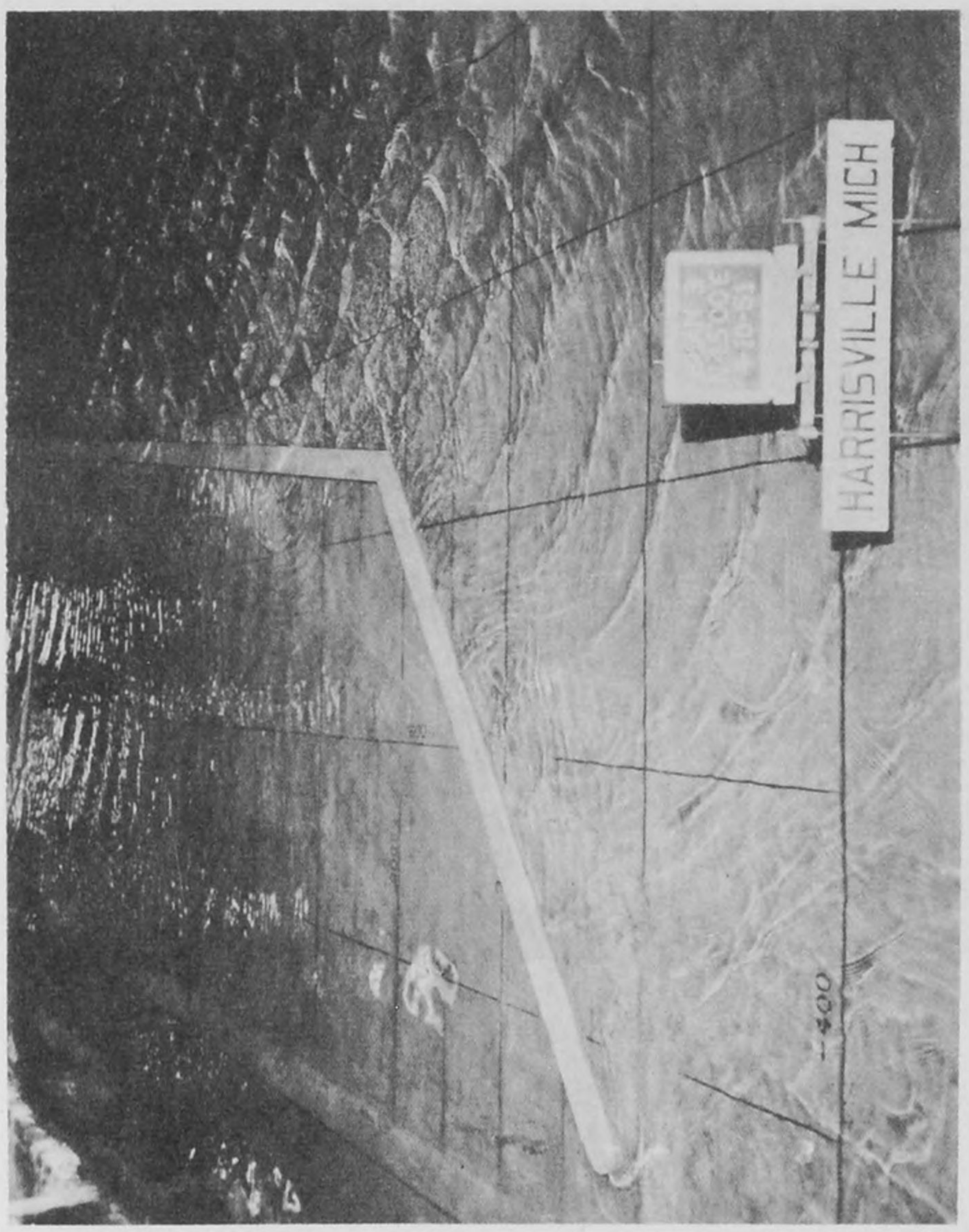


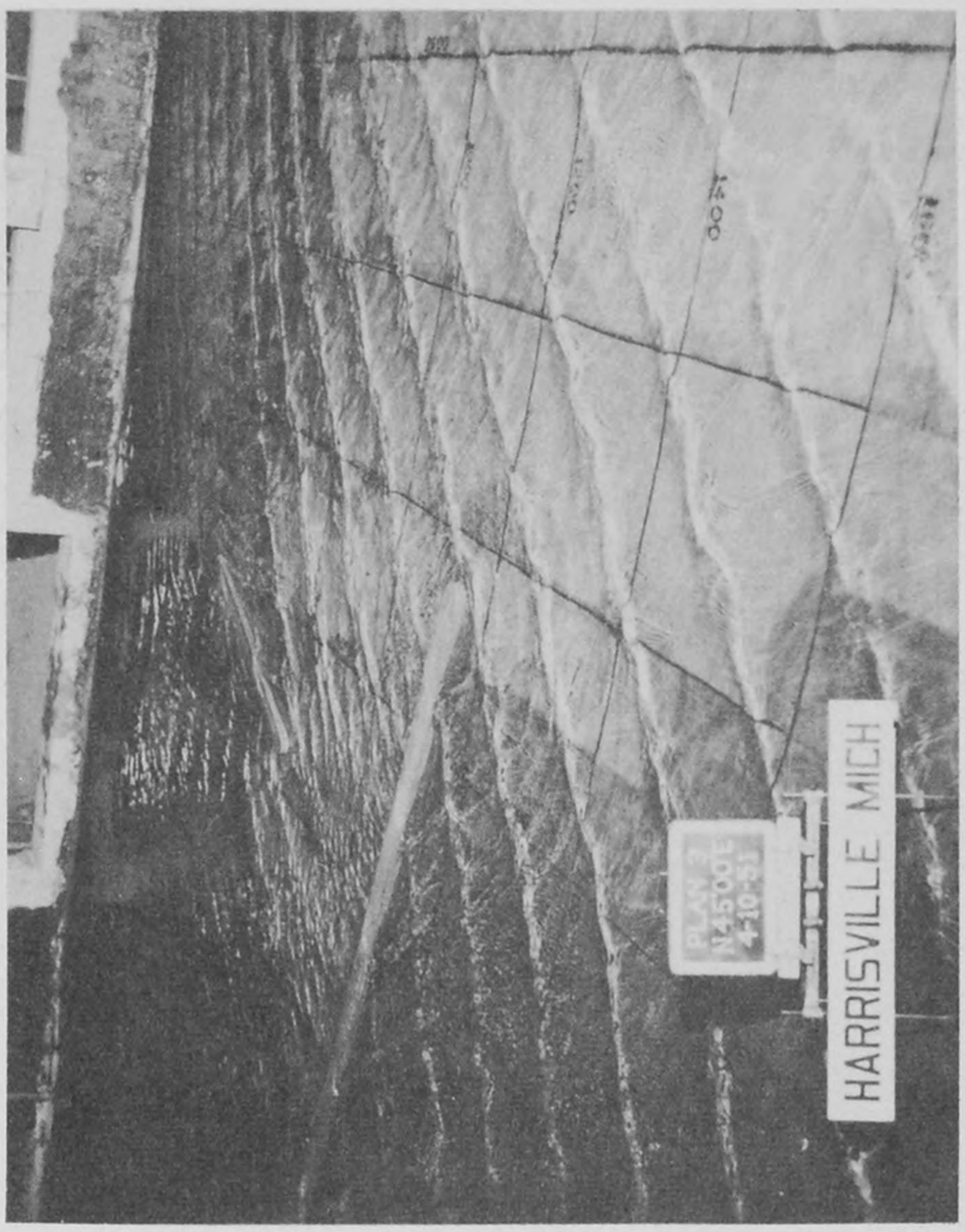


HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 16

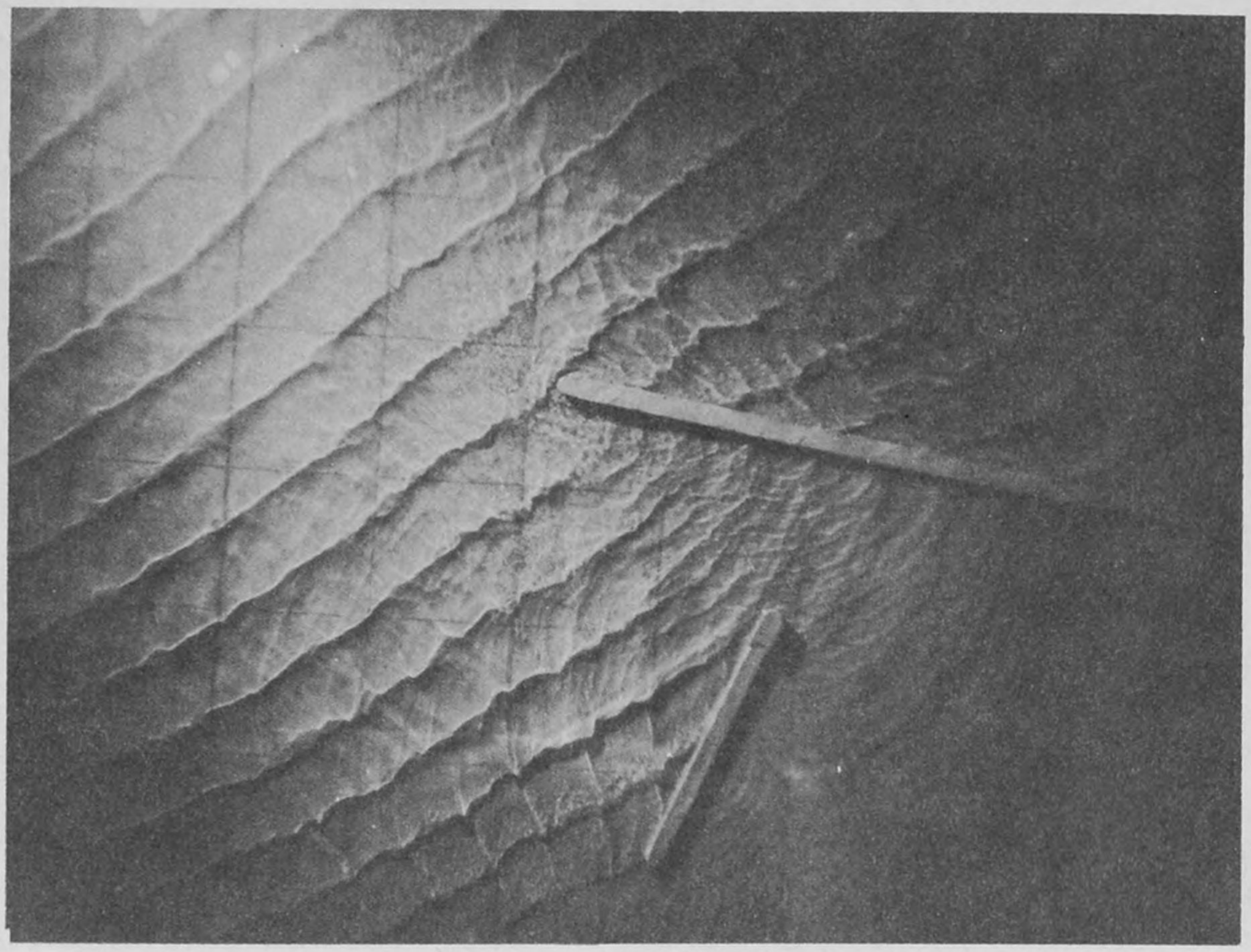








HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 17



HARRISVILLE, MICHIGAN
HARBOR MODEL
PLATE 18

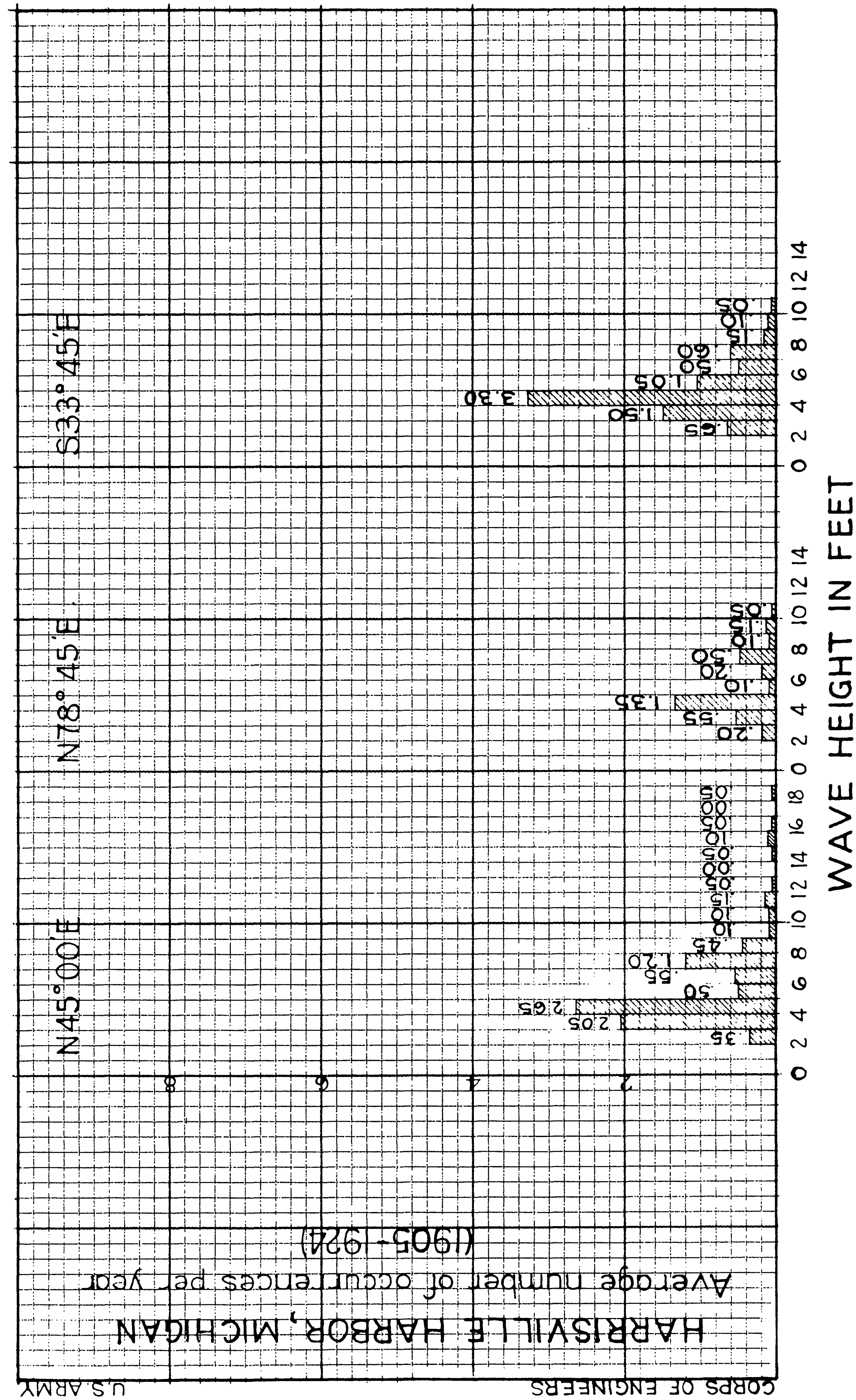
APPENDIX C

HYDROGRAPHIC CHARTS, REFRACTION DIAGRAMS, AND WAVE FREQUENCY GRAPH


LAKE HURON
Model Limits
HARRISVILLE
NOTES:
1. Diagram was constructed by the direct orthogonal method. For this purpose, the contours were generalized.
2. Contours and shoreline are referred to Low Water Datum, elevation 578.5 ft above Mean Tide at New York. For the diagram, the lake surface was considered to be 3.0 feet above Low Water Datum
3. Characteristics of the deep water wave used are: Ho = 8.0 ft., T = 4.3 sec., Vo = 22 fps., Lo = 95 ft. A storm which would produce such a wave occurs approximately once in 3.3 years.
CORPS OF ENGINEERS, U.S. ARMY
OFFICE OF THE DISTRICT ENGINEER
DETROIT DISTRICT
2015 Cadillac Tower
Detroit, Michigan
DRAWN BY M B
TRACED BY M B
CHECKED BY
SUBMITTED BY
HARRISVILLE HARBOR, MICHIGAN
WAVE REFRACTION DIAGRAM
WIND FROM S.33° 45' E.
Scale of Feet
100 0 500 1000 1500 2000
APPROVED
CHIEF ENGINEERING ASSISTANT
APPROVED:
LT. COL. C E DISTRICT ENGINEER
DATE 30 MARCH 1951
SCALE 1:5000
SPEC NO
DRAWING NUMBER
D H H 1/15
SHEET 1 OF 1

CORPS OF ENGINEERS U. S. ARMY


CORPS OF ENGINEERS
U.S. ARMY
LAKE HURON
Model Limits
HARRISVILLE
NOTES:
1. Diagram was constructed by the direct orthoganal method. For this purpose, the contours were generalized.
2. Contours and shoreline shown are referred to Low Water Datum, elevation 578.5 ft. above Mean Tide at New York. For the diagram, the lake surface was considered to be 3.0 ft. above Low Water Datum.
3. Characteristics of the deep water wave used are: Ho = 10 0 ft., T = 5.2 sec., Vo = 26.6 fps., Lo = 138 ft. A storm which would produce such a wave occurs approximately once in 3.3 years.
CORPS OF ENGINEERS, U.S. ARMY
OFFICE OF THE DISTRICT ENGINEER
DETROIT DISTRICT
2015 Cadillac Tower
Detroit, Michigan
HARRISVILLE HARBOR, MICHIGAN
WAVE REFRACTION DIAGRAM
WIND FROM NORTH 45° EAST
Scale of Feet
DRAWN BY
TRACED BY
CHECKED BY
SUBMITTED BY
APPROVED
CHIEF ENGINEERING ASSISTANT
APPROVED:
C.E. DISTRICT ENGINEER
DATE 30 MARCH 1951
SPEC. NO
DRAWING NUMBER
DHH 1/13
SHEET 1 OF 1


HARRISVILLE HARBOR, MICHIGAN
Average number of occurrences per year
(1905-1924)
N45°00'E
N78°45'E
S33°45'E
WAVE HEIGHT IN FEET
CORPS OF ENGINEERS
U.S. ARMY

UNIVERSITY OF MICHIGAN
3 9015 09911 4541

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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Bodoni Italic

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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

MESH HALFTONE WEDGES

65

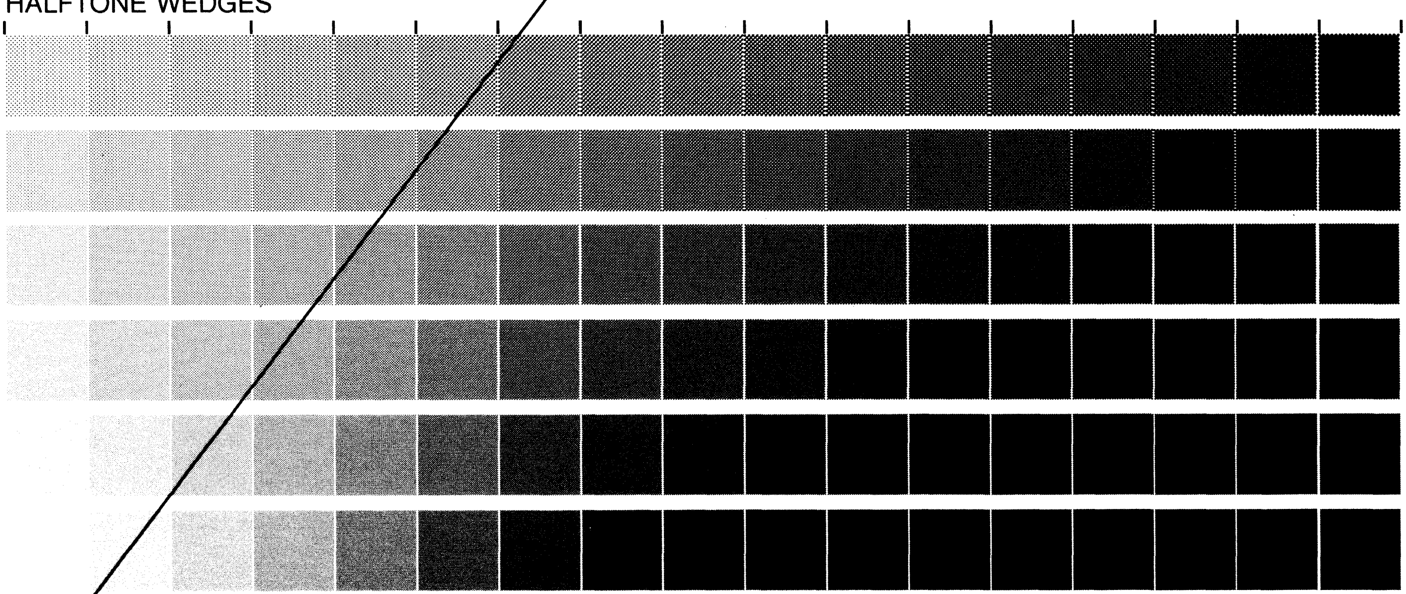
85

100

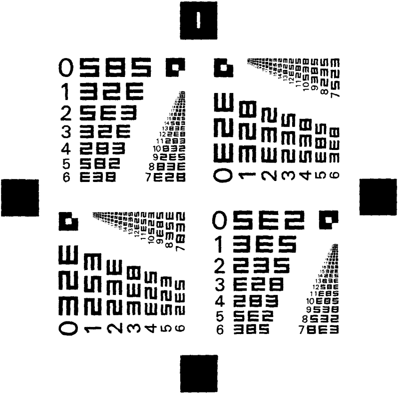
110

133

150



RIT ALPHANUMERIC RESOLUTION TEST OBJECT, RT-1-71



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ROCHESTER INSTITUTE OF TECHNOLOGY, ONE LOMB

MEMORIAL DRIVE, ROCHESTER, NEW YORK 14623