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A MODEL STUDY OF A DIKE ENCLOSURE AT THE EASTERN END OF LAKE ERIE

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A MODEL STUDY OF A DIKE ENCLOSURE AT THE EASTERN END OF LAKE ERIE

I. PURPOSE OF THE MODEL

The Bethlehem Steel Corporation is faced with the problem of finding a disposal area for solid wastes, principally slag, from its steel plant at Lackawanna, New York. Whereas the slag was previously dumped freely into Lake Erie, such dumping is now considered undesirable. The company has proposed that a diked enclosure be built into the lake opposite its plant and that the wastes be dumped into this enclosure, thus preventing them from entering the lake. The company has estimated that the dike should enclose about 620 acres to accommodate its needs to some reasonable future date.

If a dike as proposed is built, it may interfere with several aspects of lake activity. Among these are navigation, water supply, maintenance of swimming beaches, and perhaps others unknown at the time of the proposal. Specifically, the south entrance to Buffalo Harbor lies immediately adjacent to the north side of the proposed enclosure, while the principal navigation lanes lie about 2-1/2 miles to the west. The Erie County water intake lies close in to the southwest, the Buffalo water intake is some distance to the north, and the Wanakah water intake is some distance to the south. An excellent sand beach is located adjacent to the south edge of the proposed enclosure at Woodlawn. These features are indicated on the map, Chart 1.

Also indicated on the map are three creeks whose discharge is quite polluted. These are Smokes Creek, Blasdell Creek, and Rush Creek. Apparently the discharges from these creeks, although they must be affecting the water intakes and swimming beach, are presently considered tolerable. The proposed dike must not divert these flows in such a manner as to make the situation less tolerable. Also, there is some sand movement along the shoreline, and this must presently be responsible for maintaining the beach at Woodlawn. The proposed structure must not interfere with sand nourishment of the existing beach and must not cause sand to accumulate over the water intakes or in the south harbor entrance at Buffalo.

Most important from the viewpoint of navigation is the requirement that storm waves be no more severe for ships traversing the normal shipping lanes or entering the harbor with an enclosure than without one. Also, the proposed structure must not cause ice floes to block the south harbor entrance.

It is possible that the configuration of the dike may be important in some of the above considerations. That is, an obvious plan for laying out the dike may adversely affect one of the lake activities, while another plan may have no effect.

To investigate all these problems it was agreed that a physical model of the site should be built. After construction, the operation of the model would be verified by comparison of known data obtainable in Lake Erie with that obtained from the model. Following verification, one or more dike configurations would be installed in the model to determine the influence on the lake of each of the various factors discussed above.

The following sections of this report describe the model, its verification, the plan form of the enclosure selected for study, and the results of the study. Problems associated with the cross-sectional shape of the enclosure are discussed in an appendix.

II. THE MODEL

Scales

The geographical extent of the model was determined by the physical features of the site shown on Chart 1, by the need to carry the model far enough to the west into Lake Erie to permit generation of fully developed waves without objectionable reflection, and by the need to include the inlet to the Niagara River so that the water flow through the lake could be modeled with some reliability. Considering the floor area available for the model, these considerations led to the choice of a horizontal scale of 1:600. The resulting area covered in the model is shown on the map, Chart 1.

Some compromise was involved in this choice of scales, especially in connection with the east-west width of the model. The effect of the proposed enclosure at a distance from it was expected to be small (and this was verified later) except for the reflected waves which might be radiated from it. These are damped very little in deeper water and may carry energy to great distances. It would have been desirable to carry the model further west to observe the effect of the reflected waves from the enclosure on the shipping lanes and also to reduce interference with wave generation by waves reflected from the shore and shore structures. However, since only a comparison between conditions without and with an enclosure was required, and since the reflected wave energy was expected to be damped very little in deep water, it was decided that any effect of reflection outside the model area could be accounted for after reducing the data. If the wave generation area had been moved further west, a smaller horizontal scale would have had to be chosen. The scale chosen allows an open water area about two miles in width between the beach and the wave generation region.

It will also be noticed that the Wanakah water intake is on the fringe of the area modeled, and the model boundaries might interfere with flow at the intake. It was assumed that since the intake is far from the enclosure, any effect on this intake would be small and could be predicted by observing the current action in the interior of the model near its southwest corner. (As it turned out there were no changes at all in current action in the southwest corner of the model without and with an enclosure, and the assumption made is apparently justified.)

The vertical scale of the model was chosen after examination of data on lake levels [1, 2]* and bottom contours [3, 4]. The water near the enclosure will be of the order of 30 ft deep. Wave heights will be of the order of 12 ft for much of the study, as noted in the following paragraphs. Considering the sensitivity of probes for wave height measurements and the need for adequate Reynolds numbers for flow through the lake and the avoidance of surface tension effects, a vertical scale of 1:120 was selected. This means that still water near the enclosure is about 3 in. deep and major waves are about 1.2 in. high in the model.

With scale ratios different in the vertical than in the horizontal direction, the model is distorted. For wave studies an undistorted model is usually desirable, since wave speed in shallow water is dependent upon the depth; this makes wave length also a function of depth. Wave refraction around barriers and at bottom contours, especially, is dependent on the interaction of wave length and horizontal scale. Thus, distortion makes modeling

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*Numbers in brackets refer to the list of references on page 26.

of refraction effects, including sand transport along a beach, especially difficult. Special care must be used in interpreting model results which may be influenced by refraction. Again, because only a comparison of effects without and with a closure dike is required rather than absolute values, the distortion effect is probably acceptable in a qualitative sense. This is especially true since the modeling of sand transport even with an undistorted scale is not well understood.

The pertinent scale ratios finally chosen are as follows:

Horizontal distances (L)	1:600	Vertical distances (D)	1:120
Current speed ($V = \sqrt{D}$)	1:10.95	Wave speed ($C = \sqrt{D}$)	1:10.95
River discharge (Q = LDV)	1:790,000	Wave period (T = D/C)	1:10.95

The current speed is based on the Froude model law, while the wave speed is based on the assumption that the depth is very much smaller than the wave length; the latter assumption is not exactly accurate, but it is probably close enough for purposes of the model study. The time scale or period scale for waves may be given different definitions. For purposes of this study it was considered important that waves break in water of approximately the correct depth in the model. For this to occur it is necessary that the wave length be measured by the depth scale, thus producing the time scale shown above.

One other wave problem associated with the use of a distorted scale occurs when wave reflection on sloped beaches is studied. With the flat beaches occurring on the lake, little wave energy is reflected back into the lake from waves breaking on shore. With a distorted scale the model beaches are much steeper and would reflect a great deal of energy, thus distorting the incoming waves. This is especially true near the existing fill. To overcome this effect the model shores must be provided with wave-absorbing materials to absorb relatively the same energy as the flatter beaches absorb in nature. This problem is discussed further at the end of this section.

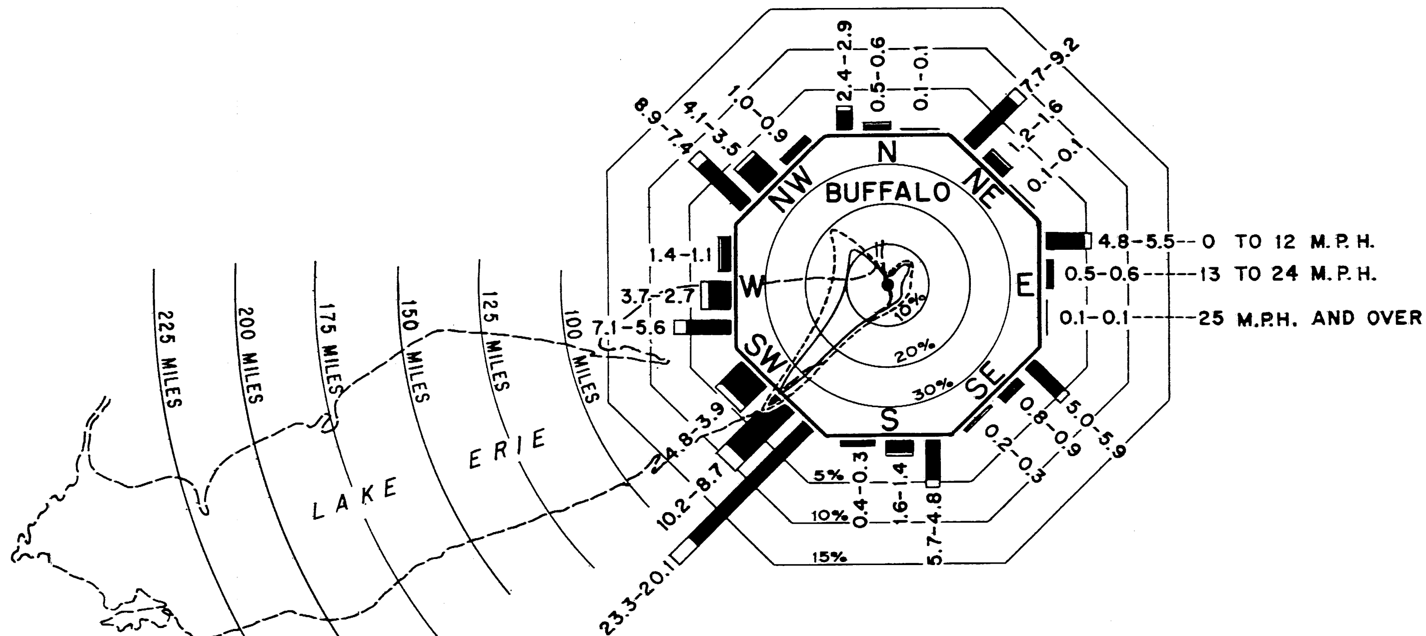
Conditions in Lake Erie

To properly design such a model it is necessary to know the wave and current conditions in Lake Erie. It is not practicable, of course, to consider all possible conditions. Rather, a few typical conditions must be selected for detailed study, and if these are wisely chosen, the main differences that would be caused by the enclosure will be determinable.

For waves, three conditions are desirable for study--calm, severe, and an intermediate condition that may help in assessment of the effects of model distortion. Waves are produced by wind blowing over water. The wind adds energy to the waves through surface shear, and the greater the distance and time the wind is in contact with the water, the more energy is carried in the waves. Hence, the most severe waves can be expected to occur in those directions from which the wind velocity is greatest and/or the over-water distance ("fetch") is greatest.

The wind diagram for Buffalo on the following page shows that storms with wind velocities over 25 mph occur with greatest frequency from the southwest and with next greatest frequency from the west. Storms of this magnitude from other directions occur only infrequently; from the south, for example, the frequency is less than 10 per cent of that from the southwest. It will be noticed from the figure that wind frequencies are given separately for the ice-free period. Actually, it is the ice-free period which is important for the model study, since only then is navigation important and only then can the storm-induced waves influence the surface and bottom currents. (It is very important to recognize that bottom currents and sand motion along a shore occur principally as a result of wave action and that sand transport which occurs largely along the bottom is especially great during severe storms when wave heights are large compared to wave length [5, p. 65].)

When the results from the wind diagram are compared with the geography of the lake, which can be done on the figure, it can be seen that the most severe wave conditions in the vicinity of the model will come from between southwest and west. Because of the much smaller over-water distances available from other directions, even the infrequent storms from those directions would not be expected to produce severe waves at the proposed enclosure. This is confirmed by examination of the wave heights actually measured on Lake Erie [1, Appendix D]. These data show that wave heights during the ice-free period of over 8 ft are associated only with motion from the west and the west-southwest. Statistical analysis of these data in Reference [1] shows that storms with waves of 12 ft height are likely to occur about once



NOTES

■ INDICATES DURATION FOR ICE-FREE PERIOD (MAR. TO DEC. INCL.) IN PERCENT OF TOTAL DURATION.

□ INDICATES DURATION FOR ICE PERIOD (JAN. TO FEB. INCL.) IN PERCENT OF TOTAL DURATION.

—— INDICATES PERCENT OF TOTAL WIND MOVEMENT OCCURRING DURING ICE-FREE PERIOD.

- - - INDICATES PERCENT OF TOTAL WIND MOVEMENT OCCURRING DURING COMBINED ICE AND ICE-FREE PERIODS.

FIGURES AT ENDS OF BARS INDICATE PERCENT OF TOTAL WIND DURATION FOR ICE-FREE PERIOD AND COMBINED ICE-FREE AND ICE PERIODS, RESPECTIVELY.

WIND DATA BASED ON RECORDS OF THE U. S. COAST GUARD AT BUFFALO, N. Y. FOR PERIOD 1 JAN. 1936 TO 31 DEC. 1943 AND 1 JAN. 1947 TO 31 DEC. 1960

WIND DIAGRAM FOR BUFFALO, N. Y.

each year and storms with wave heights of 16 ft might occur about once in ten years during the ice-free period.

Consideration of these data leads to the conclusion that severe wave conditions in the model should be represented by 12-ft-high waves from the west-southwest and from the west. These are the same criteria selected in an earlier model study of the Buffalo Harbor area by the Corps of Engineers [6]. The reason for not selecting the less frequent higher waves is that navigation will be very limited during the peak of such storms and that although important beach and current changes may occur during more severe storms, the changes are expected to be a matter of degree rather than of kind, and the situation will soon return to that produced by lesser storms when the waves begin to subside. Sand deposition patterns are a result of many large storms of different directions over a period of time, and the scars of an unusual storm are soon healed by time. As noted later, the model wave maker was actually designed to produce much higher waves than 12 ft if that had been necessary. (It should be noted at this time that the dike structure itself does have to be designed for the most severe wave conditions which may occur during winter; criteria are discussed in Appendix II.)

Having decided on the most severe wave condition, the intermediate condition was selected from the data [1] as 6 ft high and 4 sec period waves. Again, these occur with greatest frequency from the west-southwest and west, although there is a significant frequency of about 2 per cent of all storms from the southwest. To conserve effort in arranging and rearranging the wave makers, the intermediate condition was also limited to waves from the west-southwest and west.

All the wave conditions selected for study are summarized in Table I and are designated by letters for future reference.

The normal lake level in summer is 570.6 ft above sea level [2, 3]. During a storm from the west or west-southwest, however, the lake surface rises at first and the severe waves are superimposed on this increased level. The wind set-up has been taken as 4.4 ft [6], and the corresponding lake stages selected for the test are also shown in Table I.

The lake stage determines the flow into the Niagara River. The corresponding discharges as obtained from a rating curve supplied by the Buffalo District of the U.S. Army Corps of Engineers are also shown in Table I.

TABLE I Wave Conditions in Lake Erie

Condition	Wave Direction	Significant Wave Height Ft Lake	In. Model	Wave Period Sec Lake	Model	Lake Stage Ft	Niagara River Discharge - cfs Lake	Model
A	calm	0	0	0	0.0	570.6	200,000	0.253
B	S 67-1/2° W	12	1.2	7	0.639	575.0	300,000	0.380
C	S 67-1/2° W	6	0.6	4	0.365	575.0	300,000	0.380
D	S 67-1/2° W	6	0.6	4	0.365	570.6	200,000	0.253
E	W	12	1.2	7	0.639	575.0	300,000	0.380
F	W	6	0.6	4	0.365	575.0	300,000	0.380
G	W	6	0.6	4	0.365	570.6	200,000	0.253

Data on the discharges from the three small creeks within the area to be studied were collected by Mr. Louis M. Violanti, Senior Sanitary Engineer of the New York State Department of Health [7], and are shown in Table II. Flow data on the Buffalo River were supplied by the Buffalo District of the Corps of Engineers [8], and the discharge is also shown in Table II. The table shows average discharges, and no attempt was made to vary these in the model, as the discharges are so small that variation would have little effect on model performance.

TABLE II Average Inflows to Lake Erie

Stream	Inflow, cfs	Model Inflow, cfs
Smokes Creek	200	0.000253
Blasdell Creek	46	0.0000583
Rush Creek	13	0.0000164
Buffalo River	520	0.000658

Model Design

Model layout details are on Chart 2, and some pictures showing construction features are reproduced in Photos 1, 2, and 3. The model surface is of hand-troweled mortar; roughness was not considered an important factor as long as the roughness was fairly uniform. A 5.5-ft-wide depressed area was provided at the west edge of the model for the wave generators and for a perforated pipe used to produce the flow through Lake Erie to the Niagara River.

In the pipe supplying the flow it was necessary to distribute the flow through the perforations to represent approximately the flow distribution in the actual lake. As part of the preparatory work for the model study an electric analog model of the lake configuration was set up on conducting paper and the flow lines were determined as though the lake were of uniform depth at any stage. The results of this analysis are shown on Chart 3. On the chart equal discharge occurs between each pair of flow lines. This analysis, together with reference to the report on the earlier model study of Buffalo Harbor [6] and some allowance for the retardation effect of the shores, led to the input distribution to the model shown on Chart 3. This distribution is achieved in the model by four 20-ft lengths of perforated pipe laid end to end in the depression along the west model wall. Each length has a separate valve and meter to admit the percentage of the total flow shown on Chart 3. Flow to the model is supplied from the Mississippi River.

Discharges from the several small creeks were supplied through a common head tank where dye could be added when desired to mark the creek discharges. Each creek was fed by a separate pipe line with valve and flow meters to produce the model flow given in Table II.

The wave makers are of the plunger type. They were built in 8-ft sections and designed so that each section could be pivoted to permit the generating of waves from any direction between west and west-southwest. There are nine sections, making a total length of 72 ft. The generator was designed to produce controllable wave heights to a maximum of 3.2 inches in the model (much higher than required, as may be seen from Table I) at 0.6 sec periods as well as model periods as short as 0.3 sec but with wave height then limited to a maximum of 1.6 in. The sections are driven by a single motor through a common shaft, but the phase (and wave height) for each section is separately adjustable.

As has already been mentioned, the distorted beach slopes in the model produce very objectionable reflections from the shore which do not occur in nature. This was readily apparent to the naked eye. To eliminate these reflections several devices were considered for placement on the model beaches. Finally, sand, gravel, and small stones were tried, the small stones appearing to do the best job. They were placed all along the filled portions of the shore and on the existing structures, as may be seen in Photo 4. Wave reflections with the stones in place may be inferred from Charts 4, 5, 6, and 7. The first two show the time history of a short group of waves at several locations for wave conditions B and E (Table I), respectively; the latter two show the results of traversing a wave probe for the same conditions.

Some explanation of these charts is in order. Charts 4 and 5 show the history of groups of waves generated by operating the wave maker for about 5 sec and then stopping it completely. Each group moves past the probe, as illustrated by the graph in the upper left-hand corner of Chart 4, for example, where the original group is labeled "incident wave." When the group reaches the shore it is reflected back toward the probe and is again detected. The reflected wave is then again reflected from the generator and is once more detected by the probe. The reflections continue indefinitely. When the probe is placed closer to the source of reflection, as at location 3 in Chart 4, it becomes very difficult to separate the incident and reflected waves. Location 1, far from the source of reflection, is the best place to determine reflection coefficients, and the method of doing so is illustrated on Chart 4. Even at location 1, if the wave maker operates for a longer period of time the reflected wave may return in time to complicate the record just as it does at location 3. This is in fact what happens when the wave maker runs continuously.

Charts 6 and 7 show how reflection may be measured in another way when the wave makers are running continuously. The data for these charts were obtained by traversing the probe in the direction of wave motion over many wave lengths (about 50 or 60), taking about 35 sec in the process. In doing this some waves are augmented by reflection and some are partially canceled, yielding the irregular wave diagrams seen on Charts 6 and 7. The method of calculating reflection is illustrated in the upper left-hand graph of Chart 6; reflection coefficient is given by the ratio of the difference to the sum of maximum and minimum wave heights. Graphs like those on Charts 6 and 7 give smaller reflection coefficients than those in graphs 4 and 5, because the incident and reflected wave patterns are shifting with time while the wave is being traversed (as may be seen from Chart 43, for example, where the wave probe is fixed). These charts show that although reflections occur, they are reasonably small for model study purposes, especially at location 1 on the charts, which represents conditions at a great distance from the shore. The reflection coefficient here is of the order of 20 per cent.

III. VERIFICATION OF THE MODEL

It is always desirable to compare model performance with known prototype behavior to establish the reliability of the model. In this case it is especially important to do so because several assumptions have been made, particularly with regard to the effects of scale distortion. Unfortunately, very little data are available for the purpose of verification. The comparisons that can be made are discussed in the following paragraphs.

Wave Patterns

As a result of the earlier model study of Buffalo Harbor by the Corps of Engineers, Waterways Experiment Station (WES) [6], data on wave patterns at the north end of the present model are available for comparison, and these are probably the most useful data in verification of the model. The WES model was undistorted and is probably a good representation of what actually now occurs in Buffalo Harbor.

Photo 5 is reproduced from Photo 7 of the WES report for wave condition B (see Table I of Section II), but without Niagara River flow. Photo 6 shows the same condition in the present distorted model. Because the horizontal scale is so shortened in the present model, the waves appear to be much longer than in the WES model. Nevertheless, the same relative damping and diffraction occur in both models. To clarify this a little further, Photo 7 was taken with wave condition C without Niagara River flow, in which the wave lengths are shorter (and the heights are less). The similarities in Photos 5 and 7 are quite striking.

Charts 8 and 9 show measurements of wave heights taken in the present model. Chart 9 is the same as Chart 8 except that the old breakwater on Chart 9 has been increased in height to prevent overtopping as was done in the WES model. Chart 9 was compared with Plate 12 of the WES report [6] (not reproduced herein) for the corresponding condition; the comparison was very favorable.

Surface Currents

Surface current patterns have been obtained in the model without waves by photographing confetti floating on the surface and measuring the length of the streak during the time of exposure. Photo 8 is one such photograph. Chart 10 was obtained from the measurements in this photograph. For comparison, some data on ice floe movements are available from the Hydro-Electric Power Commission of Ontario [9] and are shown on Chart 11. During the field measurements the wind was blowing with considerable force from the west-northwest; however, because of the short fetch there were probably few waves. The wind had some effect on the ice floe drift, but not too much, because most of an ice floe is below the water surface. Comparison of Charts 10 and 11 shows that current magnitudes, especially, are reproduced quite well in this part of the model.

Additional surface current measurements were made in the Buffalo outer harbor to compare with field measurements obtained under ice by the Buffalo District Corps of Engineers [10]. These results are displayed on Chart 12. Although the conditions of the two measurements are somewhat different, the comparison is reasonable.

One additional current measurement was obtained by photographing the colored effluent from Smokes Creek under calm conditions, Photo 9. This pattern has been observed from shore and is sometimes seen in aerial photographs, substantiating the performance of the model in this respect. Chart 13 shows surface current patterns measured throughout the model under these calm conditions, while Charts 14 through 19 show surface current directions for various wave conditions. Field data to compare with these charts were not available.

Subsurface Currents -- Littoral Transport

It has been reported that at some times there are presently sand deposits and swirling sand around the Erie County water intake [11]. It is also known that the beach at Woodlawn near the water intake is self-sustaining, indicating that there is no net transport of sand away from the beach. Charts 14 through 19 contain records of subsurface current directions, while Charts 20 and 21 record direction and magnitude of bottom currents obtained in the model under various wave conditions. These charts show that sand could be transported along the beach from the south to Woodlawn and thence outward toward the Erie County water intake. This pattern is consistent with maintaining a good beach at Woodlawn and with finding sand around the water intake. It is also consistent with the shallow lake bottom opposite Woodlawn Beach found on various maps and shown on the charts. (It should be mentioned again in this connection that littoral transport of sand occurs largely along the bed rather than by suspension, and this is especially true during a storm, when wave height is large compared to wave length.)

Charts 22 and 23 illustrate the littoral transport in another way. Rectangular patches of sand (0.2 mm mean diameter, specific gravity 2.65, average fall velocity 0.08 fps) were placed at several places on the model bottom as shown on the charts. Whether or not the material used actually represented lake bottom material is not known, since both the fall velocity and the particle diameters were too large for the model scale used; but these scaling effects do tend to be somewhat self-compensating in a distorted model. In any event, the material did move under severe wave conditions and followed the path that would be expected from the dye traces and plastic bead measurements shown on Charts 14 through 21. The four hours required to produce the effects in the model shown on the charts correspond to about two days in nature. The charts show, for example, that sand around the Erie County water intake probably is particularly troublesome following storm waves from the west-southwest. Photo 10 shows the transport near the water intake and Woodlawn Beach for west waves and corresponds to Chart 23. A personal communication from Mr. Earl Bauer [12] describes the erosion pattern around a beached ship opposite his home on the shore of Lake Erie. The ship is outside the model area, but a similar obstruction placed a little further north along the beach in the model area, as shown on Chart 22, shows much the same erosion and deposition patterns as described by Mr. Bauer.

These are very tenuous verifications of model performance on littoral transport, but taken together with the other verifications and with the general knowledge of littoral transport that can be found in reference works such as Wiegel [13], it is believed that the model will give reliable qualitative results regarding sand transport and subsurface currents.

<u>Summary</u>

It has been found that the model, although distorted in scale, reproduces reasonably well the known features of the wave patterns in Buffalo Harbor, the surface currents at the eastern end of Lake Erie, and probably also the subsurface currents and littoral transport. Since wave patterns are reproduced fairly well in the Buffalo Harbor area, it is believed that they will also be reproduced well in the area of the proposed enclosure. Hence, it should be possible to determine in the model, at least qualitatively, the effect of the proposed enclosure on the wave patterns, currents, and littoral transport.

IV. THE ENCLOSURE

Since the purpose of the model study was to investigate the effect on the eastern end of Lake Erie of a proposed enclosure, a plan form and a cross-sectional form for the enclosure had to be selected. Several plan forms were considered, but all these can be typified by one rectangular enclosure and one curved enclosure. One of each type was constructed for use in the model, the rectangular plan form being called the "Type A Dike" and the curved plan form the "Type B Dike." Measurements, however, were made only with the rectangular plan form dike (Type A) because the results, as discussed in Section V, following, appeared to be so satisfactory that no additional tests seemed warranted.

The Type A dike as used in the model is shown in detail on Chart 24. Some comments on the utility of a curved plan form are made in Appendix I.

After the plan form of the enclosure was selected it was necessary to consider the cross section to be used in the model. This has little relation to the actual cross section to be used in Lake Erie because the distortion of the model negates any direct comparison. It is necessary, however, that the model structure have a reflection coefficient comparable to that which will occur in the real structure. Furthermore, just as in the case without the enclosure, reflection of waves from the enclosure must not interfere with wave generation in the model.

One possible form of cross section is a vertical wall facing the lake. This is the original form in which the Type A dike model was constructed. Another cross section is the vertical wall with a rubble mound on the lake side, which is the form eventually used in the model. The former will result in maximum reflection of wave energy of the order of 90 to 95 per cent, as may be seen by examining the upper right-hand graphs of Charts 25 through 30. (These charts have the same significance as Charts 4 through 7, explained earlier.) The latter will produce much less reflection, the exact coefficient depending on how well the mound is designed. For the purposes of the model study the same stones used to absorb waves on the beach were used on the face of the model dike, producing a rubble mound in the model. The enclosure used in the model study may be seen in Photo 11.

The reduced reflection obtained by using a dike with rubble mound may be seen by comparing the graphs in the upper left-hand corners of Charts 25 through 30 with the graphs for the vertical wall without stones in the upper right-hand corners of these same charts. Because of the high reflections it would not have been possible to make meaningful model studies with a vertical wall cross section in the model. The rubble mound actually used produced more moderate reflections of the order of less than 50 per cent near the wave maker, and these were considered tolerable for the model study. The actual structure used for the enclosure is likely to be a rubble mound and to be no worse than this; it may be better. A model dike cross section with even less reflection could have been constructed by further trials, but it is believed that this might have been unrealistic with regard to the eventual lake structure.

V. RESULTS OF THE MODEL STUDY

The model study was carried out by making measurements of wave height distribution, surface and sub-surface currents, sand deposits, and ice floe movements, first without and then with the Type A dike, and comparing the results.

Wave Heights

Maximum wave heights without and with the Type A dike are compared on Charts 31 through 42 for the six wave conditions studied. Each consecutive pair of charts, 31 and 32 for example, shows contours of maximum wave heights first without and then with the enclosure for one wave condition (condition B--12 ft waves from west-southwest--for Charts 31 and 32). The contours were established for each chart by measuring wave heights from a traveling carriage with a capacitance-type probe at about 250 points over the surface of the model. The probe reading was averaged for about 25 sec for each point while the gage was stationary and the wave maker was running continuously. Typical wave profile shapes are shown on Chart 43 and, to a stretched time scale, on Chart 44.

Examination of Charts 28, 29, and 30 would raise the suspicion that depending on where the gage was placed, its maximum reading could vary by several feet because of reflections. (Only the graphs on the left sides of these charts are applicable, since the data on Charts 31 through 42 were taken with rubble mounds on the enclosure.) Although the points chosen for measurement on Charts 31 through 42 were selected without reference to graphs like those shown on Charts 28, 29, and 30, it is believed that reasonable wave height contours have been obtained, since the patterns shown on the latter charts moved gradually with time and this caused the wave probes to read average wage heights. (The change with time may be seen in the long-time records of Chart 43.) It is these average heights that were used in plotting the contours on Charts 31 through 42.

The effect of the enclosure on the waves may be seen by comparing the pairs of charts. In general it appears that the wave heights in the harbor area are little, if any, different with the Type A enclosure than without it. One of the most striking results is that wave heights just inside and at the entrance to the south harbor appear to be reduced by a sheltering effect of the enclosure for west-southwest and west waves. (This would not be true for waves from the north, but such waves are not likely to be so severe in any event because of the short fetch. North waves were not studied in the model, of course.) The most unfavorable effect, and this is a slight one, occurs to the west and northwest of the south harbor entrance for wave condition E, as shown on Charts 37 and 38.

Currents and Littoral Transport

Currents were examined in the model at the surface and near the bottom without and with the enclosure. Surface current directions were obtained using paper confetti, which floated, and a red dye which was nearly neutrally buoyant. Bottom currents were investigated using the red dye for direction and 1/8-in.-diameter plastic spheres slightly heavier than water timed over short distances for both magnitude and direction.

Surface currents for calm conditions without the enclosure are shown on Chart 13; Chart 45 and Photo 12 show the result with the enclosure. Photo 12 may be compared with Photo 9 for the case without the enclosure. Except for a weak eddy to the north of the enclosure the patterns are almost identical. Floating debris and ice might collect in the eddy, but would be washed away during less clement weather. There are practically no bottom currents without waves. It should be noted that these and the following charts show model results over only a portion of the model surface close to the proposed enclosure; even at the edges of this limited area there are no detectable changes in currents due to the enclosure, and there are none outside the area shown.

Both surface and bottom currents for the various wave conditions are shown for the natural lake on Charts 14 through 19. The corresponding currents with the enclosure are shown on Charts 46 through 51. Comparison of the corresponding charts shows that except for the outward displacement of the current patterns by the enclosure, practically no changes have been produced by introduction of the enclosure in either surface or bottom current directions. Photographs have also been obtained showing details of the currents at various places in the model. Photo 13, for example, compares the surface currents marked by dye in the vicinity of Woodlawn Beach without and with the enclosure, and Photo 14 compares bottom currents marked by dye in the south harbor entrance without and with the enclosure. The photographs confirm the visual observations recorded on the charts in all cases. It should be stressed that the currents observed in the south harbor entrance are very small and barely detectable both with and without the enclosure. In fact, for the most severe wave conditions it is probably only the overtopping of the breakwater that causes the outward flow which is observed.

Measurements of bottom velocities with the plastic beads are qualitatively indicative of sand movement on the bottom. Only the most severe wave conditions, B and E of Table I, produced high enough velocities to measure in the model by this method. (Sand undoubtedly moves with smaller waves in the lake, but it is well known that littoral transport of sand is strongly dependent on refraction of storm waves and that the greatest changes in the beach are wrought by the most severe storms, as mentioned when discussing verification of the model in Section III.) Charts 20 and 21 showed these particle velocities (in fps, model) without the enclosure; Charts 52 and 53 show the same information with the enclosure. Again there is little change with the enclosure.

The effect of the particle transport under these wave conditions in depositing sand in the model with the enclosure after several hours of operation may be seen on Charts 54 and 55. The spread of the deposits is in accord with what would be expected from the charts showing subsurface currents--Charts 46 and 52 for Chart 54 and Charts 49 and 53 for Chart 55. Charts 54 and 55 may be compared with Charts 22 and 23, which show similar information without the enclosure. An explanation of the method used for obtaining the data on these charts was presented with the earlier discussion of Charts 22 and 23. Again these charts tend to show that except for outward displacement of the patterns by the enclosure there should be little, if any, change expected in sand deposition and erosion. In particular, the Erie County water intake which presently lies in an area of deposition with waves from the west-southwest, as may be seen on Chart 22, will continue to lie in an area of sand deposition under these same conditions, as may be seen on Chart 54. (Only the complete removal of the existing fill might assist in removing sand from around the intake.) The water intakes at Wanakah and Buffalo are remote from the enclosure, and there was no detectable effect from either bottom or surface currents shown by the model near these intakes.

Charts 22 and 23 indicate that in the harbor area there is presently continual transport of sand past the south harbor entrance, and Chart 55 shows that this is still true for west waves with the enclosure. However, Chart 54 for west-southwest waves with the enclosure in place seems to show very little transport past the harbor entrance. On the other hand, subsurface currents indicated on Charts 46 and 52 for the same wave conditions with the enclosure in place do indicate that there should be some transport here. To check this apparent discrepancy the sand patch at the corner of the breakwater and the patch next to the south of it shown on Chart 54 were replaced with coal particles of about the same mean diameter but with specific gravity of only 1.5 (the resulting fall velocity being about 0.02 fps). These particles did accumulate and move along the west and north sides of the enclosure and past the south harbor entrance just as on Chart 55, showing that qualitatively, at least, the sand movement will not be interrupted by the enclosure.

In summary, it appears that sand deposits will not be noticeably changed by the presence of the enclosure except that transport will be pushed further out into the lake opposite the enclosure.

Ice Drift

Some investigation has also been made of the behavior of ice floes under west and west-southwest wave conditions both with and without winds. Ice floes will tend to move largely with the surface currents, and thus Charts 13 through 19, without the enclosure, and Charts 45 through 51, with the enclosure, are pertinent to predicting the motion of ice. In addition to the data and photographs obtained for preparing these charts, additional photographs were taken of the motion of ice cubes placed at strategic places in the model, particularly near the south harbor entrance. The ice cubes sink more deeply into the flow than confetti and include any influence of deeper currents.

Photo 15 is typical of the ice cube experiments, showing motion into the harbor under combined wave and wind action. Without wind there is very little surface current motion and little ice motion for this wave condition in the harbor entrance; the winds tend to drive the floes into the entrance. Similar photographs were taken for all wave conditions and indicate that there would be little, if any, change in ice drifting into the harbor or onto the beaches without or with the enclosure for west and west-southwest waves and wind. No tests were made with north or south waves and wind, of course. It may be recalled that with calm conditions there is a large, weak surface eddy to the north of the enclosure (Chart 45). Drifting ice may collect and pack here during calm weather, but the pack should be broken up during storms.

The ice cubes do not stick together as real ice floes might, so that these experiments are not really conclusive as regards possible ice problems at the harbor entrance or elsewhere. However, since the drift patterns of the floes seem to be similar for the most part without and with the enclosure, it is probable that packing of ice would be no worse with the enclosure than without it.

Conclusions

The model study has shown that with the dike plan form shown on Chart 1 and in detail on Chart 24 it should be feasible to enclose about one square mile of Lake Erie opposite the Bethlehem Steel Company plant at Lackawanna, New York, without causing important changes in the existing regime in the lake. The study has included consideration of the reflection of waves into the shipping lanes to the west; wave conditions in and near the south harbor entrance; surface currents, including their effect on ice drifting; and subsurface currents, including their effect on sand transport, erosion, and deposition. Specifically, no adverse effects from either waves or sand deposition are expected in the south harbor entrance, and no additional adverse effects from either currents or sand deposition are expected at any of the water intakes or at the beach at Woodlawn.

Many of the results obtained in the model study are largely qualitative insofar as absolute values are concerned. But considering that only a comparison between conditions without and with an enclosure was required, the results have considerable validity for the purpose intended. It should be cautioned, however, that it was assumed in the model study that the enclosure would have a cross-sectional form that would produce considerable wave attenuation--reflections of less than 50 per cent under the most severe conditions studied. For larger reflection coefficients the results would not be valid.

This report is supplemented by a motion picture which illustrates some of the dynamic aspects of the model study better than could be done by the photographs and charts in the report. The motion picture will be available through the sponsor.

APPENDIX I

A Curved Enclosure

As indicated in the body of the report, only the rectangular plan form enclosure, Type A, was studied in the model. Since this proved to be so satisfactory as regards changes that are likely to be produced by construction of the enclosure, no tests were conducted on the curved enclosure, Type B. Nevertheless, in view of the results of the model study and from background obtainable from the literature ([5, 13] for example), some comments may be made about a curved plan form.

In water of uniform depth, water waves are reflected much like light waves. When straight-sided plan forms are used, as in the Type A dike, all waves are reflected back along parallel lines and the net wave height far out is the sum of the incoming and reflected wave, producing a net height nearly twice the height of the incoming wave. If a dike is curved, however, the reflected waves diverge if the center of curvature is inside the enclosure and converge if the center is outside. It is thus apparent that a curved enclosure with center inside would cause the wave energy of the reflected wave to spread so that the net wave height far out would hardly be more than the height of the original incoming wave. It appears, then, that there would be a great advantage as far as the shipping lanes to the west of the enclosure are concerned in having a curved enclosure.

Unfortunately, it is not possible to have curvature with center inside the enclosure without having compensating curvature of opposite sign somewhere. In this case it turns out that opposite curvature would have to occur near the south harbor entrance and would be of very short radius. Thus it can be expected that wave energy would be very concentrated outside the harbor entrance and that wave heights would be much worse than merely the sum of the incoming and reflected wave of the same height. It was for this reason, as well as for the reason that the Type A dike appeared to perform quite well, that the curved plan form was not tested.

It should be noted that the analysis of wave reflection is considerably more complicated than outlined above. When water depth changes, both incoming and reflected waves are refracted and diffracted, and this can change the results considerably. In the present case, convergence of reflected waves would occur off the beach near the south end of the enclosure. The concentration of reflected wave energy here, together with diffraction from the sloping beach, could cause wave action near the shore to be more severe than that which presently occurs and could possibly result in damage to the beach. This could be a matter for concern even with the rectangular dike which was studied and would be of more concern with a continuously curved dike. The distorted model is incapable of detecting such effects due to convergence except in the most qualitative manner. It does appear from the model study (Chart 54 vs. 22 and 55 vs. 23) that the Type A dike studied is reasonably satisfactory from this viewpoint.

APPENDIX II

Some Notes on Design of the Breakwater

Design Conditions

Whereas in the model study wave criteria were established on the basis of storms occurring with a frequency of about once a year during the summer, breakwater design calls for more severe criteria. The breakwater has to physically withstand waves which can occur at any time during the year and must do so without excessive damage being done to the structure. In most breakwaters overtopping also has to be guarded against, but in this case overtopping can probably be tolerated if the breakwater is capped so that no physical damage will occur to it. It is assumed that water carried into the enclosure would return to the lake by seepage.

Examination of the records, especially Figure D-3 of Reference [1], indicates that maximum waves of 16 ft or more may occur at Buffalo during winter storms. Hunt [14] says that waves as high as 25 ft were reported during the storm of 3 November 1955, subsequent to publication of Reference [1]. The period for these large waves is probably of the order of 7 sec and the direction is usually west-southwest. For breakwater design it is recommended that the deep water waves be taken as 18 ft high from the west-southwest with a period of 7 sec.

In addition to the effect of waves, the general water level near the enclosure will rise due to wind set-up. For the model study this rise was taken as 4.4 ft over the general summer water level of 570.6. For the more severe winter storms that the breakwater will experience, a higher rise will occur, but at the same time the mean low water (MLW) of 568.6 is the natural lake level in winter. Based on recorded data quoted in Table 5 of Hunt [14], a rise of 6.5 to 7 ft over this 568.6 level, to about 575.5, should probably be expected.*

For design purposes it is necessary to determine the height of the storm waves at the breakwater if they get that far. Waves have a length in deep water of $L_o = gT^2/2\pi$ where T is the period and g is the

*It is reported in the Great Lakes Newsletter for November-December 1968 that during the storm on December 5, 1968, the water level at Buffalo reached 576.86.

acceleration of gravity. For $T = 7$ sec, $L_o = 251$ ft, the water depth, D, near the breakwater is of the order of 27.5 ft referred to MLW and about 34 ft when the wind set-up is considered. The key parameter is $D/L_o = 0.135$. Referring to Wiegel [13], Chapter 7 and Appendix I, the wave length near the structure is reduced to about 200 ft, assuming constant period. And, assuming additionally constant transmission of energy, the wave height is reduced by the theoretical factor 0.9156. However, there is energy loss due to both friction and refraction of the waves by the sloping bottom. An arbitrary additional factor of 0.9 may be applied for this reason, so that the ratio of wave height to deep water height H/H_o equals approximately 0.82. Hence an 18 ft storm wave in deep water would be reduced to about 14.8 ft near the structure, and the structure would have to be designed for such a wave.

Large waves from Lake Erie may break before reaching the proposed breakwater, and to investigate this possibility the depth of breaking should be studied. Using Wiegel [13], Figure 2.31, and assuming the bottom in the vicinity of the proposed dike slopes outward flatter than 1:50 [4], the breaker height is about 0.9 of the maximum wave height for an 18 ft wave, or 16.2 ft. From the same reference, the breaker depth is a little over 1.4 times the breaker height, or about 23 ft. Considering the wind set-up, these 18 ft waves should break where the bottom lies, at about 16 to 16.5 ft below MLW. From Lake Survey Chart 314 [4], this means that 18 ft waves will not reach the southern part of the breakwater, and the breakwater here can be less bulky than further north. A 12 ft, 6 sec wave, as another example, would break in 15 ft water, or about 9 ft below MLW, by the same reasoning.

The most critical design condition for stability of the breakwater occurs when waves break against it. This occurs when 14.8 ft high waves (reduced from 18 ft farther out) break in water 23 ft deep (at about the place where the breakwater is in water 16 to 17 ft below MLW). The remainder of the breakwater to the north of this point should probably be designed for the same conditions, while to the south somewhat more moderate conditions could be used.

Cross Section of the Breakwater

Many forms of cross section may be made adequate to withstand the forces imposed on them by breaking waves and have been used for breakwaters.

Preferred types include rubble mounds, mounds of interlocking concrete units, steel pile cells, and steel pile cells with rubble mounds on the deep water side. Frequently, economy of construction under local conditions determines the cross section that is selected. Where shipping lanes are involved, however, a sloping, permeable breakwater is necessary on the deep water side for the reasons outlined in the following paragraphs. The main shipping lane is about 2-1/2 miles west of the proposed enclosure, and a harbor entrance lies just to the north.

Vertical walls have reflection coefficients of 0.9 to 0.95 for high waves, whereas well-designed rubble mounds of proper slope have much smaller reflection coefficients of the order of 0.2 to 0.3 [15]. For example, Charts 25 through 30 illustrate this difference in the present model. Wave reflection in water of uniform depth is much like light reflection--angle of reflection equals angle of incidence. The reflected waves are not damped very rapidly as they move outward from a wall, and thus a vertical wall could be expected to reflect a 12 ft wave as, say, a 10 ft wave, making a maximum possible wave height where an incident and a reflected wave meet of 12 plus 10, or 22 ft. A good rubble mound could limit reflection to 2 or 3 ft for a total height of 15 ft, a much more tolerable situation. Charts 28 through 30 illustrate the advantages of a rubble mound over a vertical wall.

The model is not really very suitable for this kind of demonstration because of its distortion and the short distance between the enclosure and the wave maker, in addition to the fact that the rubble mound in the model was not designed to be an ideal rubble mound structure. A better demonstration could be made in a two-dimensional channel with an undistorted model of larger scale. Nevertheless, the model is qualitatively correct and gives an idea of the improvement that shipping would experience from a properly designed sloping-face breakwater as opposed to a vertical-face breakwater. The reflections illustrated by the charts would persist with little attenuation far to the west and into the shipping lanes.

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[11] Bauer, E. R., Personal Letter to Professor Silberman concerning Sand Deposits at the Erie County Water Intake, January 3, 1969.

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[15] Lee, C. E., "On Wave Damping in Harbors," ASCE Journal Waterways and Harbors Division, WW 4: pp. 489-501, November 1968.

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PHOTO 1 (Serial No. 183-6) Construction detail of the model looking toward the south.

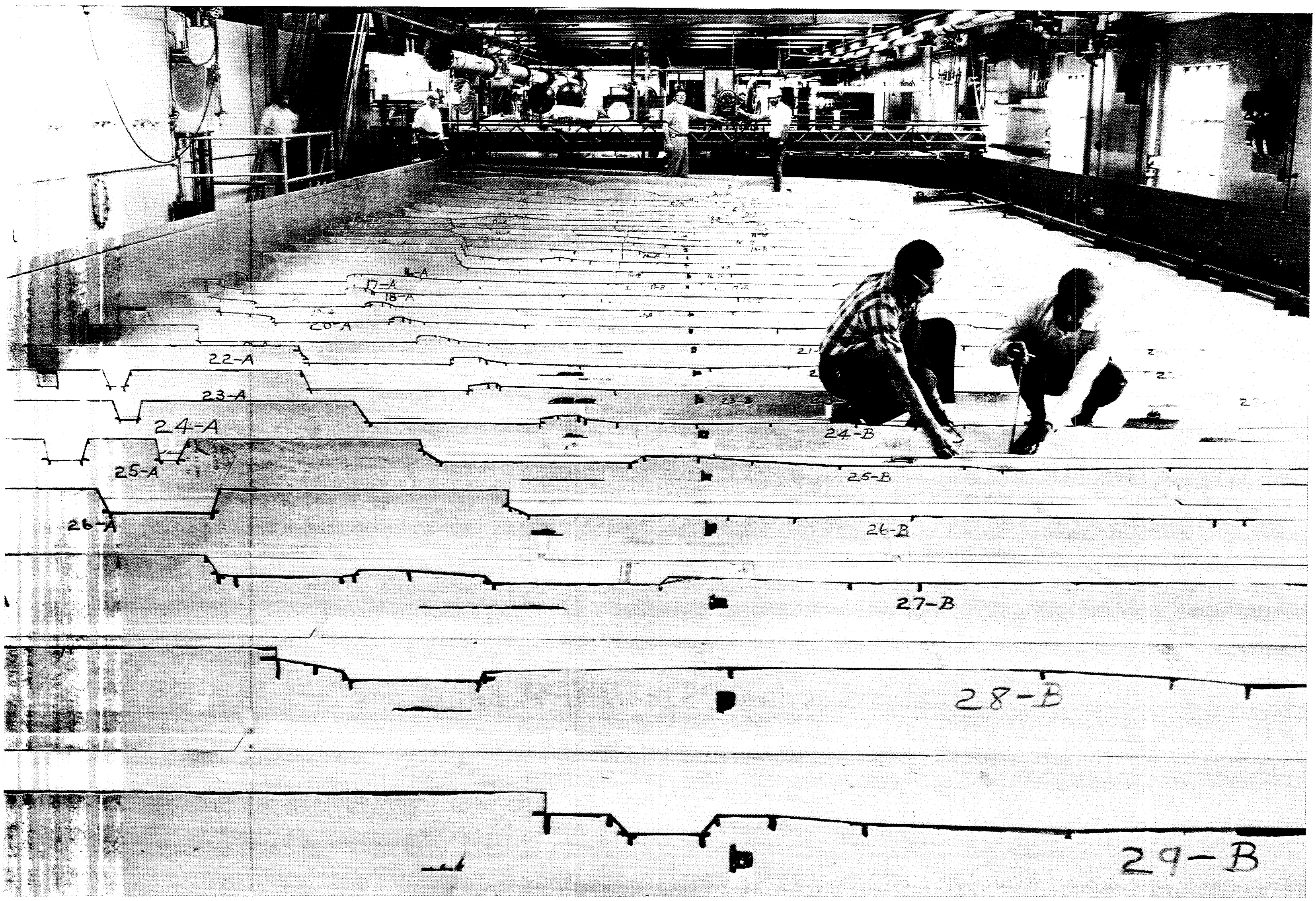

Photo 1

PHOTO 2 (Serial No. 183-16) The completed model looking toward the south.

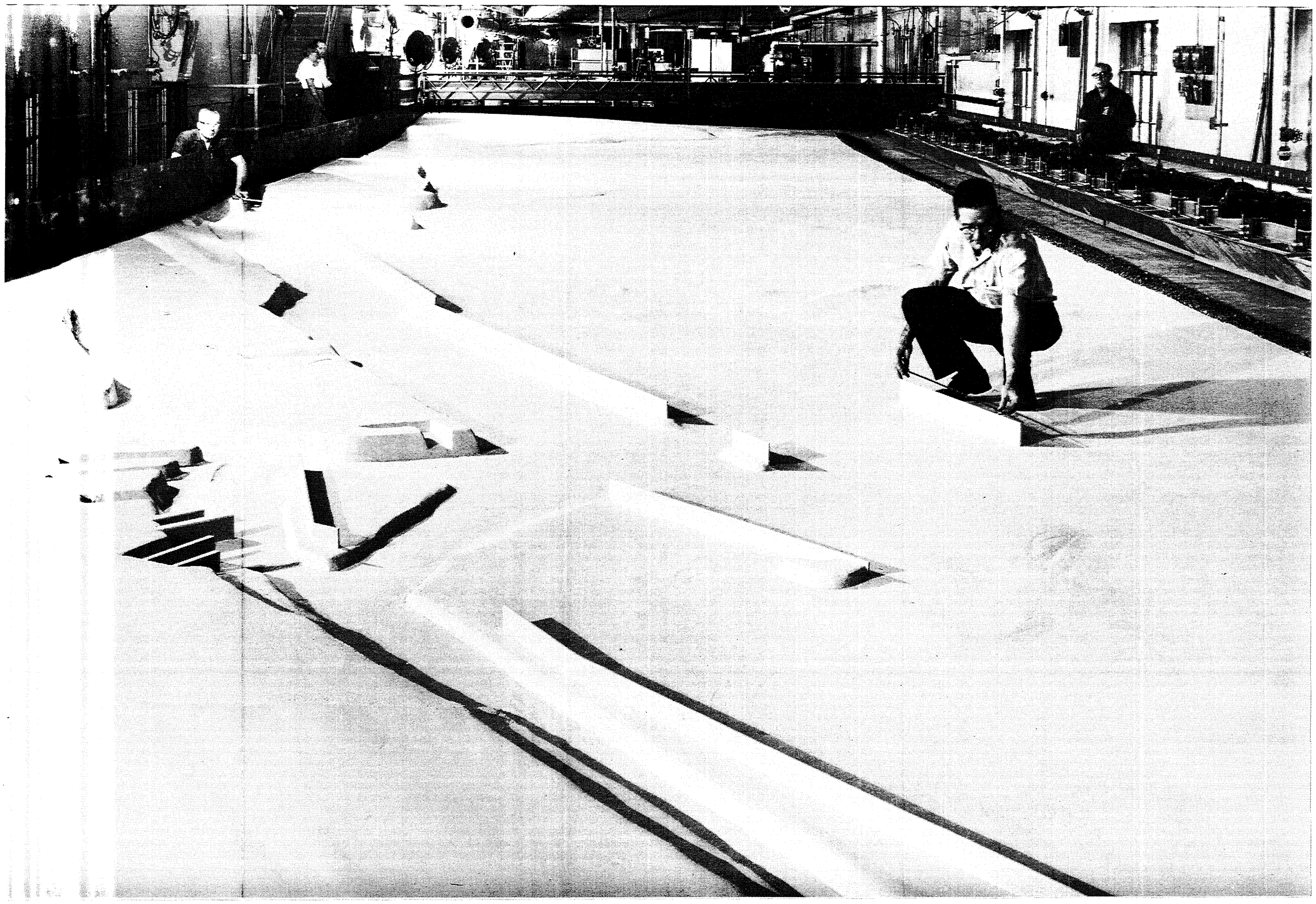

Photo 2

PHOTO 3 (Serial No. 183-20) The completed model looking toward the north.

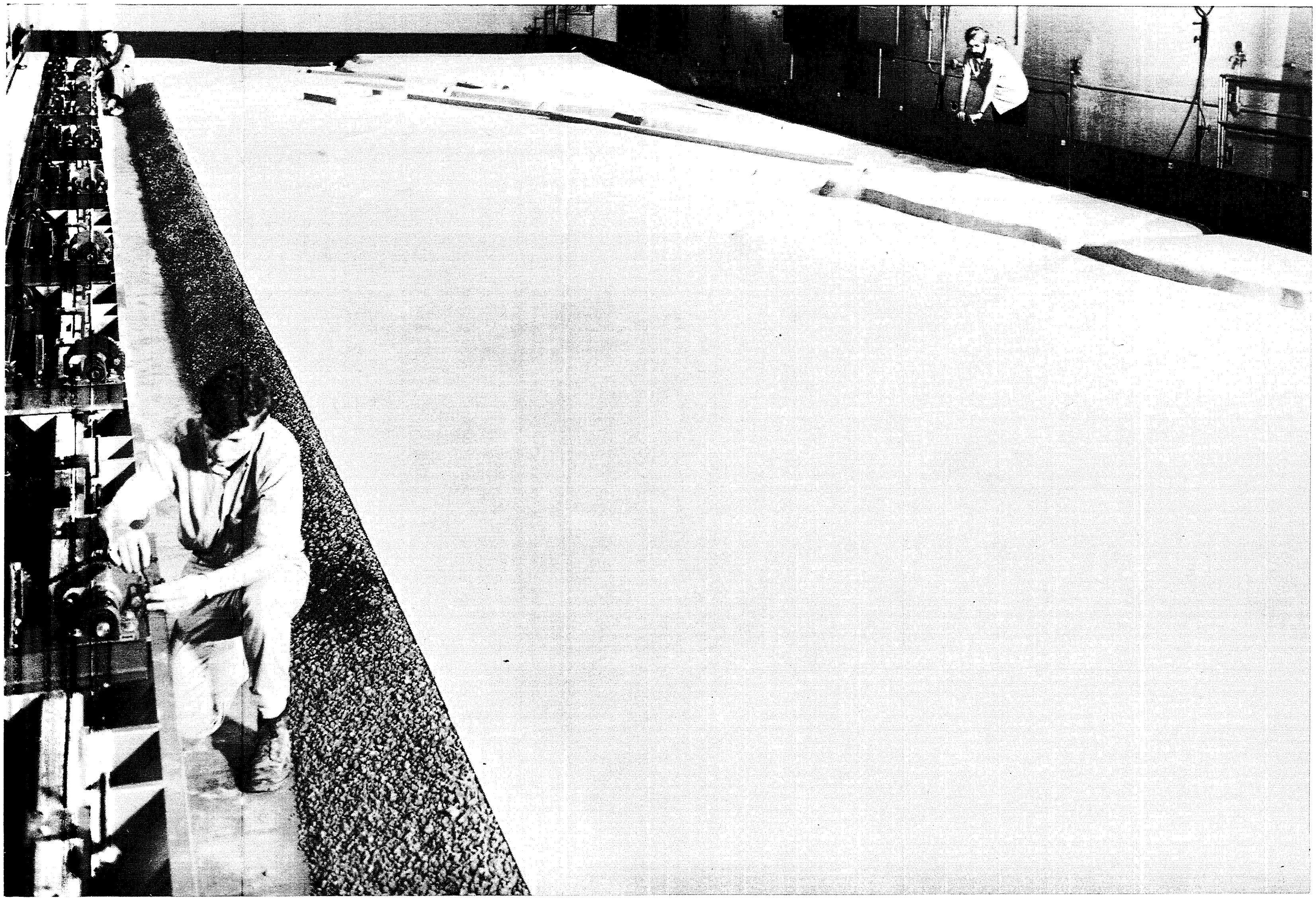

Photo 3

PHOTO 4 (Serial No. 183-67) Stones used for damping reflections from shore, wave condition C.

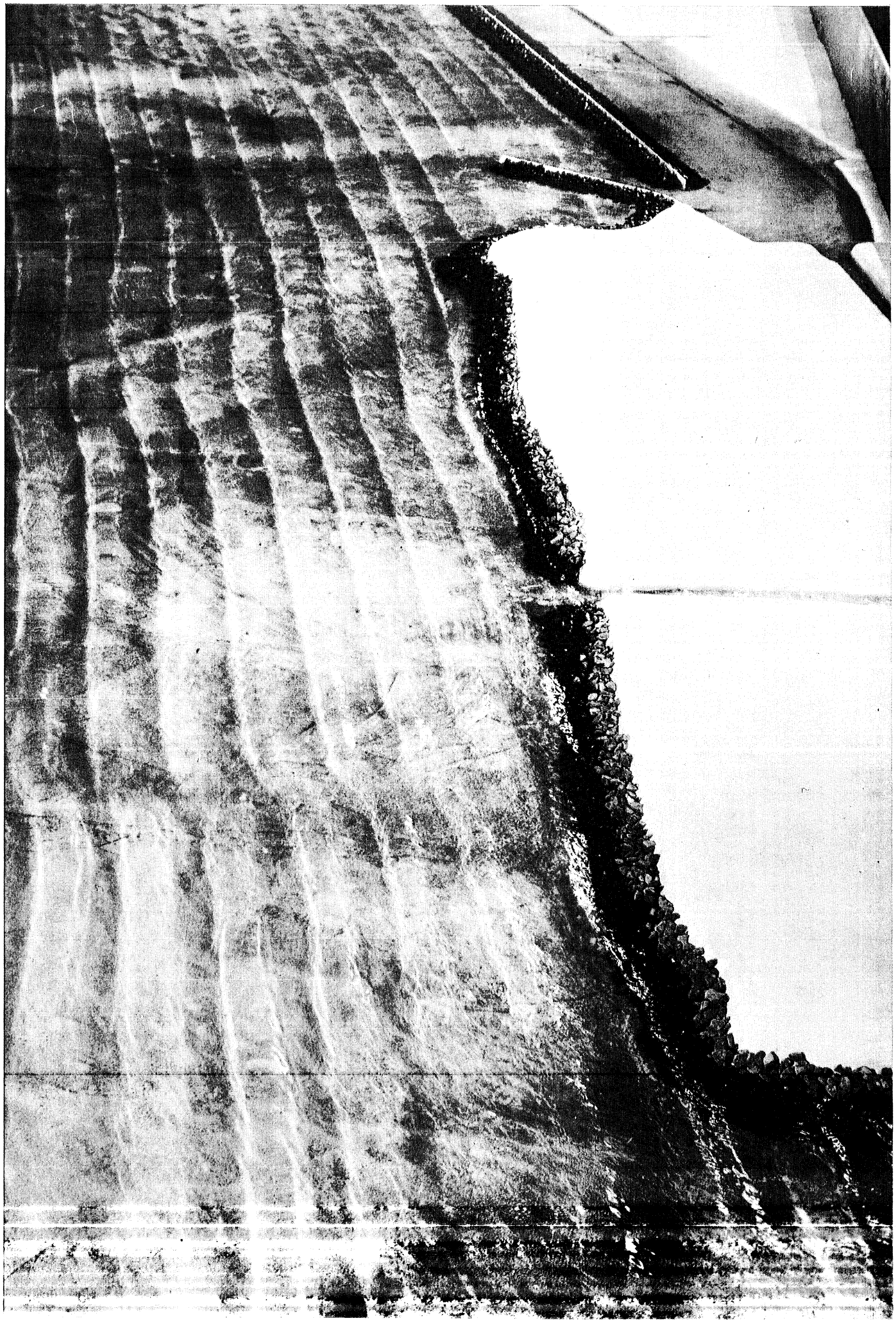

Photo 4

PHOTO 5 (Serial No. 183-51) An overhead view of the north entrance to Buffalo Harbor showing the wave patterns with 12 ft by 7 sec waves from S 67-1/2° W, no flow into the Niagara River. Photo is reproduced from Photo 7 of the WES report on Buffalo Harbor.

Photo 5

PHOTO 6 (Serial No. 183-41) An overhead view of the north entrance to Buffalo Harbor showing the wave patterns with 12 ft by 7 sec waves from S 67-1/2° W, no flow into the Niagara River.

Photo 6

PHOTO 7 (Serial No. 183-52) An overhead view of the north entrance to Buffalo Harbor showing the wave patterns with 6 ft by 4 sec waves from S 67-1/2° W, no flow into the Niagara River.

Photo 7

PHOTO 8 (Serial No. 183-82) An overhead view of the entrance to the Niagara River with a flow of 160,000 cfs and Lake Erie elevation of 569.0 ft, no waves being generated.

Photo 8

PHOTO 9 (Serial No. 183-63) Surface currents under calm conditions marked by effluent from Smokes Creek.

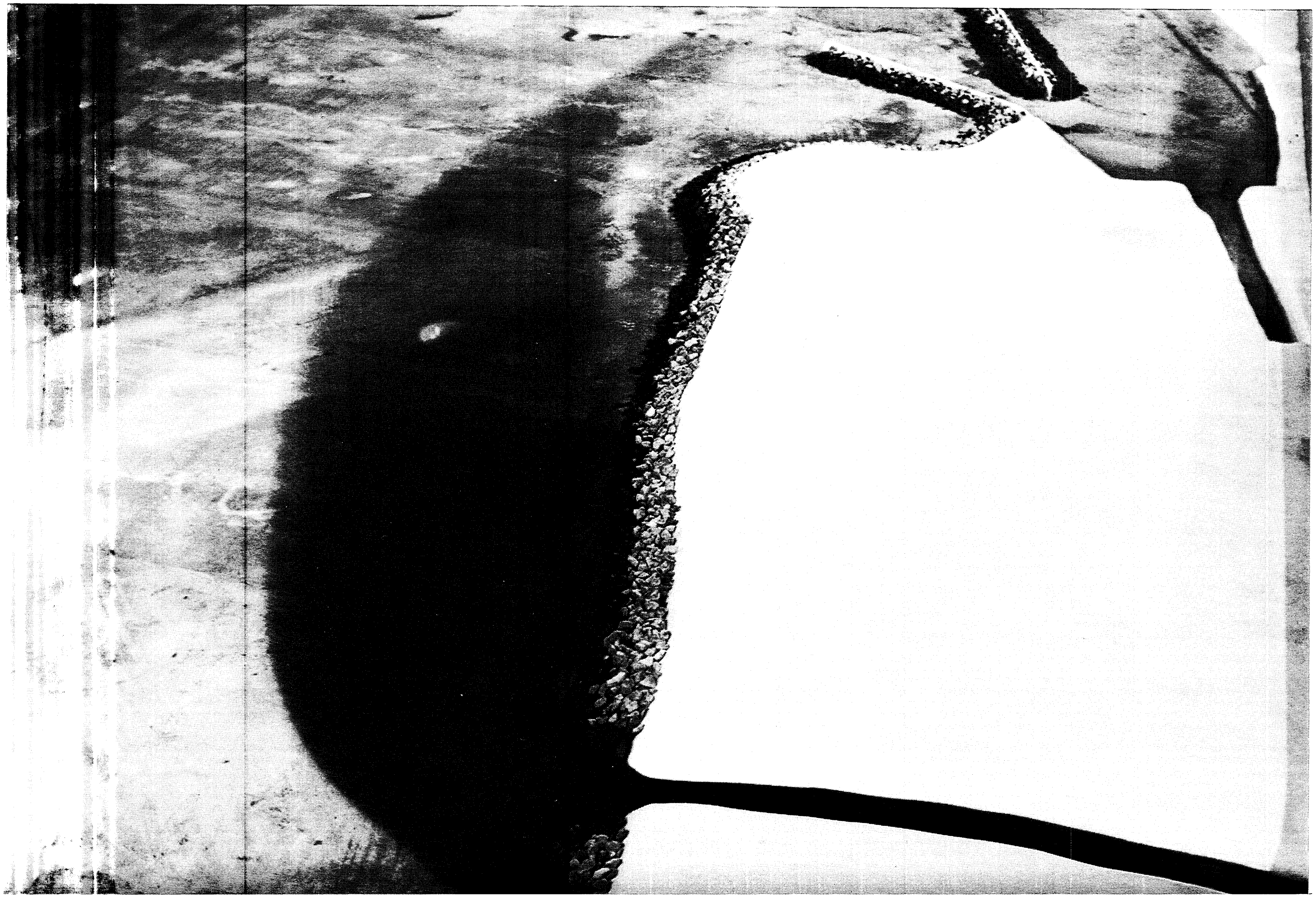

Photo 9

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a. Before wave action

b. After 6 hours of wave condition E

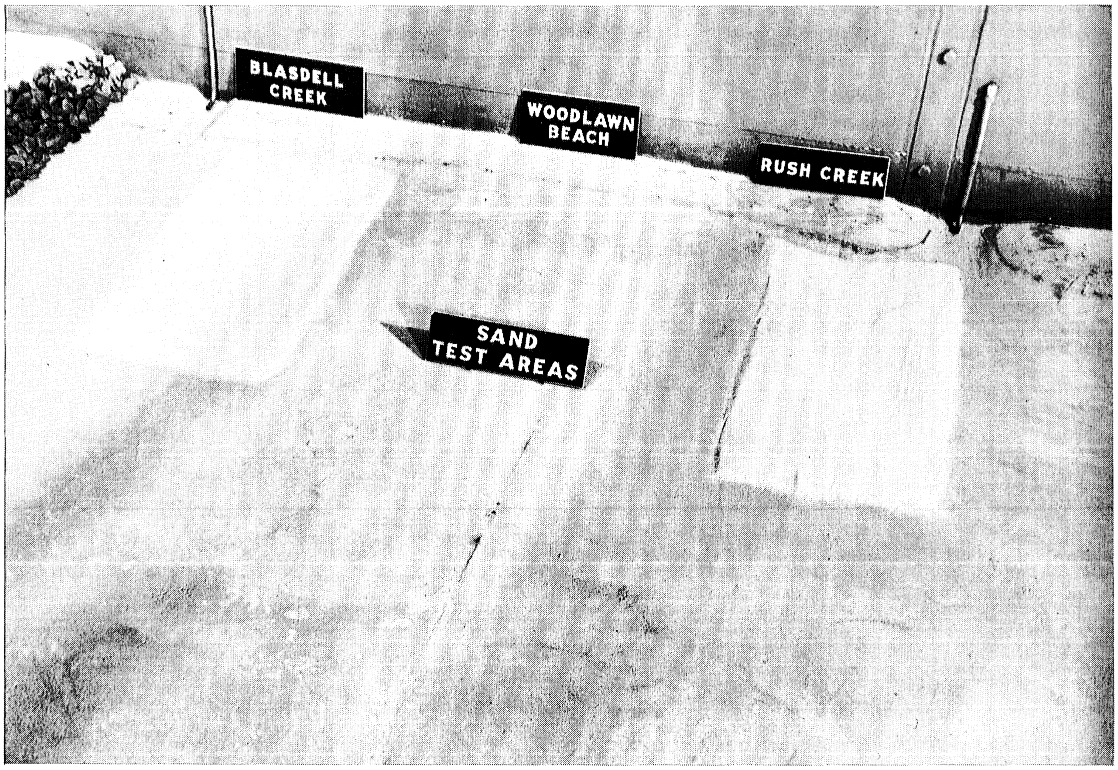

Photo 10a

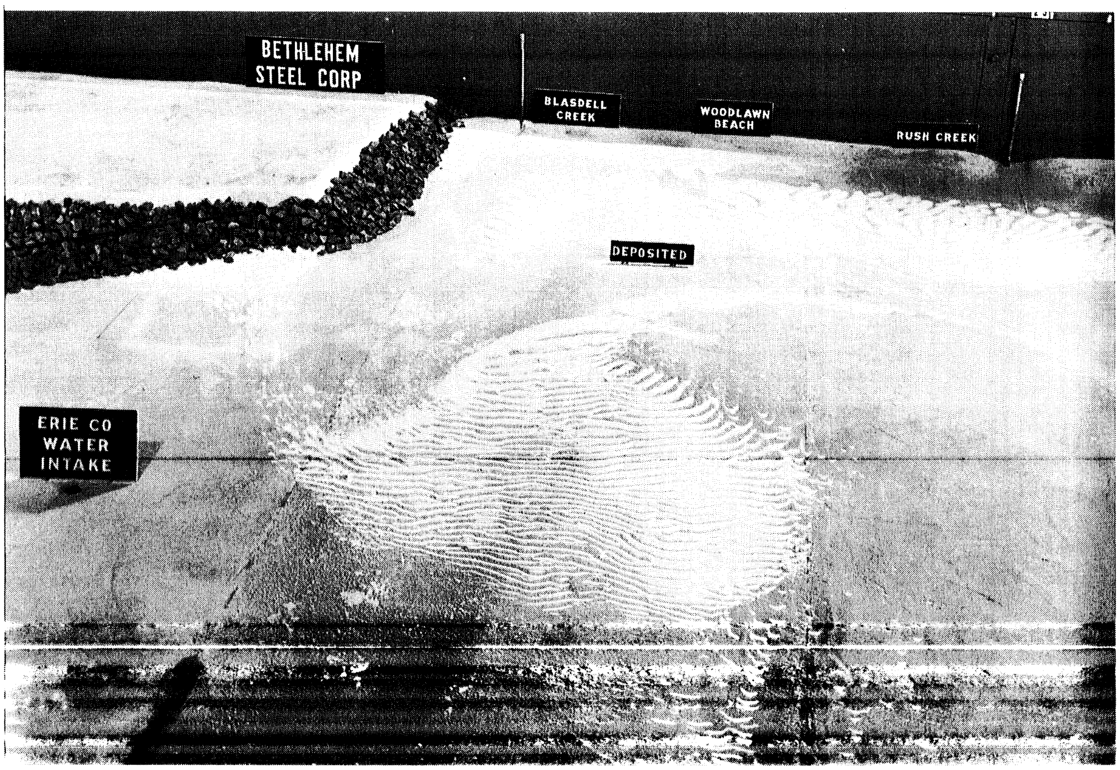

Photo 10b

PHOTO 11 (Serial Nos. 183-191 and 183-146) The Type A dike:

a. Wave condition G

b. Wave condition B

Photo 11a

Photo 11b

PHOTO 12 (Serial No. 183-142) Surface currents under calm conditions with Type A dike.


TYPE A
DIKE
SMOKES
CREEK
BETHLEHEM
STEEL CORP
BLASDELL
CREEK

Photo 12

PHOTO 13 (Serial Nos. 183-90 and 183-150) Surface currents near Woodlawn Beach, wave condition B:

a. Without enclosure

b. With Type A dike

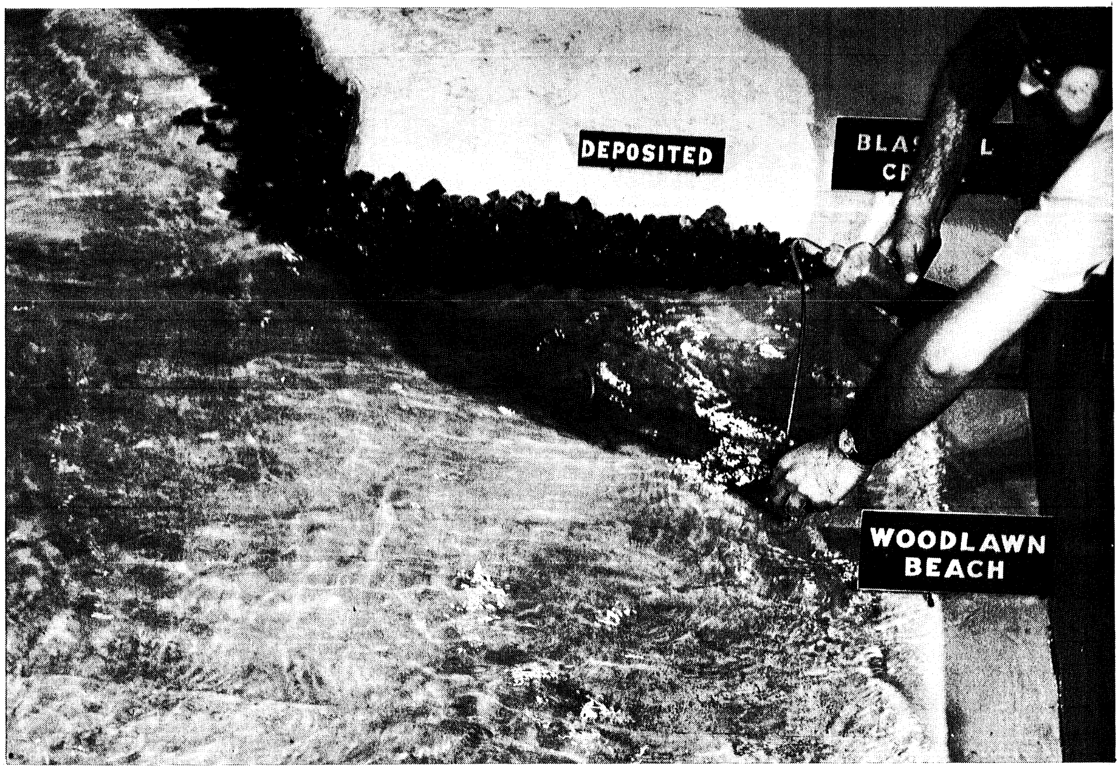

Photo 13a

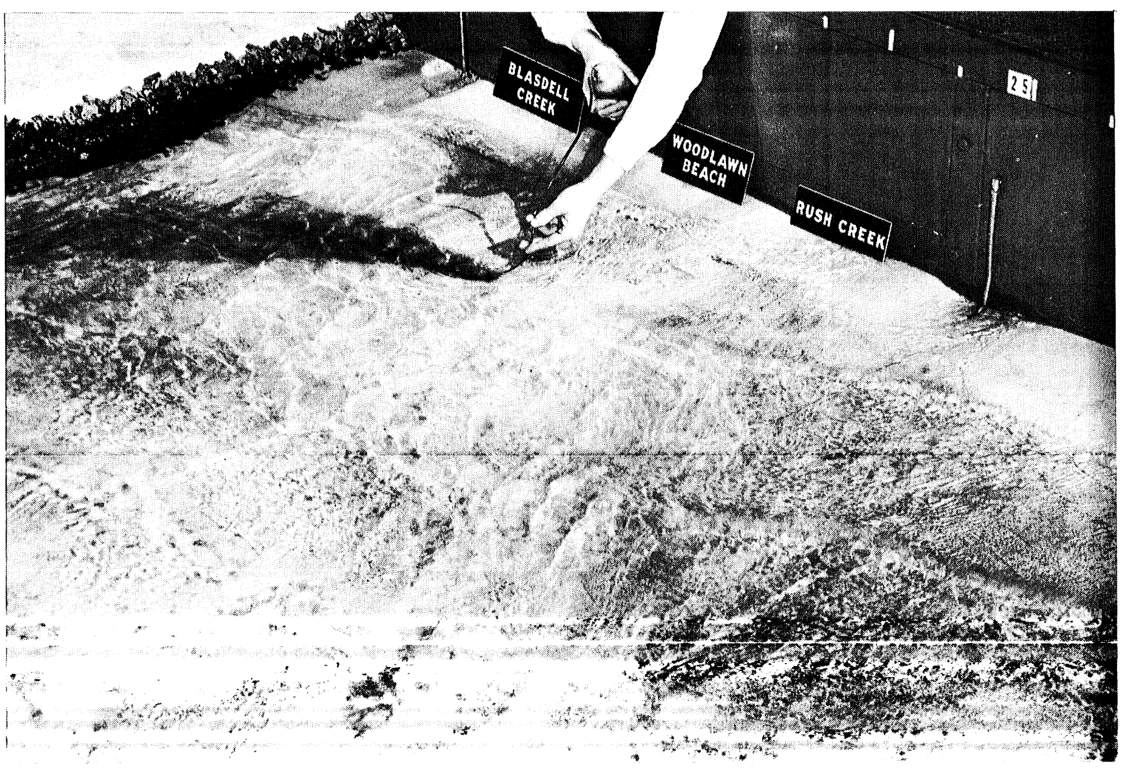

Photo 13b

PHOTO 14 (Serial Nos. 183-126 and 183-186) Bottom currents at south harbor entrance, wave condition F:

a. Without enclosure

b. With Type A dike

Dye has been placed on the bottom just outside the harbor entrance and is being slowly carried inward by bottom currents.

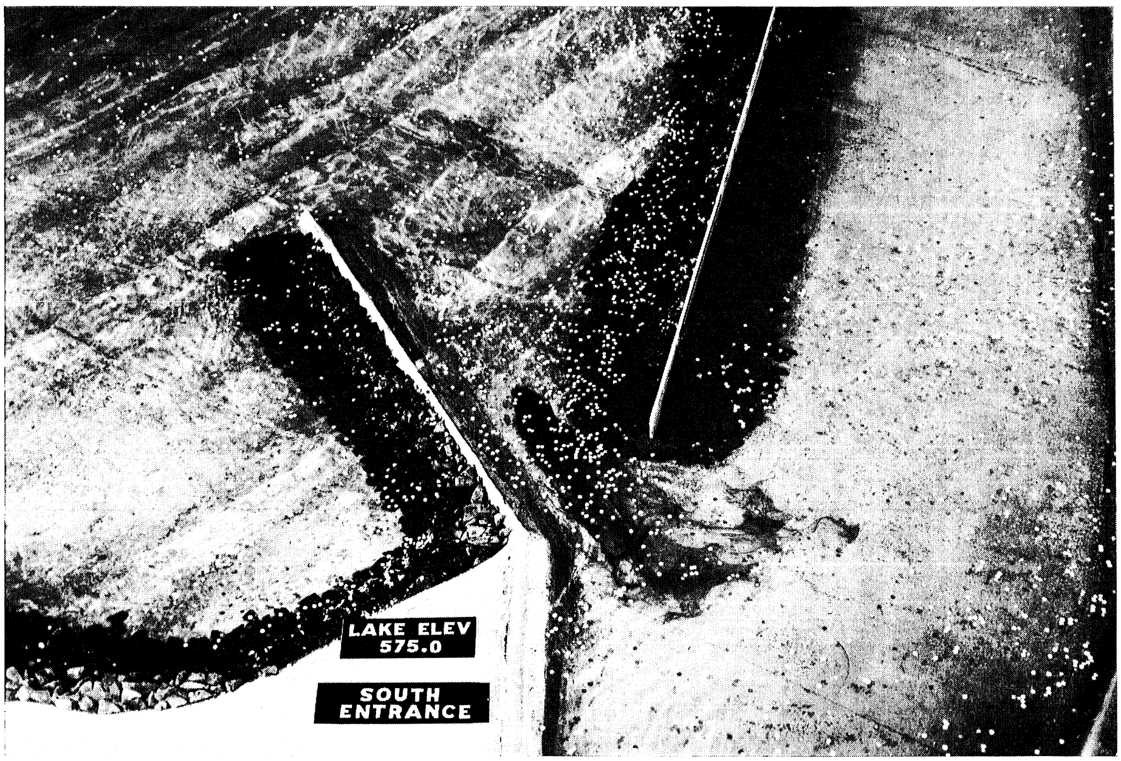

Photo 14a

Photo 14b

PHOTO 15 (Serial Nos. 183-120 and 183-179) Ice cubes moving into south harbor entrance, wave condition E plus 2 fps, wind from west:

a. Without enclosure

b. With Type A dike

Photo 15a

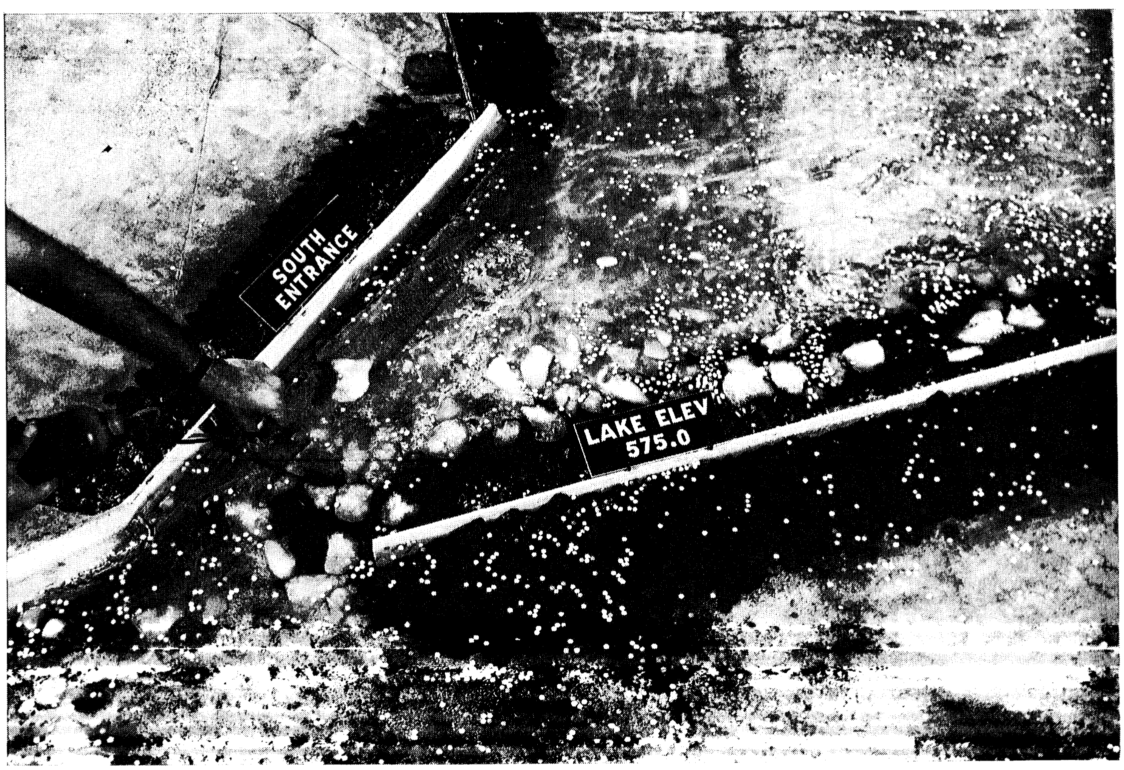

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CHART 37 (183B482-15) Wave heights without enclosure, wave condition E.

CHART 38 (183B482-21) Wave heights with Type A dike, wave condition E.

CHART 39 (183B482-16) Wave heights without enclosure, wave condition F.

CHART 40 (183B482-22) Wave heights with Type A dike, wave condition F.

CHART 41 (183B482-17) Wave heights without enclosure, wave condition G.

CHART 42 (183B482-23) Wave heights with Type A dike, wave condition G.

CHART 43 (183B482-68) Typical wave profile shapes, wave condition B.

CHART 44 (183B482-46) Typical wave profile shapes on stretched time scale, wave condition B.

CHART 45 (183B482-31) Surface currents in model with no waves or wind with Type A dike.

CHART 46 (183B482-32) Currents in model with Type A dike, wave condition B.

CHART 47 (183B482-33) Currents in model with Type A dike, wave condition C.

CHART 48 (183B482-34) Currents in model with Type A dike, wave condition D.

CHART 49 (183B482-35) Currents in model with Type A dike, wave condition E.

CHART 50 (183B482-36) Currents in model with Type A dike, wave condition F.

CHART 51 (183B482-37) Currents in model with Type A dike, wave condition G.

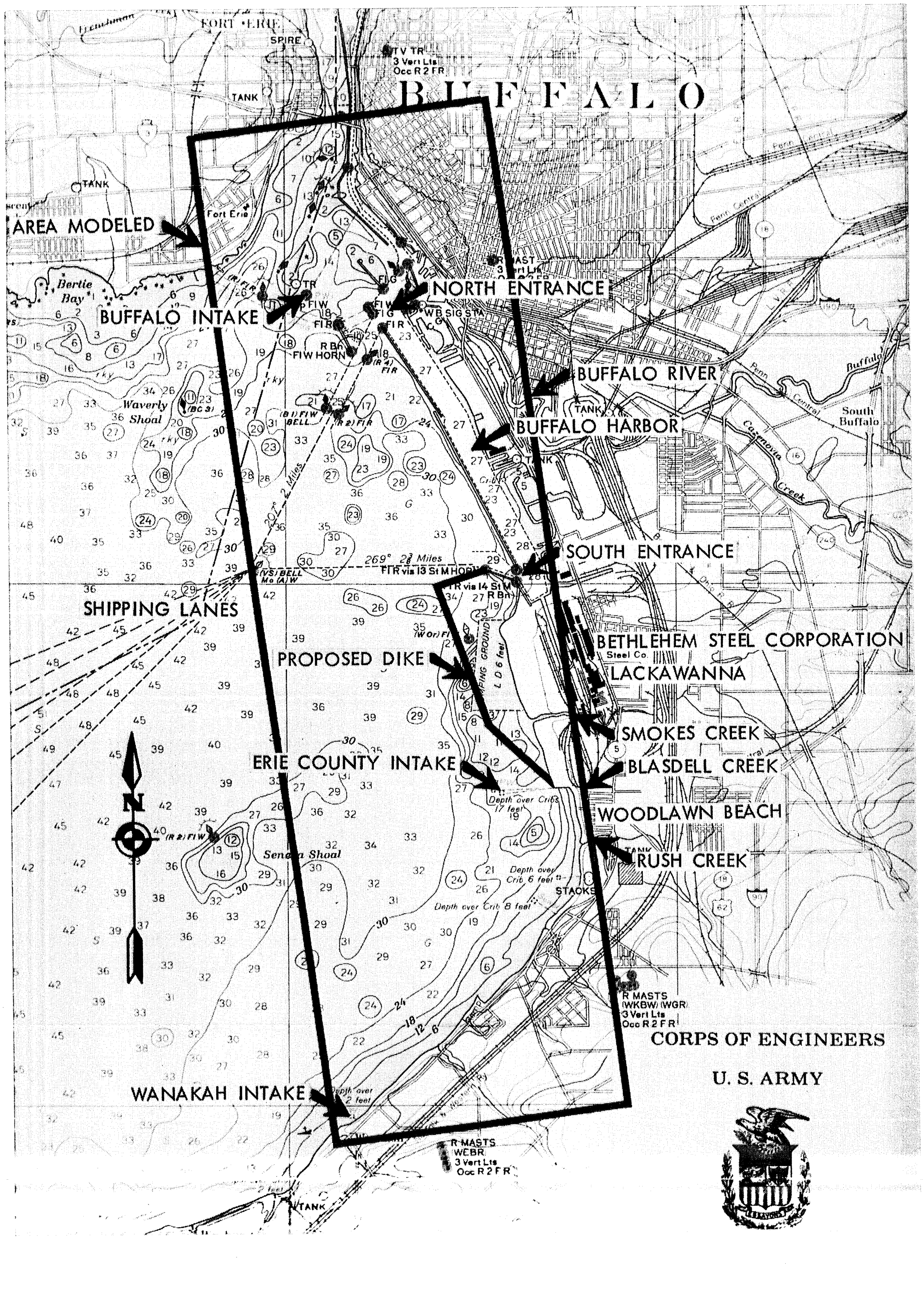
CHART 52 (183B482-40) Littoral drift velocities with Type A dike, wave condition B.

CHART 53 (183B482-41) Littoral drift velocities with Type A dike, wave condition E.

CHART 54 (183B482-44) Littoral drift deposits with Type A dike, wave condition B.

CHART 55 (183B482-45) Littoral drift deposits with Type A dike, wave condition E.

CHART I


BUFFALO
FORT ERIE
AREA MODELED
NORTH ENTRANCE
BUFFALO INTAKE
BUFFALO RIVER
BUFFALO HARBOR
SOUTH ENTRANCE
SHIPPING LANES
BETHLEHEM STEEL CORPORATION
PROPOSED DIKE
LACKAWANNA
SMOKES CREEK
ERIE COUNTY INTAKE
BLASDELL CREEK
WOODLAWN BEACH
RUSH CREEK
WANAKAH INTAKE
Bertie Bay
Waverly Shoal
Seneca Shoal
South Buffalo
N
CORPS OF ENGINEERS
U. S. ARMY

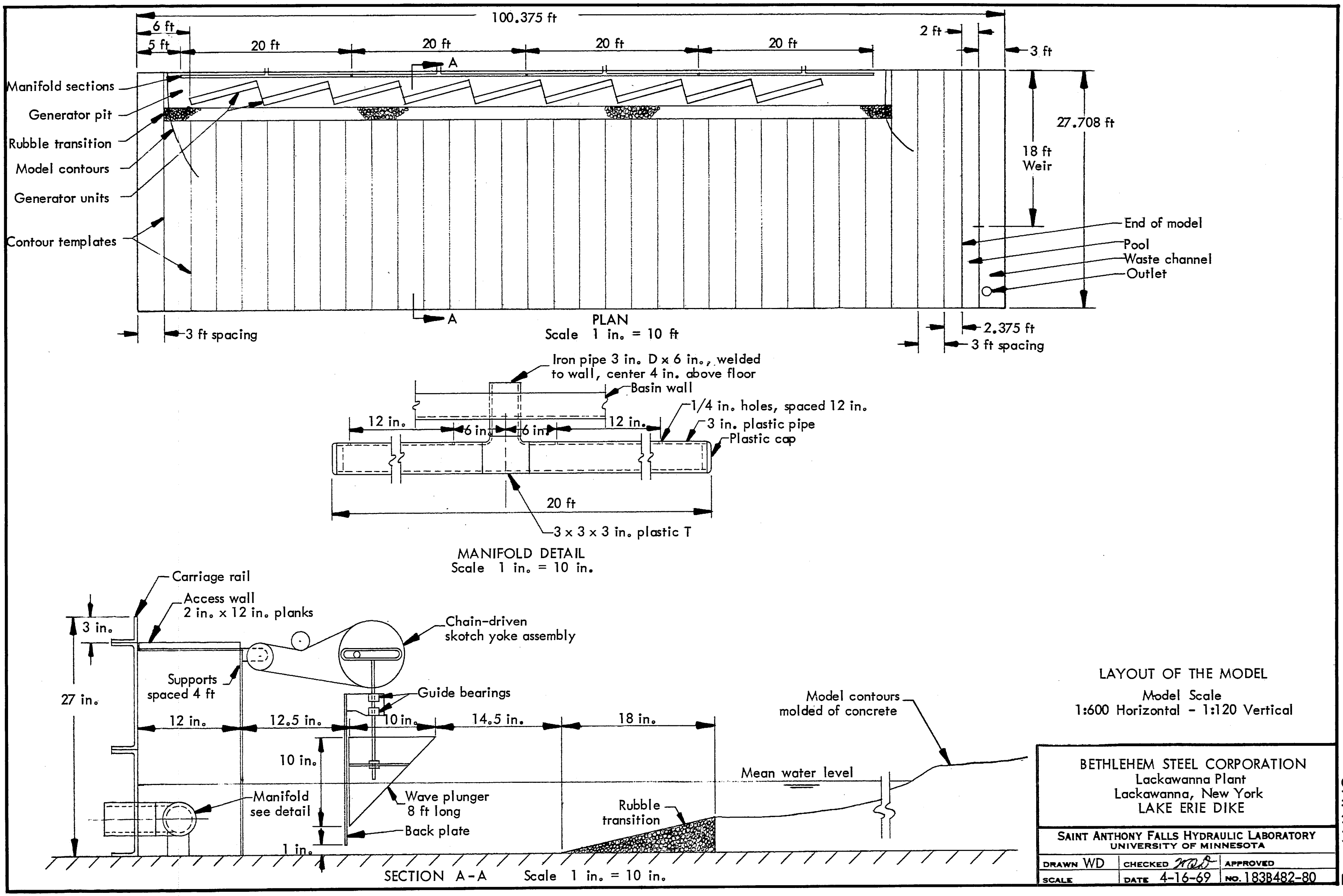
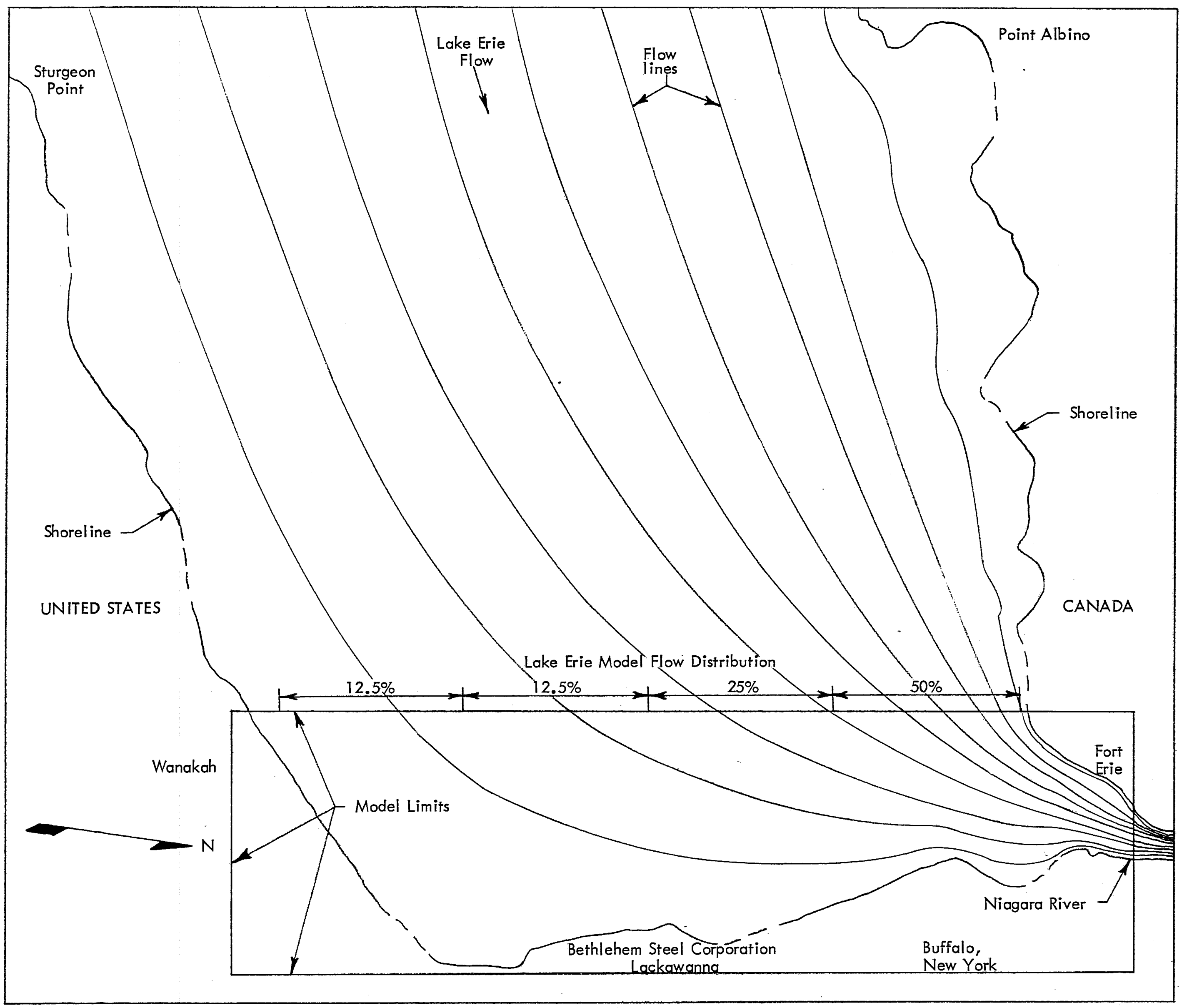

100.375 ft
6 ft
5 ft
20 ft
20 ft
20 ft
20 ft
2 ft
3 ft
A
Manifold sections
Generator pit
Rubble transition
Model contours
Generator units
Contour templates
27.708 ft
18 ft
Weir
End of model
Pool
Waste channel
Outlet
A
3 ft spacing
2.375 ft
3 ft spacing
PLAN
Scale 1 in. = 10 ft
Iron pipe 3 in. D x 6 in., welded to wall, center 4 in. above floor
Basin wall
1/4 in. holes, spaced 12 in.
3 in. plastic pipe
Plastic cap
12 in.
6 in.
6 in.
12 in.
20 ft
3 x 3 x 3 in. plastic T
MANIFOLD DETAIL
Scale 1 in. = 10 in.
Carriage rail
Access wall
2 in. x 12 in. planks
Chain-driven
skotch yoke assembly
3 in.
27 in.
Supports
spaced 4 ft
Guide bearings
12 in.
12.5 in.
10 in.
14.5 in.
18 in.
10 in.
Manifold
see detail
Wave plunger
8 ft long
Back plate
1 in.
Rubble
transition
Mean water level
Model contours
molded of concrete
SECTION A-A Scale 1 in. = 10 in.
LAYOUT OF THE MODEL
Model Scale
1:600 Horizontal - 1:120 Vertical
BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN WD
CHECKED
APPROVED
SCALE
DATE 4-16-69
NO. 183B482-80

CHART 2



FLOW PATTERN FROM LAKE ERIE
TO NIAGARA RIVER
Obtained by Electric Analog Field Plotter
Model Scale
1:600 Horizontal, 1:120 Vertical

BETHLEHEM STEEL CORPORATION
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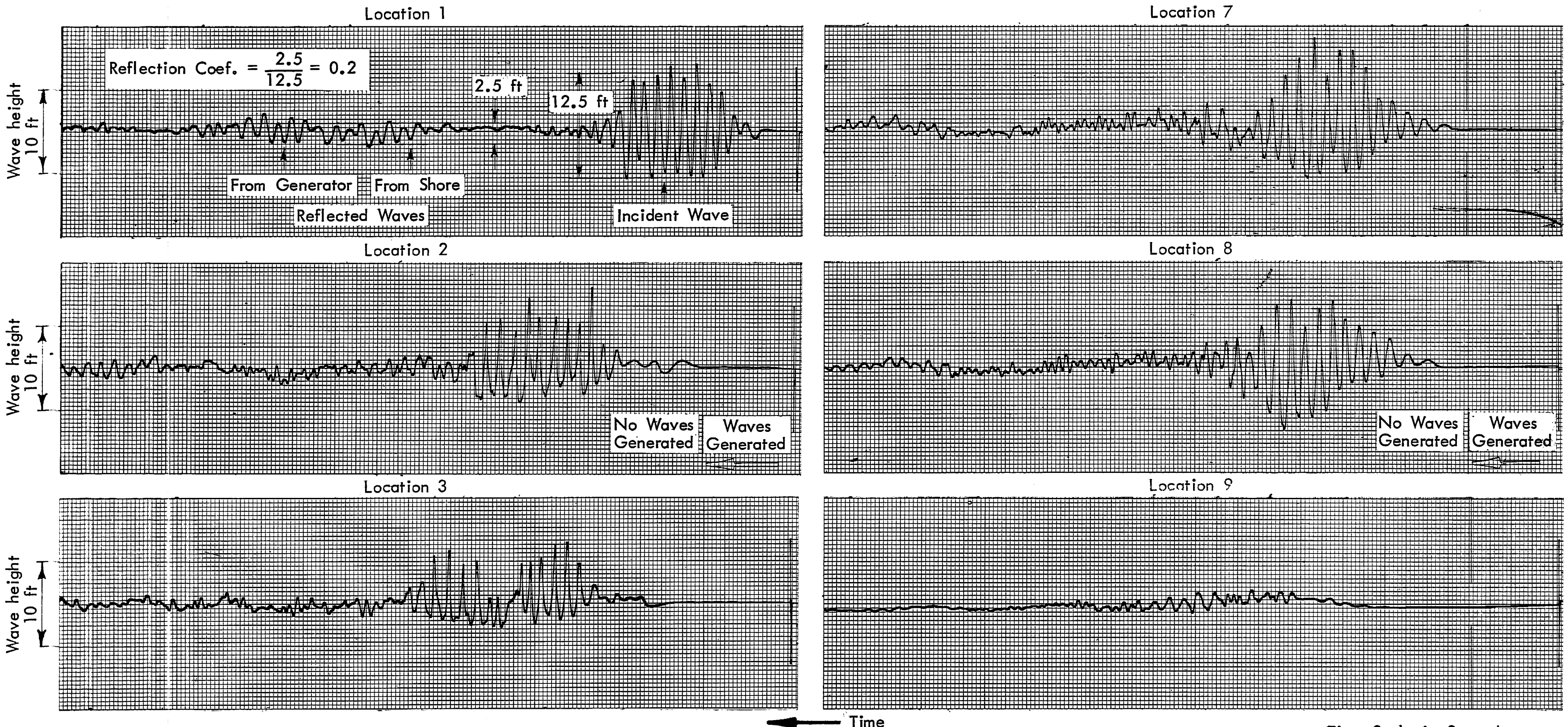
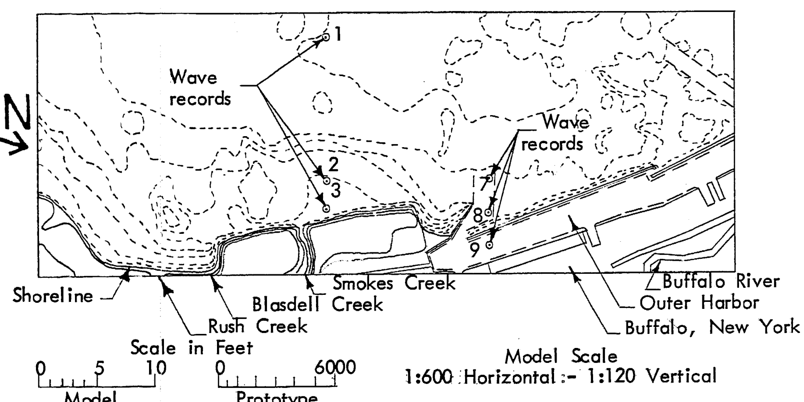
UNIVERSITY OF MINNESOTA

DRAWN - JF	CHECKED WBJ	APPROVED
SCALE	DATE 12-3-68	NO. 183B482-4

CHART 3





Model Scale
1:600 Horizontal :- 1:120 Vertical

WAVE REFLECTIONS AT SELECTED LOCATIONS
FOR ORIGINAL CONDITIONS

Flow Conditions
12 ft x 7 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft

Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave profiles obtained using a 2-wire capacitance type wave probe.

Time Scale in Seconds
0 5
Model
0 50
Prototype

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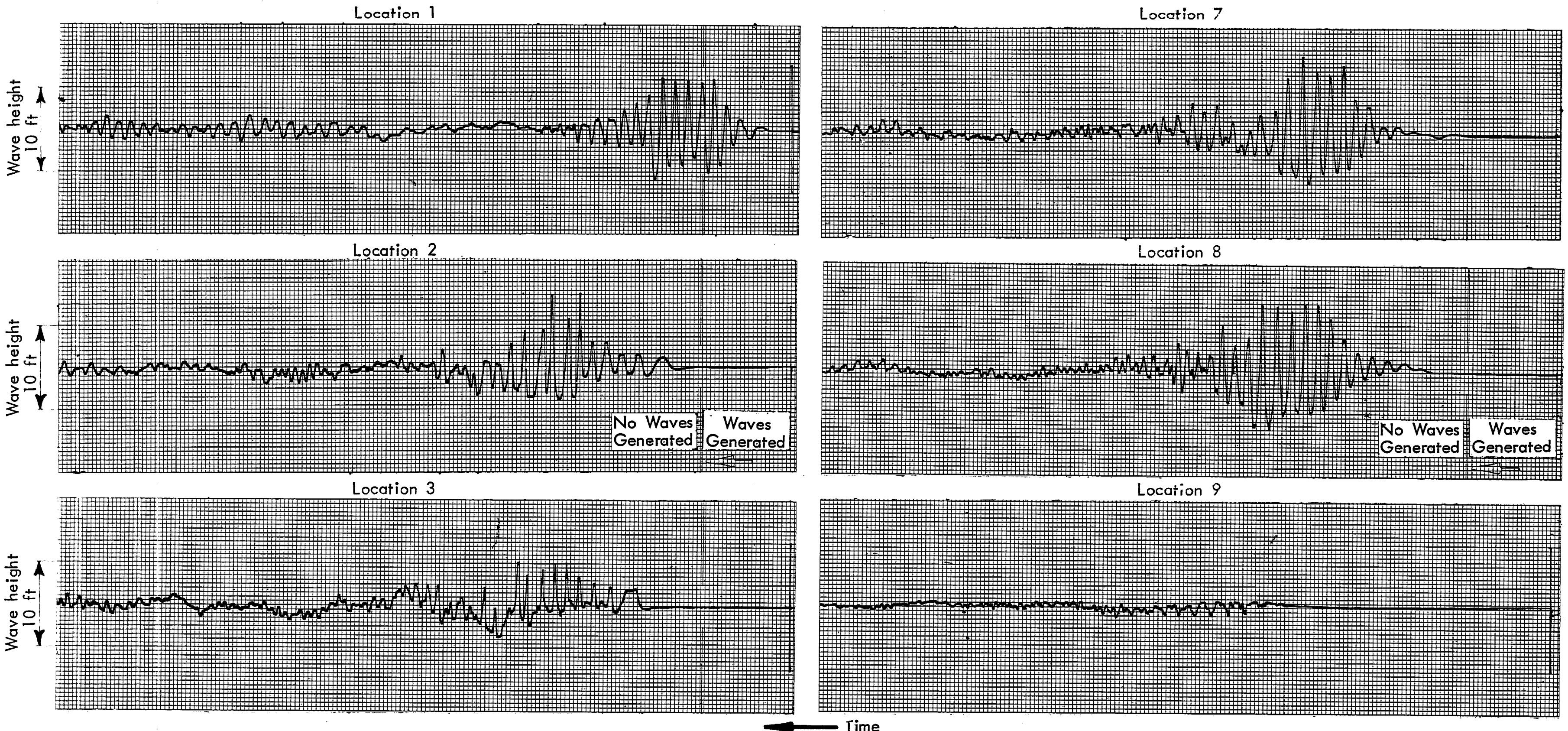
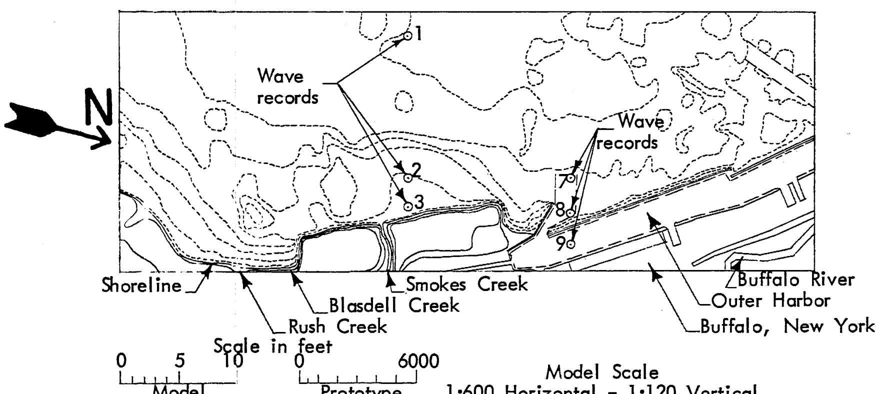
DRAWN JF	CHECKED [signature]	APPROVED
SCALE	DATE 3-17-69	NO. 183B482-70

CHART 4



Time Scale in Seconds
0 5
Model
0 50
Prototype



Model Scale
1:600 Horizontal - 1:120 Vertical

WAVE REFLECTIONS AT SELECTED LOCATIONS FOR ORIGINAL CONDITIONS

Flow Conditions
12 ft x 7 sec Waves from the West
Lake Erie Elevation = 575.0 ft

Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave profiles obtained using a 2-wire capacitance type wave probe.

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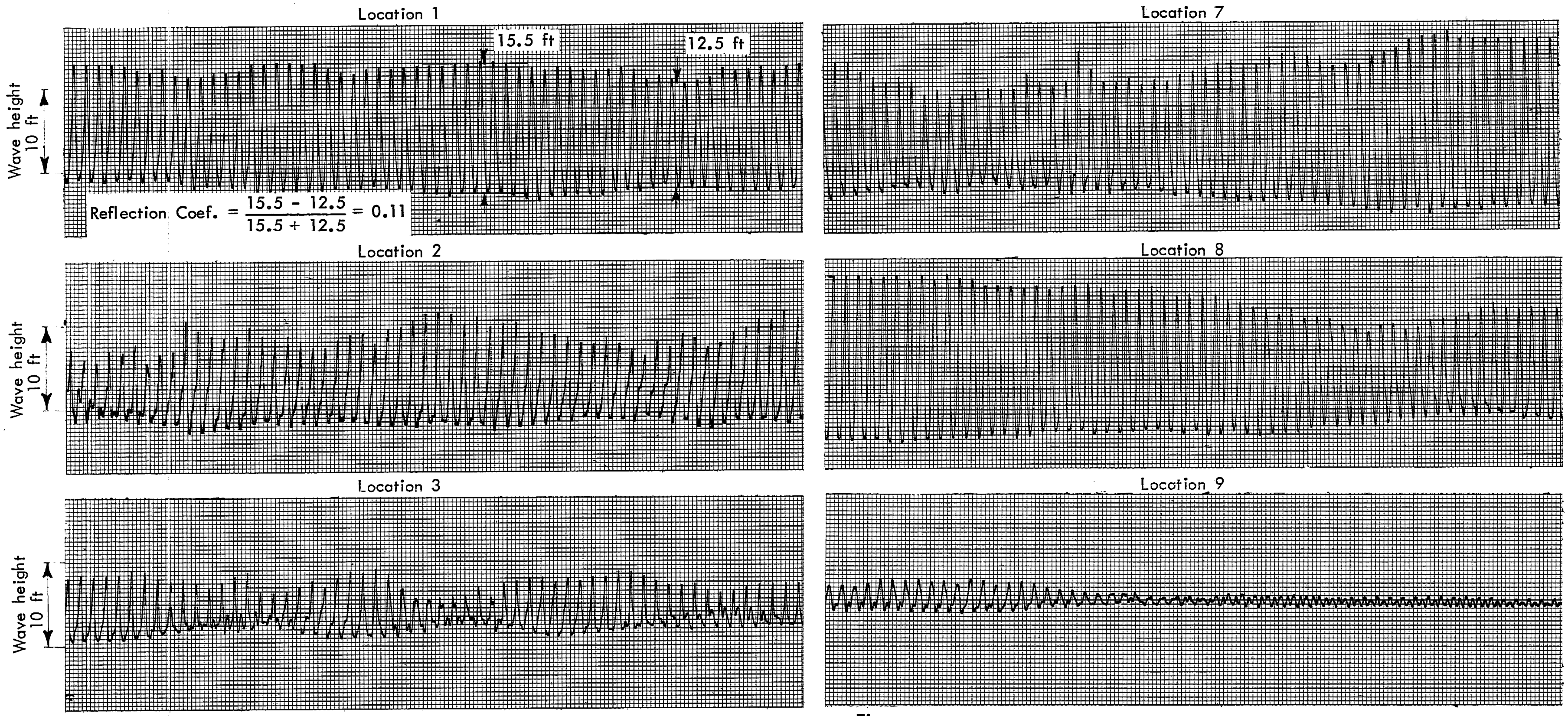
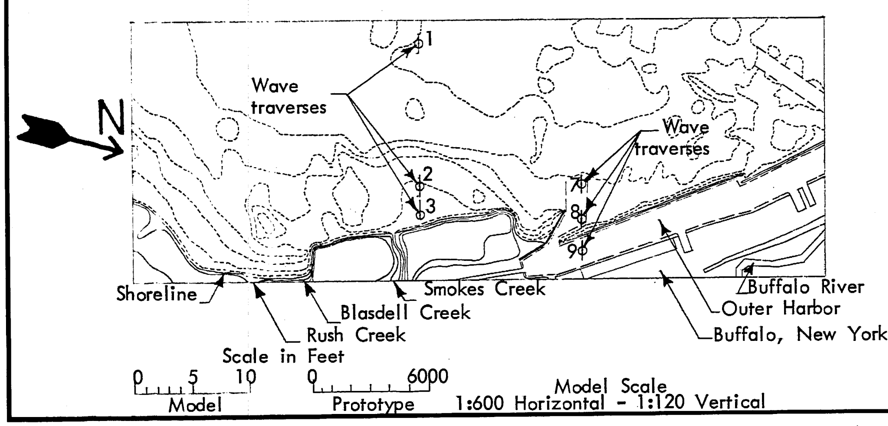
DRAWN WG	CHECKED [illegible]	APPROVED
SCALE	DATE 3-17-69	NO. 183B482-67

CHART 5



← Time



WAVE TRAVERSES AT SELECTED LOCATIONS
FOR ORIGINAL CONDITIONS

Flow Conditions

12 ft x 7 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft

Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave profiles obtained using a 2-wire capacitance type wave probe.

Time Scale in Seconds

0 5
Model

0 50
Prototype

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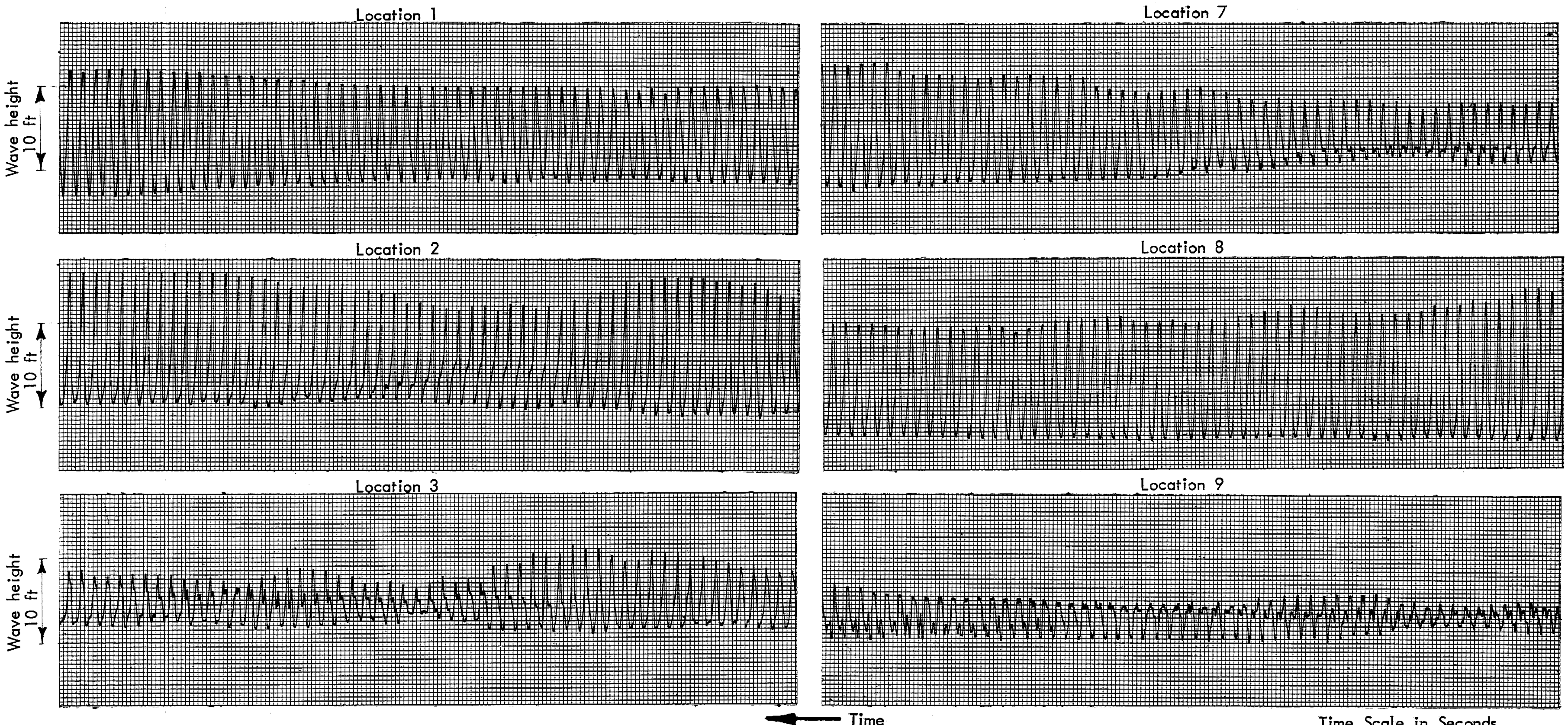
UNIVERSITY OF MINNESOTA

DRAWN WG	CHECKED	APPROVED
SCALE	DATE 3-17-69	NO. 183B482-69

CHART 6



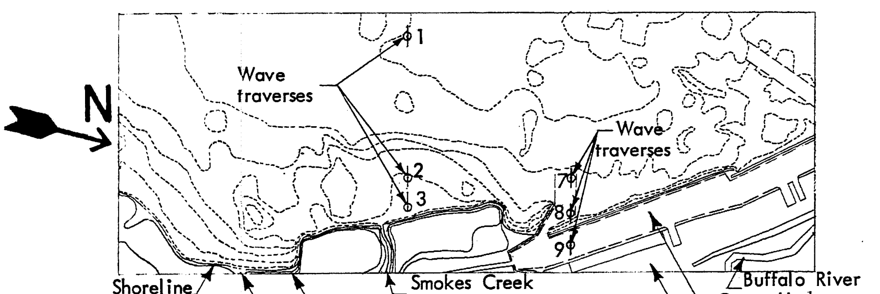
Time Scale in Seconds
0 5
Model
0 50
Prototype

WAVE TRAVERSES AT SELECTED LOCATIONS FOR ORIGINAL CONDITIONS

Flow Conditions
12 ft x 7 sec Waves from the West
Lake Erie Elevation = 575.0 ft

Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave profiles obtained using a 2-wire capacitance type wave probe.



Scale in feet
0 5 10 Model
0 6000 Prototype

Model Scale
1:600 Horizontal - 1:120 Vertical

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Lackawanna, New York
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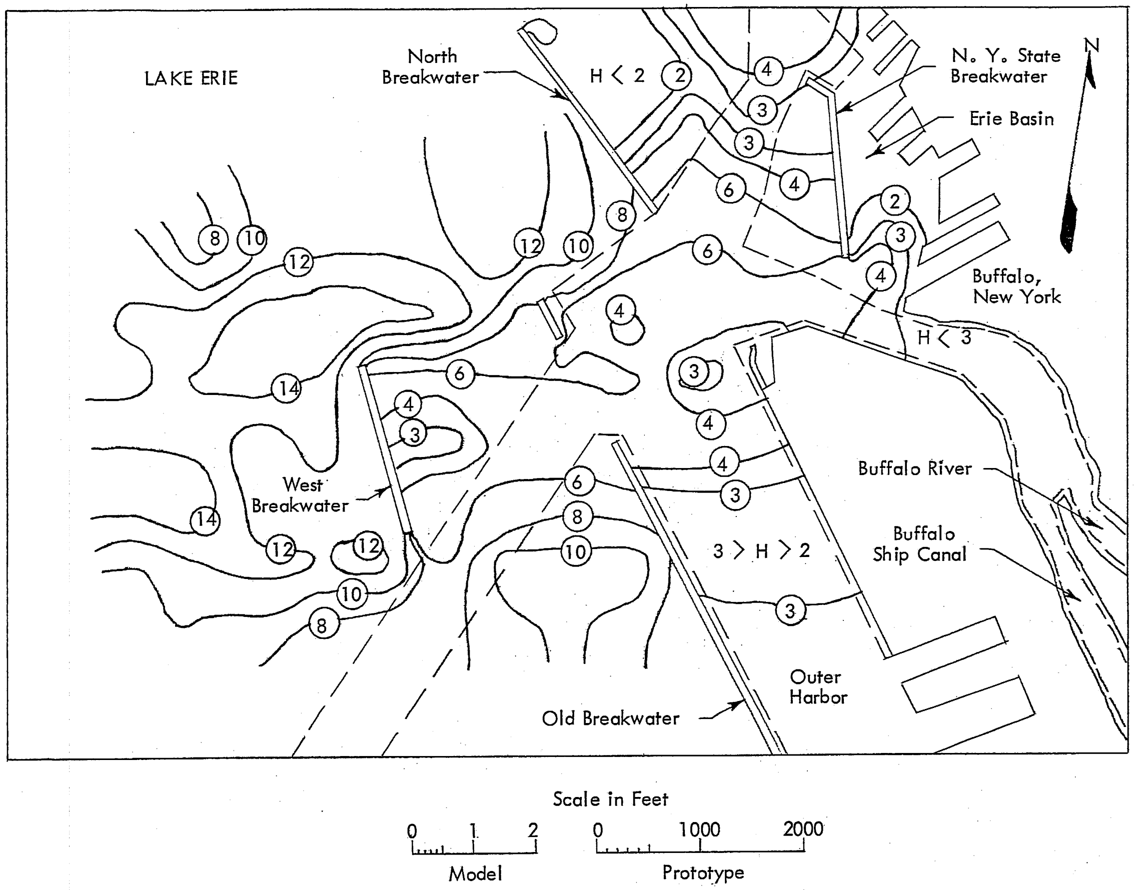
DRAWN WG	CHECKED [signature]	APPROVED
SCALE	DATE 3-17-69	NO. 183B482-66

CHART 7



MODEL BEHAVIOR, ORIGINAL CONDITIONS
Wave Height Contours in Feet
Model Scale
1:600 Horizontal - 1:120 Vertical

Flow Conditions
Lake Erie Elevation = 575 ft
Niagara River Discharge = 300,000 cfs
12 ft x 7 sec Waves from S 67 1/2° W

Wave heights were recorded using a 2-wire capacitance type wave probe. Contours were plotted using recorded heights as guides.

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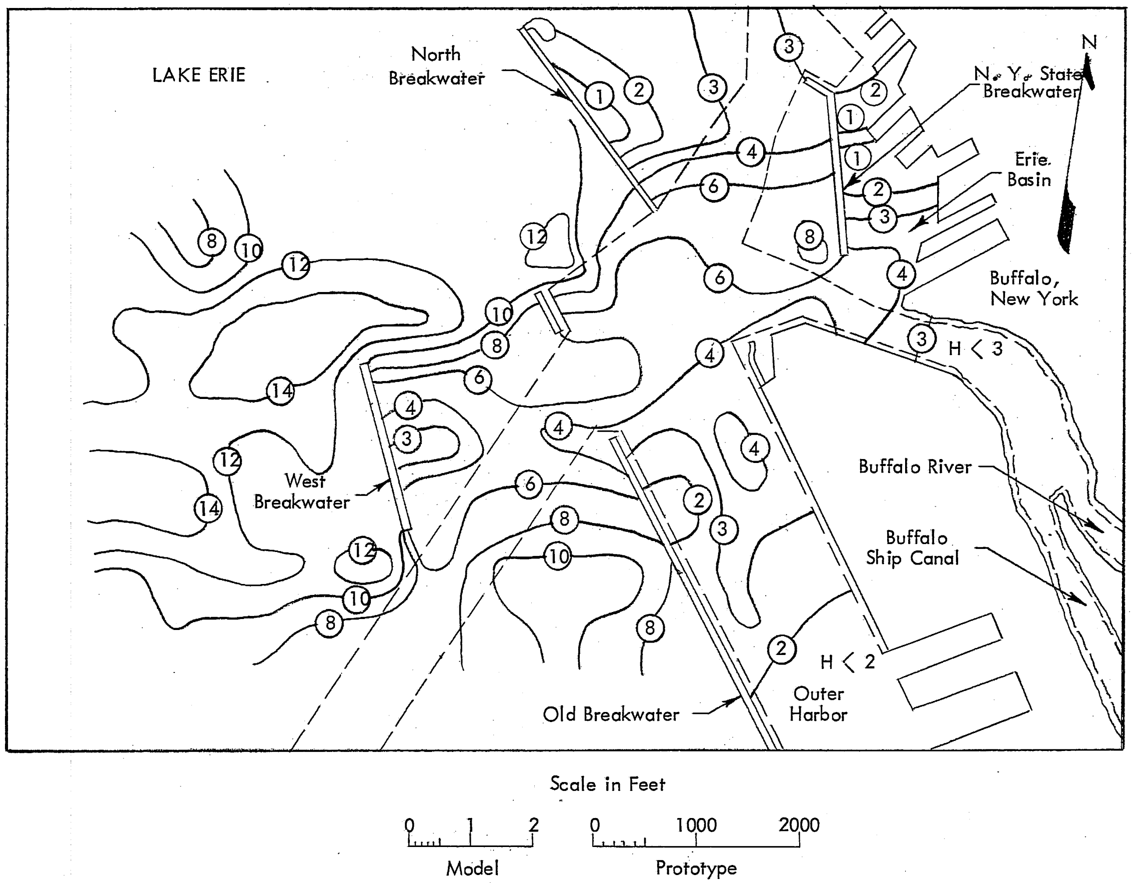
DRAWN JF	CHECKED [illegible]	APPROVED
SCALE	DATE 12-4-68	NO. 183B482-5

CHART 8



MODEL BEHAVIOR, ORIGINAL CONDITIONS
Wave Height Contours in Feet
Model Scale
1:600 Horizontal - 1:120 Vertical

Flow Conditions
Lake Erie Elevation = 575 ft
Niagara River Discharge = 300,000 cfs
12 ft x 7 sec Waves From S 67 1/2° W

Wave heights were recorded using a 2-wire capacitance type wave probe and contours plotted. The Old Breakwater was raised 10 ft (prototype scale) to prevent overtopping.

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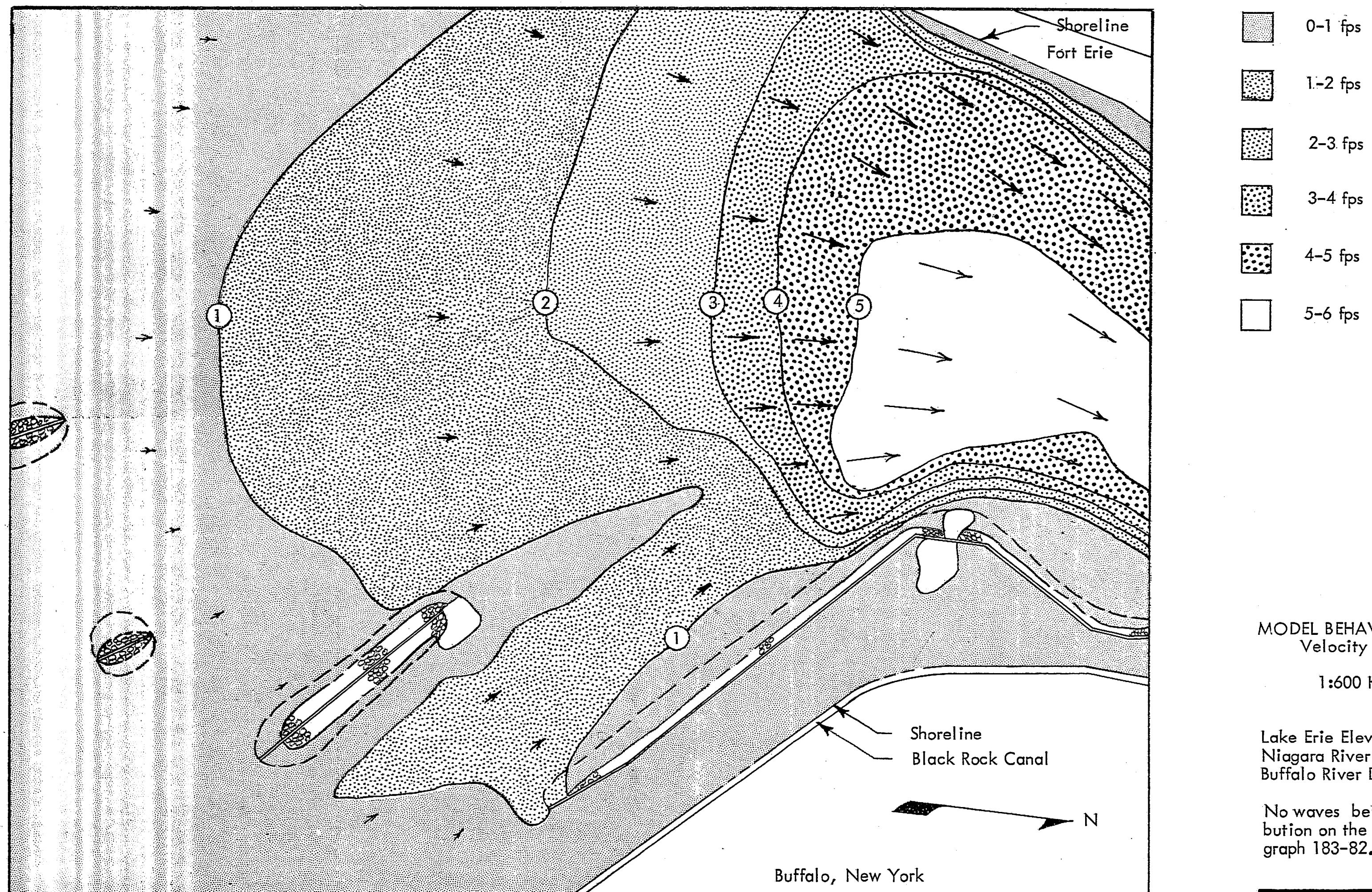
DRAWN JF	CHECKED [illegible]	APPROVED
SCALE	DATE 12-4-68	NO. 183B482-6

CHART 9



MODEL BEHAVIOR, ORIGINAL CONDITIONS
Velocity Distribution on Water Surface
Model Scale
1:600 Horizontal - 1:120 Vertical

Flow Conditions
Lake Erie Elevation = 569 ft
Niagara River Discharge = 160,000 cfs
Buffalo River Discharge = 520 cfs

No waves being generated. Velocity Distribution on the water surface taken from Photograph 183-82.

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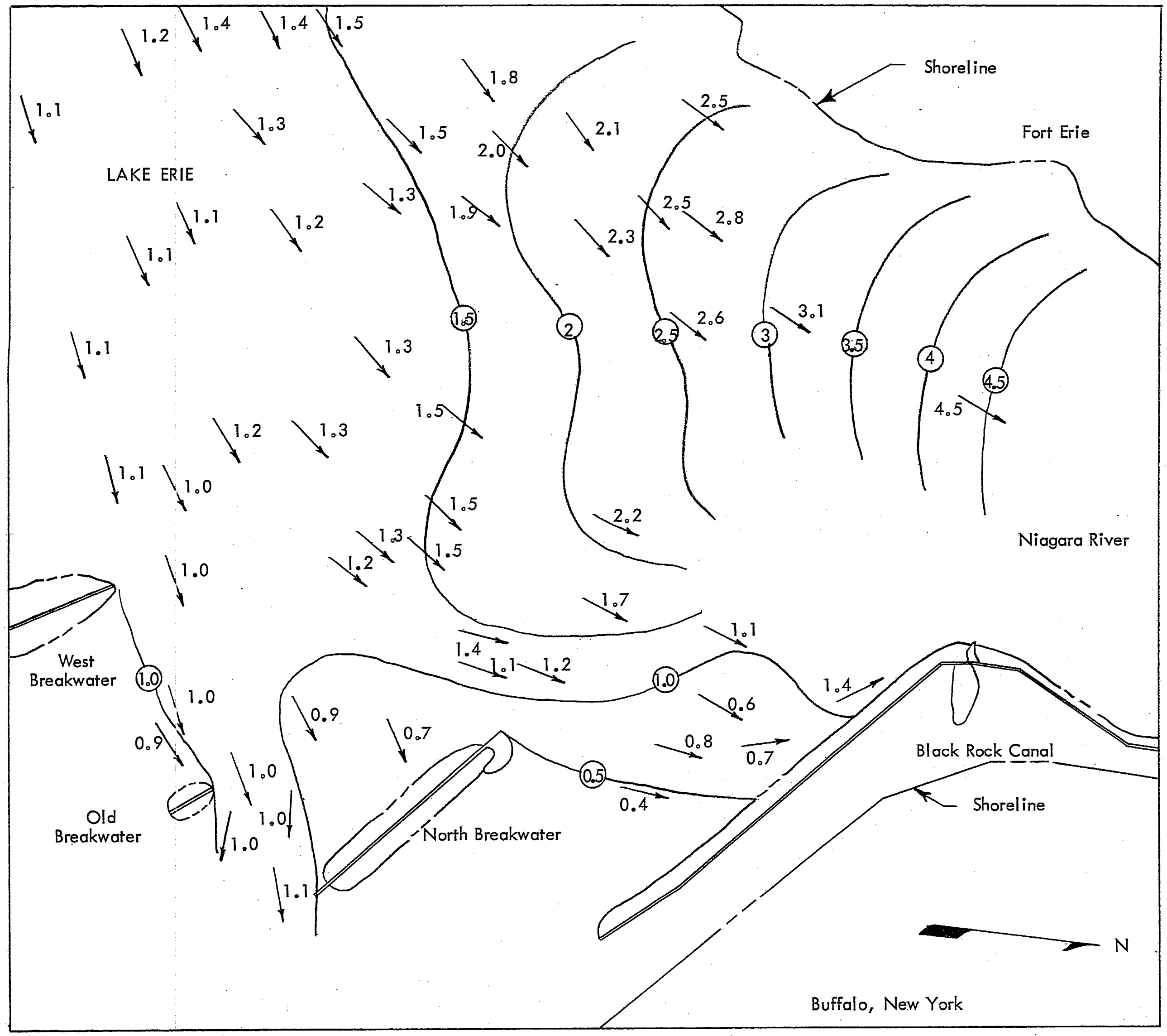
DRAWN RP	CHECKED HGS	APPROVED
SCALE	DATE 12-4-68	NO. 183B482-8

CHART 10



ENTRANCE TO NIAGARA RIVER
Velocities of Ice Floes
Flow Conditions

Lake Erie Elevation = 570.94 ft
Niagara River Discharge = 160,000 cfs
Wind Velocity 18-20 mph, W. by N.W.
Temperature 19°

Velocity readings in fps and flow directions were obtained from aerial photographs of ice floes. The information presented on this chart is reproduced from drawing No. 210-ℓ-1031 R of the Hydro-Electric Power Commission of Ontario, dated February 4, 1964.

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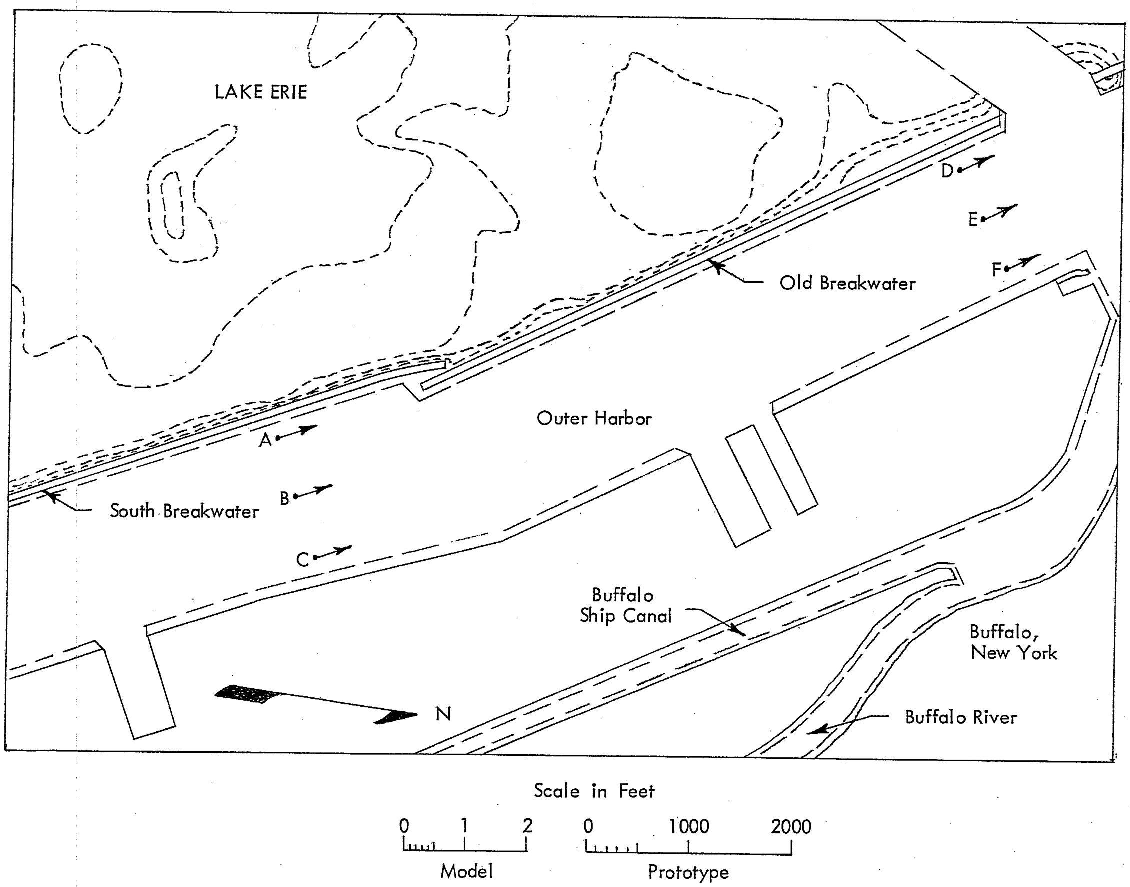
DRAWN RP	CHECKED [signature]	APPROVED
SCALE	DATE 12-4-68	NO. 183B482-9

CHART 11



Location	Velocities in fps		
	Model Observations	Prototype Observations	
		Near bottom	10 ft from top
A	0.28	0.24	
B	0.45	0.28	0.37
C	0.32	0.29	0.46
D	0.38		
E	0.65	0.37	0.45
F	0.51		

MODEL BEHAVIOR, ORIGINAL CONDITIONS
Velocities in Buffalo Outer Harbor
Model Scale
1:600 Horizontal - 1:120 Vertical

Flow Conditions
Lake Erie Elevation = 568.3 ft
Niagara River Discharge = 153,300 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs
No waves being generated.

Model velocity readings in the Buffalo Outer Harbor are compared to actual measurements made by the Buffalo District Corps of Engineers at the prototype site on February 24, 1965. Prototype measurements were made under ice and model measurements on the water surface.

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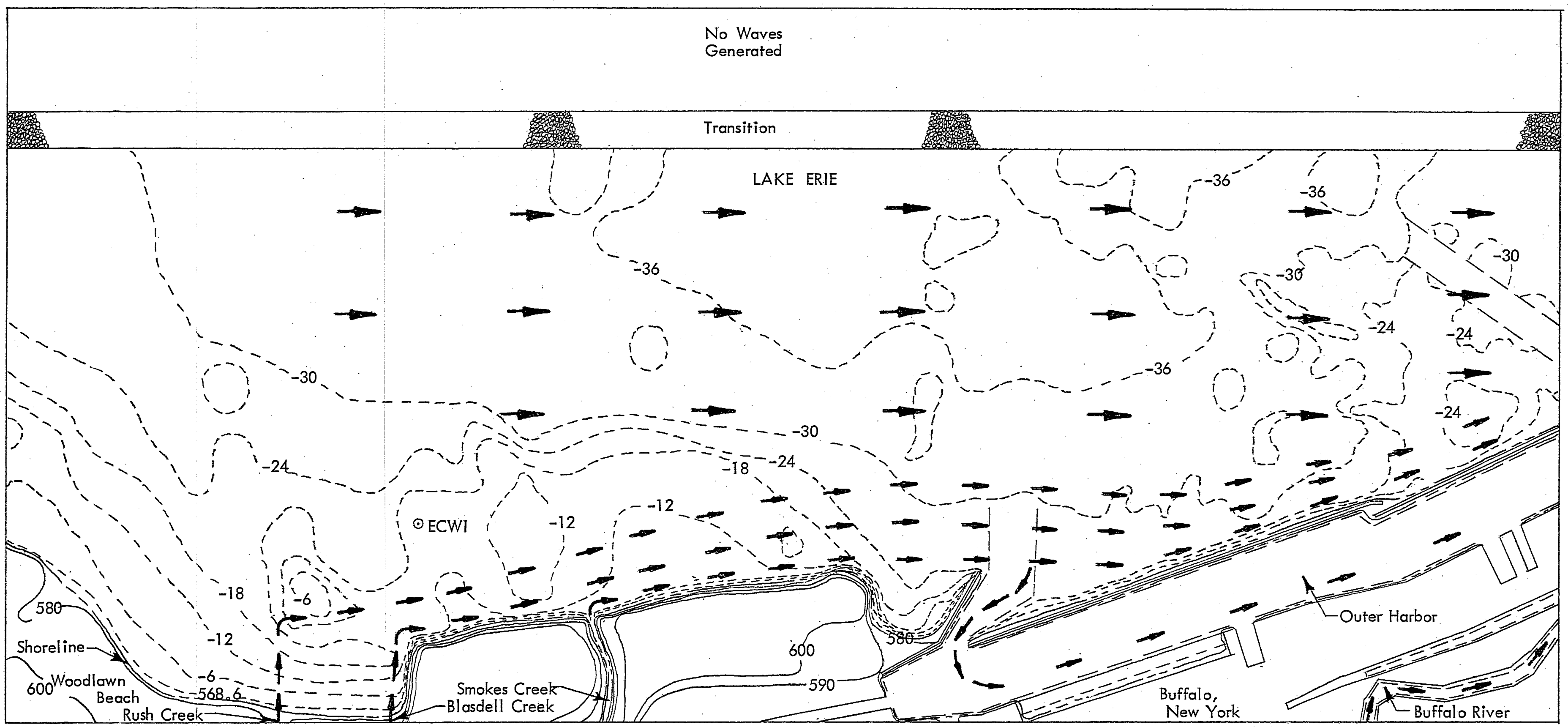
DRAWN JF	CHECKED [signature]	APPROVED
SCALE	DATE 12-4-68	NO. 183B482-10

CHART 12



Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

Lake Erie Currents

Creek Currents

MODEL BEHAVIOR, ORIGINAL CONDITIONS

Lake Erie and Creek Currents

Without Waves

Flow Conditions

Lake Erie Elevation = 570.6 ft

Niagara River Discharge = 200,000 cfs

Buffalo River Discharge = 520 cfs

Smokes Creek Discharge = 200 cfs

Blasdell Creek Discharge = 46 cfs

Rush Creek Discharge = 13 cfs

Currents obtained using red dye and paper confetti.

N

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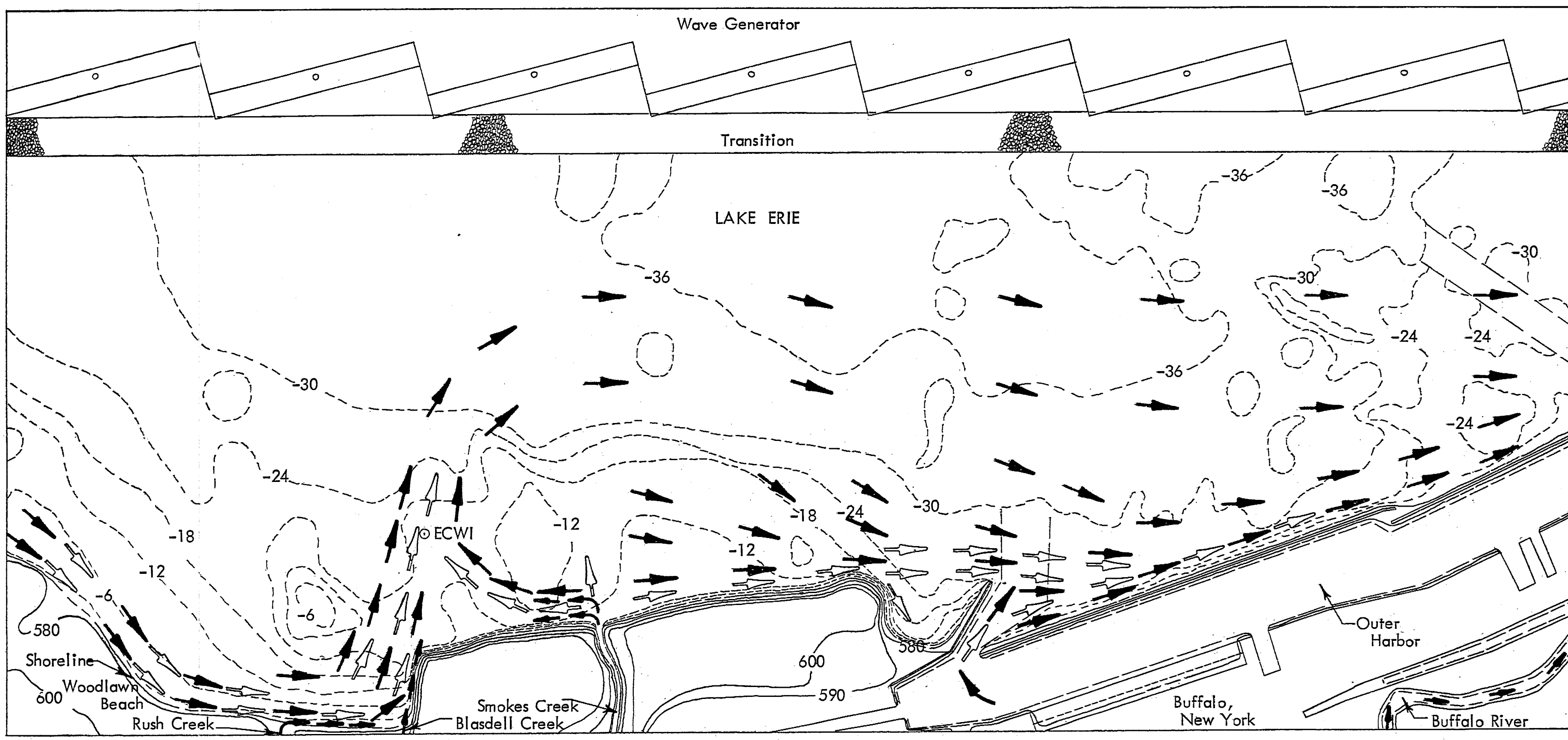
DRAWN WD	CHECKED	APPROVED
SCALE	DATE 2-26-69	NO. 183B482-24

CHART 13



Scale in Feet
0 5 — Model
0 3000 — Prototype

Model Scale
1:600 Horizontal - 1:120 Vertical

Surface Currents
Littoral Drift Currents
Creek Currents

N

MODEL BEHAVIOR, ORIGINAL CONDITIONS
Surface, Littoral Drift, and Creek Currents

Flow Conditions
12 ft x 7 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Currents obtained using red dye and paper confetti.

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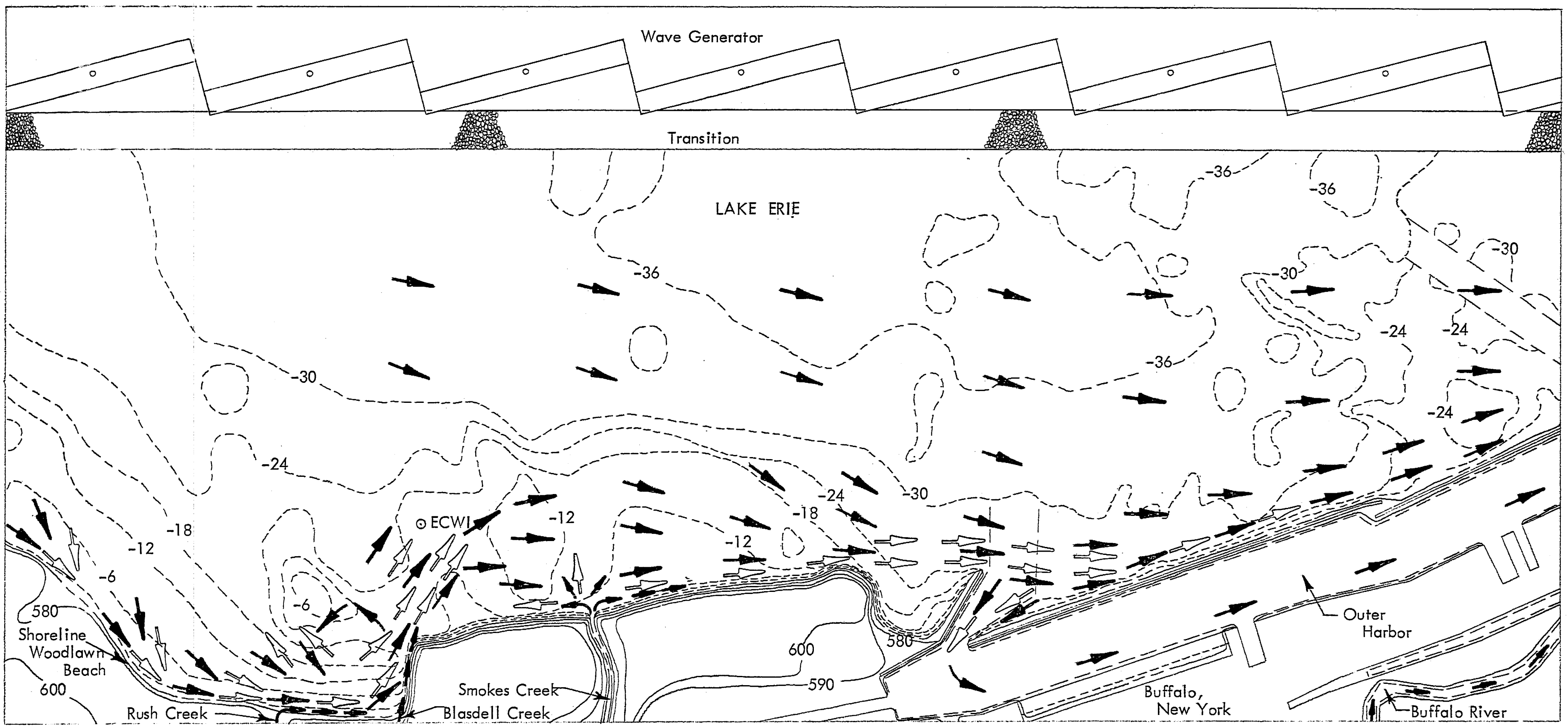
DRAWN WD	CHECKED	APPROVED
SCALE	DATE 2-26-69	NO. 183B482-25

CHART 14



Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

Surface Currents

Littoral Drift Currents

Creek Currents

MODEL BEHAVIOR, ORIGINAL CONDITIONS

Surface, Littoral Drift, and Creek Currents

Flow Conditions

6 ft x 4 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Currents obtained using red dye and paper confetti.

N

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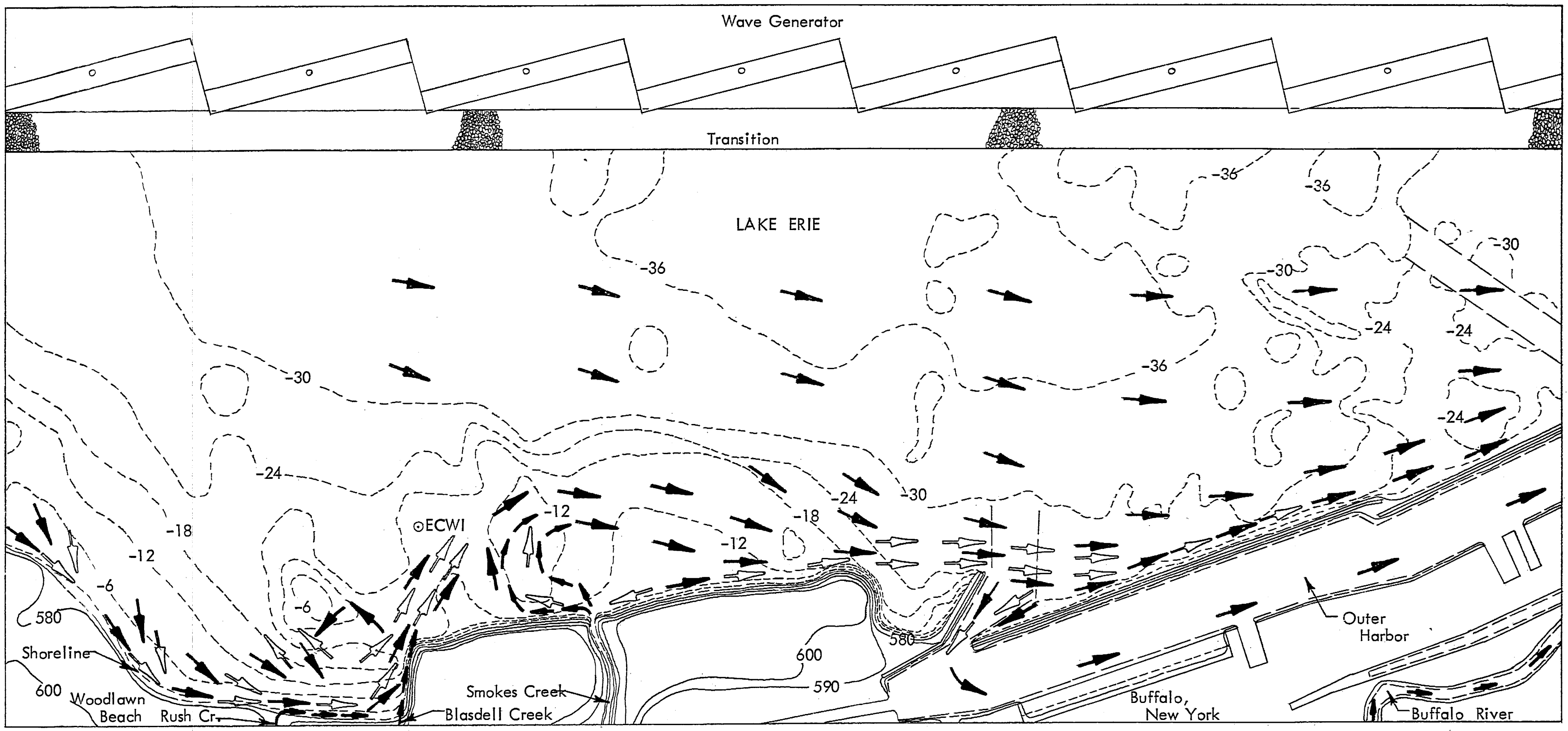
DRAWN WD	CHECKED	APPROVED
SCALE	DATE 2-26-69	NO. 183B482-26

CHART 15



Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

Surface Currents

Littoral Drift Currents

Creek Currents

MODEL BEHAVIOR, ORIGINAL CONDITIONS

Surface, Littoral Drift, and Creek Currents

N

Flow Conditions

6 ft x 4 sec Waves from S 67-1/2° W

Lake Erie Elevation = 570.6 ft

Niagara River Discharge = 200,000 cfs

Buffalo River Discharge = 520 cfs

Smokes Creek Discharge = 200 cfs

Blasdell Creek Discharge = 46 cfs

Rush Creek Discharge = 13 cfs

Currents obtained using red dye and paper confetti.

BETHLEHEM STEEL CORPORATION

Lackawanna Plant

Lackawanna, New York

LAKE ERIE DIKE

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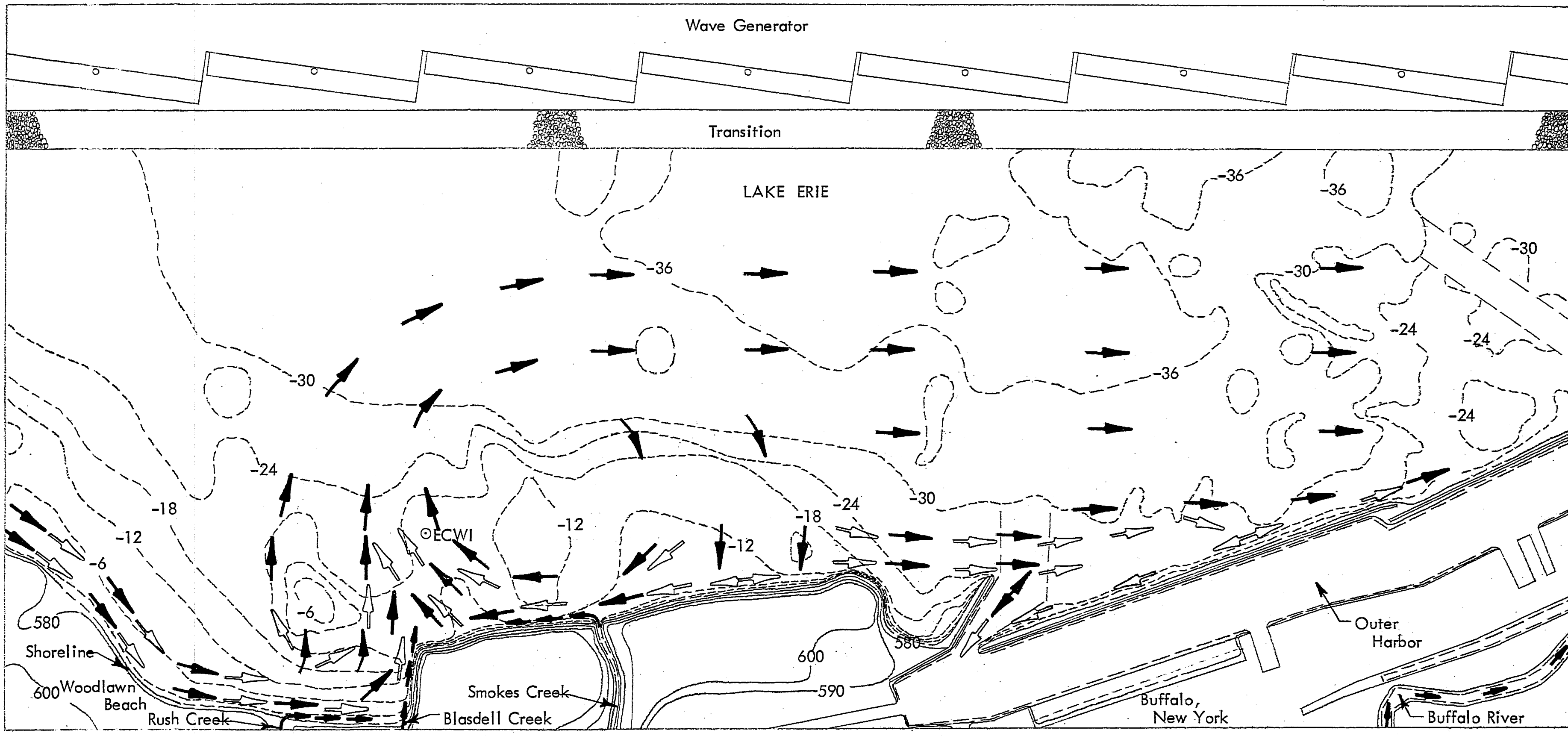
DRAWN DF	CHECKED WQD	APPROVED
SCALE	DATE 2-26-69	NO. 18?B482-27

CHART 16



Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

Surface Currents

Littoral Drift Currents

Creek Currents

N

MODEL BEHAVIOR, ORIGINAL CONDITIONS

Surface, Littoral Drift, and Creek Currents

Flow Conditions

12 ft x 7 sec Waves from the West
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Currents obtained using red dye and paper confetti.

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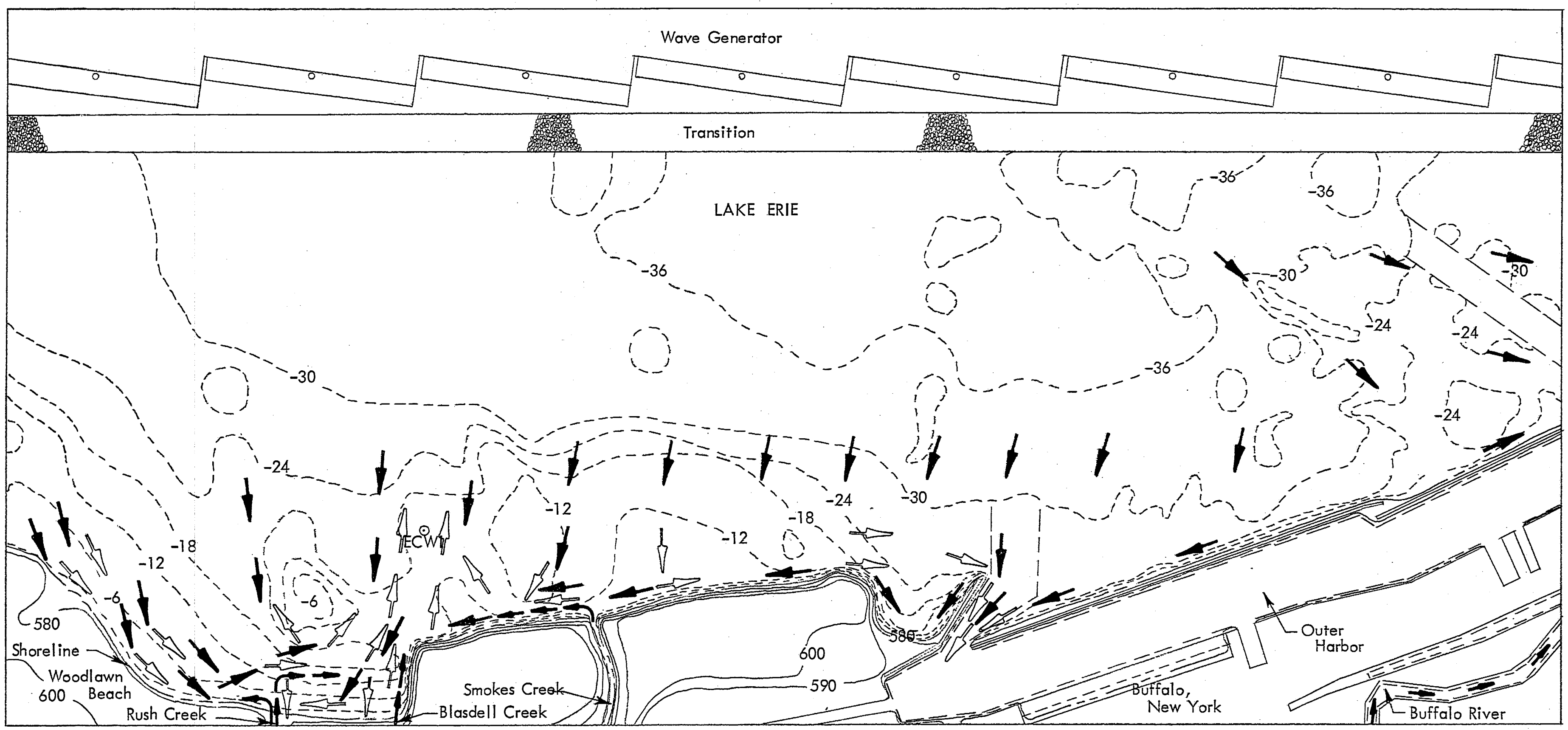
DRAWN WG	CHECKED [illegible]	APPROVED
SCALE	DATE 2-26-69	NO. 183B482-28

CHART 17



Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal – 1:120 Vertical

Surface Currents

Littoral Drift Currents

Creek Currents

MODEL BEHAVIOR, ORIGINAL CONDITIONS
Surface, Littoral Drift, and Creek Currents

Flow Conditions
6 ft x 4 sec Waves from the West
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Currents obtained using red dye and paper confetti.

N

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Lackawanna, New York
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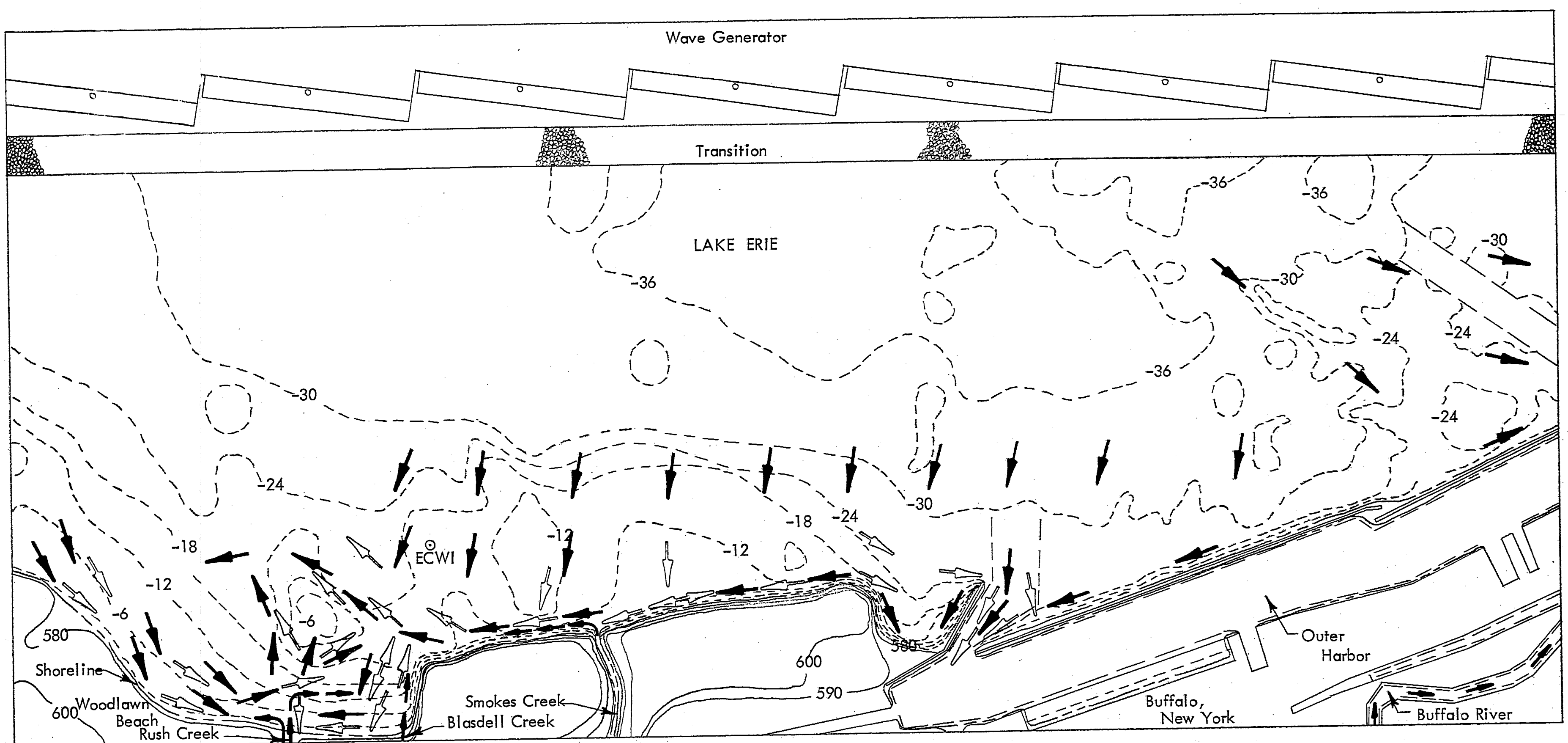
DRAWN WG	CHECKED	APPROVED
SCALE	DATE 2-26-69	NO. 183B482-29

CHART 18



N

Surface Currents

Littoral Drift Currents

Creek Currents

Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal – 1:120 Vertical

MODEL BEHAVIOR, ORIGINAL CONDITIONS

Surface, Littoral Drift, and Creek Currents

Flow Conditions

6 ft x 4 sec Waves from the West
Lake Erie Elevation = 570.6 ft
Niagara River Discharge = 200,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Currents obtained using red dye and paper confetti.

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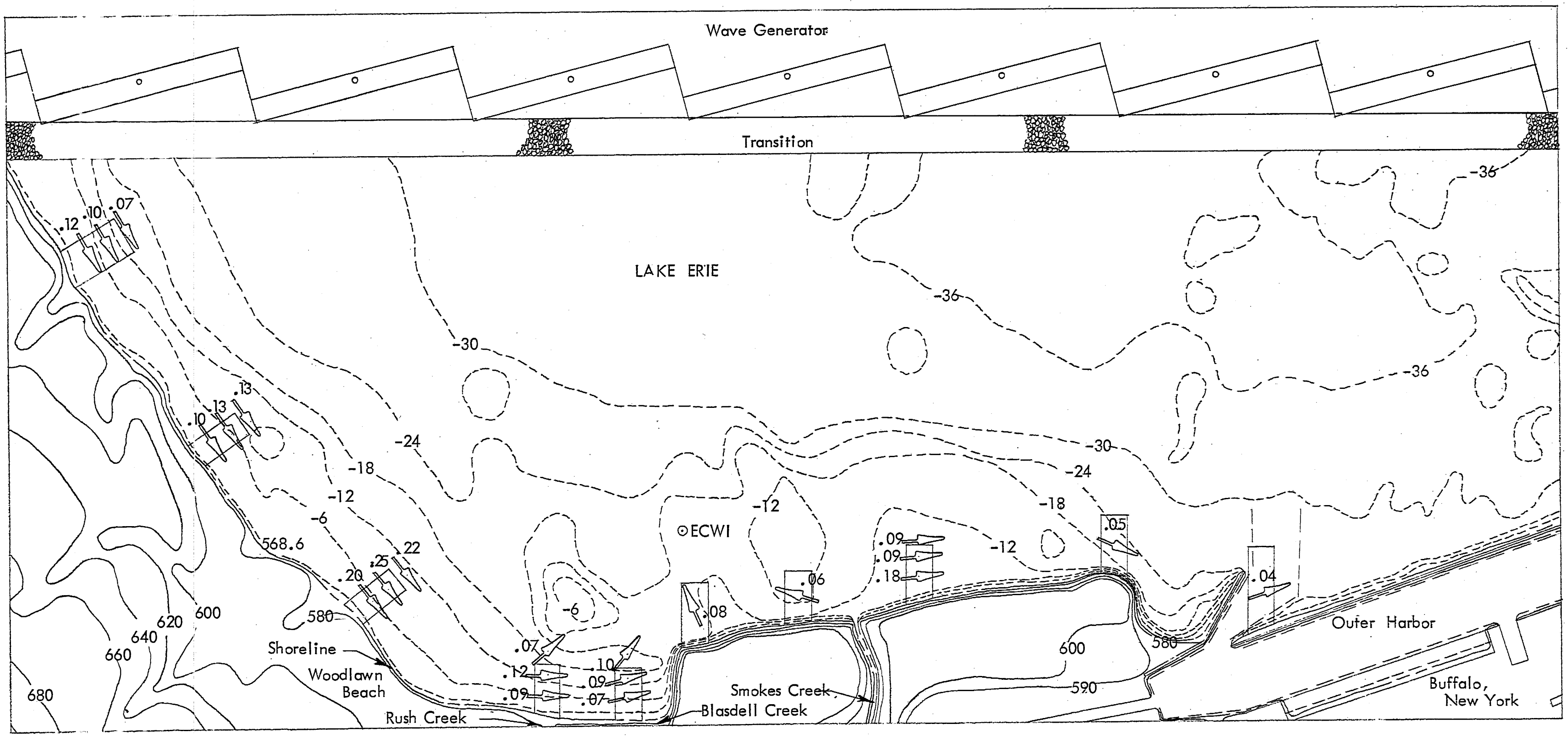
DRAWN JF	CHECKED	APPROVED
SCALE	DATE 2-26-69	NO. 183B482-30

CHART 19



MODEL BEHAVIOR, ORIGINAL CONDITIONS
Littoral Drift Velocities

Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

Flow Conditions

12 ft x 7 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Littoral drift velocities were estimated using a 1/8 in. diameter plastic sphere with a specific gravity of 1.3. Velocities are in fps model.

BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York

LAKE ERIE DIKE

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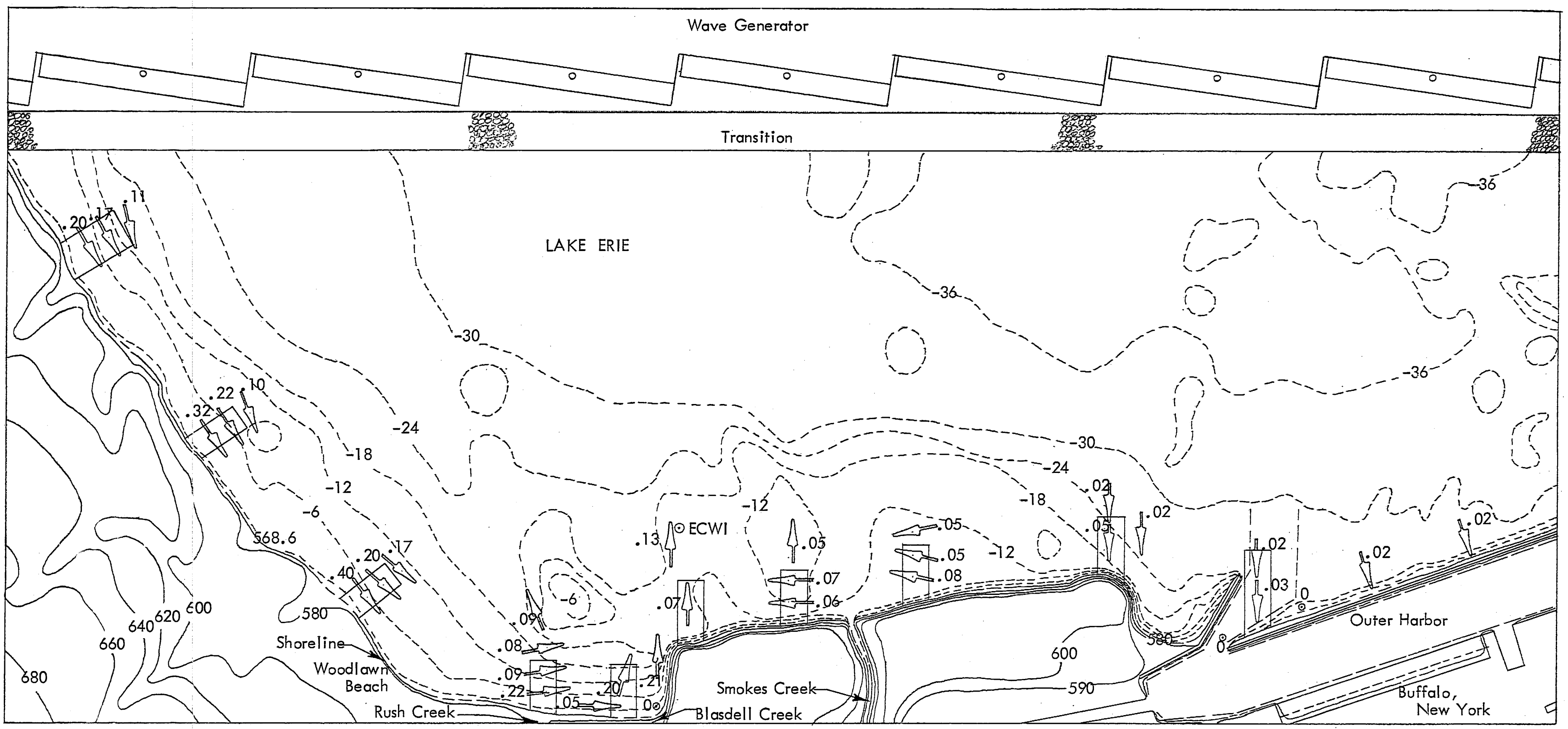
UNIVERSITY OF MINNESOTA

DRAWN WD	CHECKED	APPROVED
SCALE	DATE 2-27-69	NO. 183B482-38

CHART 20



MODEL BEHAVIOR, ORIGINAL CONDITIONS
Littoral Drift Velocities

Scale in Feet
0 5 Model
0 3000 Prototype

Model Scale
1:600 Horizontal - 1:120 Vertical

Flow Conditions
12 ft x 7 sec Waves from the West
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Littoral drift velocities were estimated using a 1/8 in. diameter plastic sphere with a specific gravity of 1.3. Velocities are in fps model.

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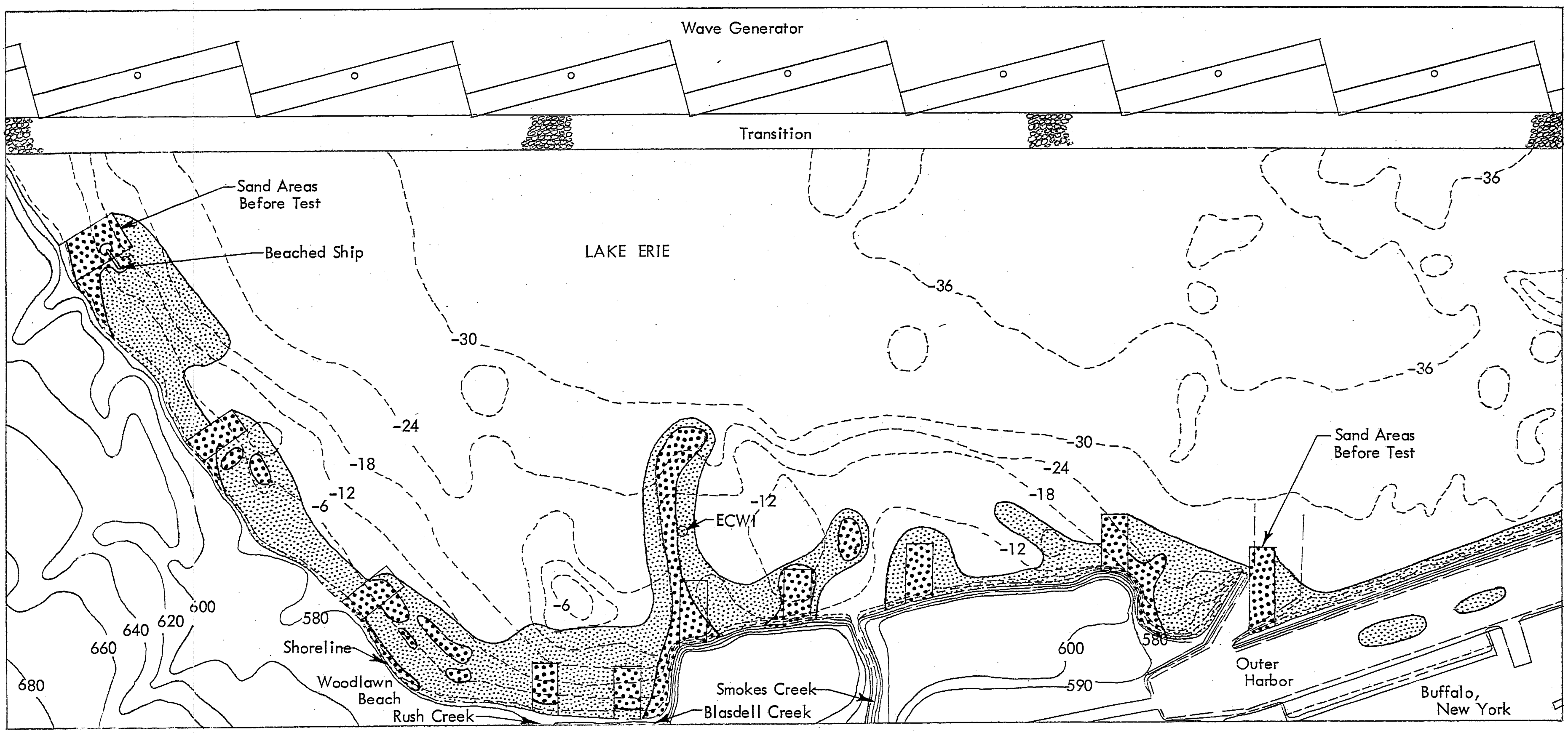
DRAWN DF	CHECKED	APPROVED
SCALE	DATE 2-27-69	NO. 183B482-39

CHART 21



N

Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal – 1:120 Vertical

Heavy Deposits

Light Deposits

A thin layer of sand was placed in marked rectangular areas before test. The sand distribution pattern after a 4 hour test is shown. Sand with a mean diameter of 0.2 mm was used.

MODEL BEHAVIOR, ORIGINAL CONDITIONS
Littoral Drift

Flow Conditions
12 ft x 7 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

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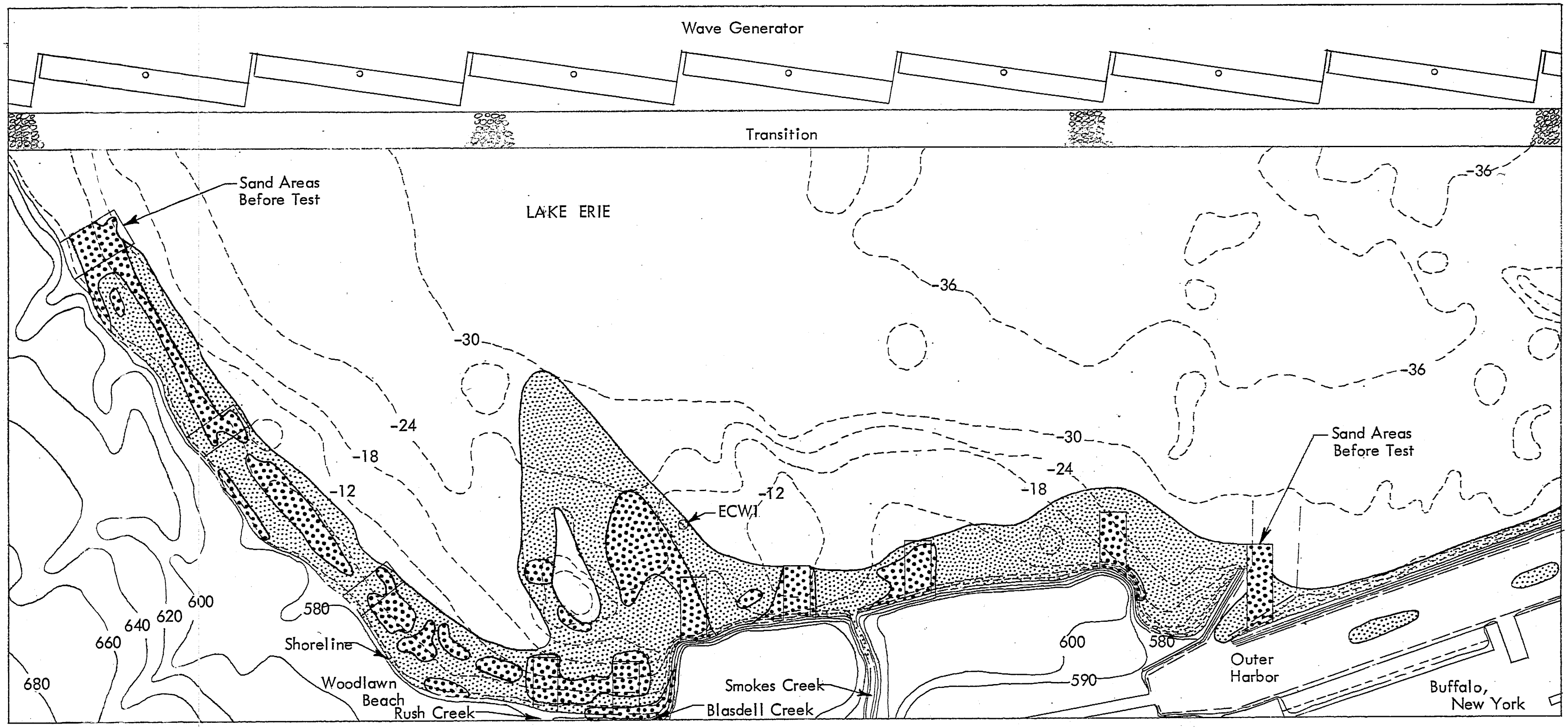
DRAWN WD	CHECKED MBP	APPROVED
SCALE	DATE 2-27-69	NO. 183B482 - 42

CHART 22



Scale in Feet

0 5 — Model

0 3000 — Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

Heavy Deposits

Light Deposits

A thin layer of sand was placed in marked rectangular areas before test. The sand distribution pattern after a 4 hour test is shown. Sand with a mean diameter of 0.2 mm was used.

MODEL BEHAVIOR, ORIGINAL CONDITIONS

Littoral Drift

Flow Conditions

12 ft x 7 sec Waves from the West
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

N

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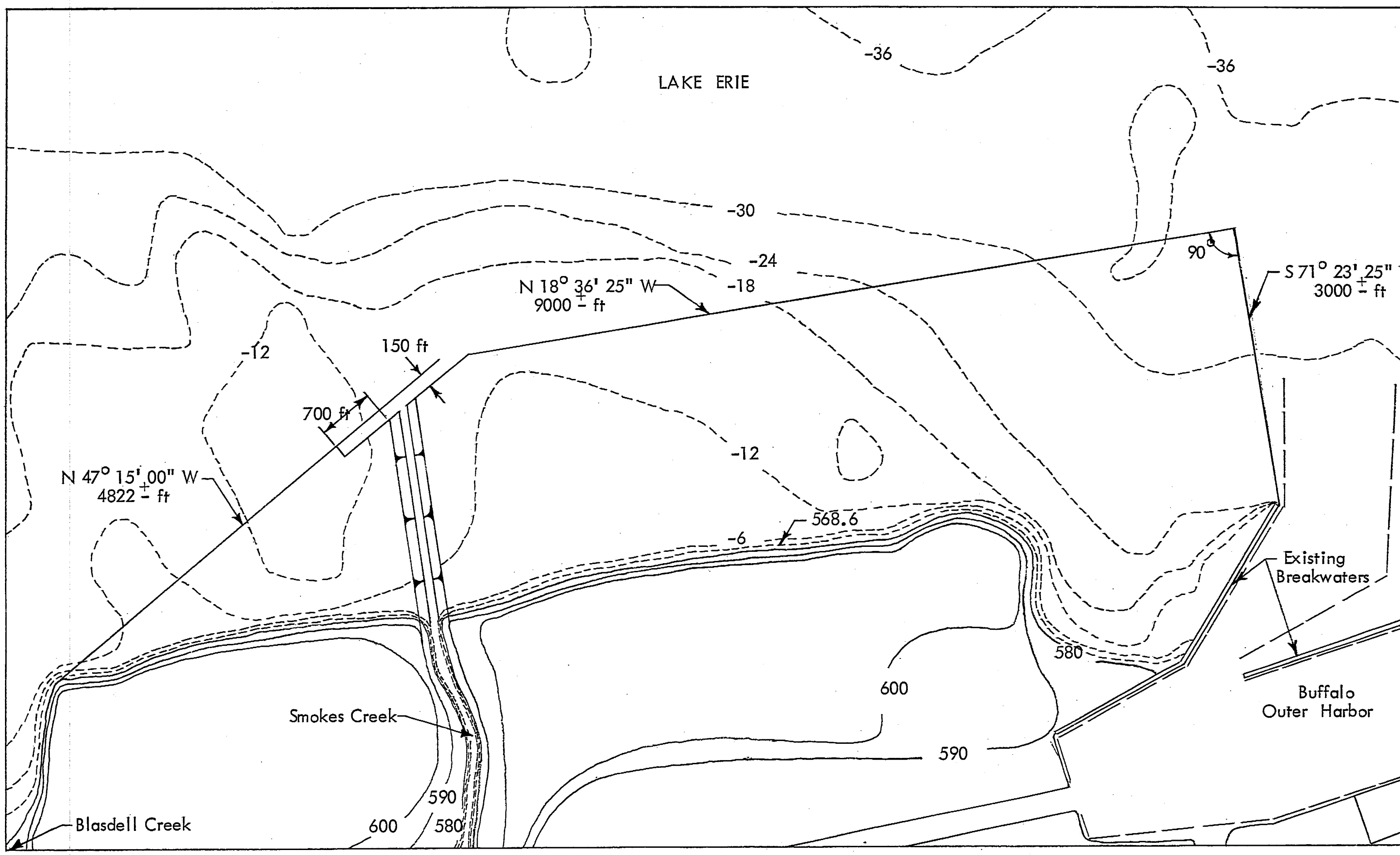
DRAWN WD	CHECKED [signature]	APPROVED
SCALE	DATE 2-27-69	NO. 183B482-43

CHART 23



LAYOUT, TYPE A DIKE
Prototype Dimensions are Given

Dike layout from Bethlehem Steel Corporation, drawing number 124181, dated 1967.

Solid contours are elevation in feet above mean sea level; dashed contours are depths in feet below the low water datum of 568.6 ft.

Scale in Feet

0 — 5
Model

0 — 3000
Prototype

Model Scale
1:600 Horizontal - 1:120 Vertical

PLANT
N
N

BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE

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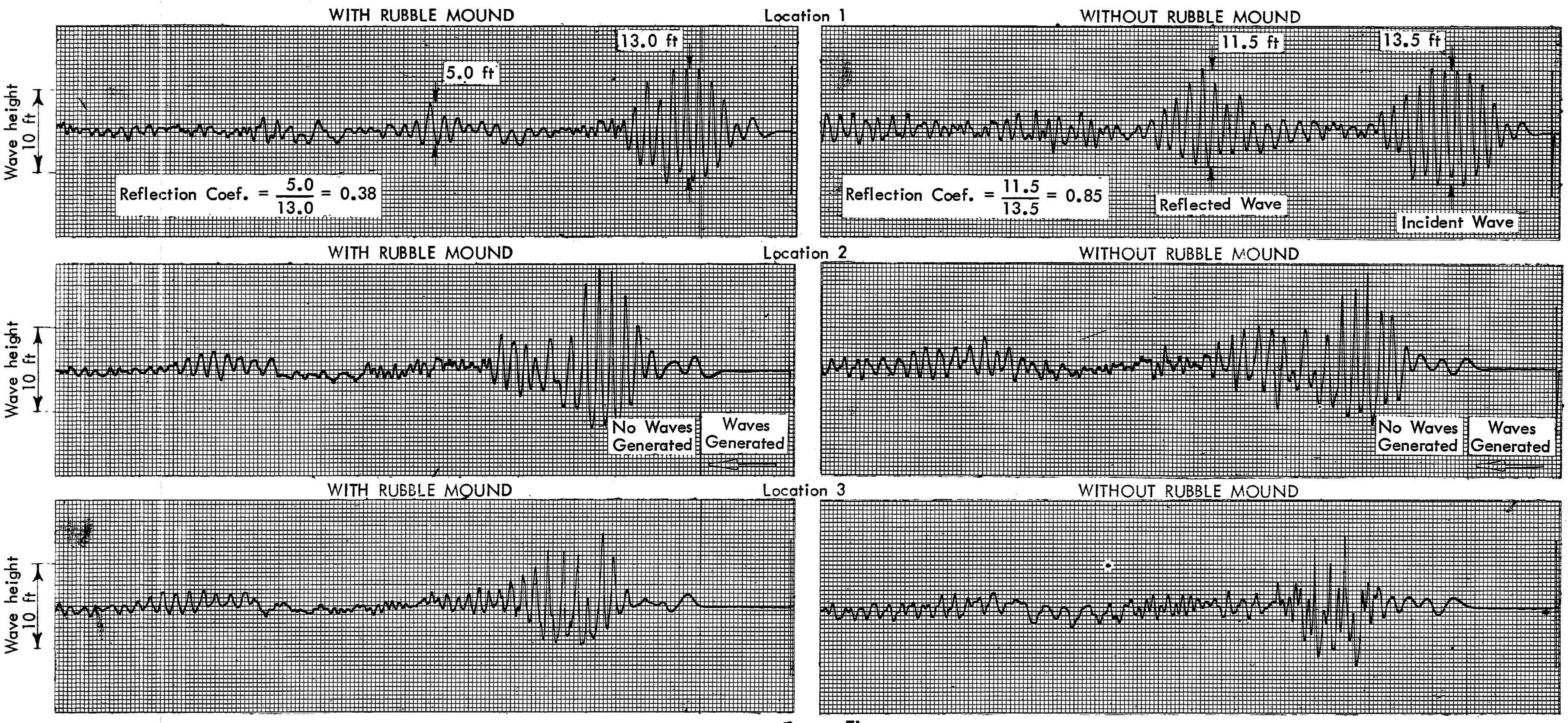
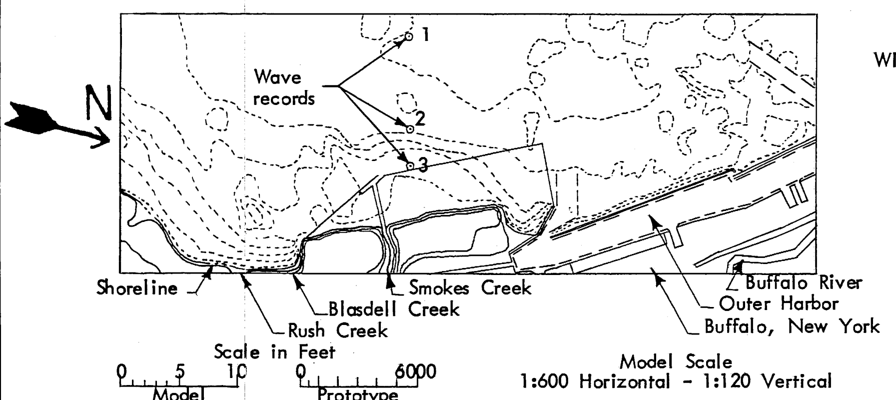
DRAWN DF	CHECKED [illegible]	APPROVED
SCALE	DATE 3-11-69	NO. 183B482-64

CHART 24





Model Scale
1:600 Horizontal - 1:120 Vertical

Time Scale in Seconds
0 5
Model
0 50
Prototype

WAVE REFLECTIONS AT SELECTED LOCATIONS
WITH AND WITHOUT RUBBLE MOUND ON TYPE A DIKE

Flow Conditions
12 ft x 7 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft

Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave profiles obtained using a 2-wire capacitance type wave probe.

BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE

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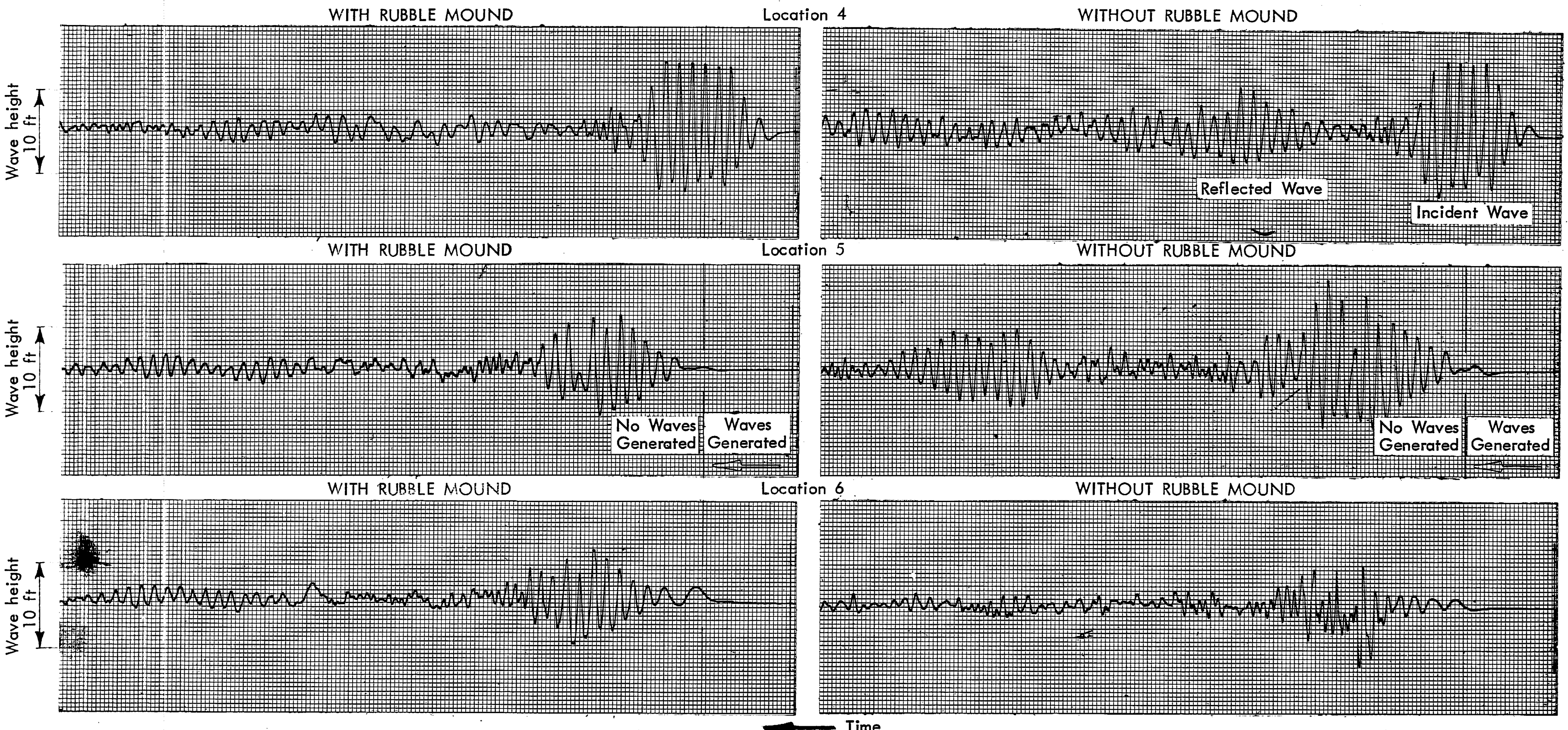
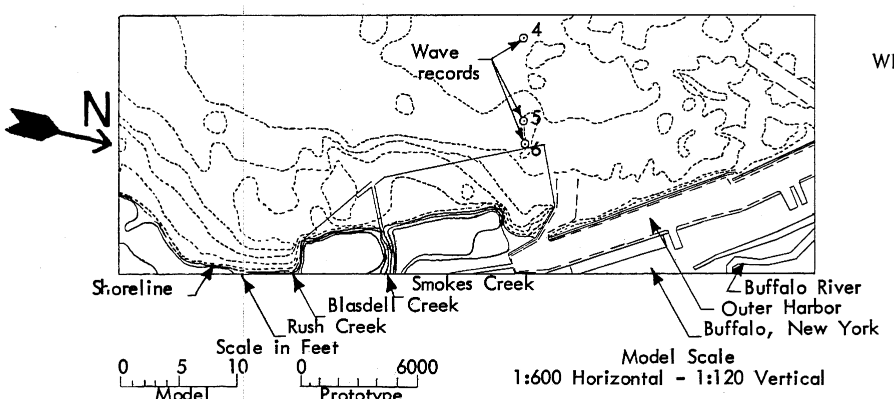
UNIVERSITY OF MINNESOTA

DRAWN WG	CHECKED [illegible]	APPROVED
SCALE	DATE 3-17-69	NO. 183B482-77

CHART 25





WAVE REFLECTIONS AT SELECTED LOCATIONS
WITH AND WITHOUT RUBBLE MOUND ON TYPE A DIKE

Time Scale in Seconds
0 5
Model
0 50
Prototype

Flow Conditions
12 ft x 7 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft

Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave profiles obtained using a 2-wire capacitance type wave probe.

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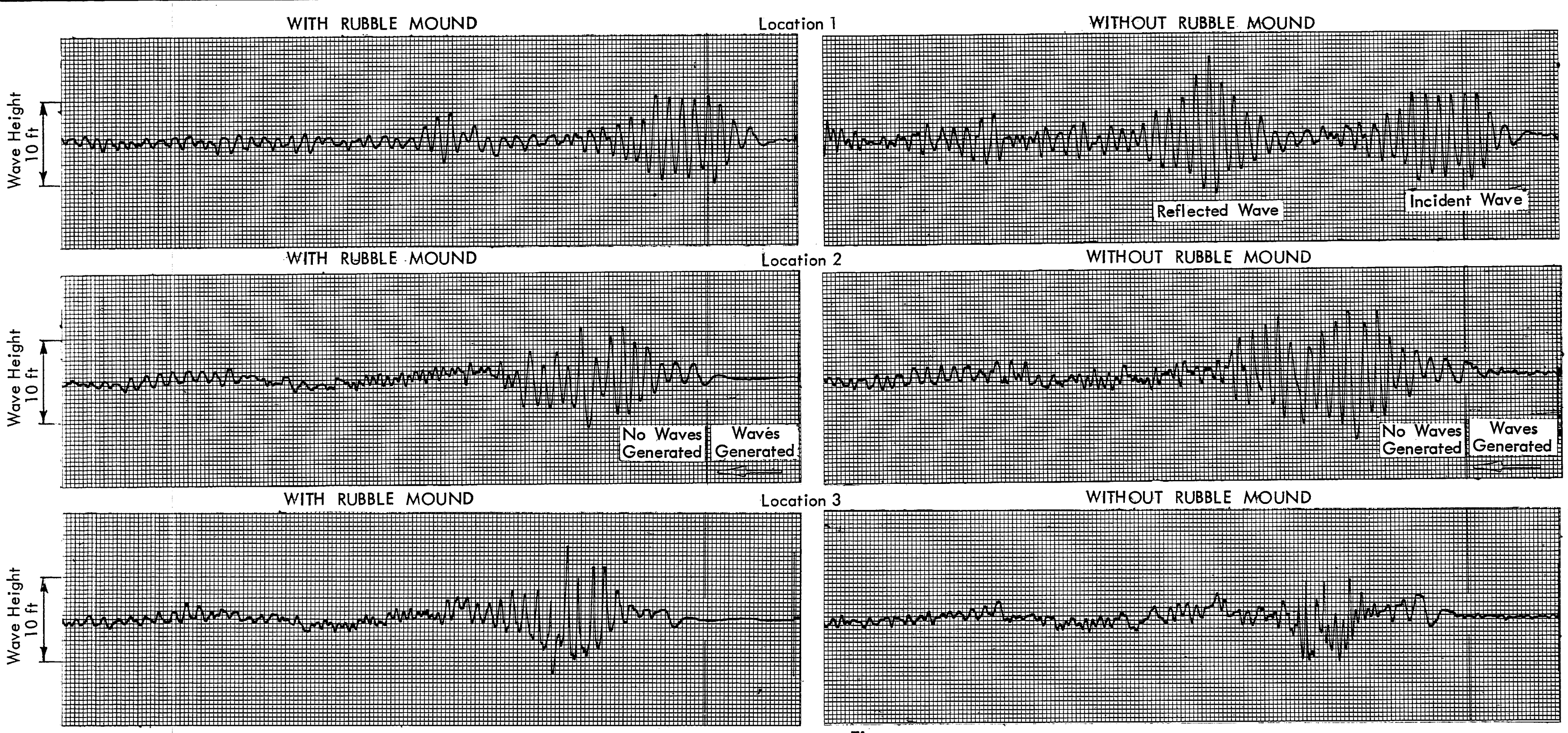
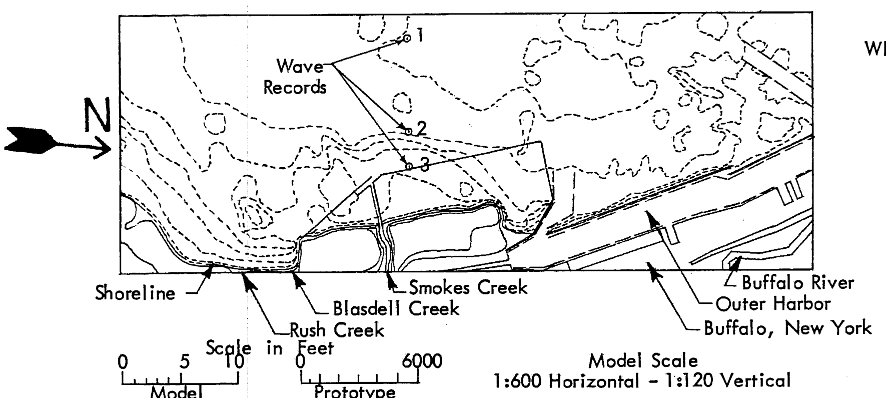
DRAWN HP	CHECKED [signature]	APPROVED
SCALE	DATE 3-17-69	NO. 183B482-78

CHART 26





Model Scale
1:600 Horizontal - 1:120 Vertical

WAVE REFLECTIONS AT SELECTED LOCATIONS
WITH AND WITHOUT RUBBLE MOUND ON TYPE A DIKE

Time Scale in Seconds
0 5
Model
0 50
Prototype

Flow Conditions
12 ft x 7 sec Waves from the West
Lake Erie Elevation = 575.0 ft

Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave profiles obtained using a 2-wire capacitance type wave probe.

BETHLEHEM STEEL CORPORATION
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Lackawanna, New York
LAKE ERIE DIKE

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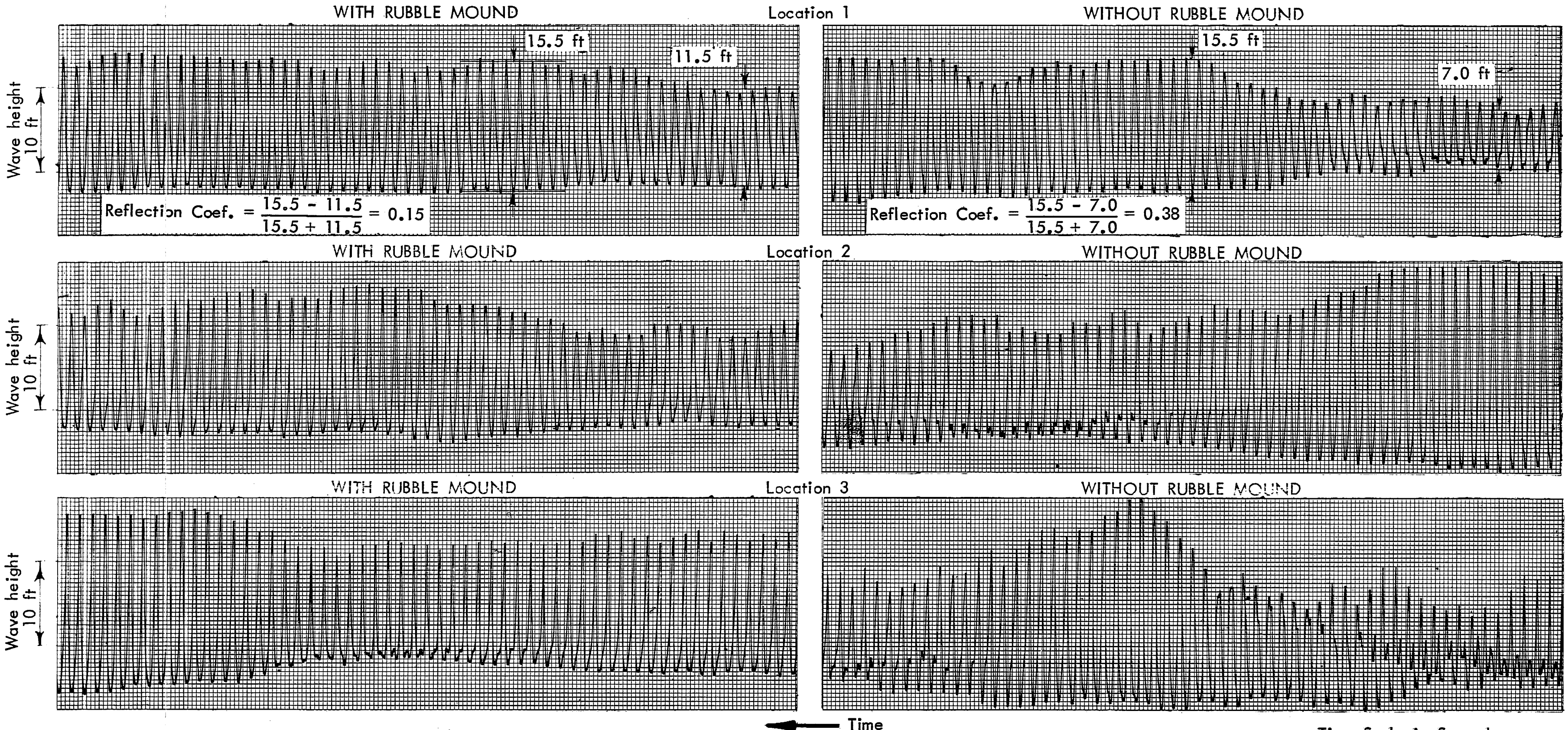
UNIVERSITY OF MINNESOTA

DRAWN DF	CHECKED	APPROVED
SCALE	DATE 3-7-69	NO. 183B482-62

CHART 27



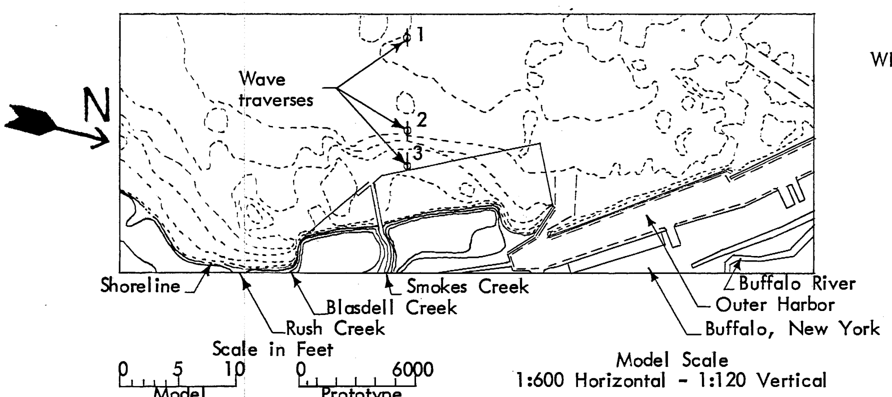
Time Scale in Seconds

0 5

Model

0 50

Prototype



Model Scale
1:600 Horizontal - 1:120 Vertical

WAVE TRAVERSES AT SELECTED LOCATIONS WITH AND WITHOUT RUBBLE MOUND ON TYPE A DIKE

Flow Conditions

12 ft x 7 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft

Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave profiles obtained using a 2-wire capacitance type wave probe.

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Lackawanna, New York
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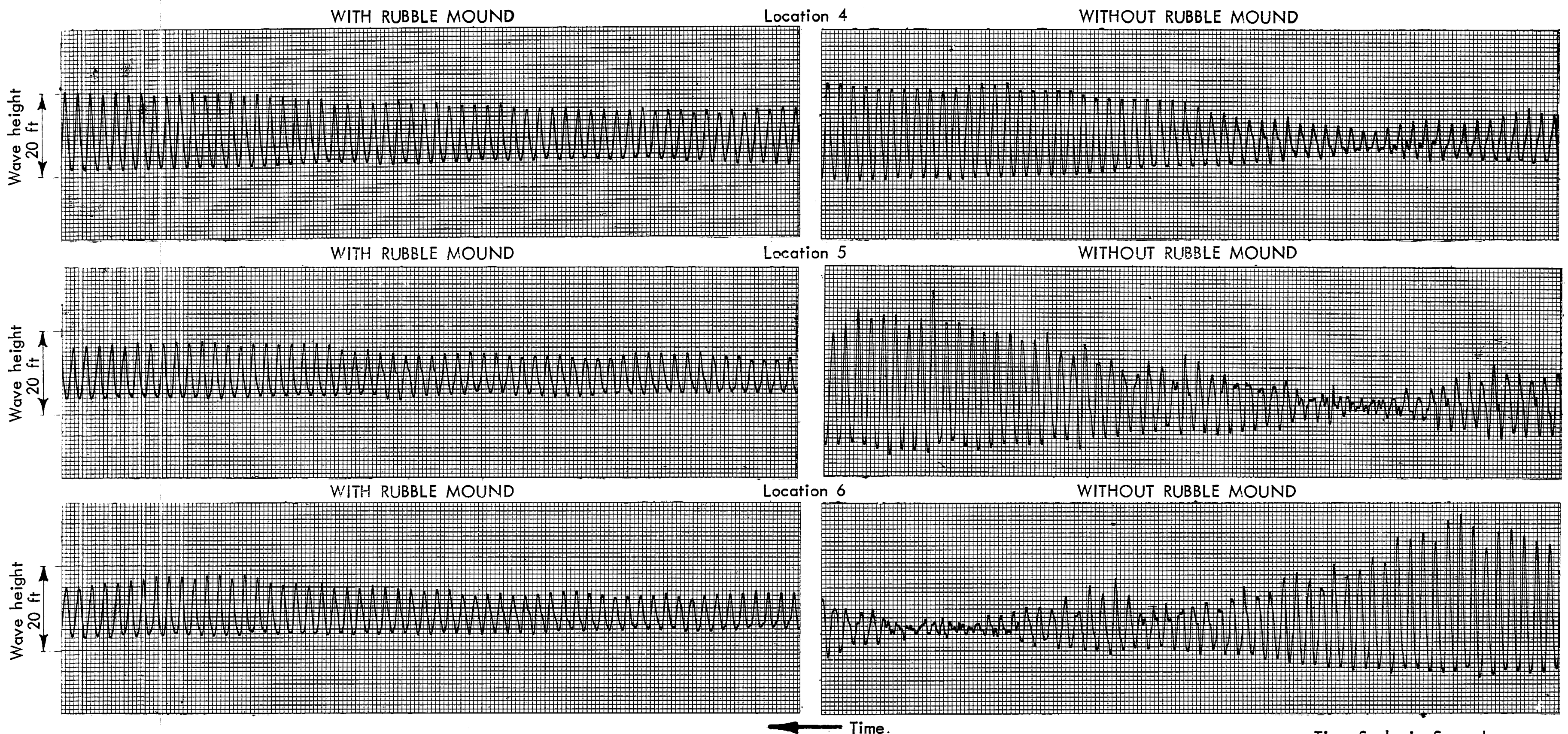
DRAWN WG	CHECKED [signature]	APPROVED
SCALE	DATE 3-17-69	NO. 183B482-74

CHART 28



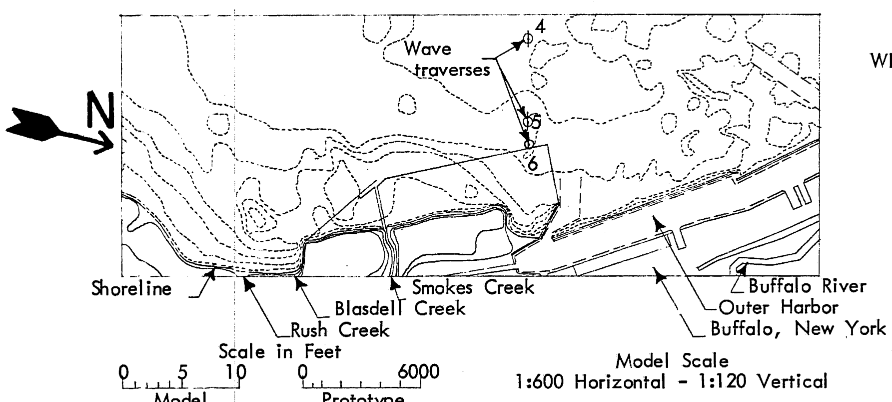
Time Scale in Seconds

0 5

Model

0 50

Prototype



Model Scale
1:600 Horizontal - 1:120 Vertical

WAVE TRAVERSES AT SELECTED LOCATIONS WITH AND WITHOUT RUBBLE MOUND ON TYPE A DIKE

Flow Conditions

12 ft x 7 sec. Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft

Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave profiles obtained using a 2-wire capacitance type wave probe.

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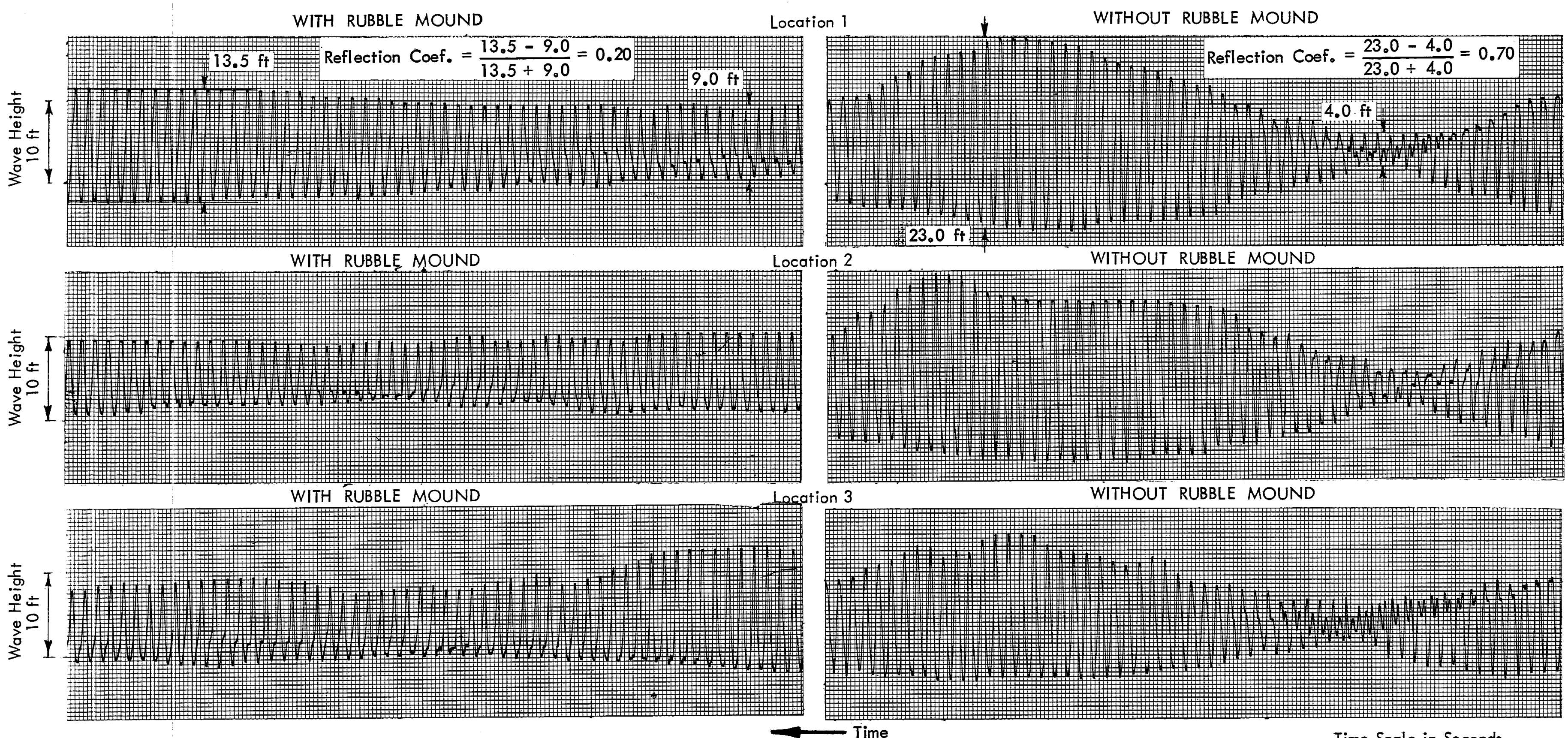
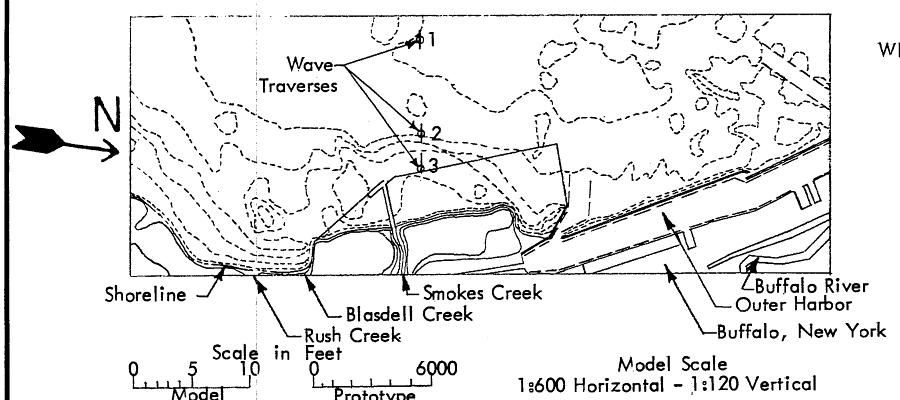
DRAWN WG	CHECKED	APPROVED
SCALE	DATE 3-17-69	NO. 183B482-75

CHART 29



WAVE TRAVERSES AT SELECTED LOCATIONS
WITH AND WITHOUT RUBBLE MOUND ON TYPE A DIKE

Time Scale in Seconds
0 5
Model
0 50
Prototype



Flow Conditions
12 ft x 7 sec Waves from the West
Lake Erie Elevation = 575.0 ft

Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave profiles obtained using a 2-wire capacitance type wave probe.

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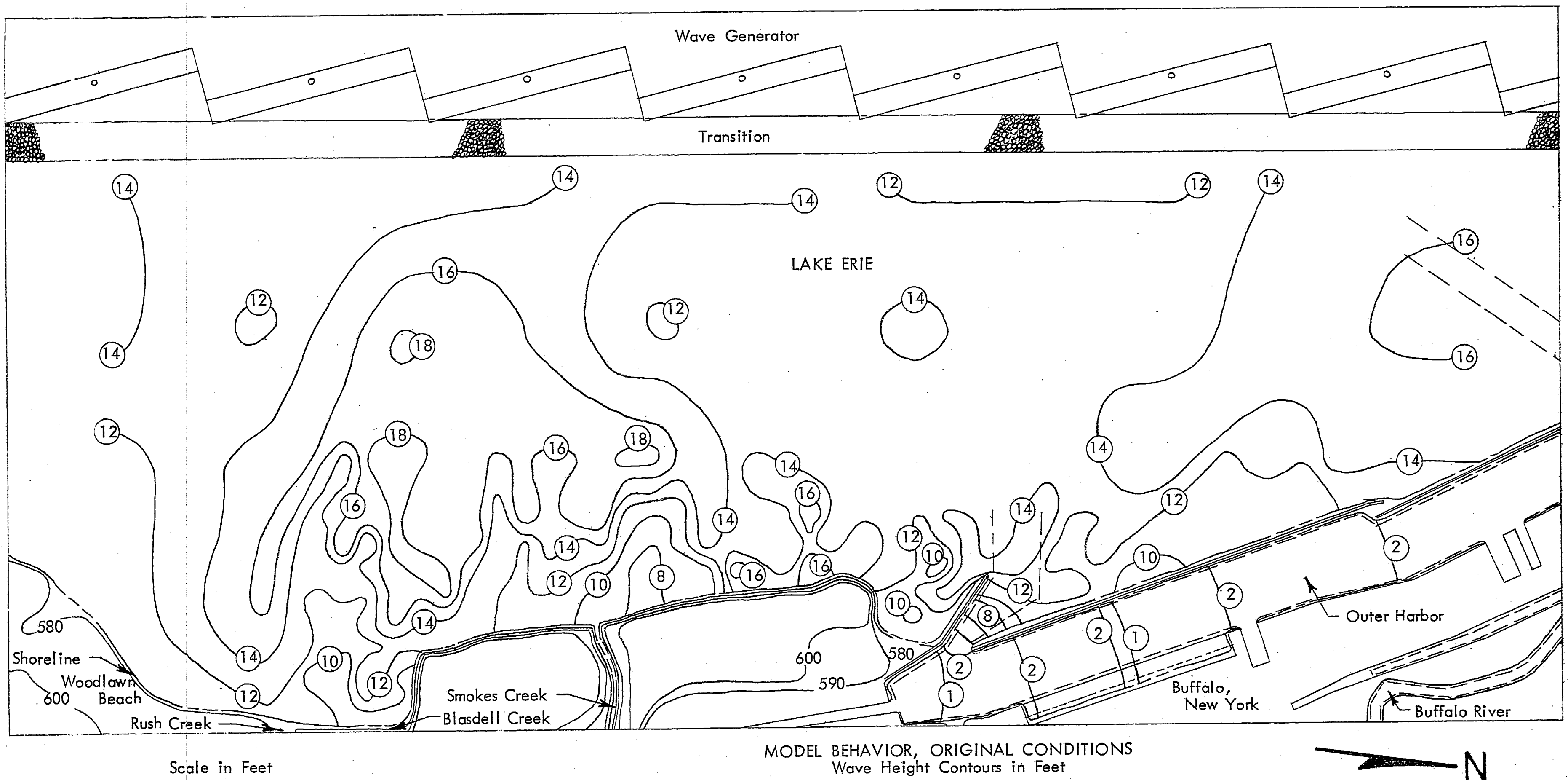
DRAWN DF	CHECKED	APPROVED
SCALE	DATE 3-7-69	NO. 183B482-60

CHART 30



Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, ORIGINAL CONDITIONS
Wave Height Contours in Feet

Flow Conditions

12 ft x 7 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave heights obtained using a 2-wire capacitance type wave probe.

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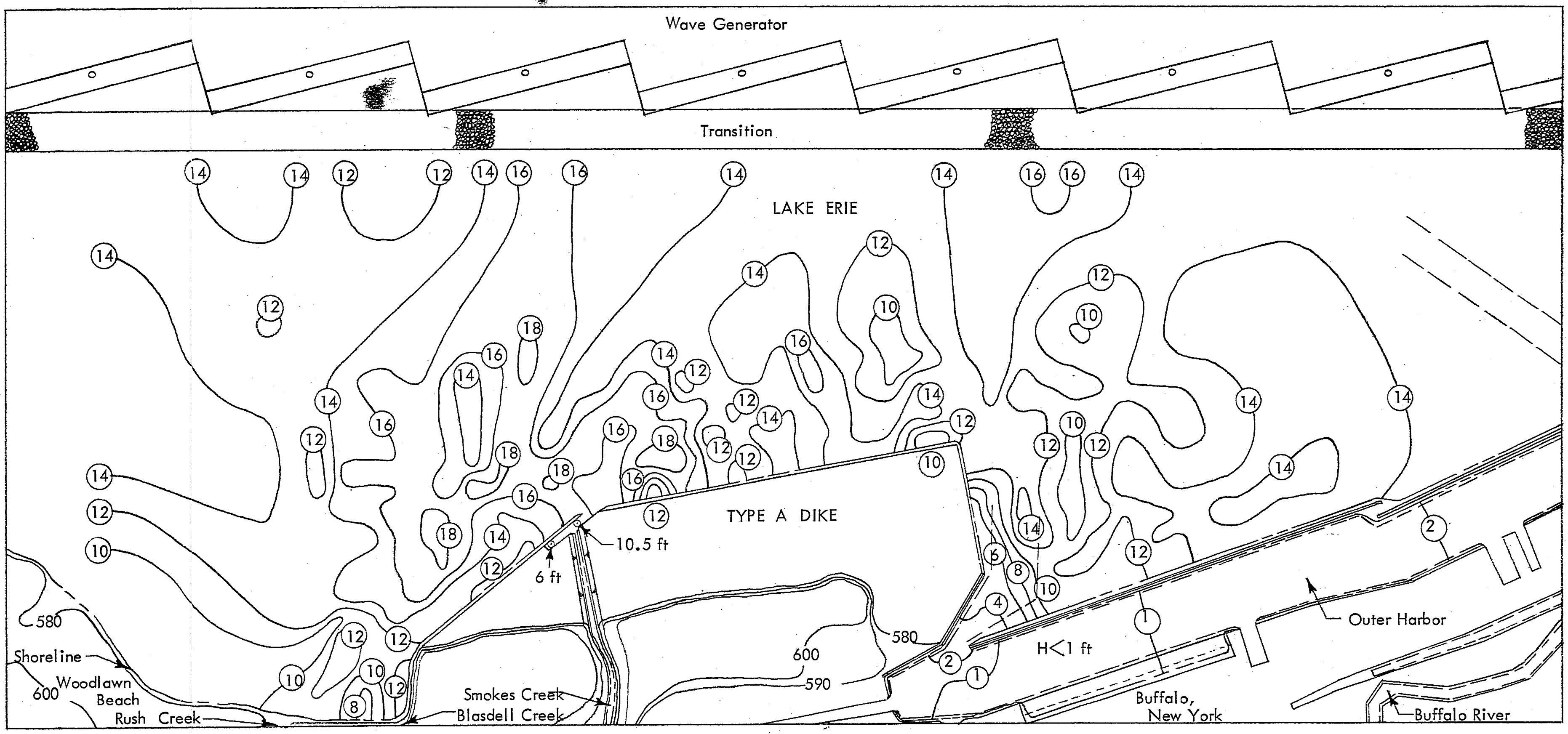
DRAWN WG	CHECKED	APPROVED
SCALE	DATE 2-19-69	NO. 183B482-12

CHART 31



Scale in Feet

0 5 Model — 0 3000 Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, TYPE A DIKE

Wave Height Contours in Feet

Flow Conditions

12 ft x 7 sec Waves from S 67-1/2° W

Lake Erie Elevation = 575.0 ft

Niagara River Discharge = 300,000 cfs

Buffalo River Discharge = 520 cfs

Smokes Creek Discharge = 200 cfs

Blasdell Creek Discharge = 46 cfs

Rush Creek Discharge = 13 cfs

Wave heights obtained using a 2-wire capacitance type wave probe.

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Lackawanna, New York

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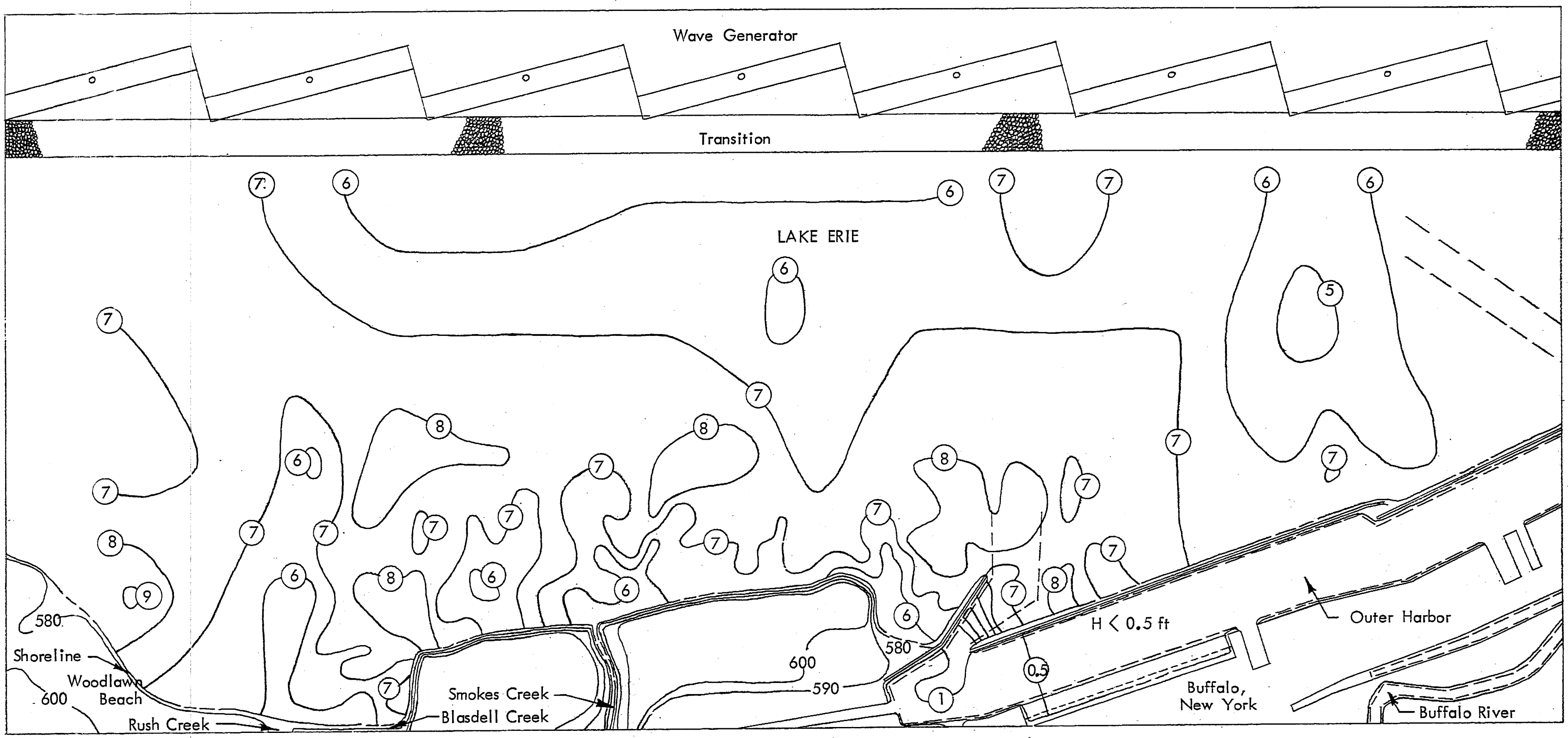
DRAWN EK	CHECKED MD	APPROVED
SCALE	DATE 2-19-69	NO. 183B482-18

CHART 32



Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, ORIGINAL CONDITIONS

Wave Height Contours in Feet

Flow Conditions

6 ft x 4 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave heights obtained using a 2-wire capacitance type wave probe.

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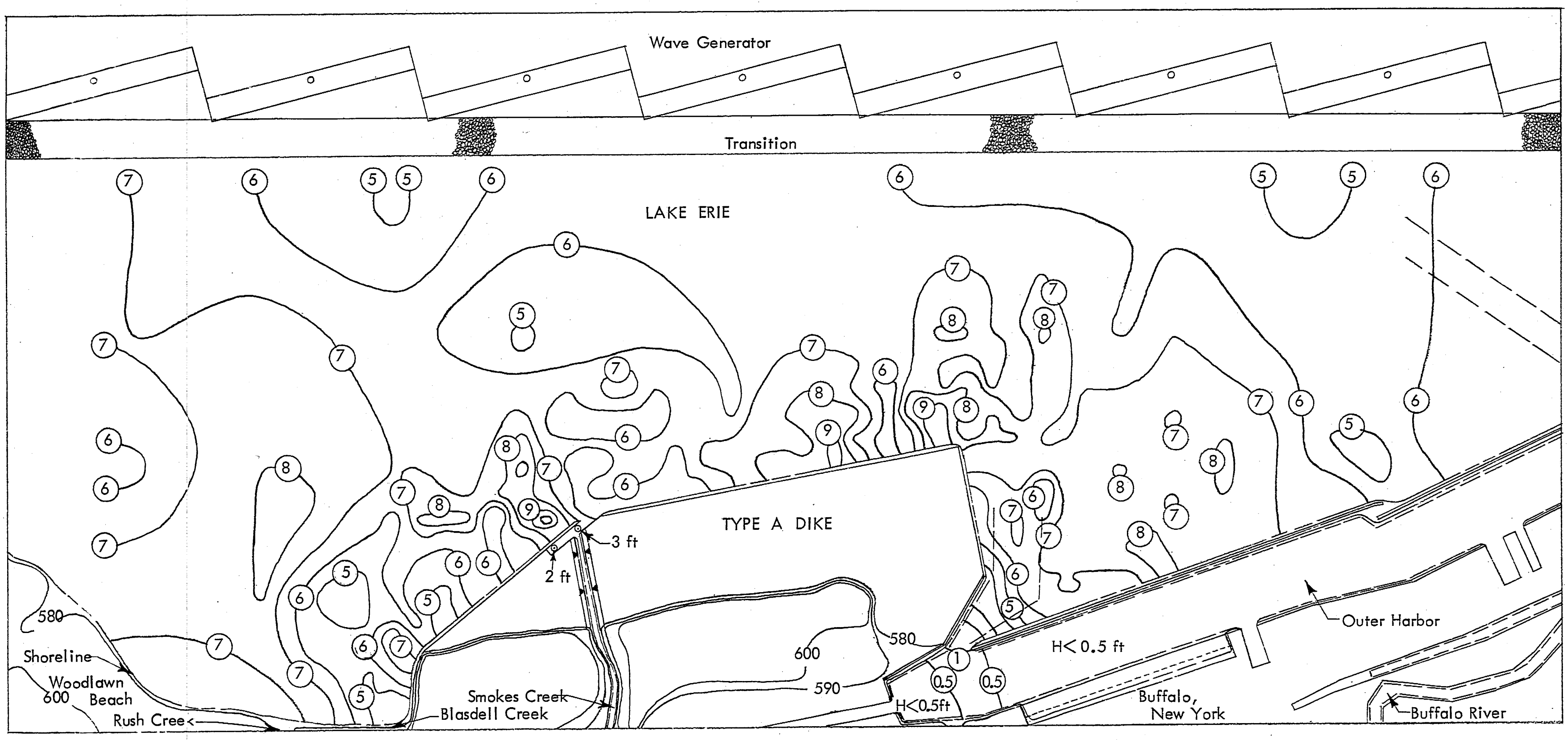
DRAWN WG	CHECKED [signature]	APPROVED
SCALE	DATE 2-19-69	NO. 183B482-13

CHART 33



Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, TYPE A DIKE
Wave Height Contours in Feet

Flow Conditions
6 ft x 4 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave heights obtained using a 2-wire capacitance type wave probe.

N

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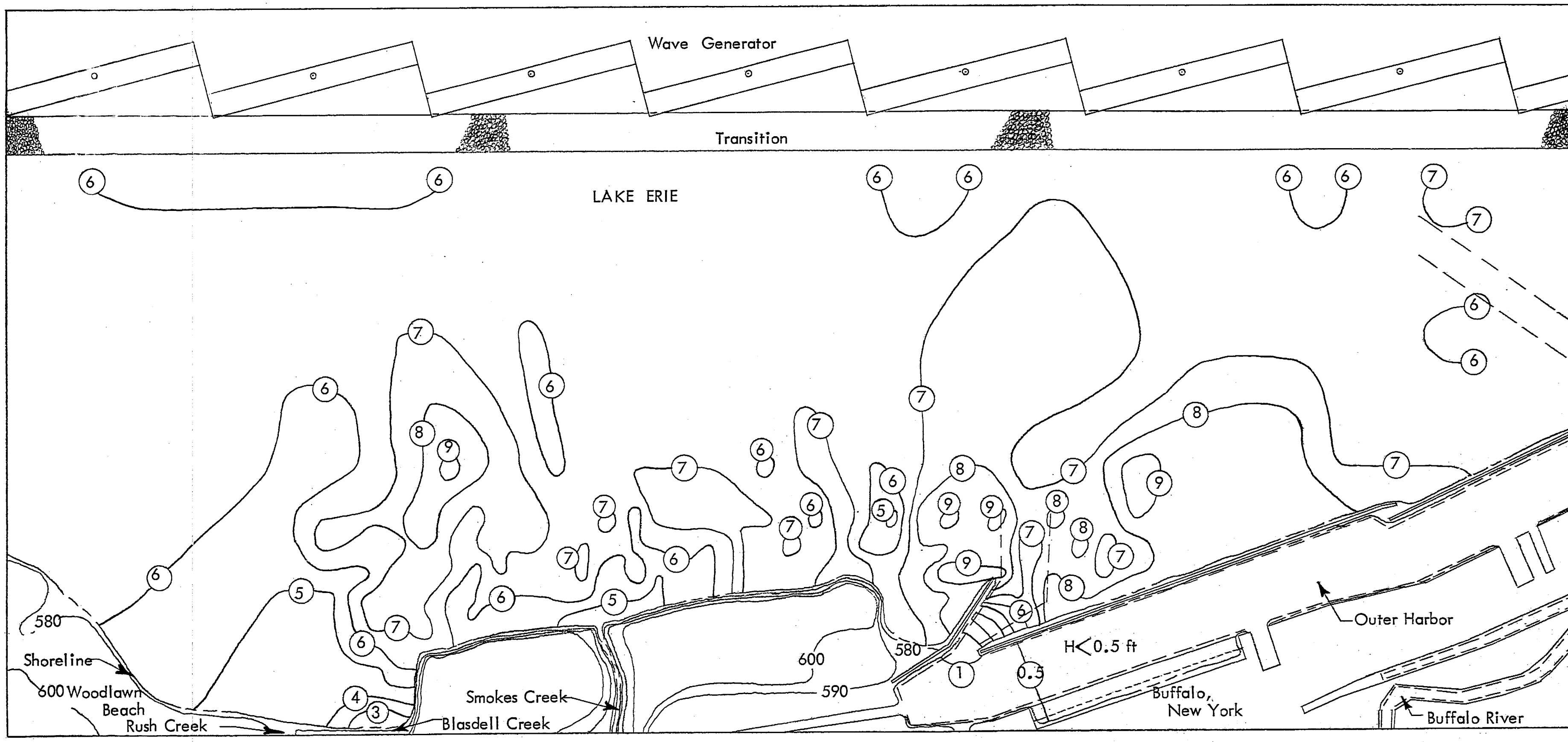
DRAWN DF	CHECKED MAD	APPROVED
SCALE	DATE 2-19-69	NO. 183B482-19

CHART 34



Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, ORIGINAL CONDITIONS
Wave Height Contours in Feet

Flow Conditions
6 ft x 4 sec Waves from S 67-1/2° W
Lake Erie Elevation = 570.6 ft
Niagara River Discharge = 200,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave heights obtained using a 2-wire capacitance type wave probe.

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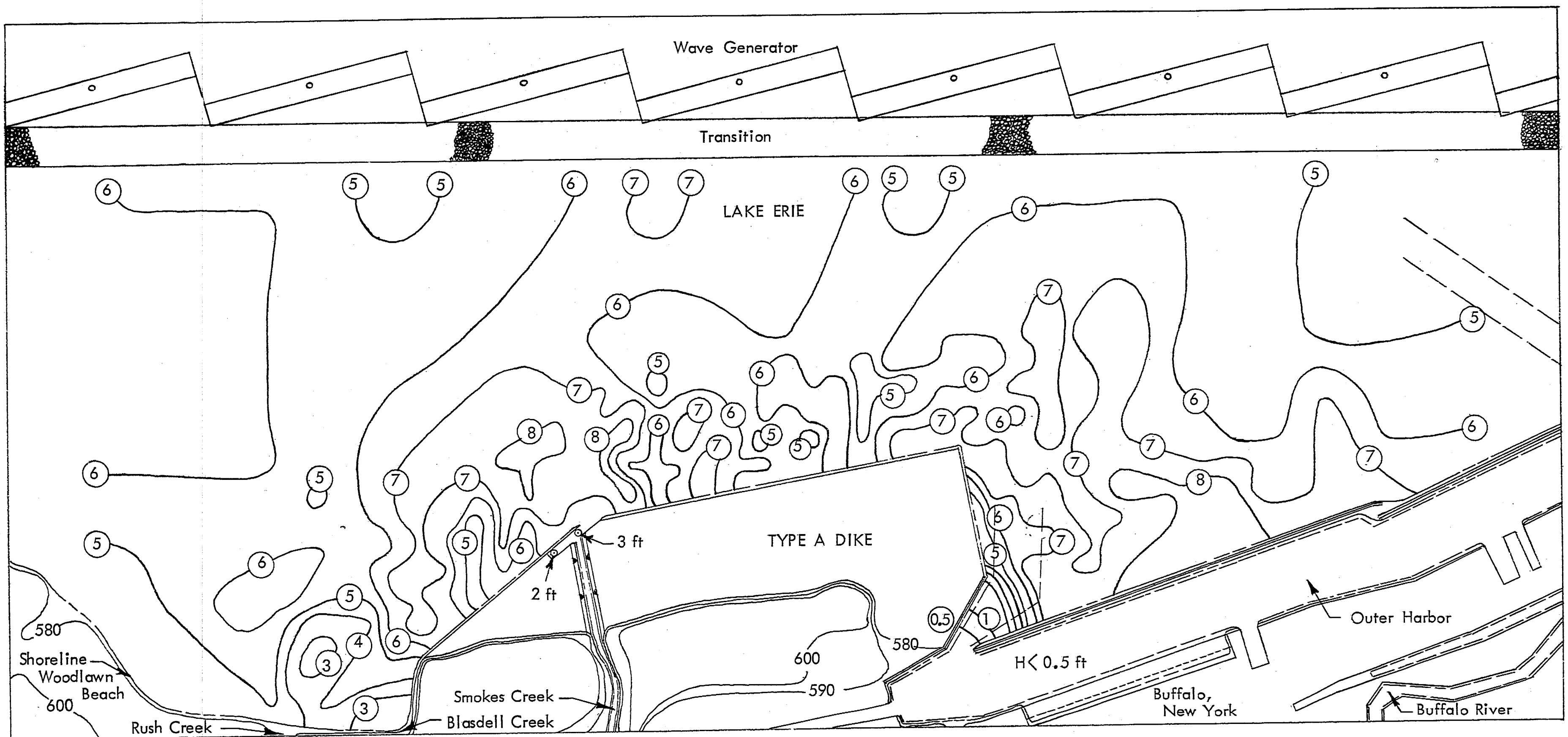
DRAWN JF	CHECKED [signature]	APPROVED
SCALE	DATE 2-19-69	NO. 183B482-14

CHART 35



MODEL BEHAVIOR, TYPE A DIKE
Wave Height Contours in Feet

N

Scale in Feet

0 5 — Model

0 3000 — Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

Flow Conditions

6 ft x 4 sec Waves from S 67-1/2° W
Lake Erie Elevation = 570.6 ft
Niagara River Discharge = 200,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave heights obtained using a 2-wire capacitance type wave probe.

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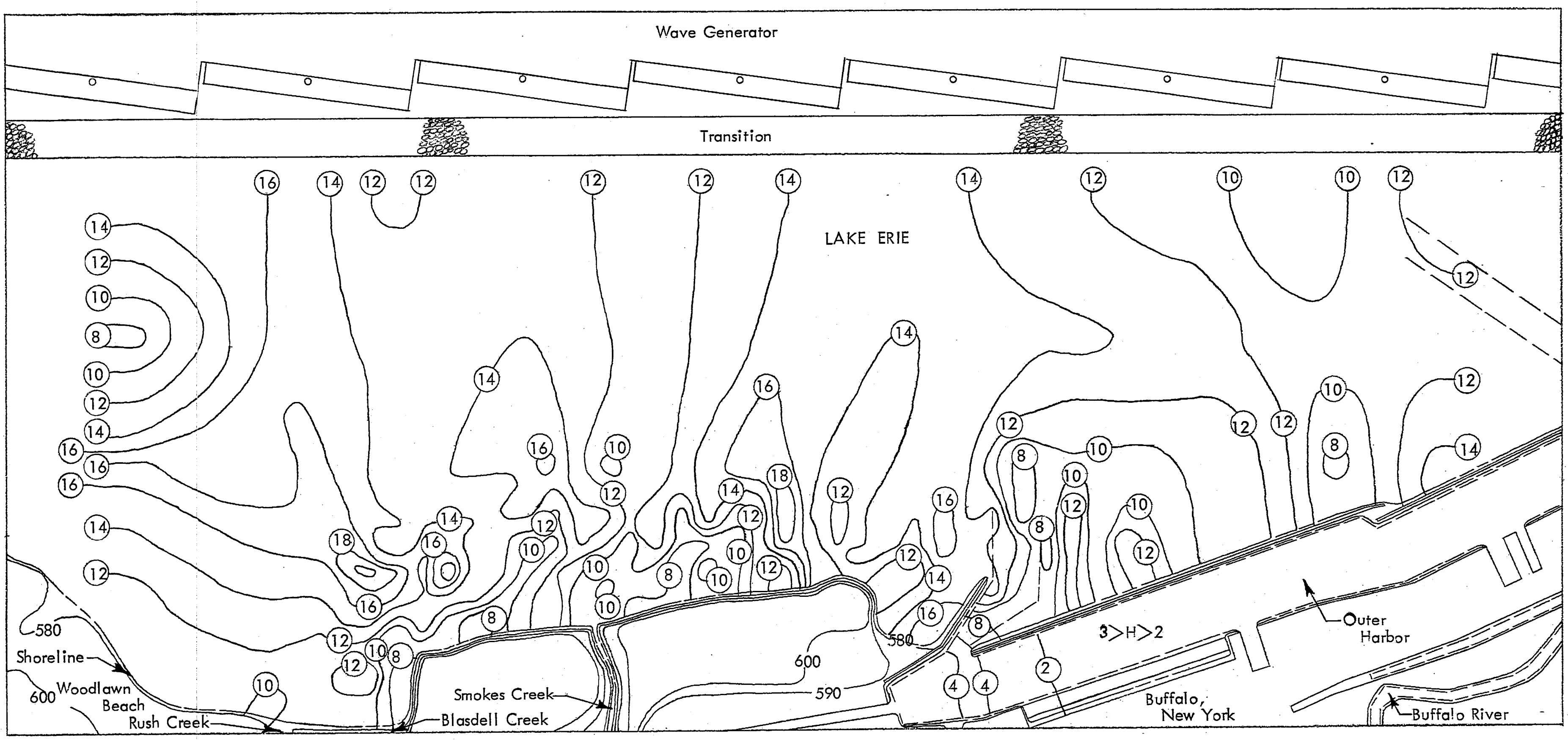
DRAWN DF	CHECKED	APPROVED
SCALE	DATE 2-19-69	NO. 183B482-20

CHART 36



N

Scale in Feet

0 5 0 3000

Model Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, ORIGINAL CONDITIONS

Wave Height Contours in Feet

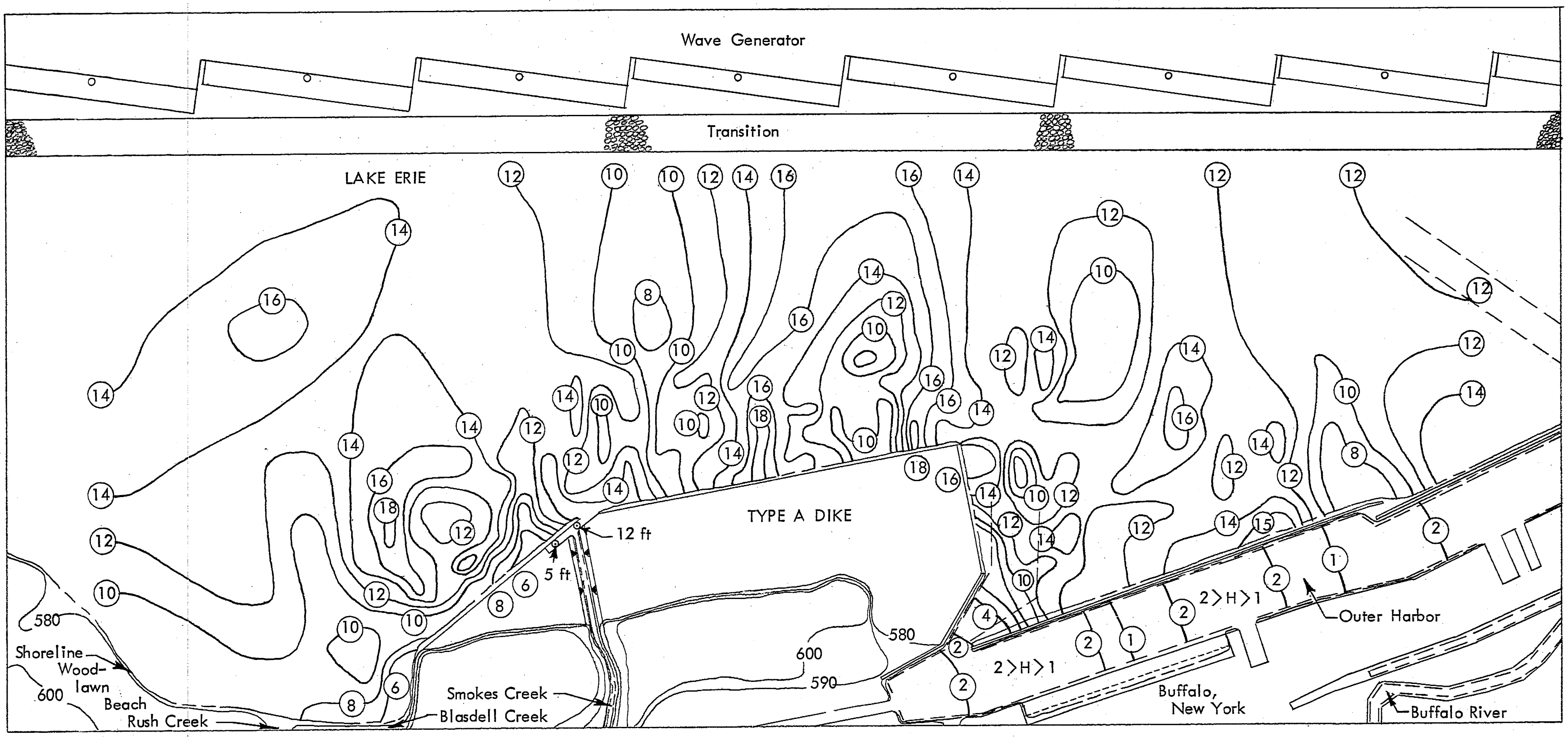
Flow Conditions

12 ft x 7 sec Waves from the West
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave heights obtained using a 2-wire capacitance type wave probe.

BETHLEHEM STEEL CORPORATION Lackawanna Plant Lackawanna, New York LAKE ERIE DIKE		
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DF	CHECKED [signature]	APPROVED
SCALE	DATE 2-19-69	NO. 183B482-15

CHART 37



N

Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale
1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, TYPE A DIKE
Wave Height Contours in Feet

Flow Conditions
12 ft x 7 sec Waves from the West
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave heights obtained using a 2-wire capacitance type wave probe.

BETHLEHEM STEEL CORPORATION Lackawanna Plant Lackawanna, New York LAKE ERIE DIKE		
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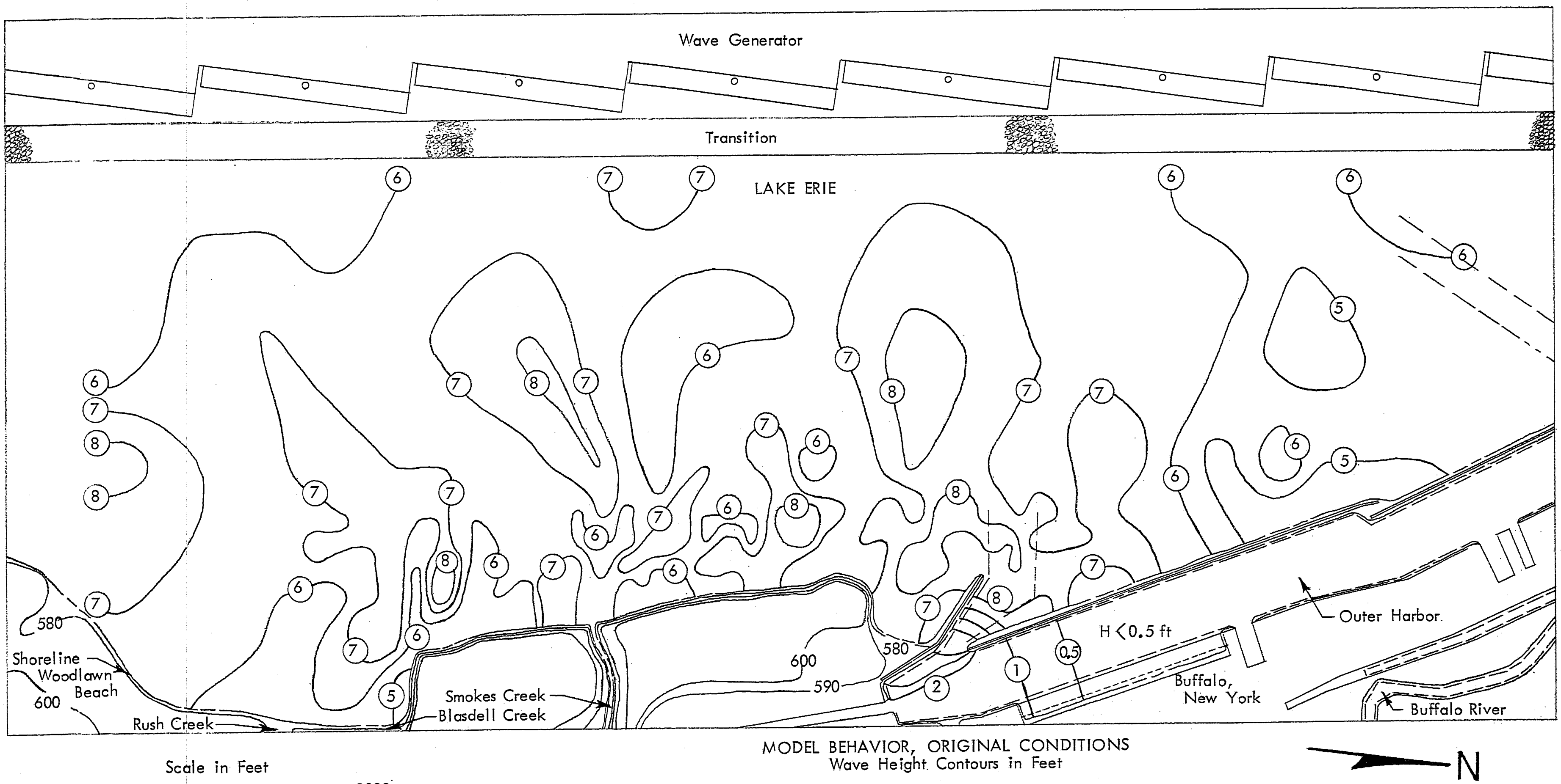
DRAWN JF	CHECKED [illegible]	APPROVED
SCALE	DATE 2-19-69	NO. 183B482-21

CHART 38



MODEL BEHAVIOR, ORIGINAL CONDITIONS
Wave Height Contours in Feet

Scale in Feet

0 5 Model — 0 3000 Prototype

Model Scale
1:600 Horizontal - 1:120 Vertical

Flow Conditions
6 ft x 4 sec Waves from the West
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave heights obtained using a 2-wire capacitance type wave probe.

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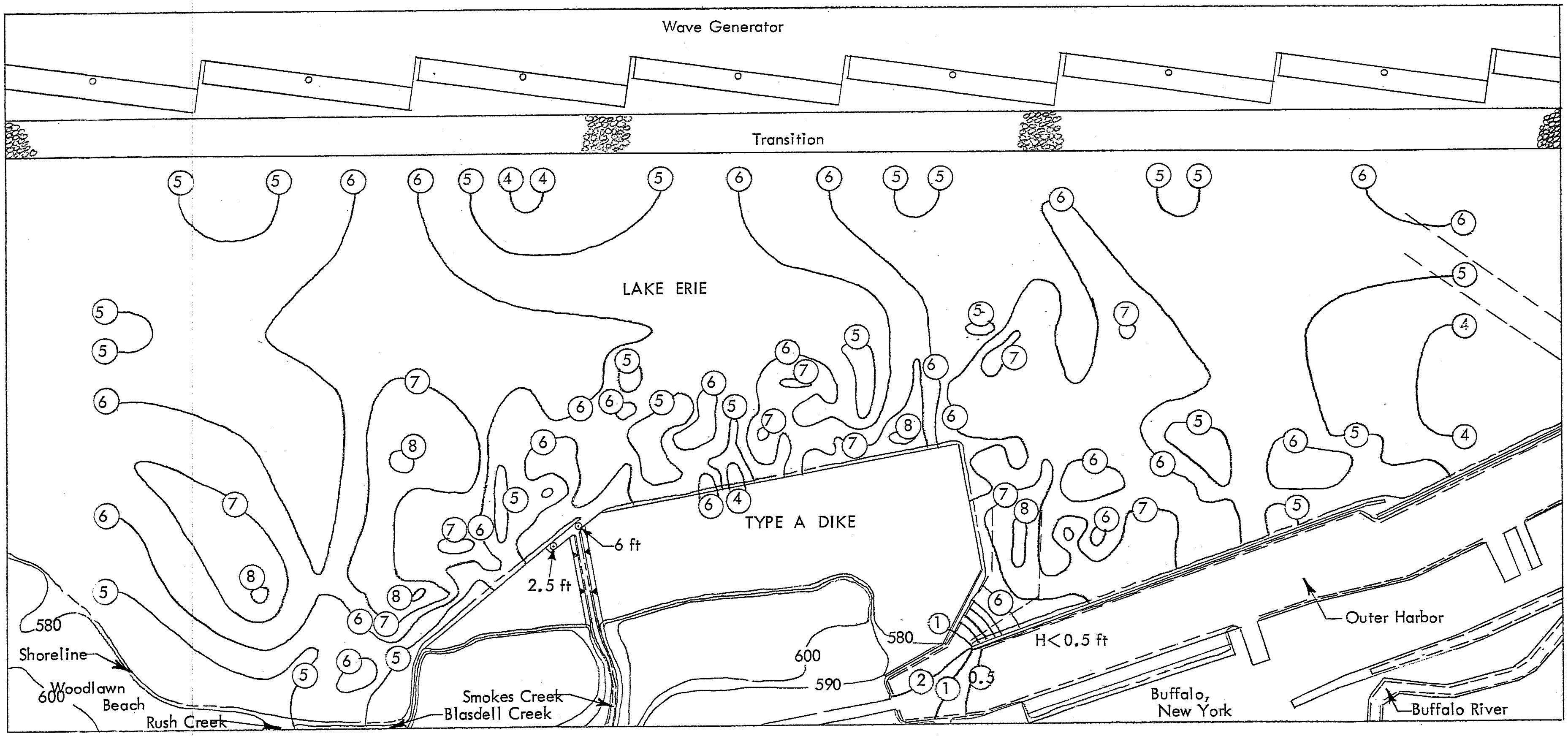
SCALE	DATE 2-19-69	NO. 183B482-16

CHART 39



Scale in Feet

0 5 (Model) — 0 3000 (Prototype)

Model Scale

1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, TYPE A DIKE

Wave Height Contours in Feet

Flow Conditions

6 ft x 4 sec Waves from the West
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave heights obtained using a 2-wire capacitance type wave probe.

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Lackawanna, New York
LAKE ERIE DIKE

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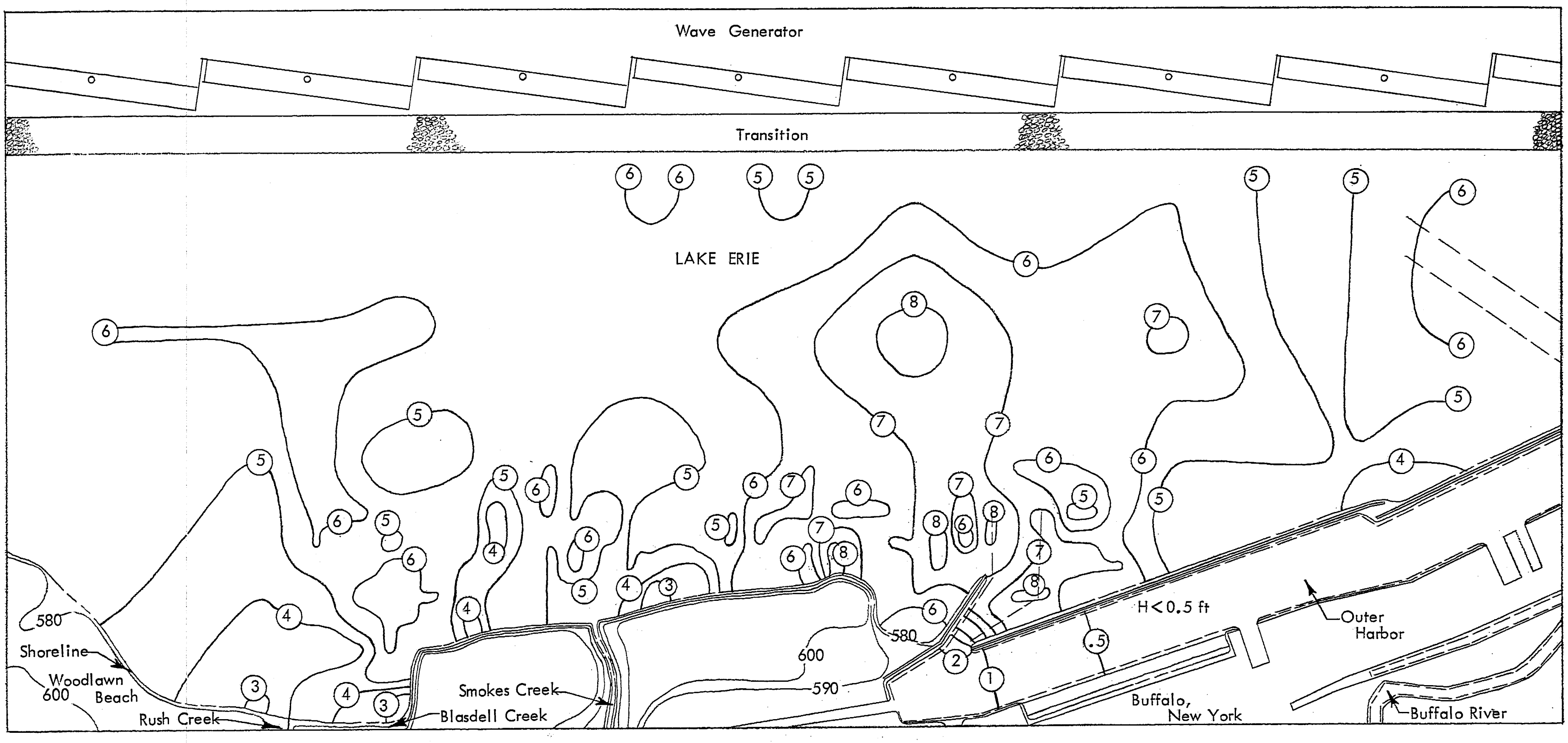
SCALE	DATE 2-19-69	NO. 183B482-22

CHART 40



N

Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, ORIGINAL CONDITIONS

Wave Height Contours in Feet

Flow Conditions

6 ft x 4 sec Waves from the West
Lake Erie Elevation = 570.6 ft
Niagara River Discharge = 200,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave heights obtained using a 2-wire capacitance type wave probe.

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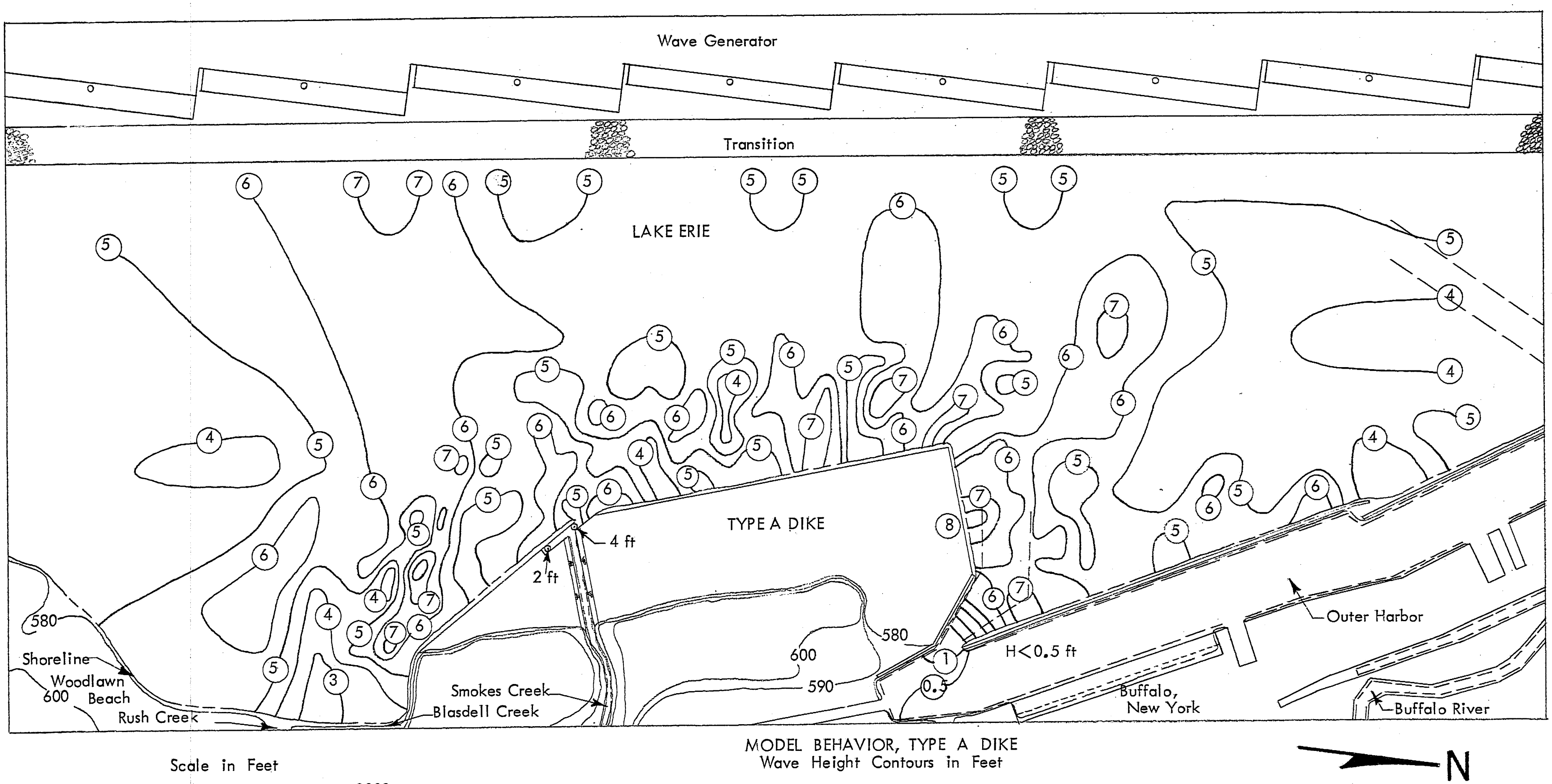
SCALE	DATE 2-19-69	NO. 183B482-17

CHART 41



Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, TYPE A DIKE
Wave Height Contours in Feet

Flow Conditions
6 ft x 4 sec Waves from the West
Lake Erie Elevation = 570.6 ft
Niagara River Discharge = 200,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave heights obtained using a 2-wire capacitance type wave probe.

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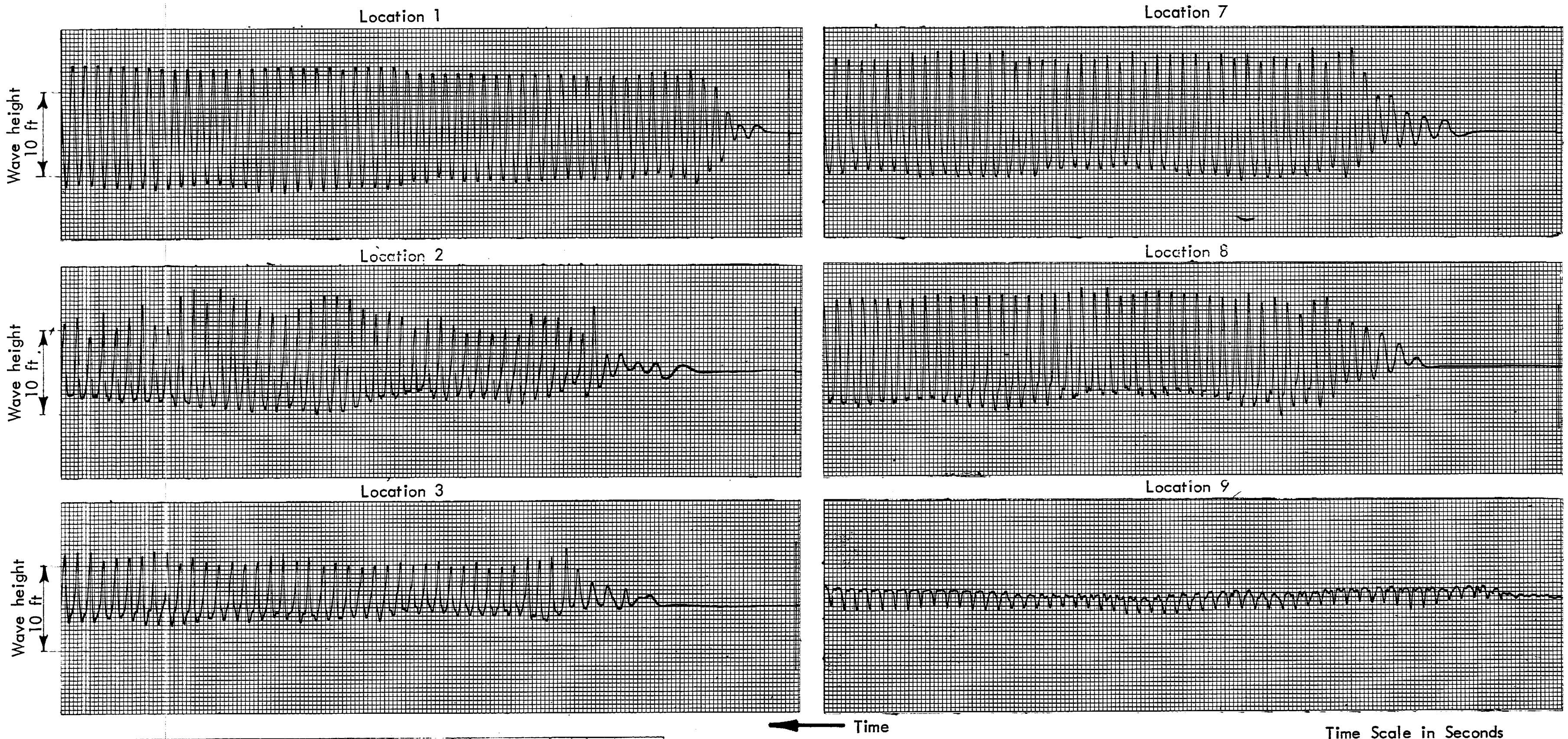
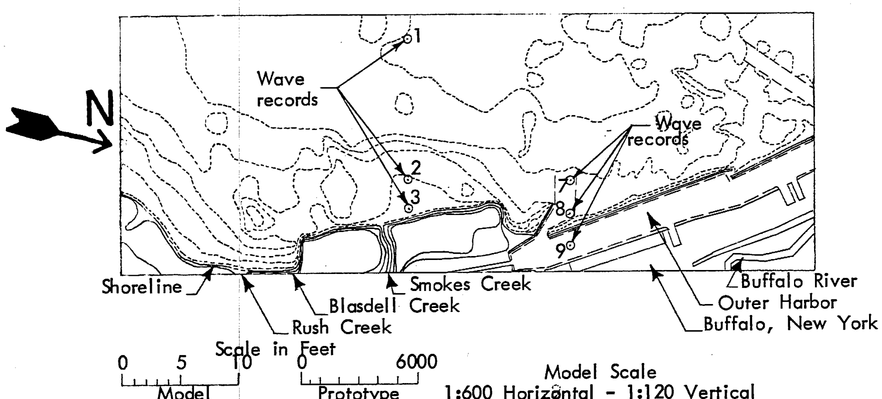
SCALE	DATE 2-19-69	NO. 183B482-23

CHART 42





WAVE HEIGHTS AT SELECTED LOCATIONS FOR ORIGINAL CONDITIONS

Flow Conditions

12 ft x 7 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft

Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave profiles obtained using a 2-wire capacitance type wave probe.

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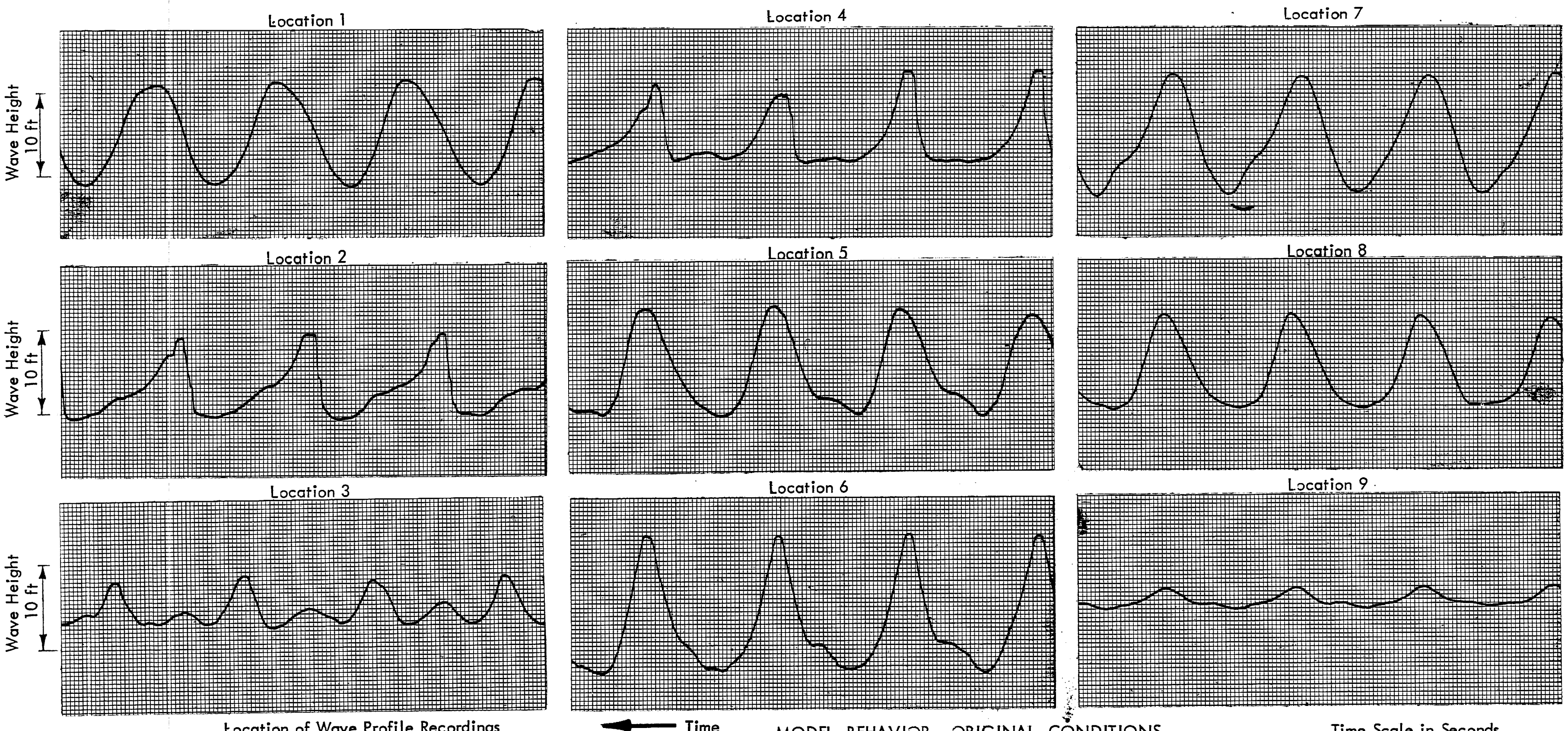
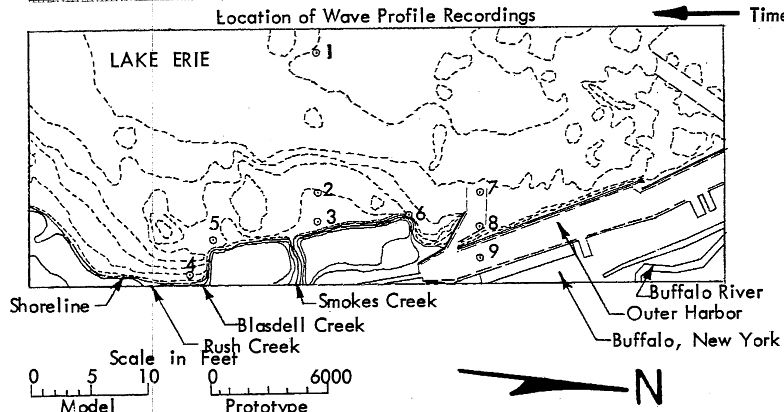
DRAWN WG	CHECKED	APPROVED
SCALE	DATE 3-17-69	NO. 183B482-68

CHART 43



Location of Wave Profile Recordings



MODEL BEHAVIOR, ORIGINAL CONDITIONS
Typical Wave Profiles

Model Scale
1:600 Horizontal - 1:120 Vertical

Flow Conditions
12 ft x 7 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Wave profiles obtained using a 2-wire capacitance type wave probe.

Time Scale in Seconds
0 1
Model
0 5 10
Prototype

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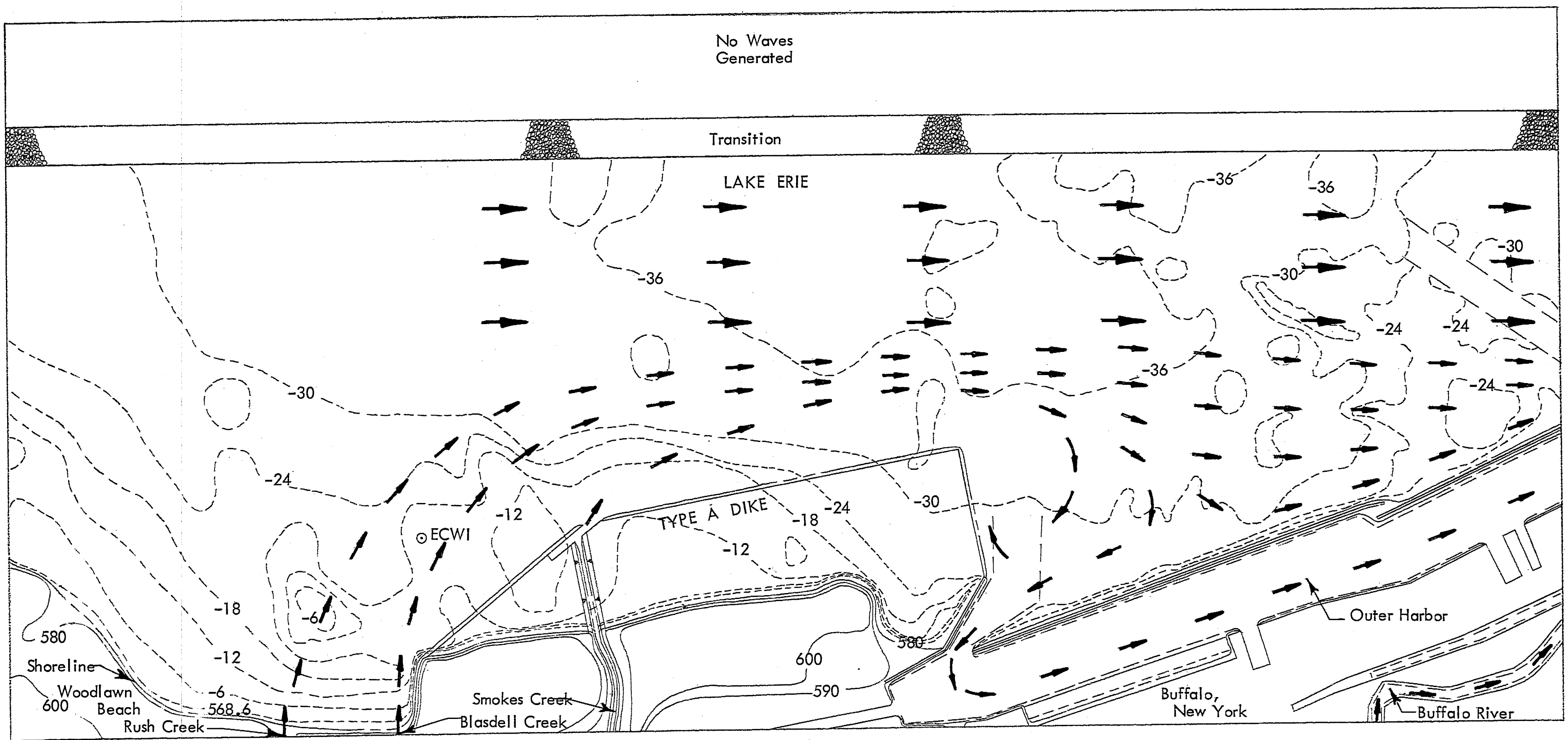
SCALE	DATE 2-28-69	NO. 183B482-46

CHART 44



Lake Erie Currents
Creek Currents

N

Scale in Feet

0 5 (Model) — 0 3000 (Prototype)

Model Scale

1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, TYPE A DIKE

Lake Erie and Creek Currents
Without Waves

Flow Conditions

Lake Erie Elevation = 570.6 ft
Niagara River Discharge = 200,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Currents obtained using red dye and paper confetti.

BETHLEHEM STEEL CORPORATION Lackawanna Plant Lackawanna, New York LAKE ERIE DIKE		
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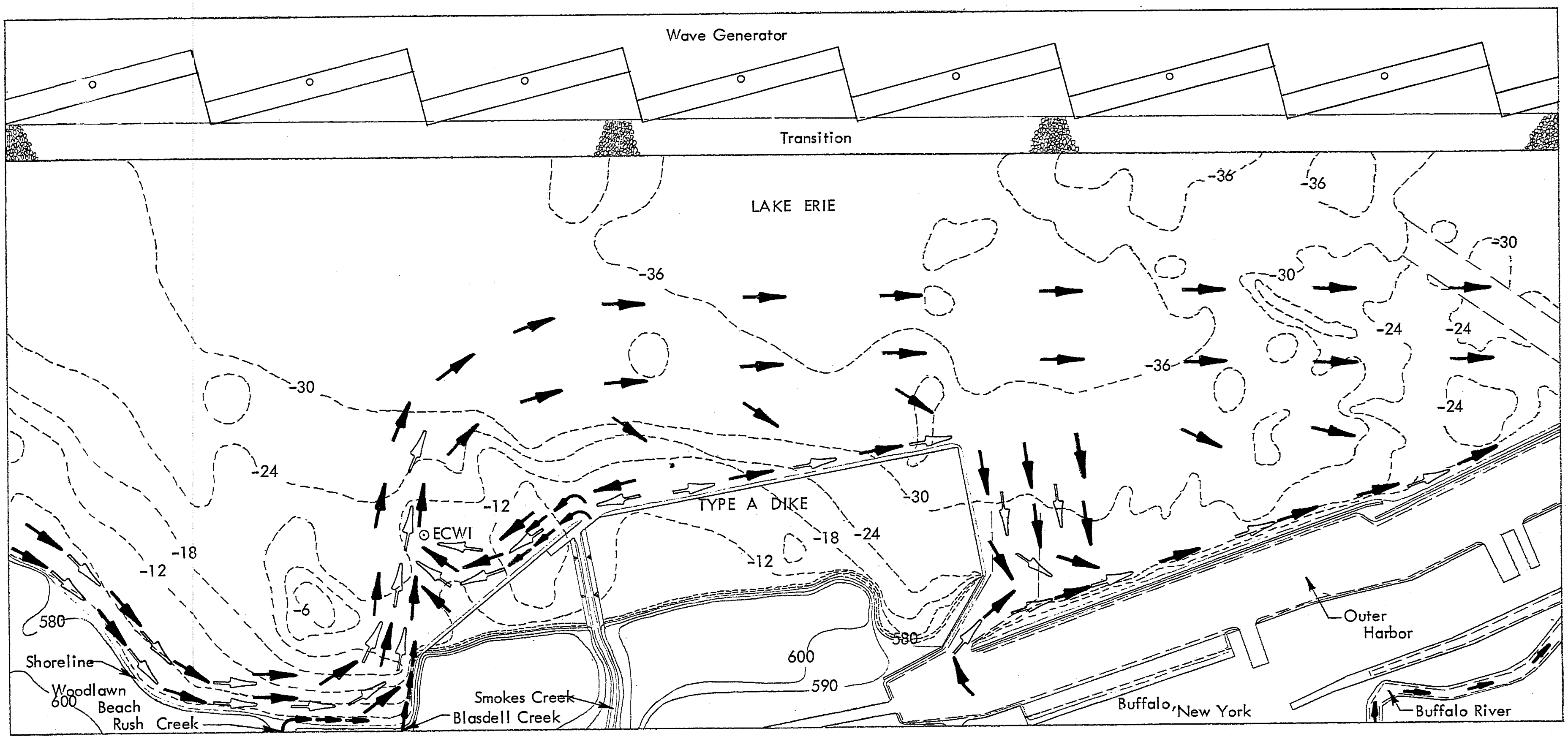
SCALE	DATE 2-26-69	NO. 183B482-31

CHART 45



N

Surface Currents

Littoral Drift Currents

Creek Currents

Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, TYPE A DIKE

Surface, Littoral Drift, and Creek Currents

Flow Conditions

12 ft x 7 sec Waves from S 67-1/2° W

Lake Erie Elevation = 575.0 ft

Niagara River Discharge = 300,000 cfs

Buffalo River Discharge = 520 cfs

Smokes Creek Discharge = 200 cfs

Blasdell Creek Discharge = 46 cfs

Rush Creek Discharge = 13 cfs

Currents obtained using red dye and paper confetti.

BETHLEHEM STEEL CORPORATION

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Lackawanna, New York

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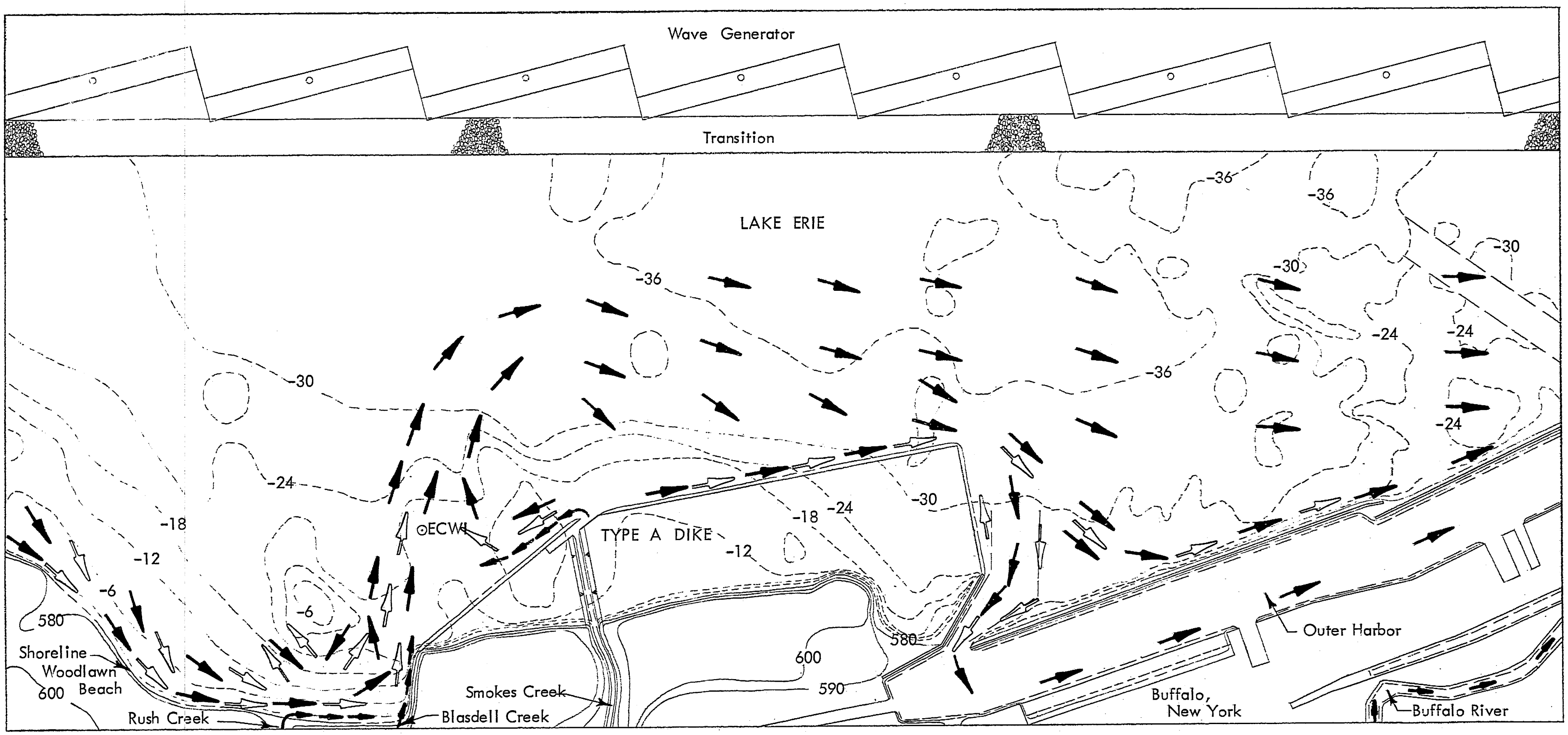
DRAWN DS	CHECKED	APPROVED
SCALE	DATE 2-26-69	NO. 183B482-32

CHART 46



Surface Currents

Littoral Drift Currents

Creek Currents

Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, TYPE A DIKE

Surface, Littoral Drift, and Creek Currents

N

Flow Conditions

6 ft x 4 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Currents obtained using red dye and paper confetti.

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Lackawanna, New York

LAKE ERIE DIKE

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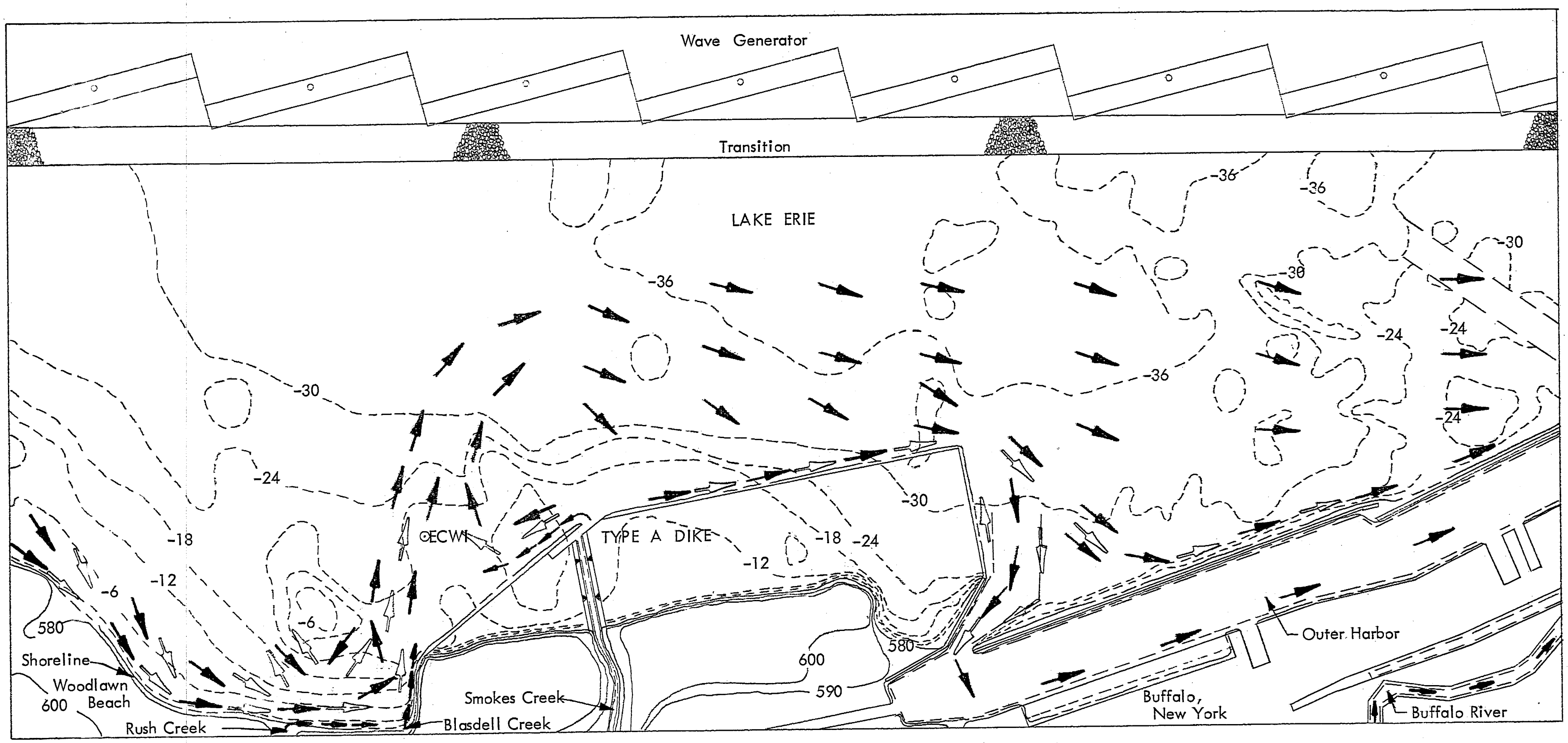
SCALE	DATE 2-26-69	NO. 18?B482-33

CHART 47



Scale in Feet

0 5 — Model

0 3000 — Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

Surface Currents

Littoral Drift Currents

Creek Currents

MODEL BEHAVIOR, TYPE A DIKE

Surface, Littoral Drift, and Creek Currents

Flow Conditions

6 ft x 4 sec Waves from S 67-1/2° W

Lake Erie Elevation = 570.6 ft

Niagara River Discharge = 200,000 cfs

Buffalo River Discharge = 520 cfs

Smokes Creek Discharge = 200 cfs

Blasdell Creek Discharge = 46 cfs

Rush Creek Discharge = 13 cfs

Currents obtained using red dye and paper confetti.

BETHLEHEM STEEL CORPORATION Lackawanna Plant Lackawanna, New York LAKE ERIE DIKE		
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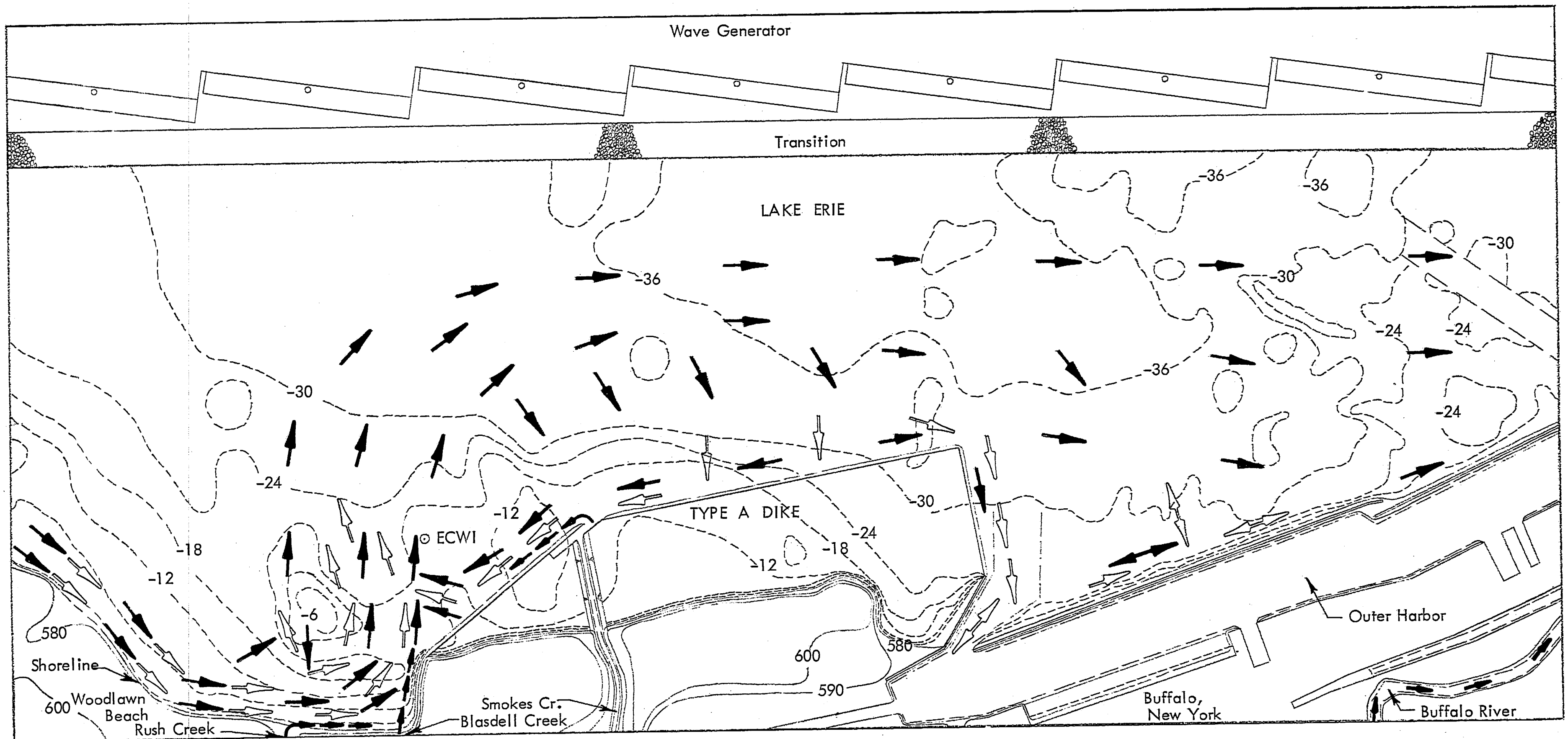
CHART 48



Surface Currents

Littoral Drift Currents

Creek Currents

Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, TYPE A DIKE

Surface, Littoral Drift, and Creek Currents

Flow Conditions

12 ft x 7 sec Waves from the West

Lake Erie Elevation = 575.0 ft

Niagara River Discharge = 300,000 cfs

Buffalo River Discharge = 520 cfs

Smokes Creek Discharge = 200 cfs

Blasdell Creek Discharge = 46 cfs

Rush Creek Discharge = 13 cfs

Currents obtained using red dye and paper confetti.

BETHLEHEM STEEL CORPORATION

Lackawanna Plant

Lackawanna, New York

LAKE ERIE DIKE

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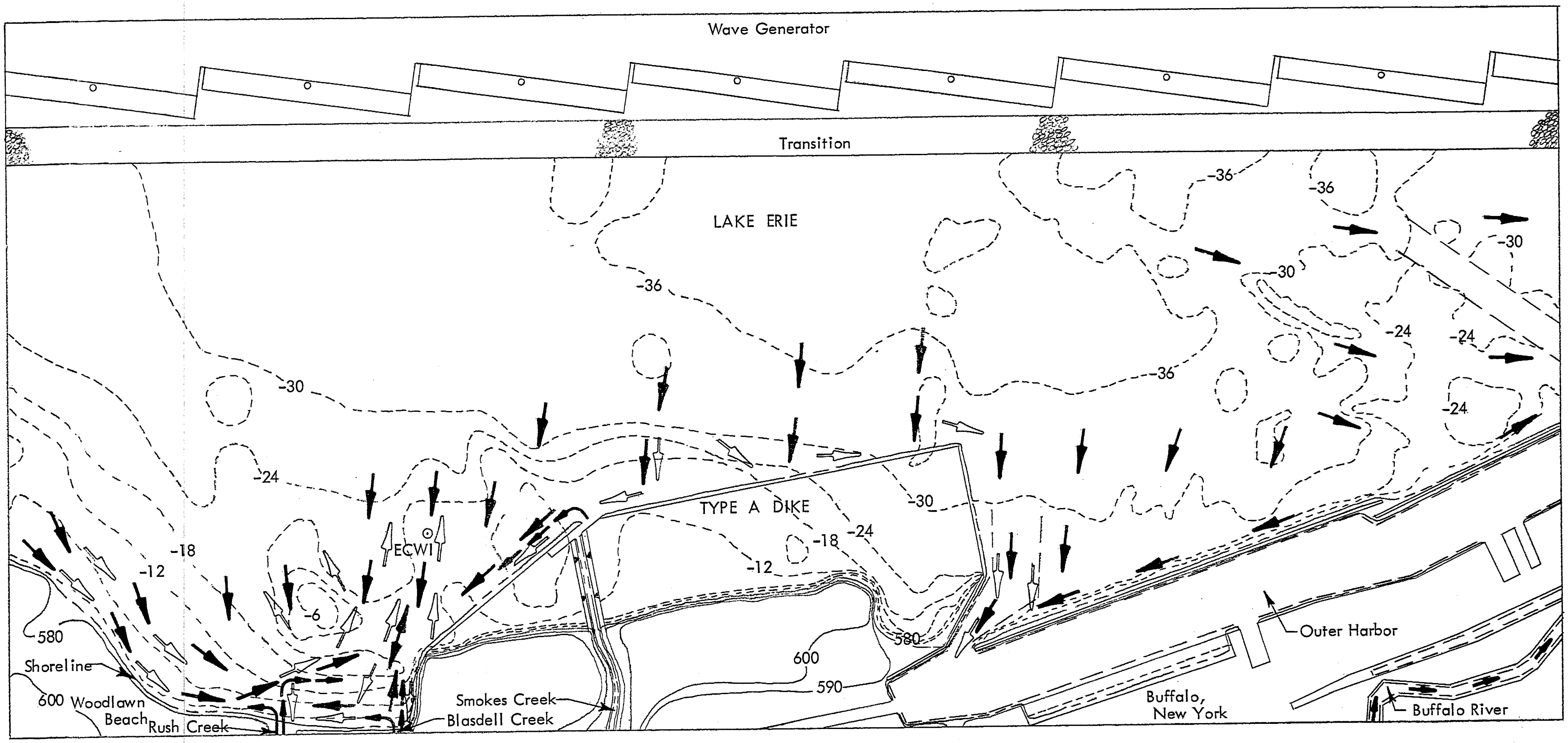
SCALE	DATE 2-26-69	NO. 183B482-35

CHART 49



Surface Currents
Littoral Drift Currents
Creek Currents

Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale
1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, TYPE A DIKE
Surface, Littoral Drift, and Creek Currents

Flow Conditions
6 ft x 4 sec Waves from the West
Lake Erie Elevation = 575.0 ft

Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Currents obtained using red dye and paper confetti.

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LAKE ERIE DIKE

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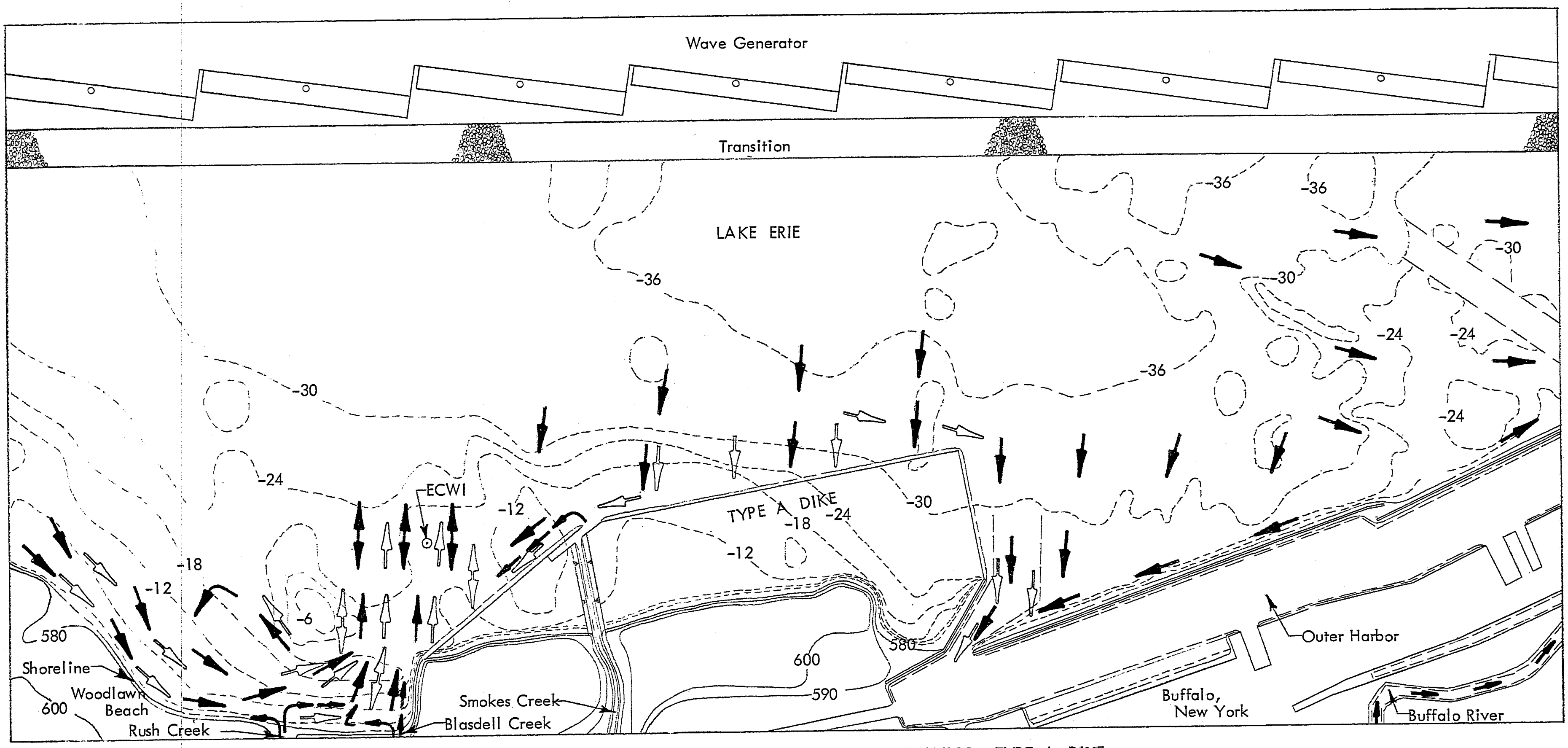
CHART 50



Surface Currents
Littoral Drift Currents
Creek Currents

Scale in Feet
0 5 Model
0 3000 Prototype

Model Scale
1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, TYPE A DIKE
Surface, Littoral Drift, and Creek Currents

Flow Conditions
6 ft x 4 sec Waves from the West
Lake Erie Elevation = 570.6 ft

Niagara River Discharge = 200,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Currents obtained using red dye and paper confetti.

BETHLEHEM STEEL CORPORATION Lackawanna Plant Lackawanna, New York LAKE ERIE DIKE		
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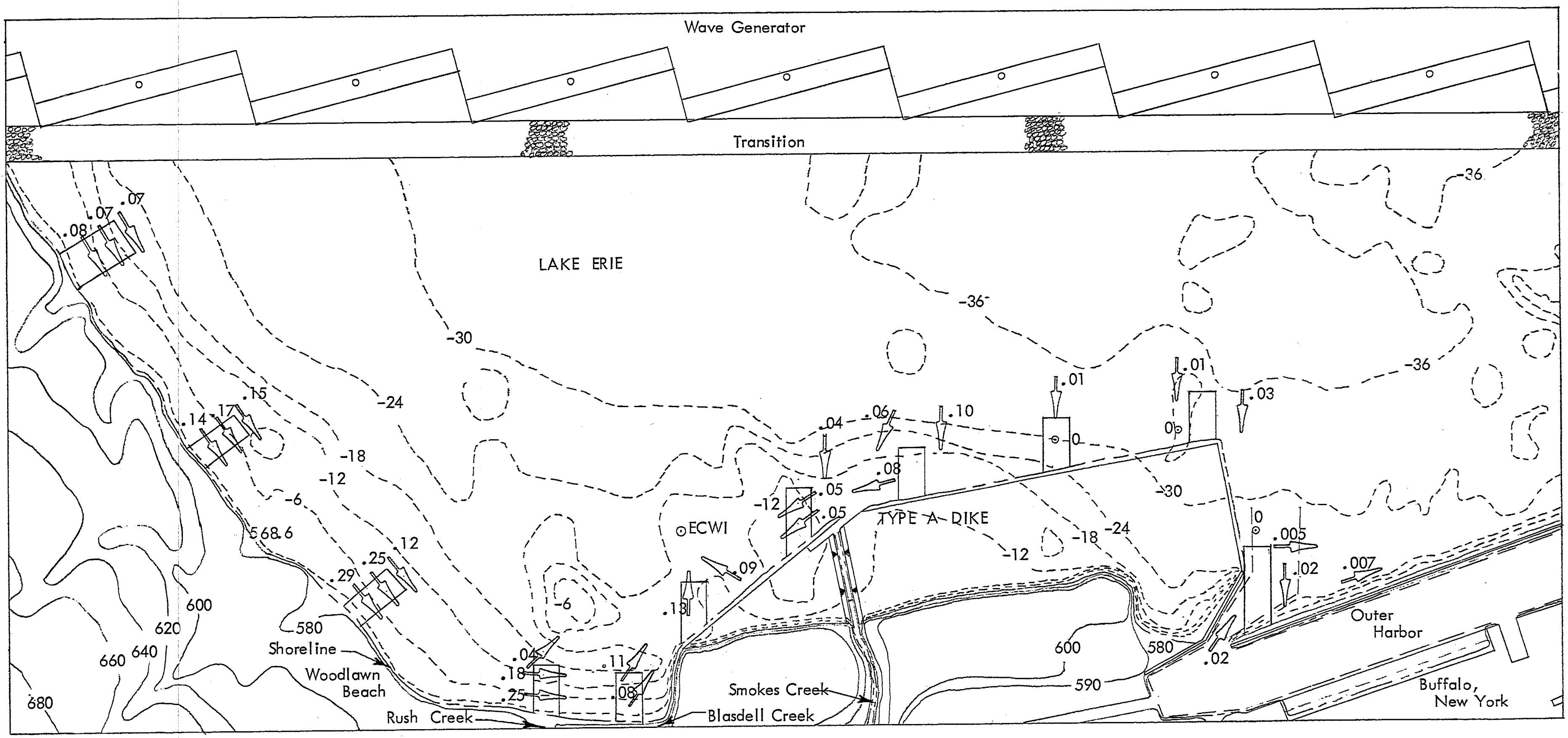
DRAWN DS	CHECKED [illegible]	APPROVED
SCALE	DATE 2-26-69	NO. 183B482-37



Scale in Feet

0 5 (Model) — 0 3000 (Prototype)

Model Scale

1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, TYPE A DIKE

Littoral Drift Velocities

Flow Conditions

12 ft x 7 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Littoral drift velocities were estimated using a 1/8 in. diameter plastic sphere with a specific gravity of 1.3. Velocities are in fps model.

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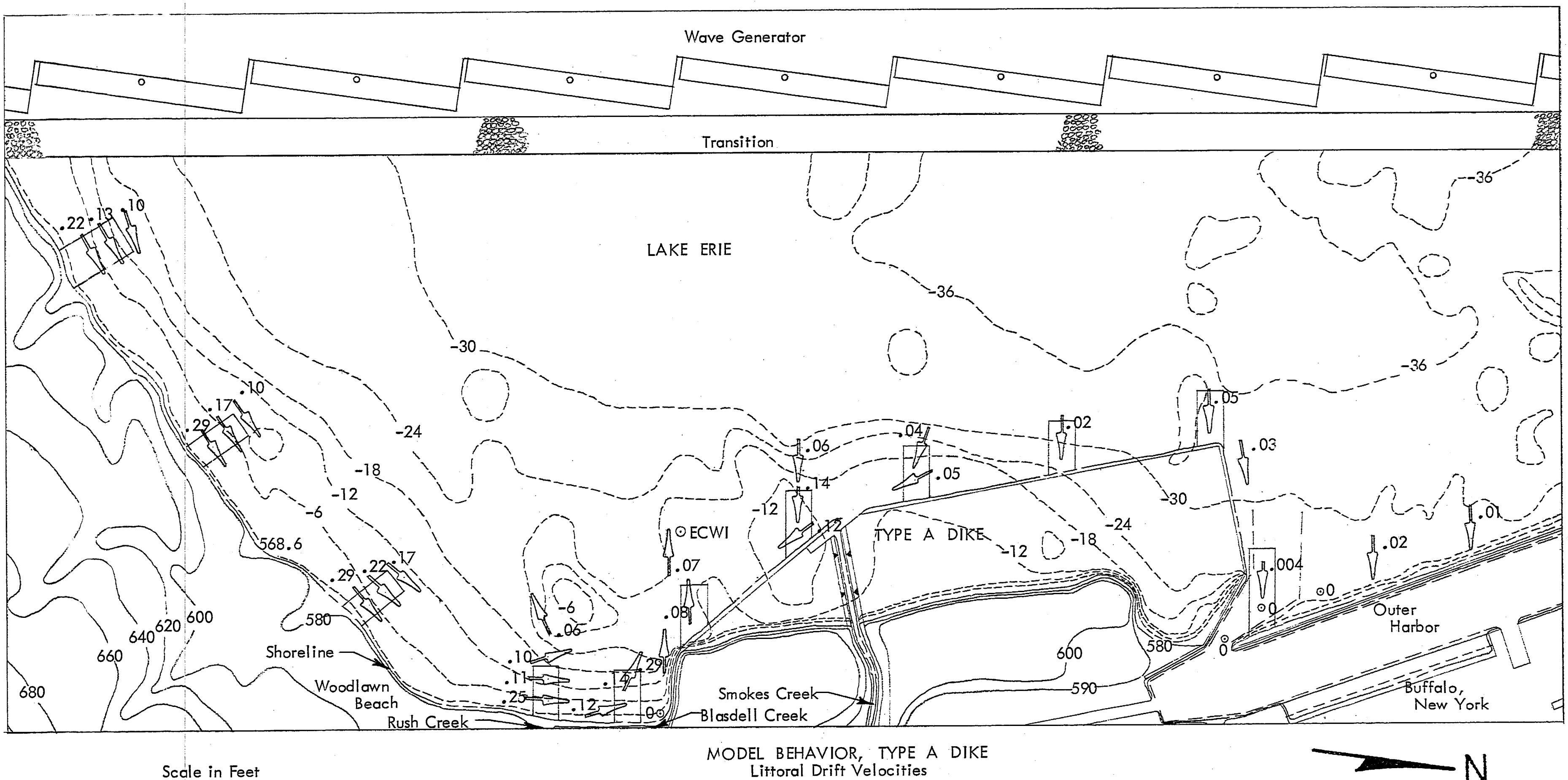
DRAWN JF	CHECKED	APPROVED
SCALE	DATE 2-27-69	NO. 183B482-40



Scale in Feet

0 5 0 3000

Model Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

MODEL BEHAVIOR, TYPE A DIKE

Littoral Drift Velocities

Flow Conditions

12 ft x 7 sec Waves from the West
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

Littoral drift velocities were estimated using a 1/8 in. diameter plastic sphere with a specific gravity of 1.3. Velocities are in fps model.

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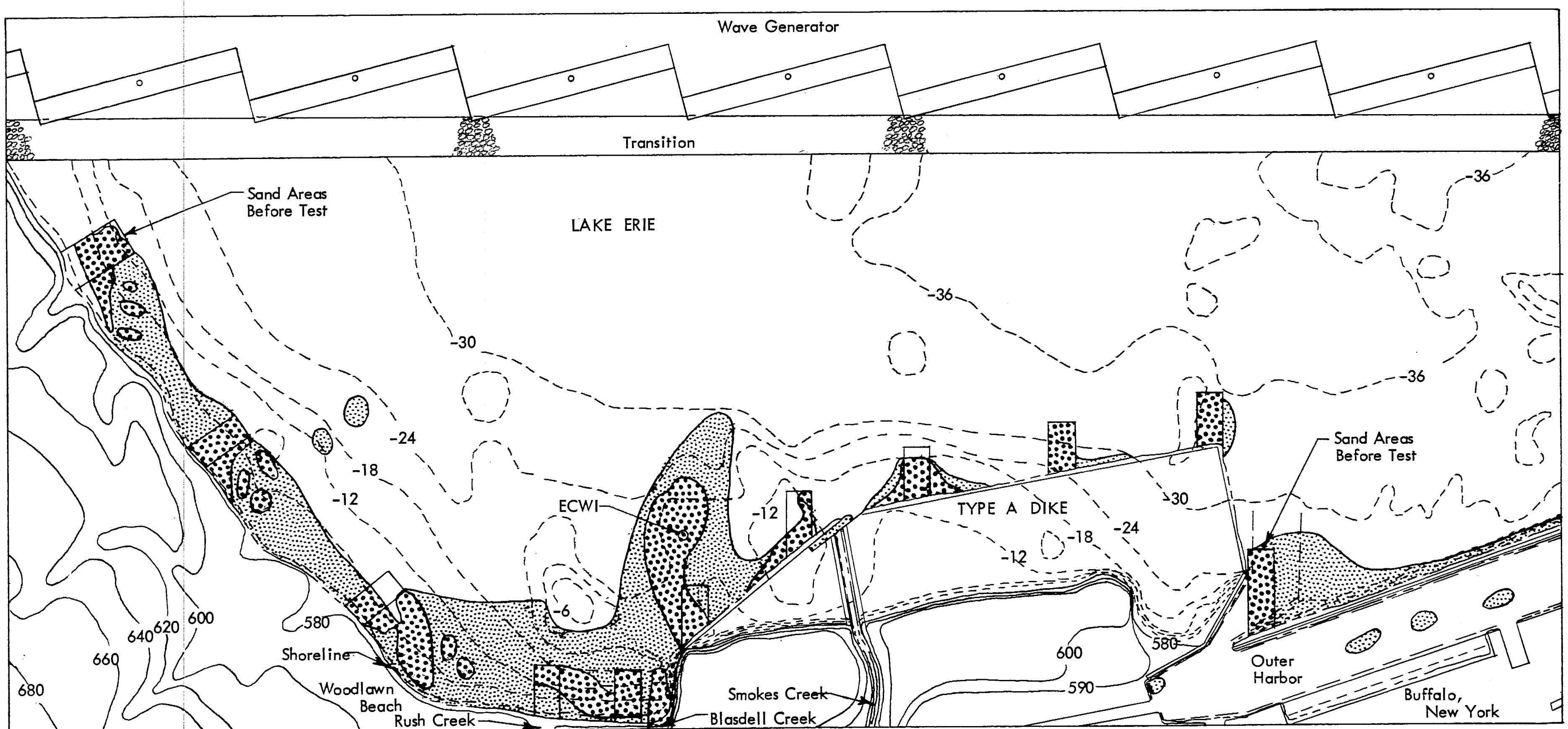
DRAWN WG	CHECKED [signature]	APPROVED
SCALE	DATE 2-27-69	NO. 183B482-41

CHART 53



Scale in Feet

0 5 — Model

0 3000 — Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

Heavy Deposits

Light Deposits

A thin layer of sand was placed in marked rectangular areas before test. The sand distribution pattern after a 4 hour test is shown. Sand with a mean diameter of 0.2 mm was used.

MODEL BEHAVIOR, TYPE A DIKE
Littoral Drift

Flow Conditions
12 ft x 7 sec Waves from S 67-1/2° W
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

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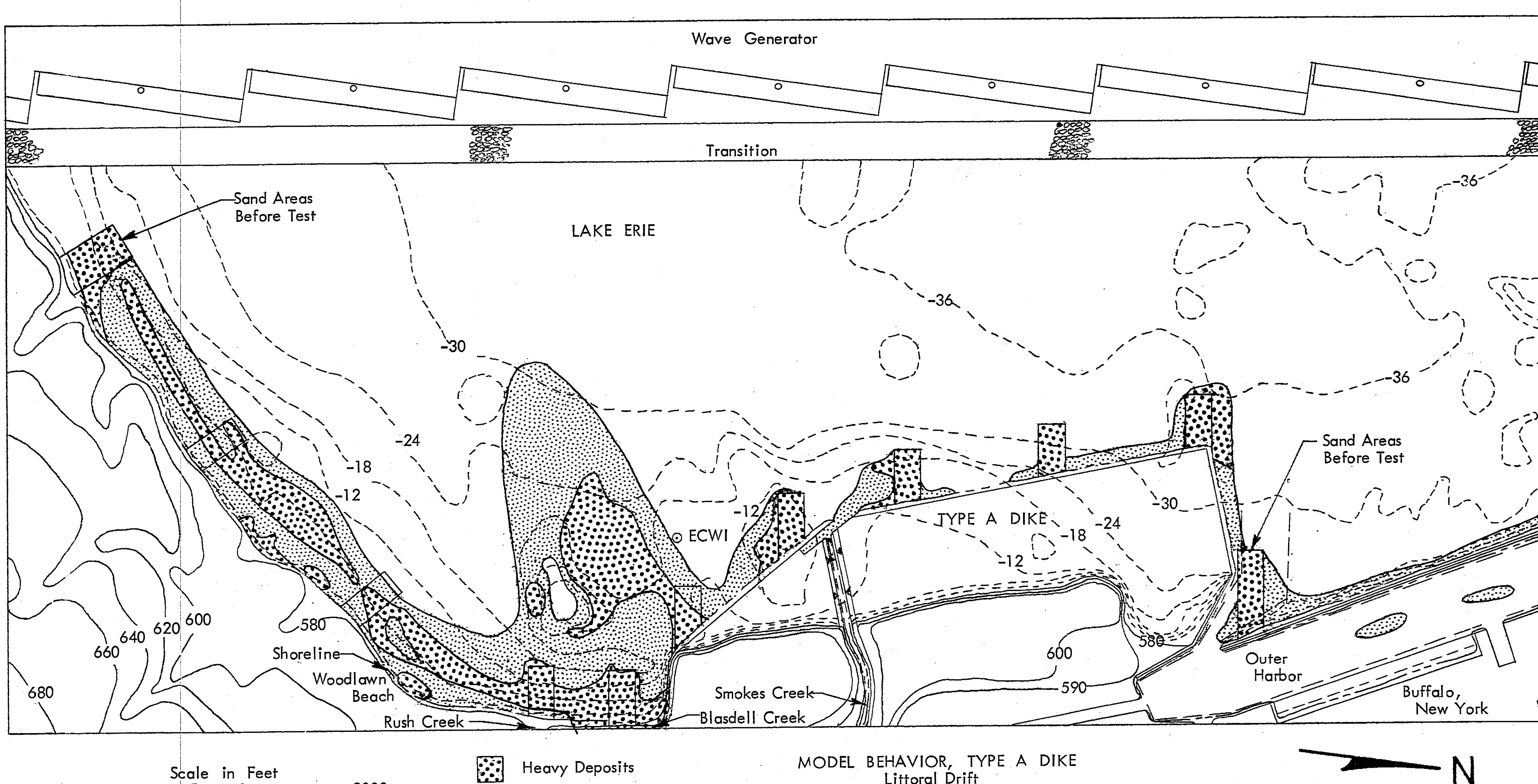
SCALE	DATE 2-27-69	NO. 183B482 - 44

CHART 54



Scale in Feet

0 5 Model

0 3000 Prototype

Model Scale

1:600 Horizontal - 1:120 Vertical

Heavy Deposits

Light Deposits

A thin layer of sand was placed in marked rectangular areas before test. The sand distribution pattern after a 4 hour test is shown. Sand with a mean diameter of 0.2 mm was used.

MODEL BEHAVIOR, TYPE A DIKE
Littoral Drift

Flow Conditions
12 ft x 7 sec Waves from the West
Lake Erie Elevation = 575.0 ft
Niagara River Discharge = 300,000 cfs
Buffalo River Discharge = 520 cfs
Smokes Creek Discharge = 200 cfs
Blasdell Creek Discharge = 46 cfs
Rush Creek Discharge = 13 cfs

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LAKE ERIE DIKE

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DRAWN WG	CHECKED	APPROVED
SCALE	DATE 2-27-69	NO. 183B482-45

CHART 35

University of Minnesota
ST. ANTHONY FALLS HYDRAULIC LABORATORY

Supplement I to

Project Report No. 104

A MODEL STUDY OF A DIKE ENCLOSURE AT THE EASTERN END OF LAKE ERIE

by
Edward Silberman
and
Warren Q. Dahlin

Prepared for
THE BETHLEHEM STEEL CORPORATION
Lackawanna, New York

August 1970
Minneapolis, Minnesota

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II. THE MODEL STUDY 1

III. CONCLUSIONS 5

List of References 6

List of Photos (with 3 accompanying Photos)

List of Charts (with 17 accompanying Charts)

Supplement I to

Project Report No. 104

A MODEL STUDY OF A DIKE ENCLOSURE AT THE EASTERN END OF LAKE ERIE

I. INTRODUCTION

In an earlier model study [1]* some tests were made on a plan form for a dike at the eastern end of Lake Erie at the Lackawanna plant of the Bethlehem Steel Corporation. In the earlier model study it was predicated that the dike cross section would not produce excessive reflection. The model study described herein was directed at examining the reflection characteristics of various cross sections.

The plan form of the dike was shown in detail on Chart 24 of the earlier study [1] and is not reproduced herein. A consulting engineer to the Bethlehem Steel Corporation proposed various forms of dike cross sections based on steel pile cells with and without rubble mounds on the lake side. The cells proposed had sloping, beach-like tops facing the lake except for every ninth cell, which was to be level on top. Chart 1 shows the configurations that were selected for testing from among the consultant's proposals.

II. THE MODEL STUDY

The model dike cross sections were tested in a wave tank 30 in. wide by 52 ft long. The tank, with one of the models installed, is sketched on Chart 2 and can be seen in Photo 1. Photo 2 shows waves approaching one of the models in the tank.

All the tests were conducted at a 1:50 scale. This made it possible to include three complete cells across the wave channel as indicated on Chart 1. It also enabled measurement of wave reflections 1000 ft into the lake without interference from the wave maker. Although the consultant had recommended both 1:2 and 1:1-1/2 slopes on the top surface of the bulkhead, only the flatter slope was tested, since the steeper one would have produced larger reflections, and those at 1:2 slope were already quite large. The bulkheads were placed in the model where the water is 30 ft deep below low water datum in the prototype.

*Numbers in brackets refer to the list of references on page 6.

Seven variations of the cross section were tested using cells with sloping top faces entirely across the wave channel. These appeared in plan as shown for the type A dike on Chart 1. The cross-section characteristics are summarized in Table I and on Chart 1 as tests A through G. In addition, one set of tests (test H) was conducted with half of a flat-topped cell at one side of the test section and sloping top faces on the remaining cells. Chart 1 shows its plan form in the wave channel. Other combinations of model characteristics could have been tested, but those model variations which were tested produced enough information for evaluating the utility of any useful combinations.

TABLE I

Models Tested

(All top faces 1:2 slope)

Model Designation	Elev. of Top of Slope ft	Elev. of Bottom of Slope ft	Wave Screen and Curb	Surface Roughness	Other Conditions
A	+13	+4	None	None	
B {1, 2}	+20	+4	{None, Yes}	None	
C	+20	+4	Yes	Steps	
D	+20	+4	Yes	Sills	Also tested with solid wave deflector at top
E	+20	-1	Yes	Steps	
F	+13	+4	None	None	Rubble Mound*
G	+20	+4	Yes	Steps	Rubble Mound*

*Rubble mound is continuation of 1:2 top slope of models A and C to the bottom of the channel. Top layer of stones--26 ton. Inner layers graded down.

The tests were made with the lake at elevations +2 and +6.4 with respect to mean low water (568.6 ft) using 6 ft by 4 sec waves and at elevation +6.4 using 12 ft by 7 sec and 18 ft by 7 sec waves. The 18 ft wave tests were directed primarily at checking the stability of the rubble mound, but since the capability was present, other tests were also conducted with these waves.

Wave reflections were generally measured at 1000 ft from the bulkhead in water 30 to 34 ft deep. The measurements reported were obtained from short groups of about 10 to 12 waves for 6 ft waves and about 5 to 6 waves for larger waves, each moving from the generator past the probe to be reflected back past the probe by the bulkhead. A two-wire capacitance-type probe was used. Typical records as well as all the data for wave reflections are reproduced on Charts 3 through 10 for tests A through G. Reflections were also measured at 500 ft from the bulkhead for 6 ft by 4 sec waves, and those results are averaged with results from 1000 ft. Typical comparisons between records at 1000 ft and those at 500 ft are shown on Charts 11 and 12 for tests A and F. The wave reflection measurements are summarized in Table II. Reflection measurements were also made for continuous wave trains, but these soon became contaminated by re-reflection from the wave maker, and the results are not reliable. Typical results are shown on Charts 13 and 14 for tests A and F.

TABLE II

Average Wave Reflection Coefficients

(Measured 1000 and 500 ft from bulkhead)

Model Designation	Wave Condition and Water Elevation			
	6 ft x 4 sec		12 ft x 7 sec	18 ft x 7 sec
	+2	+6.4	+6.4	+6.4
A	0.61	0.27	0.57	0.54
B 1	0.57	0.27	0.52	0.48
B 2	0.58	0.28	0.51	0.46
C	0.66	0.37	0.56	0.56
D	0.71	0.32	0.61	0.59
E	0.46	0.24	0.42	0.46
F	0.20	0.19	0.34	0.30
G	0.24	0.22	0.30	0.27

The model containing one flat-topped cell, model H, produced a three-dimensional crisscross wave reflection pattern, as might have been expected. (The previous patterns were all two-dimensional.) In some places the reflections cancelled out, but in others they were combined, and the reflections became very much larger than when only sloping top faces were used. Photo 3 shows one test result. From this pattern it was concluded that it would be harmful to use a warped bulkhead surface with variable slope angles on the face, and no further tests of this kind were made.

During the wave reflection tests, observations on bottom erosion were made. There was some erosion in all tests with 18 ft waves and also a little in some of the tests with 12 ft waves. The cross sections with longer surfaces under mean water level caused more erosion than those with shorter underwater surfaces. Erosion should not be considered a serious problem, since storm erosion of this limited magnitude will be repaired by natural processes between storms.

The rubble mound bulkheads, models F and G, were stable under 18 ft waves, some top stones rocking just a little. As noted on Chart 1 and in Table I, the top stones represent 26-ton stones in the prototype. There was no visible disturbance with 12 ft waves.

In addition to the tests on reflection, measurements were made of overtopping and of maximum pressure on the sloping dike surfaces. Overtopping measurements are recorded on Charts 3 through 10 and summarized in Table III. The measurements were made by collecting the overtopping water in a pan behind the model for a measured period of time and then measuring the volume of water collected.

TABLE III

Overtopping

(cfs per ft of bulkhead, prototype)

Model Designation	Wave Condition and Water Elevation			
	6 ft x 4 sec		12 ft x 7 sec	18 ft x 7 sec
	+2	+6.4	+6.4	+6.4
A	0.07	0.32	5.4	15.7
B 1	0	0	1.9	8.9
B 2	0	0	0.8	7.0
C	0	0	0.2	3.5
D	0	0	1.4	4.8
E	0	0	0.7	4.4
F	0.07	0.59	7.6	22.2
G	0	0	1.3	8.0

Wave pressure measurements were recorded on models A, B-1, and B-2 only. The results are shown on Charts 15, 16, and 17 and are summarized in Table IV. Pressure variations were obtained through a small piezometer hole drilled in the sloping top face of the dike near the center of one cell as shown on the charts. This was directly connected to a cavity containing a diaphragm-type pressure transducer. The recorded pressure variations were measured with respect to hydrostatic pressure at the piezometer location. As can be observed from the records on the charts, the pressure recorded depended very much on the location of the piezometer tap relative to the position of the breaking wave. It is suspected that there may be some attenuation of the pressure surge by the measuring arrangement, and the values derived from the model should not be relied upon absolutely. An earlier attempt to measure surface pressure directly with a diaphragm exposed on the surface proved unworkable because there were instrument compensation problems and the diaphragm covered too much surface area.

TABLE IV

Maximum Fluctuating Pressure

(ft, prototype)

Model Designation	Wave Condition and Water Elevation			
	6 ft x 4 sec		12 ft x 7 sec	18 ft x 7 sec
	+2	+6.4	+6.4	+6.4
A	2.1	3.0	8.5	8.4
B 1	5.5	4.7	9.7	13.2
B 2	2.0	6.4	9.5	14.0

III. CONCLUSIONS

It can be seen from Table II that reflections will generally be excessive if steel cell bulkheads are used without rubble mounds. Excessive reflections can be alleviated by providing a rubble mound in front of the cells as tested with models F and G. (The reason F appears to be slightly more effective than G for small waves is that overtopping on F relieves some of the reflection.) The prototype reflection may actually be slightly less for the rubble mound than is indicated by the model because of the relatively small scale of the model [2].

Reflection can also be reduced by extending the sloping top face below water level, as was shown by the tests on model E. This would mean that construction would have to be carried out under water. The longer the underwater slope, the more effective the bulkhead becomes in reducing wave reflection. Reflection from a submerged bulkhead would also be less than reflection from one that extended above the surface [3]. No tests were made on submerged bulkheads. Small changes in overtopping produced by screens and roughness, as summarized in Table III, have little effect on reflection.

With regard to overtopping, the height of the dike is the controlling factor; the wave screen is effective in reducing overtopping without increasing reflection, as can be seen from the tests on models B-1 and B-2. Surface roughness also reduces overtopping, but may have an adverse effect on reflection, as is indicated by a comparison of the tests of models B-2 and C. At one point in the tests on model D the wave screen was replaced by a solid, curved deflector, and this reduced the overtopping from the larger waves by 50 per cent without influencing reflection; this result is not shown in Table III. It can be observed by comparing the overtopping tests of models E and G with those of model C that extending the length of the bulkhead top surface below water increases overtopping.

REFERENCES

[1] Silberman, Edward; Dahlin, Warren Q.; and Paintal, Amreek S., A Model Study of a Dike Enclosure at the Eastern End of Lake Erie, Project Report No. 104, St. Anthony Falls Hydraulic Laboratory, University of Minnesota, April 1969.

[2] Lee, C. E., "On Wave Damping in Harbors," Journal of the Hydraulics Division, ASCE, 94, WW4: 489-501, November 1968.

[3] Wiegel, R. L., Oceanographical Engineering, Prentice-Hall, Englewood Cliffs, N.J., 1964, p. 132.

LIST OF PHOTOS

PHOTO 1 The Wave Tank, Type F Dike in Place (Neg. no. 183-344).

PHOTO 2 Model A in the Wave Tank: (a) Side View (Neg. no. 183-242); (b) Top View (Neg. no. 183-339).

PHOTO 3 Model H under Test with 12 ft High Waves of 7 sec Period, Lake Elevation +6.4: (a) Side View (Neg. no. 183-338); (b) Top View (Neg. no. 183-342).

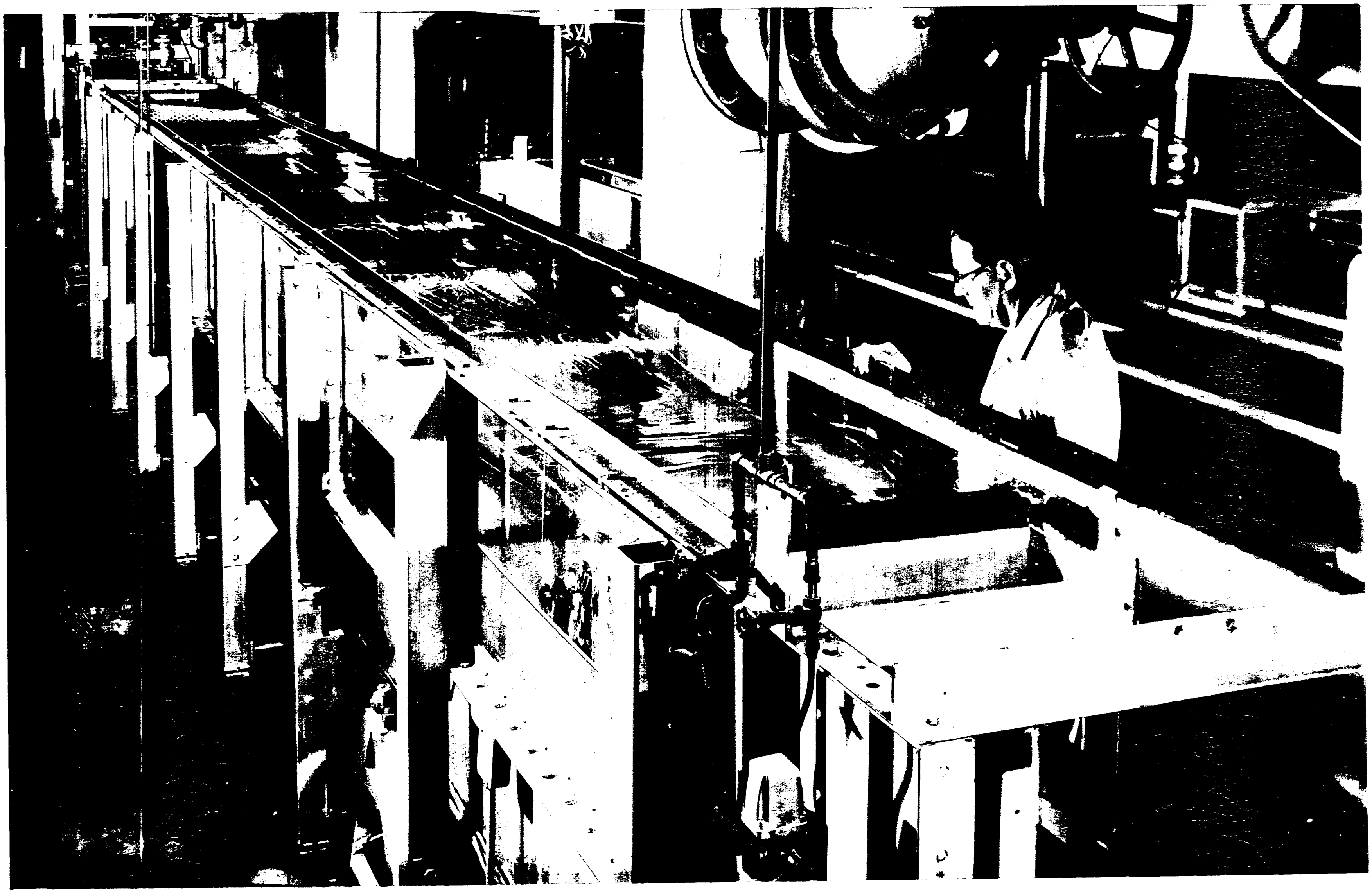
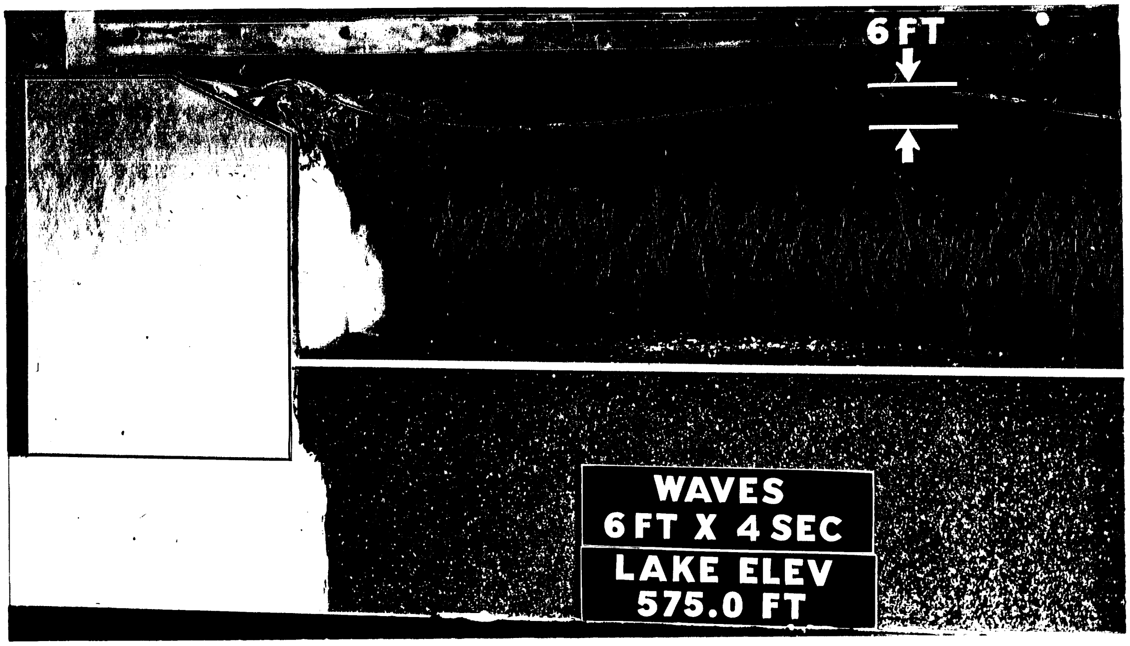
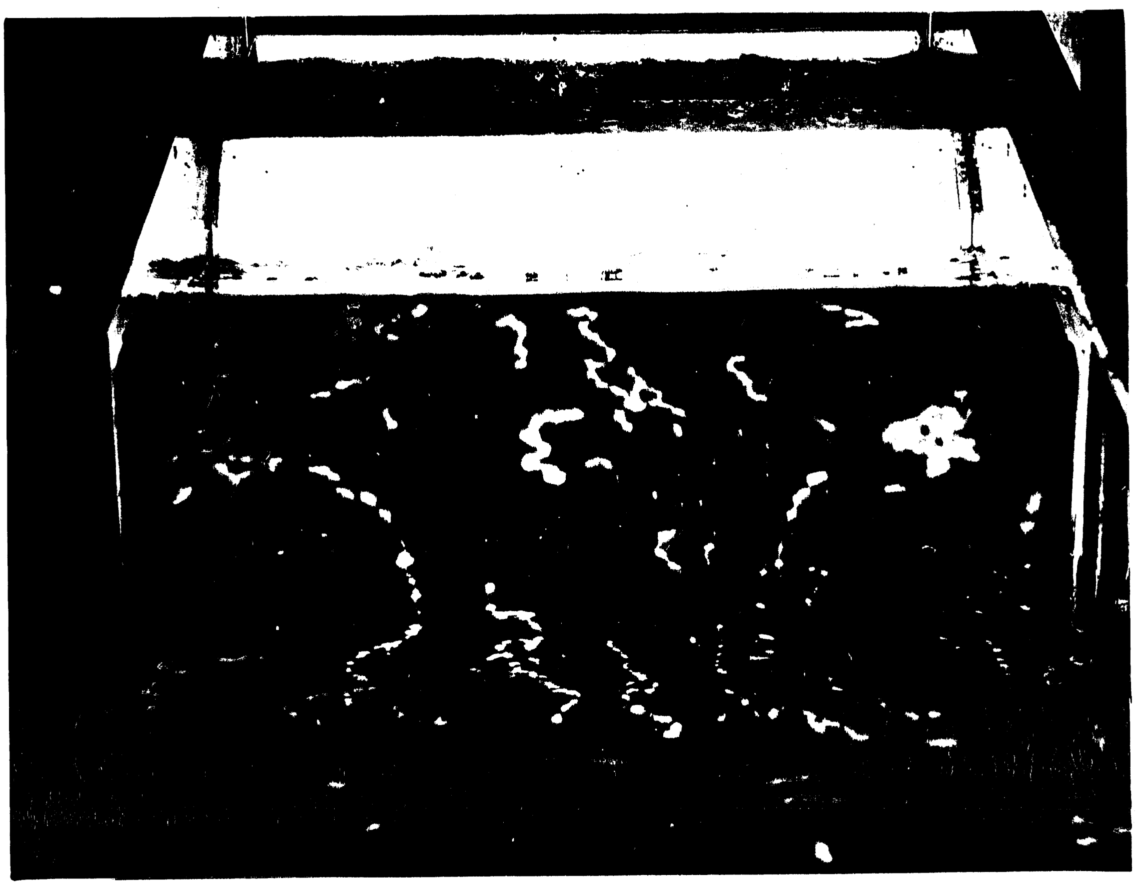


Photo 1 The Wave Tank, Type F Dike in Place (Neg. no 183-344)

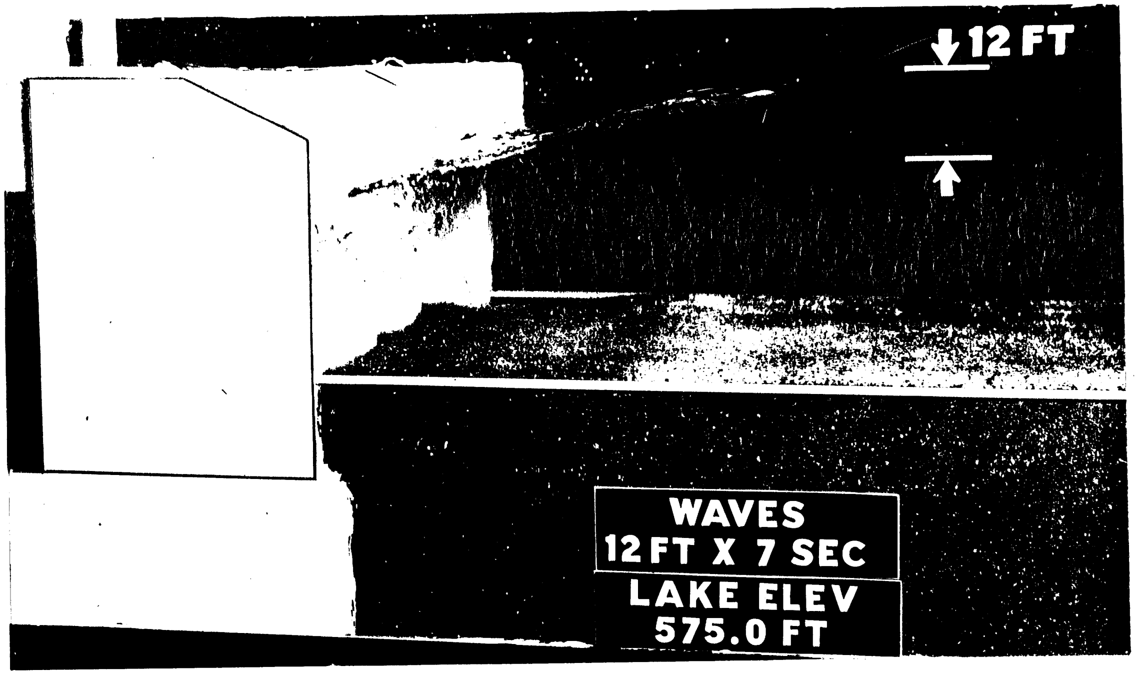


(a) Side View (Neg. no. 183-242)

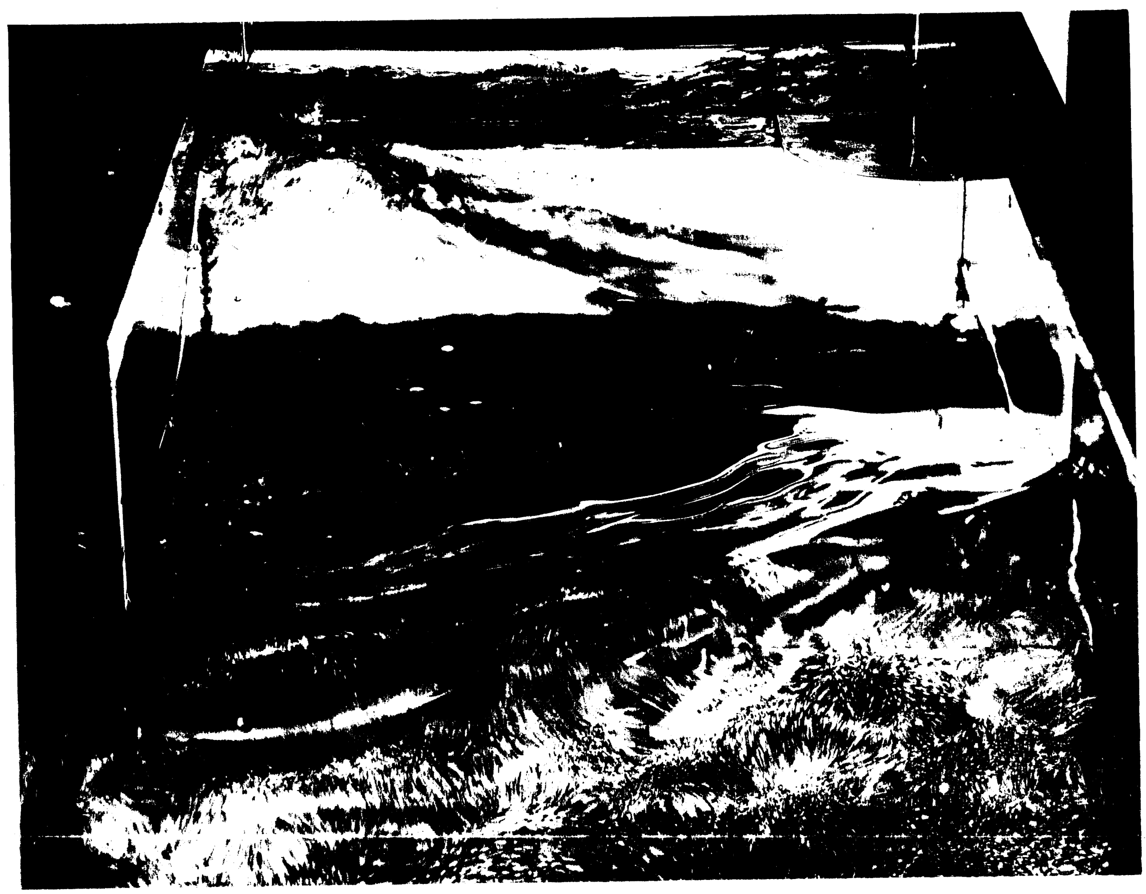


(b) Top View (Neg. no. 183-339)

Photo 2 Model A in the Wave Tank



(a) Side View (Neg. no. 183-338)



(b) Top View (Neg. no. 183-342)

Photo 3 Model H under Test with 12 ft High Waves of 7 sec Period. Lake Elevation +6.4.

LIST OF CHARTS

CHART 1 (183B482-101) Dike configurations tested

CHART 2 (183B482-102) Model wave channel

CHART 3 (183B482-85) Wave reflections from Type A dike

CHART 4 (183B482-86) Wave reflections from Type B-1 dike

CHART 5 (183B482-87) Wave reflections from Type B-2 dike

CHART 6 (183B482-88) Wave reflections from Type C dike

CHART 7 (183B482-89) Wave reflections from Type D dike

CHART 8 (183B482-90) Wave reflections from Type E dike

CHART 9 (183B482-91) Wave reflections from Type F dike

CHART 10 (183B482-92) Wave reflections from Type G dike

CHART 11 (183B482-94) Comparisons of wave reflections measured at 500 ft and 1000 ft from dike - Type A dike

CHART 12 (183B482-95) Comparisons of wave reflections measured at 500 ft and 1000 ft from dike - Type F dike

CHART 13 (183B482-96) Records of continuous waves - Type A dike

CHART 14 (183B482-97) Records of continuous waves - Type F dike

CHART 15 (183B482-98) Surface pressure fluctuations - Type A dike

CHART 16 (183B482-99) Surface pressure fluctuations - Type B-1 dike

CHART 17 (183B482-100) Surface pressure fluctuations - Type B-2 dike

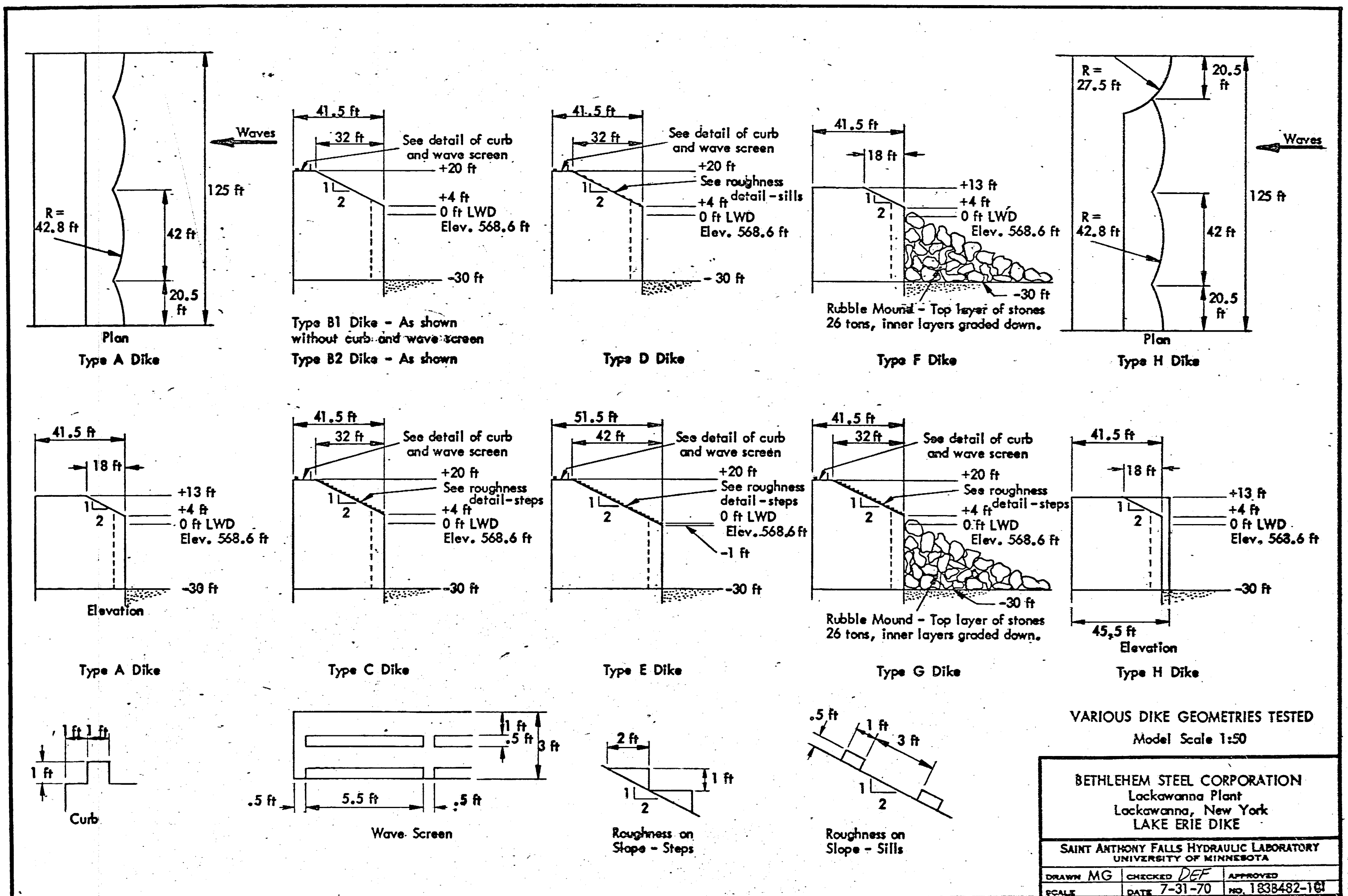
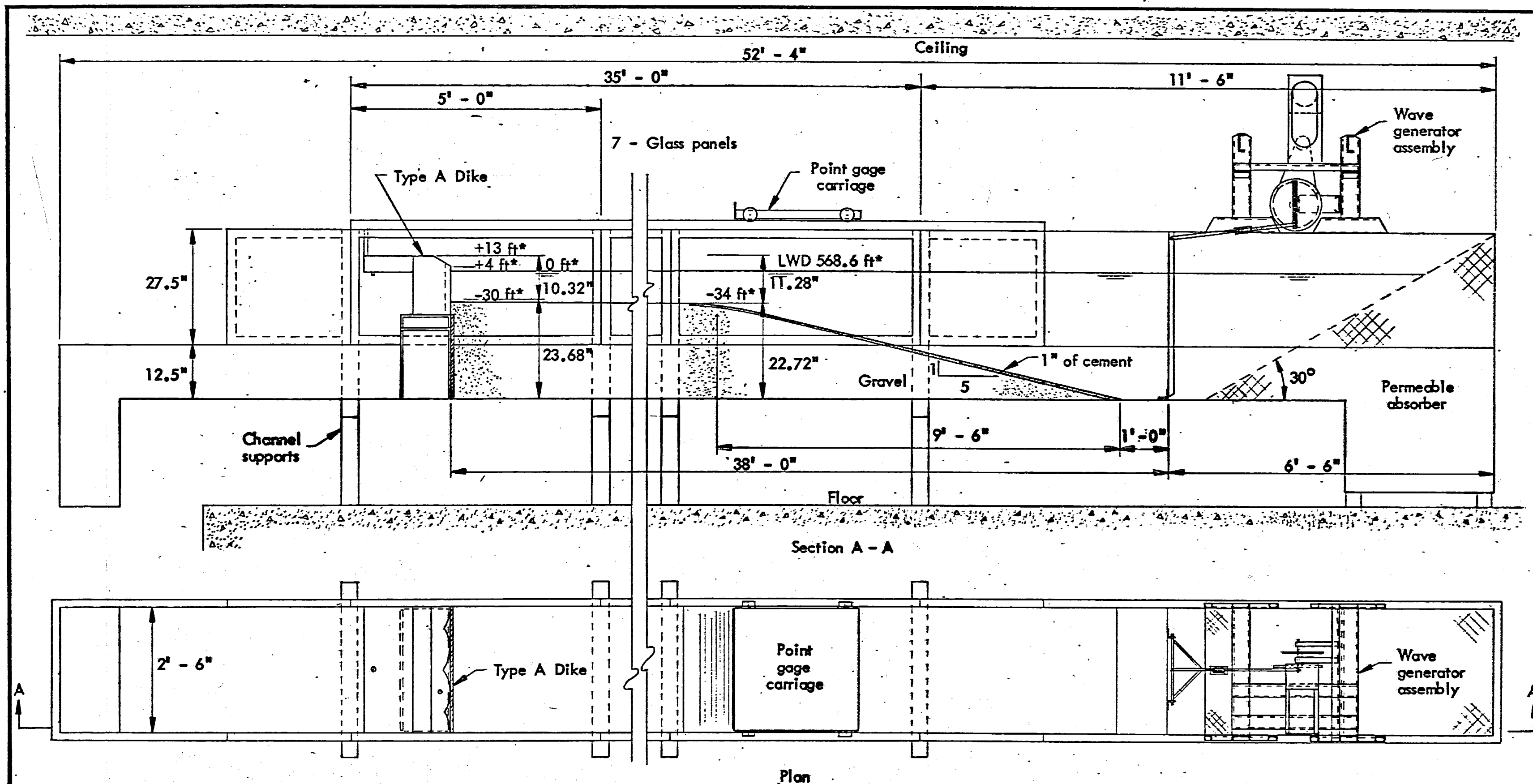

Waves
R = 42.8 ft
125 ft
42 ft
20.5 ft
Plan
Type A Dike
41.5 ft
32 ft
See detail of curb and wave screen
+20 ft
+4 ft
0 ft LWD
Elev. 568.6 ft
-30 ft
Type B1 Dike - As shown without curb and wave screen
Type B2 Dike - As shown
See roughness detail - sills
Type D Dike
18 ft
+13 ft
Rubble Mound - Top layer of stones 26 tons, inner layers graded down.
Type F Dike
R = 27.5 ft
Type H Dike
Elevation
Type A Dike
See roughness detail - steps
Type C Dike
51.5 ft
42 ft
-1 ft
Type E Dike
Type G Dike
45.5 ft
Type H Dike
1 ft
Curb
.5 ft
3 ft
5.5 ft
Wave Screen
2 ft
Roughness on Slope - Steps
Roughness on Slope - Sills
VARIOUS DIKE GEOMETRIES TESTED
Model Scale 1:50
BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN MG
CHECKED DEF
APPROVED
SCALE
DATE 7-31-70
NO. 1838482-161

CHART 1



MODEL LAYOUT
WITH TYPE A DIKE INSTALLED

Model Scale 1:50

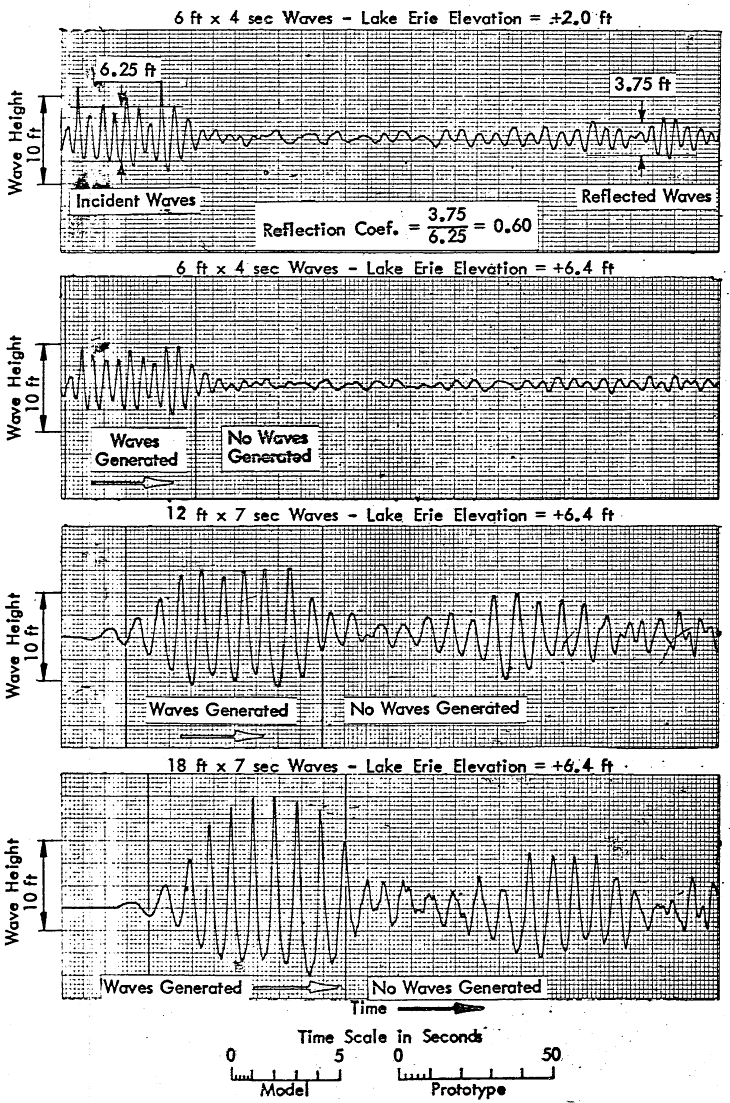
*Prototype elevations

BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

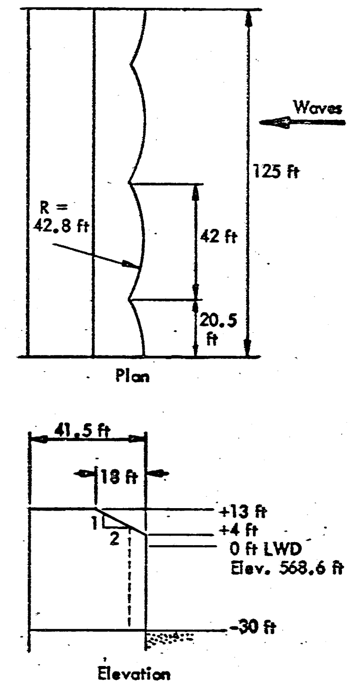
DRAWN MG	CHECKED DEF	APPROVED
SCALE	DATE 7-31-70	NO. 183B482-102

CHART 2



SUMMARY OF DATA

Meas. Dist. from Bulkhead ft	Lake Elev. ft	Avg. Incid. Wave Ht. ft	Avg. Refl. Wave Ht. ft	Refl. Coef. H_R/H_I	Over-topping cfs/ft
1000	+2.0	6.25	3.25	.52	0.07
500	+2.0	6.25	3.75	.60	
1000	+2.0	6.25	3.50	.56	
500	+2.0	6.25	4.00	.64	
1000	+2.0	6.25	3.75	.60	
500	+2.0	6.00	4.00	.67	
1000	+2.0	6.25	3.50	.56	
500	+2.0	6.00	4.00	.67	
1000	+2.0	6.00	3.00	.50	
500	+2.0	6.00	4.50	.75	
1000	+6.4	6.00	1.25	.21	0.32
500	+6.4	6.00	1.75	.29	
1000	+6.4	6.00	1.50	.25	
500	+6.4	5.50	1.75	.32	
1000	+6.4	5.50	1.25	.23	
500	+6.4	6.00	1.75	.29	
1000	+6.4	5.75	1.50	.26	
500	+6.4	6.00	1.75	.29	
1000	+6.4	6.00	1.50	.25	
500	+6.4	6.00	1.50	.25	
1000	+6.4	5.75	1.75	.30	
500	+6.4	5.75	1.75	.30	
1000	+6.4	11.50	6.00	.52	5.4
1000	+6.4	12.00	6.50	.54	
1000	+6.4	12.00	7.00	.58	
1000	+6.4	12.00	7.25	.60	
1000	+6.4	12.00	7.25	.60	
1000	+6.4	18.25	9.50	.52	15.7
1000	+6.4	18.00	10.25	.57	
1000	+6.4	18.00	10.25	.57	
1000	+6.4	18.25	9.50	.52	

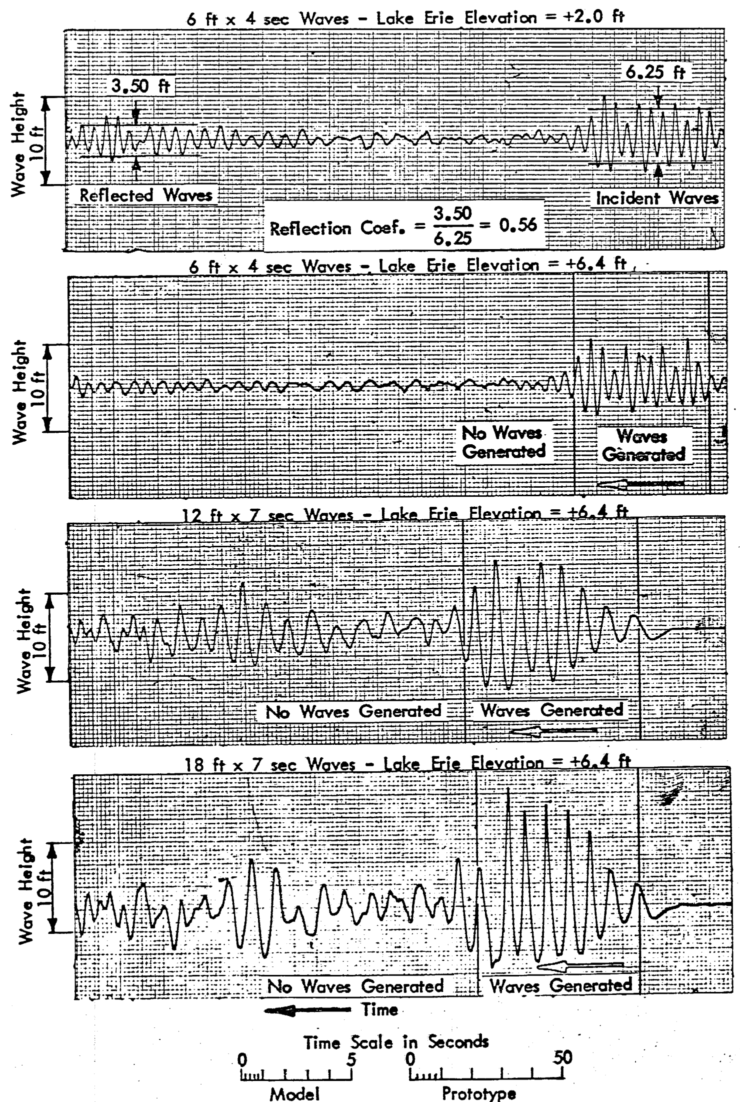


WAVE REFLECTIONS FROM TYPE A DIKE

Wave profiles obtained using a 2-wire capacitance type wave probe.

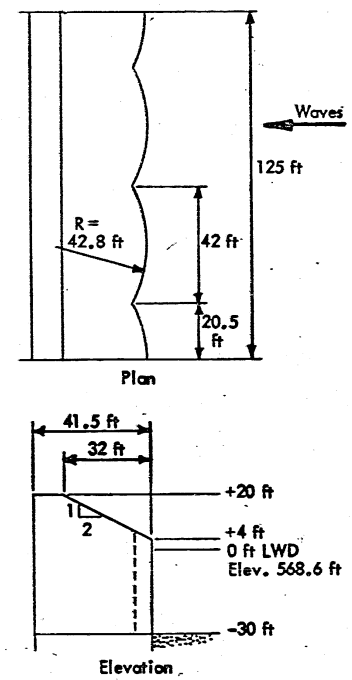
BETHLEHEM STEEL CORPORATION Lackawanna Plant Lackawanna, New York LAKE ERIE DIKE		
SAINT ANTHONY FALLS HYDRAULIC LABORATORY UNIVERSITY OF MINNESOTA		
DRAWN DF	CHECKED WQD	APPROVED
SCALE	DATE 7-31-70	NO. 183B482-85

CHART 3



SUMMARY OF DATA

Meas. Dist. from Bulkhead	Lake Elev. ft	Avg. Incid. Wave Ht. ft	Avg. Refl. Wave Ht. ft	Refl. Coef. H_R/H_I	Over-topping cfs/ft
1000	+2.0	6.00	3.25	.54	0
500	+2.0	6.00	3.50	.58	
1000	+2.0	6.25	3.25	.52	
500	+2.0	5.75	3.25	.56	
1000	+2.0	6.50	3.25	.50	
500	+2.0	5.75	3.50	.61	
1000	+2.0	6.25	3.50	.56	
500	+2.0	5.75	3.25	.56	
1000	+2.0	6.50	3.50	.54	
500	+2.0	6.00	3.50	.58	
1000	+2.0	6.00	3.75	.62	
500	+2.0	6.00	3.25	.54	
1000	+2.0	6.00	3.75	.62	
500	+2.0	5.75	3.50	.61	
1000	+6.4	6.00	1.50	.25	0
500	+6.4	5.75	1.50	.26	
1000	+6.4	6.25	1.50	.24	
500	+6.4	5.50	1.50	.27	
1000	+6.4	6.00	1.50	.25	
500	+6.4	5.75	1.75	.30	
1000	+6.4	5.75	1.75	.30	
500	+6.4	5.75	1.75	.30	
1000	+6.4	12.00	6.25	.52	1.9
1000	+6.4	12.00	6.00	.50	
1000	+6.4	12.50	7.00	.56	
1000	+6.4	12.50	6.00	.48	
1000	+6.4	16.50	8.00	.48	8.9
1000	+6.4	16.50	8.00	.48	
1000	+6.4	16.50	8.00	.48	
1000	+6.4	17.50	8.50	.49	



WAVE REFLECTIONS FROM TYPE B1 DIKE

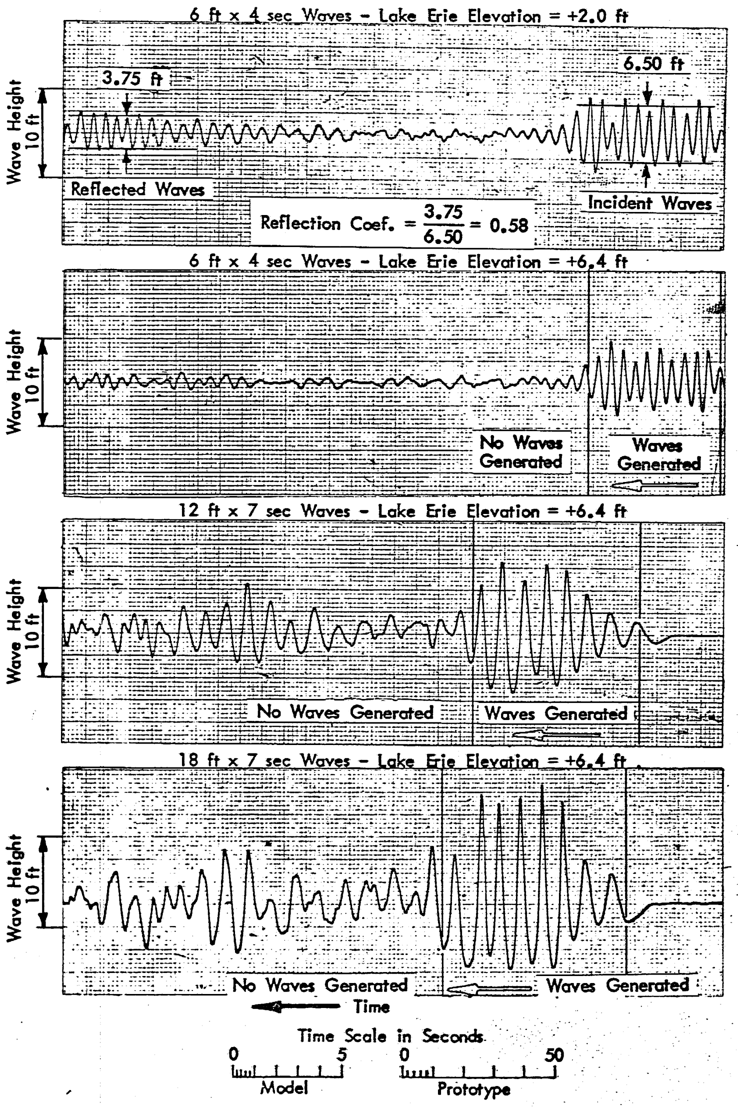
Wave profiles obtained using a 2-wire capacitance type wave probe.

BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

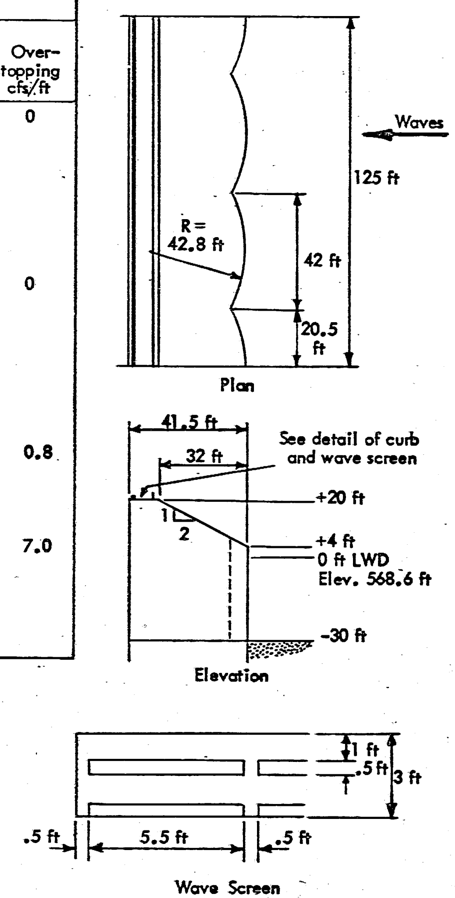
DRAWN DF	CHECKED DEF	APPROVED
SCALE	DATE 7-31-70	NO. 183B482-86

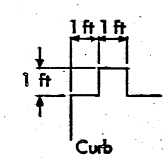
CHART 4



SUMMARY OF DATA

Meas. Dist. from Bulkhead ft	Lake Elev. ft	Avg. Incid. Wave Ht. ft	Avg. Refl. Wave Ht. ft	Refl. Coef. H_R/H_I	Over-topping cfs/ft
1000	+2.0	6.50	3.75	.58	0
500	+2.0	6.00	3.50	.58	
1000	+2.0	6.50	3.50	.54	
500	+2.0	5.75	3.50	.61	
1000	+2.0	6.50	3.25	.50	
500	+2.0	6.00	3.25	.54	
1000	+2.0	6.00	3.75	.62	
500	+2.0	5.50	3.50	.64	
1000	+6.4	6.00	1.75	.29	0
500	+6.4	6.00	1.75	.29	
1000	+6.4	6.00	1.50	.25	
500	+6.4	5.75	1.75	.30	
1000	+6.4	6.00	1.50	.25	
500	+6.4	5.75	1.75	.30	
1000	+6.4	5.75	1.50	.26	
500	+6.4	5.75	1.75	.30	
1000	+6.4	12.00	5.75	.48	0.8
1000	+6.4	12.00	6.50	.54	
1000	+6.4	12.50	6.00	.48	
1000	+6.4	12.00	6.50	.54	
1000	+6.4	18.00	7.75	.43	7.0
1000	+6.4	18.00	8.00	.44	
1000	+6.4	18.00	9.00	.50	
1000	+6.4	18.50	9.00	.49	
1000	+6.4	18.00	8.00	.44	
1000	+6.4	18.50	8.00	.43	





WAVE REFLECTIONS FROM TYPE B2 DIKE

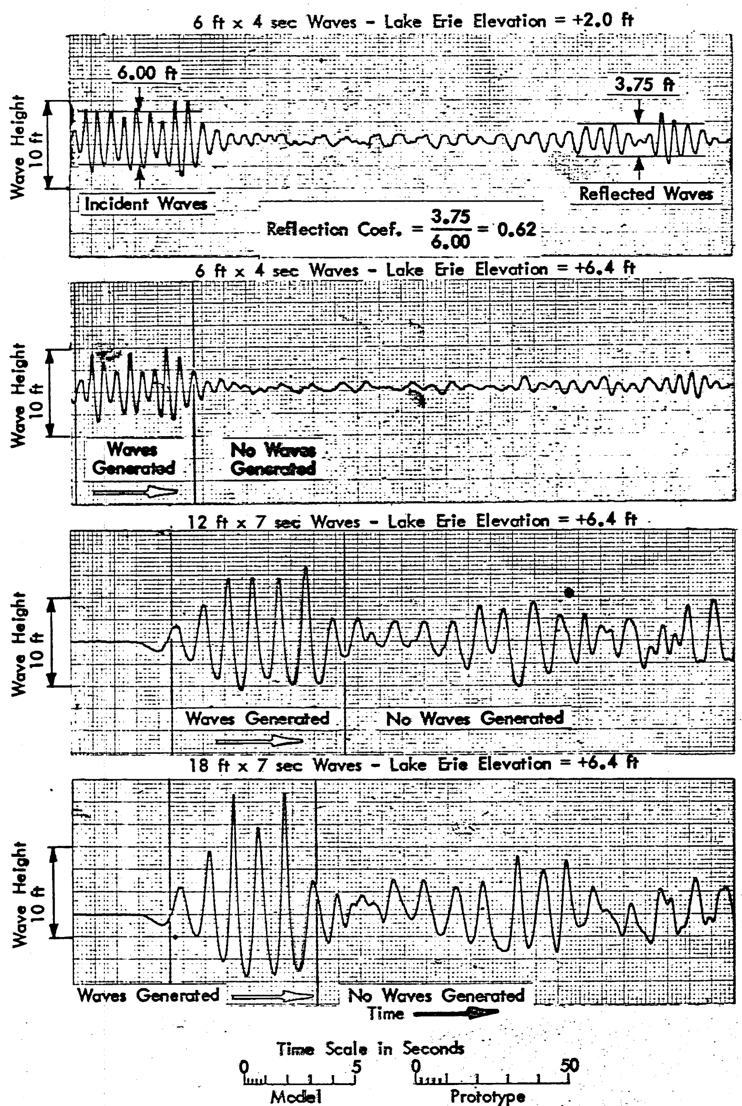
Wave profiles obtained using a 2-wire capacitance type wave probe.

BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

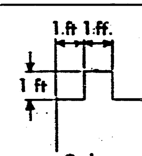
DRAWN DF	CHECKED DEF	APPROVED
SCALE	DATE 7-31-70	NO. 183B482-87

CHART 5

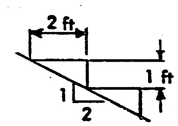


SUMMARY OF DATA

Meas. Dist. from Bulkhead ft	Lake Elev. ft	Avg. Incid. Wave Ht. ft	Avg. Refl. Wave Ht. ft	Refl. Coef. H_R/H_I	Over-topping cfs/ft
1000	+2.0	6.25	4.00	.64	0
500	+2.0	6.50	4.75	.73	
1000	+2.0	6.00	3.75	.62	
500	+2.0	6.25	4.50	.72	
1000	+2.0	6.25	3.50	.56	
500	+2.0	6.50	4.50	.69	
1000	+2.0	6.00	3.50	.58	
500	+2.0	6.00	4.50	.75	
1000	+2.0	5.75	3.50	.61	
500	+2.0	6.25	4.25	.68	
1000	+6.4	5.50	2.00	.36	0
500	+6.4	5.00	2.50	.50	
1000	+6.4	5.75	1.75	.30	
500	+6.4	5.75	2.00	.35	
1000	+6.4	5.75	2.25	.39	
500	+6.4	5.75	2.25	.39	
1000	+6.4	6.00	2.00	.33	
500	+6.4	5.75	2.50	.44	
1000	+6.4	5.75	1.75	.30	
500	+6.4	5.75	2.00	.35	
1000	+6.4	11.50	5.25	.46	0.2
1000	+6.4	12.00	7.50	.62	
1000	+6.4	12.00	7.00	.58	
1000	+6.4	12.00	7.00	.58	
1000	+6.4	12.00	6.75	.56	
1000	+6.4	17.75	10.50	.59	3.5
1000	+6.4	17.50	10.00	.57	
1000	+6.4	17.00	9.50	.56	
1000	+6.4	17.25	9.50	.55	
1000	+6.4	17.00	9.50	.56	
1000	+6.4	17.75	10.00	.56	
1000	+6.4	18.00	9.50	.53	



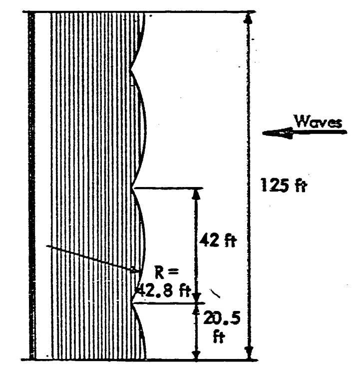
Curb



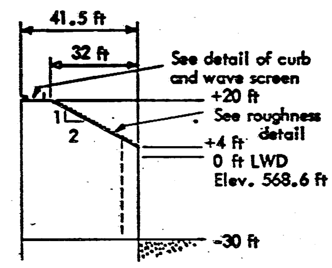
Roughness on Slope-Steps

WAVE REFLECTIONS FROM TYPE C DIKE

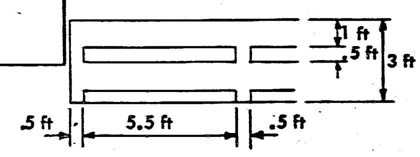
Wave profiles obtained using a 2-wire capacitance type wave probe.



Plan



Elevation



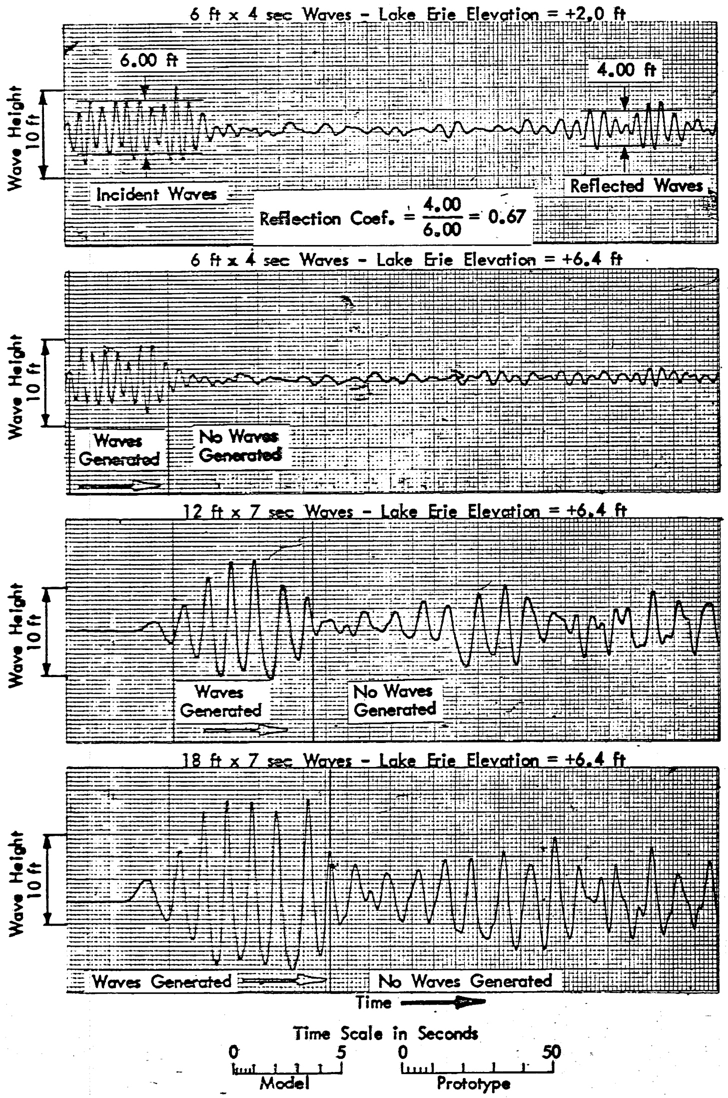
Wave Screen

BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

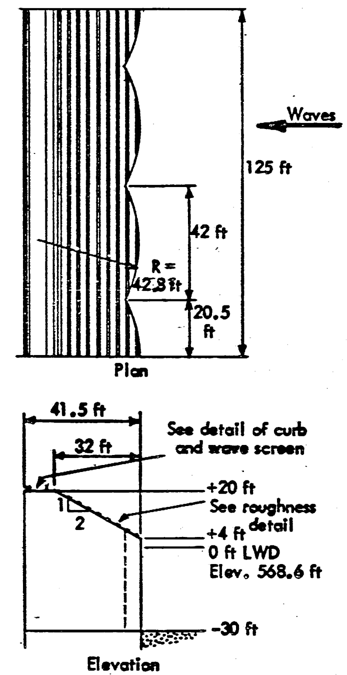
DRAWN DF	CHECKED DEF	APPROVED
SCALE	DATE 7-31-70	NO. 183B482-88

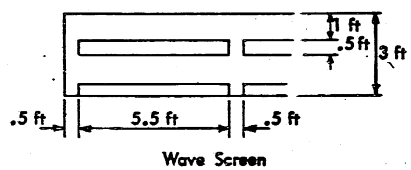
CHART 6

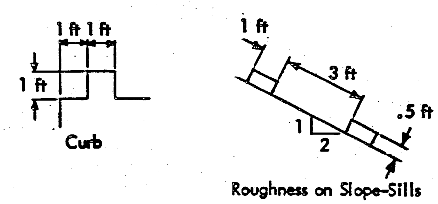


SUMMARY OF DATA

Meas. Dist. from Bulkhead ft	Lake Elev. ft	Avg. Incid. Wave Ht. ft	Avg. Refl. Wave Ht. ft	Refl. Coef. H_R/H_I	Over-topping cfs/ft
1000	+2.0	6.00	5.00	.83	0
500	+2.0	6.00	4.50	.75	
1000	+2.0	6.00	4.00	.67	
500	+2.0	6.00	4.50	.75	
1000	+2.0	6.00	3.50	.58	
500	+2.0	6.00	4.50	.75	
1000	+2.0	5.75	3.50	.61	
500	+2.0	6.00	4.50	.75	
1000	+2.0	5.50	3.75	.68	
500	+2.0	6.00	4.50	.75	
1000	+2.0	5.50	3.50	.64	
500	+2.0	5.50	4.00	.73	
1000	+6.4	5.25	1.75	.33	0
500	+6.4	5.25	2.00	.38	
1000	+6.4	5.25	1.50	.29	
500	+6.4	5.50	1.75	.32	
1000	+6.4	5.75	1.50	.26	
500	+6.4	5.50	2.00	.36	
1000	+6.4	5.50	1.25	.23	
500	+6.4	5.50	2.00	.36	
1000	+6.4	11.50	6.25	.54	1.4
1000	+6.4	12.00	6.50	.54	
1000	+6.4	11.75	8.50	.72	
1000	+6.4	11.00	7.00	.64	
1000	+6.4	12.00	7.25	.60	
1000	+6.4	18.25	11.50	.63	4.8
1000	+6.4	18.00	10.00	.56	
1000	+6.4	18.00	10.00	.56	
1000	+6.4	18.00	11.00	.61	







WAVE REFLECTIONS FROM TYPE D DIKE

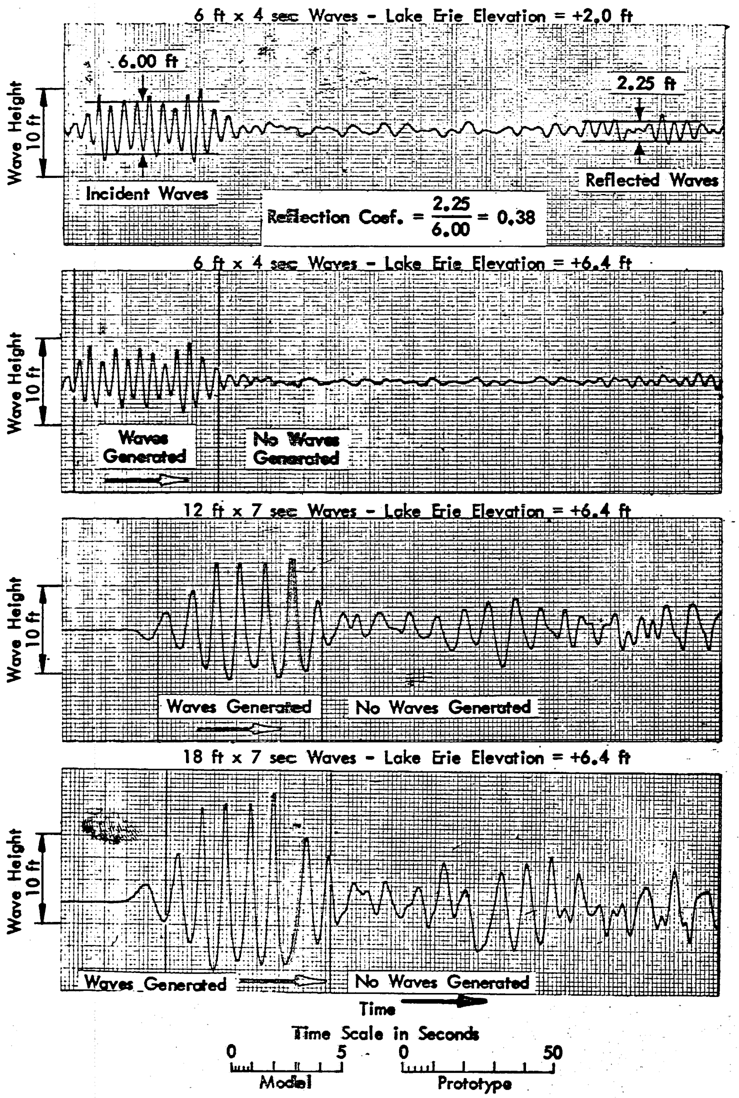
Wave profiles obtained using a 2-wire capacitance type wave probe.

BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE

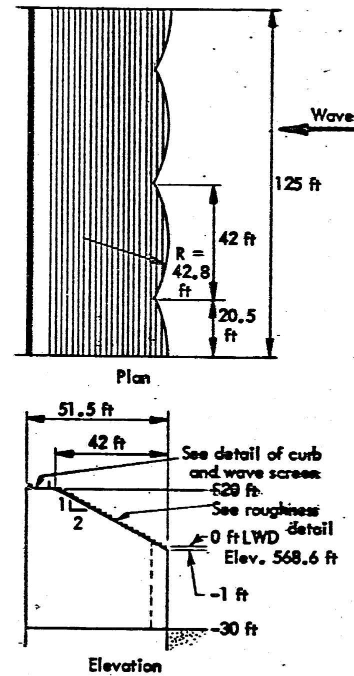
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

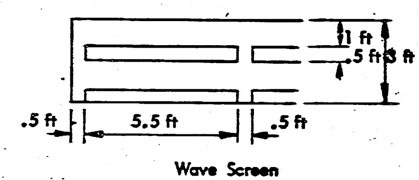
DRAWN DF	CHECKED DEF	APPROVED
SCALE	DATE 7-31-70	NO. 183B482-89

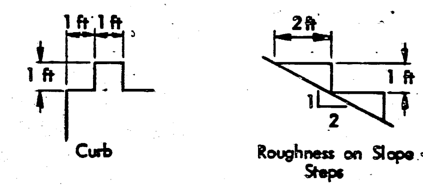
CHART 7



SUMMARY OF DATA					
Meas. Dist. from Bulkhead ft	Lake Elev. ft	Avg. Incid. Wave Ht. ft	Avg. Refl. Wave Ht. ft	Refl. Coef. H_R/H_I	Over-topping cfs/ft
1000	+2.0	6.00	2.50	.42	0
500	+2.0	6.25	3.25	.52	
1000	+2.0	6.00	2.25	.38	
500	+2.0	6.25	3.00	.48	
1000	+2.0	5.50	2.50	.46	
500	+2.0	6.00	3.00	.50	
1000	+2.0	5.75	2.50	.44	
500	+2.0	6.50	3.00	.46	
1000	+6.4	5.25	1.25	.24	0
500	+6.4	5.50	1.50	.27	
1000	+6.4	6.00	1.25	.21	
500	+6.4	6.00	1.25	.21	
1000	+6.4	6.00	1.25	.21	
500	+6.4	6.00	1.50	.25	
1000	+6.4	5.75	1.75	.30	
500	+6.4	6.00	1.50	.25	
1000	+6.4	5.25	1.25	.24	
500	+6.4	5.75	1.50	.26	
1000	+6.4	12.25	5.50	.45	0.7
1000	+6.4	12.25	5.00	.41	
1000	+6.4	12.75	5.25	.41	
1000	+6.4	12.75	5.00	.39	
1000	+6.4	18.00	7.75	.43	4.4
1000	+6.4	18.00	9.00	.50	
1000	+6.4	18.00	8.75	.49	
1000	+6.4	18.75	8.00	.43	
1000	+6.4	18.50	8.00	.43	







WAVE REFLECTIONS FROM TYPE E DIKE

Wave profiles obtained using a 2-wire capacitance type wave probe.

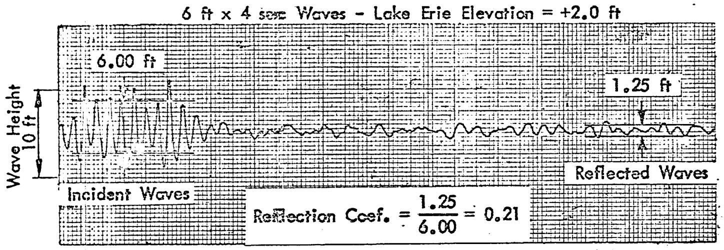
BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

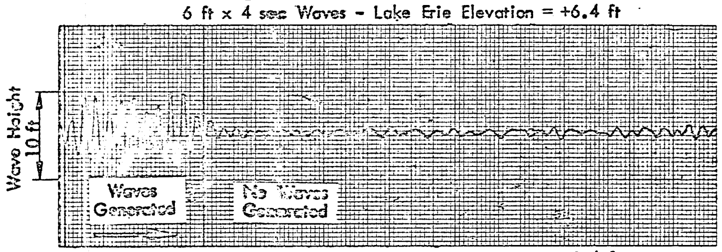
DRAWN MG	CHECKED DEF	APPROVED
SCALE	DATE 7-31-70	NO. 183B482-90

CHART 8

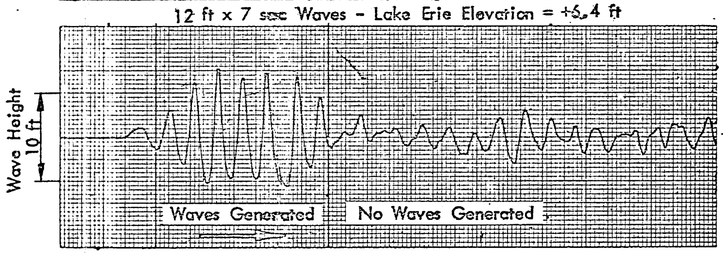
6 ft x 4 sec Waves - Lake Erie Elevation = +2.0 ft



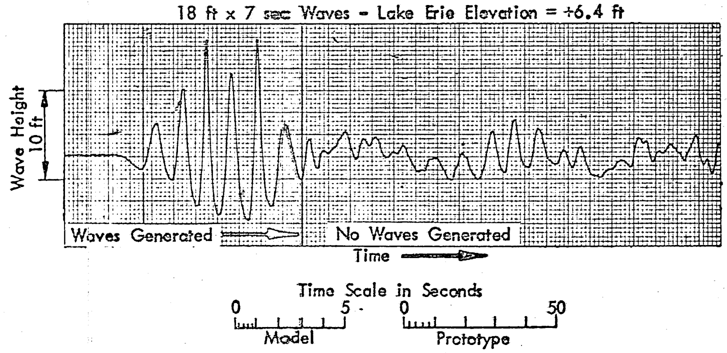
6 ft x 4 sec Waves - Lake Erie Elevation = +6.4 ft



12 ft x 7 sec Waves - Lake Erie Elevation = +6.4 ft

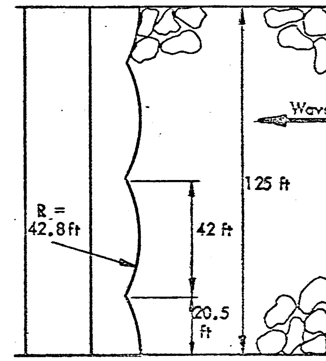


18 ft x 7 sec Waves - Lake Erie Elevation = +6.4 ft

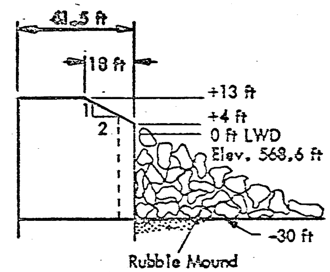


SUMMARY OF DATA

Meas. Dist. from Bulkhead ft	Lake Elev. ft	Avg. Incid. Wave Ht. ft	Avg. Refl. Wave Ht. ft	Refl. Coef. H_R/H_I	Over-topping cfs/ft
1000	+2.0	6.00	1.25	.21	0.07
500	+2.0	6.50	1.50	.23	
1000	+2.0	6.00	1.00	.17	
500	+2.0	6.00	1.25	.21	
1000	+2.0	6.00	1.00	.17	
500	+2.0	6.00	1.25	.21	
1000	+2.0	6.00	1.25	.21	
500	+2.0	6.00	1.25	.21	
1000	+6.4	6.00	1.00	.17	0.59
500	+6.4	6.00	1.25	.21	
1000	+6.4	5.75	1.00	.17	
500	+6.4	6.00	1.25	.21	
1000	+6.4	5.50	1.00	.18	
500	+6.4	6.00	1.25	.21	
1000	+6.4	5.75	1.25	.22	
500	+6.4	5.50	1.00	.18	
1000	+6.4	11.50	4.00	.35	7.6
1000	+6.4	12.00	4.00	.33	
1000	+6.4	12.00	4.00	.33	
1000	+6.4	12.00	4.00	.33	
1000	+6.4	18.00	5.50	.31	22.2
1000	+6.4	18.00	5.00	.28	
1000	+6.4	18.00	5.50	.31	
1000	+6.4	18.00	5.25	.29	



Plan



Top layer of stones - 26 tons, inner layers graded down.

Elevation

WAVE REFLECTIONS FROM TYPE F DIKE

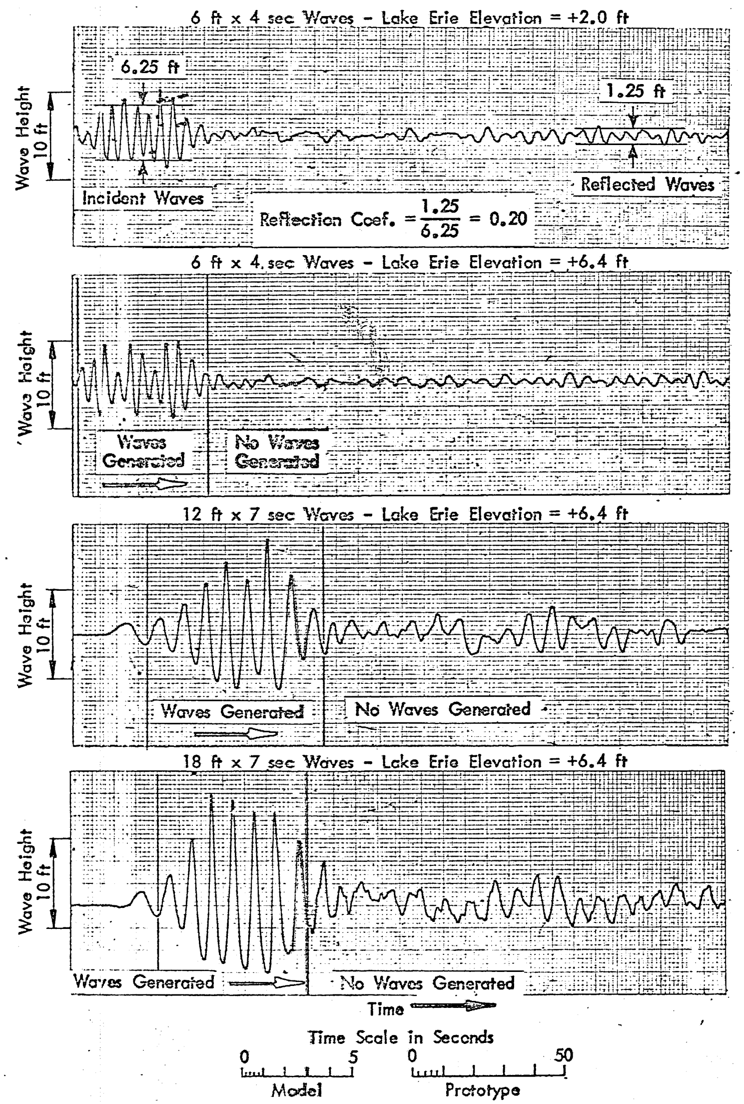
Wave profiles obtained using a 2-wire capacitance type wave probe.

BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

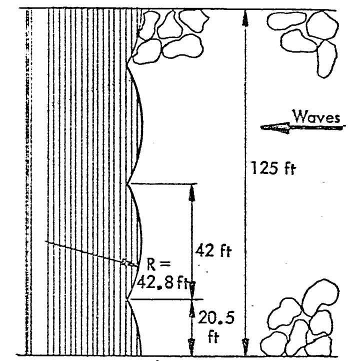
DRAWN DF | CHECKED DEF | APPROVED
SCALE | DATE 7-31-70 | NO. 1833432-91

CHART 9

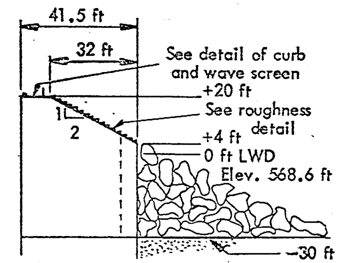


SUMMARY OF DATA

Meas. Dist. from Bulkhead ft	Lake Elev. ft	Avg. Incid. Wave Ht. ft	Avg. Refl. Wave Ht. ft	Refl. Coef. H_R/H_I	Over-topping cfs/ft
1000	+2.0	6.00	1.25	.21	0
500	+2.0	6.00	1.50	.25	
1000	+2.0	6.25	1.25	.20	
500	+2.0	6.00	1.50	.25	
1000	+2.0	6.50	1.50	.23	
500	+2.0	5.75	1.50	.26	
1000	+2.0	6.25	1.25	.20	
500	+2.0	5.75	2.00	.35	
1000	+2.0	6.50	1.25	.19	
500	+2.0	6.50	1.50	.23	
1000	+6.4	6.25	1.25	.20	0
500	+6.4	6.50	1.50	.23	
1000	+6.4	6.00	1.25	.21	
500	+6.4	6.00	1.25	.21	
1000	+6.4	6.25	1.25	.20	
500	+6.4	6.25	1.50	.24	
1000	+6.4	6.00	1.25	.21	
500	+6.4	6.00	1.50	.25	
1000	+6.4	6.00	1.25	.21	
500	+6.4	6.00	1.25	.21	
1000	+6.4	12.50	3.50	.28	1.3
1000	+6.4	12.50	3.75	.30	
1000	+6.4	12.25	3.75	.31	
1000	+6.4	12.50	3.75	.30	
1000	+6.4	18.00	4.75	.26	8.0
1000	+6.4	17.00	4.50	.26	
1000	+6.4	17.75	4.75	.27	
1000	+6.4	17.25	4.75	.28	
1000	+6.4	17.00	4.75	.28	

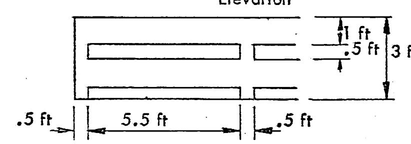


Plan

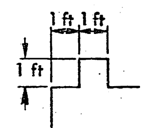


Rubble Mound - Top layer of stones 26 tons, inner layers graded down

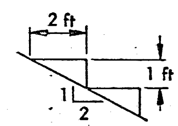
Elevation



Wave Screen



Curb



Roughness on Slope - Steps

WAVE REFLECTIONS FROM TYPE G DIKE

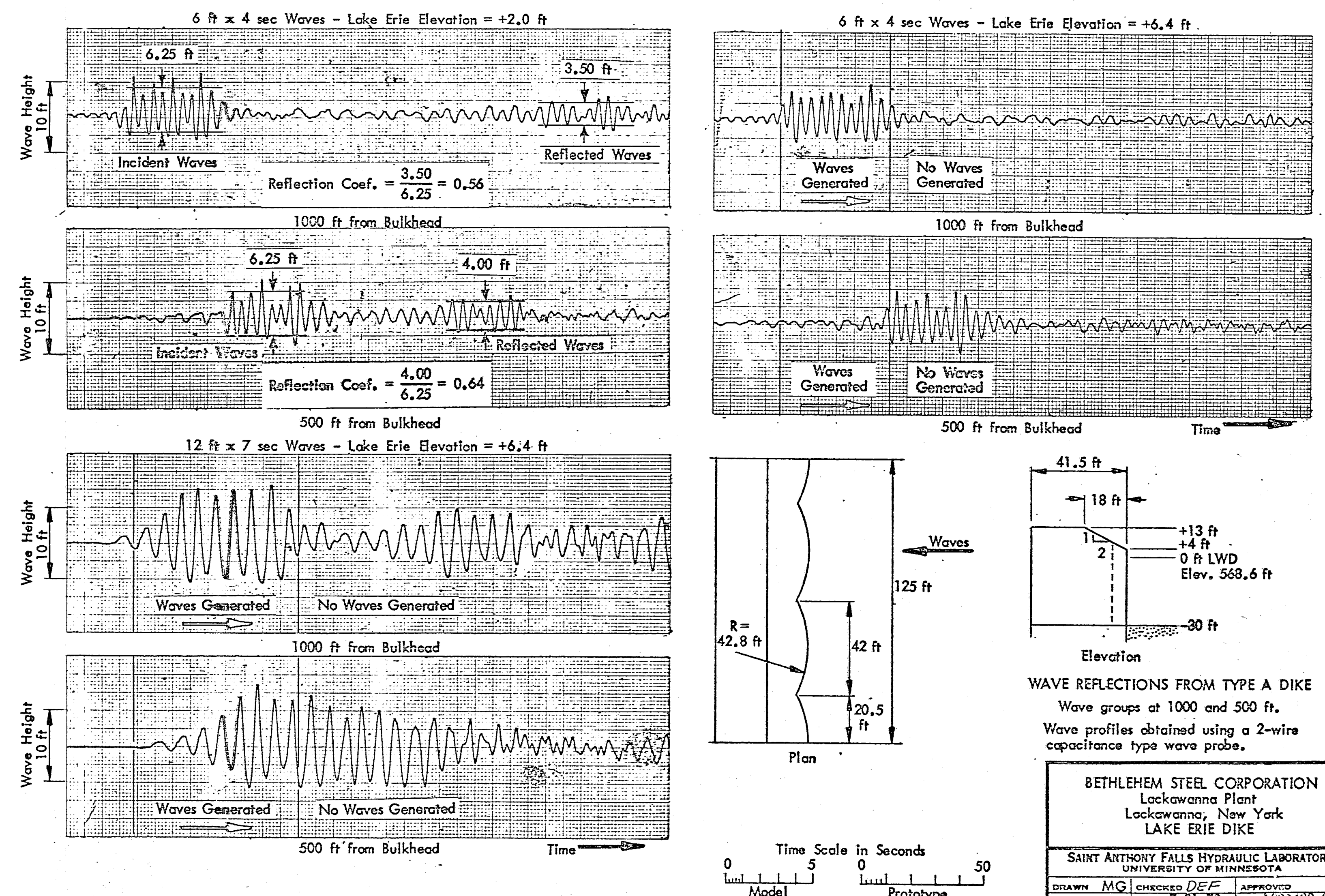
Wave profiles obtained using a 2-wire capacitance type wave probe.

BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN M.G	CHECKED DEF	APPROVED
SCALE	DATE 7-31-70	NO. 1833482-92

CHART 10



WAVE REFLECTIONS FROM TYPE A DIKE

Wave groups at 1000 and 500 ft.

Wave profiles obtained using a 2-wire capacitance type wave probe.

BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN MG	CHECKED DEF	APPROVED
SCALE	DATE 7-31-70	NO. 1838482-94

CHART 11

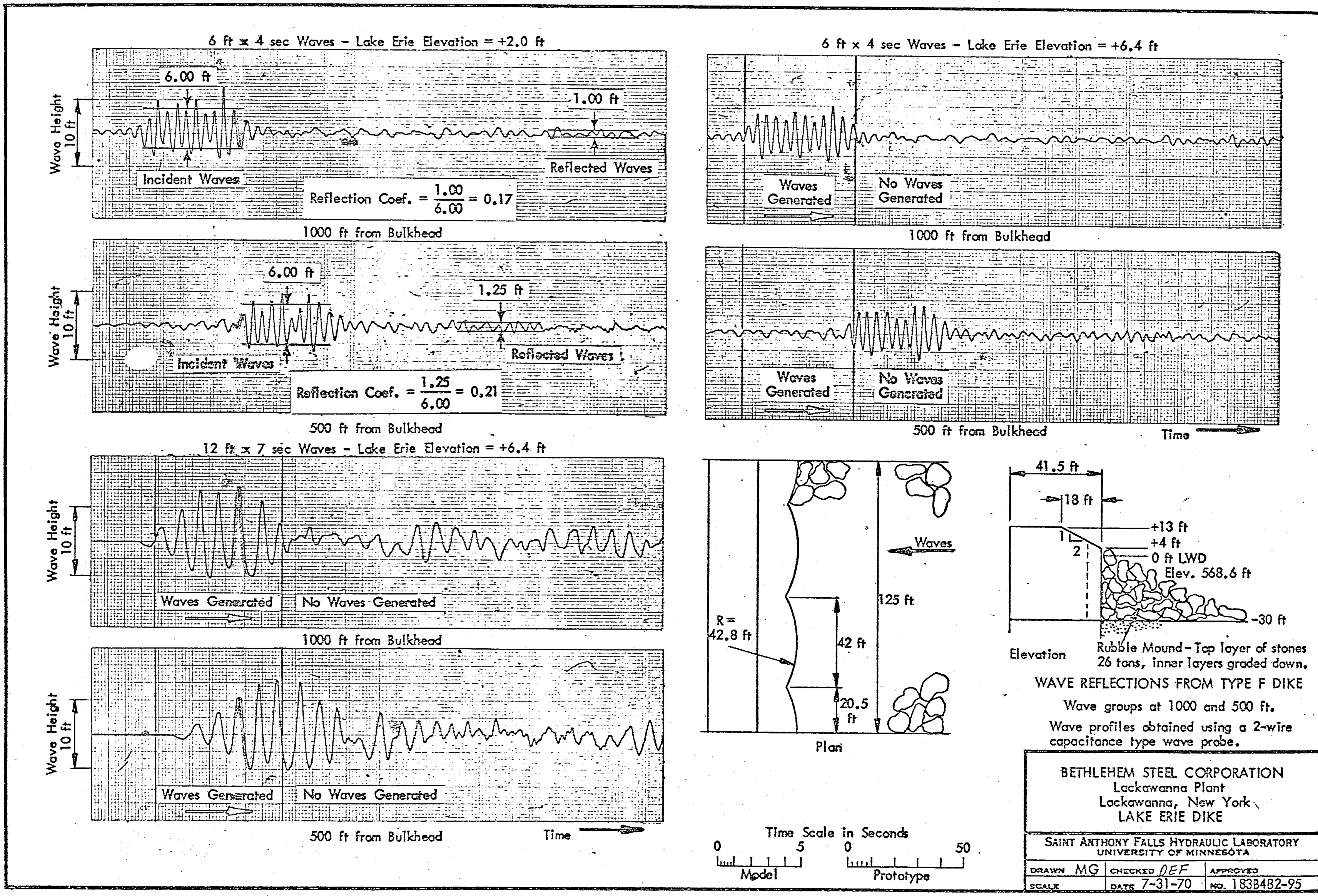

6 ft x 4 sec Waves - Lake Erie Elevation = +2.0 ft
Wave Height 10 ft
6.00 ft
1.00 ft
Incident Waves
Reflected Waves
Reflection Coef. = 1.00/6.00 = 0.17
1000 ft from Bulkhead
6.00 ft
1.25 ft
Incident Waves
Reflected Waves
Reflection Coef. = 1.25/6.00 = 0.21
500 ft from Bulkhead
12 ft x 7 sec Waves - Lake Erie Elevation = +6.4 ft
Waves Generated
No Waves Generated
1000 ft from Bulkhead
Waves Generated
No Waves Generated
500 ft from Bulkhead
Time
6 ft x 4 sec Waves - Lake Erie Elevation = +6.4 ft
Waves Generated
No Waves Generated
1000 ft from Bulkhead
Waves Generated
No Waves Generated
500 ft from Bulkhead
Time
Waves
R = 42.8 ft
125 ft
42 ft
20.5 ft
Plan
41.5 ft
18 ft
+13 ft
+4 ft
0 ft LWD
Elev. 568.6 ft
-30 ft
1
2
Elevation
Rubble Mound - Top layer of stones 26 tons, inner layers graded down.
WAVE REFLECTIONS FROM TYPE F DIKE
Wave groups at 1000 and 500 ft.
Wave profiles obtained using a 2-wire capacitance type wave probe.
Time Scale in Seconds
0 5
Model
0 50
Prototype
BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN MG
CHECKED DEF
APPROVED
SCALE
DATE 7-31-70
NO. 183B482-95

CHART 12

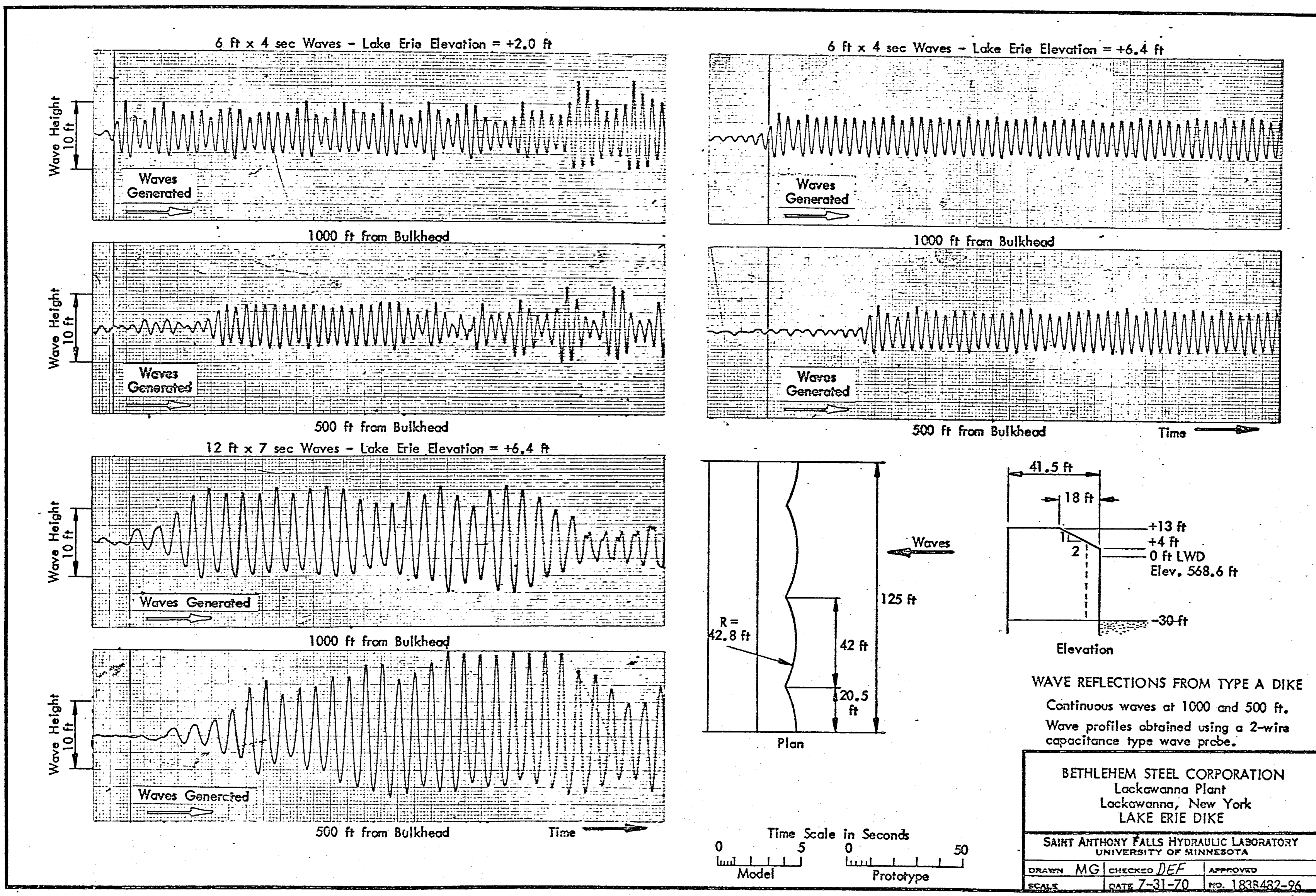

6 ft x 4 sec Waves - Lake Erie Elevation = +2.0 ft
Wave Height 10 ft
Waves Generated
1000 ft from Bulkhead
Wave Height 10 ft
Waves Generated
500 ft from Bulkhead
12 ft x 7 sec Waves - Lake Erie Elevation = +6.4 ft
Wave Height 10 ft
Waves Generated
1000 ft from Bulkhead
Wave Height 10 ft
Waves Generated
500 ft from Bulkhead
Time
6 ft x 4 sec Waves - Lake Erie Elevation = +6.4 ft
Waves Generated
1000 ft from Bulkhead
Waves Generated
500 ft from Bulkhead
Time
Waves
125 ft
R = 42.8 ft
42 ft
20.5 ft
Plan
41.5 ft
18 ft
+13 ft
+4 ft
0 ft LWD
Elev. 568.6 ft
1
2
-30 ft
Elevation
Time Scale in Seconds
0 5
Model
0 50
Prototype
WAVE REFLECTIONS FROM TYPE A DIKE
Continuous waves at 1000 and 500 ft.
Wave profiles obtained using a 2-wire capacitance type wave probe.
BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN MG
CHECKED DEF
APPROVED
SCALE
DATE 7-31-70
NO. 183B482-96

CHART 13

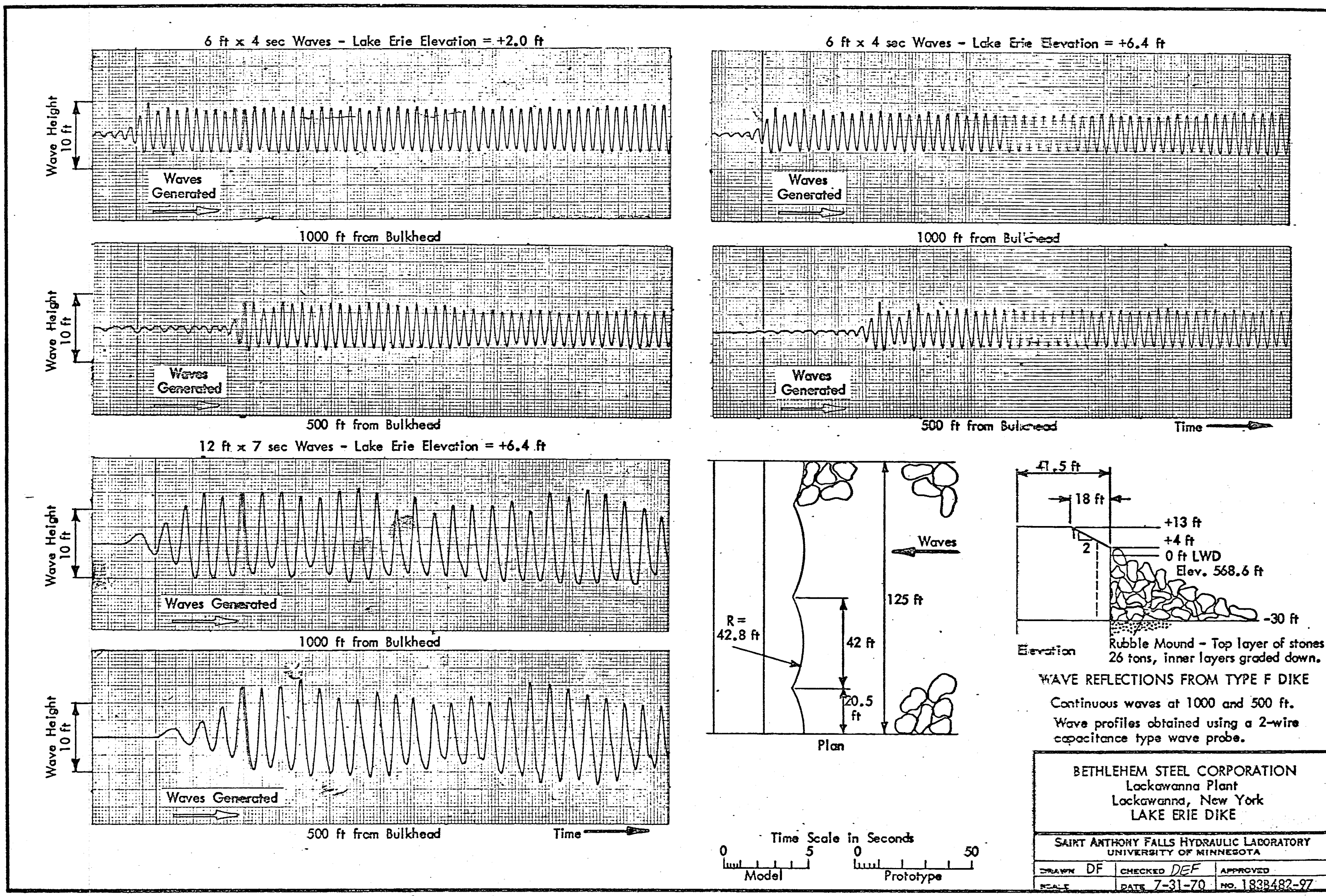
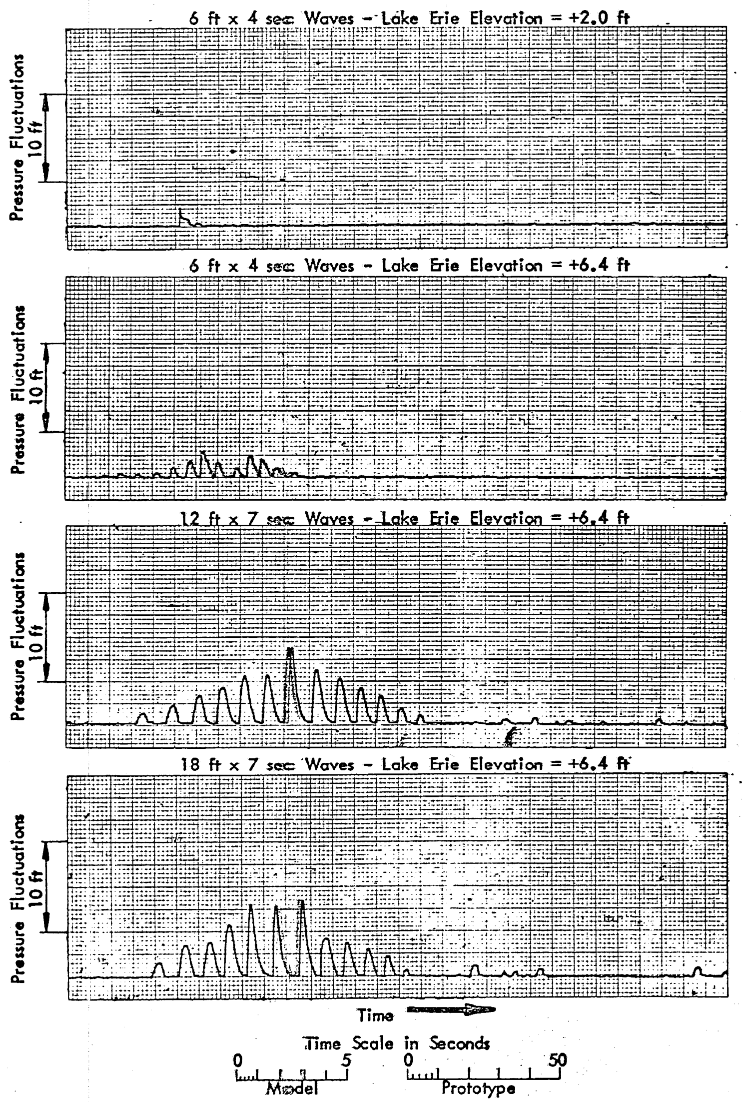
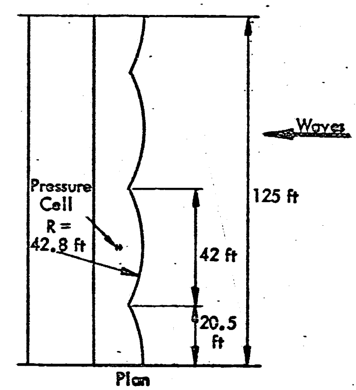
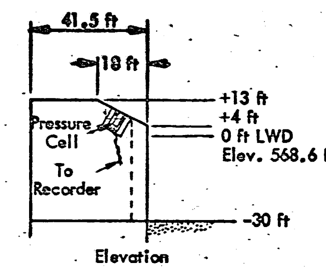

6 ft x 4 sec Waves - Lake Erie Elevation = +2.0 ft
Wave Height 10 ft
Waves Generated
1000 ft from Bulkhead
Wave Height 10 ft
Waves Generated
500 ft from Bulkhead
6 ft x 4 sec Waves - Lake Erie Elevation = +6.4 ft
Waves Generated
1000 ft from Bulkhead
Waves Generated
500 ft from Bulkhead
Time
12 ft x 7 sec Waves - Lake Erie Elevation = +6.4 ft
Wave Height 10 ft
Waves Generated
1000 ft from Bulkhead
Wave Height 10 ft
Waves Generated
500 ft from Bulkhead
Time
Waves
125 ft
R = 42.8 ft
42 ft
20.5 ft
Plan
41.5 ft
18 ft
+13 ft
+4 ft
0 ft LWD
Elev. 568.6 ft
1
2
-30 ft
Elevation
Rubble Mound - Top layer of stones 26 tons, inner layers graded down.
WAVE REFLECTIONS FROM TYPE F DIKE
Continuous waves at 1000 and 500 ft.
Wave profiles obtained using a 2-wire capacitance type wave probe.
Time Scale in Seconds
0 5
Model
0 50
Prototype
BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA
DRAWN DF
CHECKED DEF
APPROVED
SCALE
DATE 7-31-70
NO. 183B482-97

CHART 14



MAXIMUM PRESSURE FLUCTUATIONS ON BULKHEAD			
Wave Height ft	Wave Period sec	Lake Elev. ft	Max. Pressure Fluctuations ft
6	4	+2.0	2.1
6	4	+6.4	3.0
12	7	+6.4	8.5
18	7	+6.4	8.4





PRESSURE FLUCTUATIONS ON TYPE A DIKE

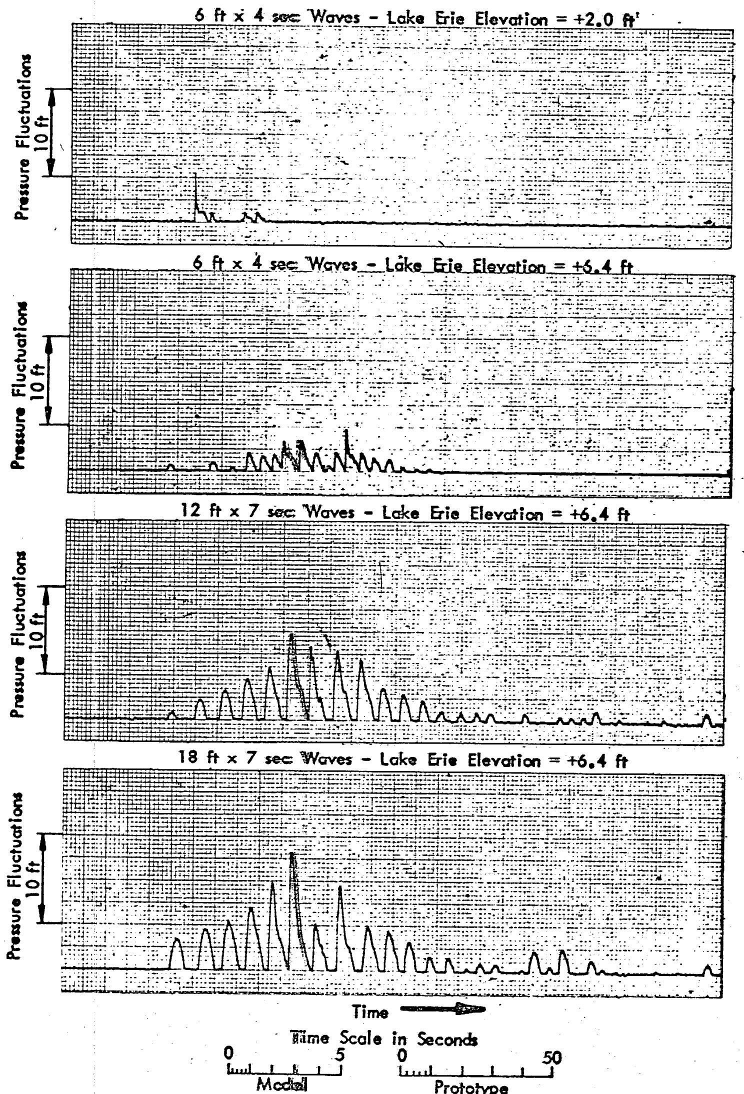
Pressure fluctuations recorded with a 5 psi pressure cell mounted on the sloping face of the bulkhead.

BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE

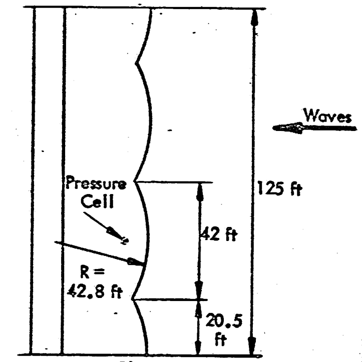
SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN MG	CHECKED DEF	APPROVED
SCALE	DATE 7-31-70	NO. 1838482-98

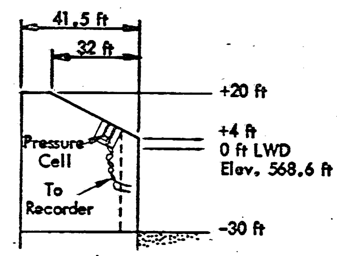
CHART 15



MAXIMUM PRESSURE FLUCTUATIONS ON BULKHEAD			
Wave Height ft	Wave Period sec	Lake Elev. ft	Max. Pressure Fluctuations ft
6	4	+2.0	5.5
6	4	+6.4	4.7
12	7	+6.4	9.7
18	7	+6.4	13.2



Plan



Elevation

PRESSURE FLUCTUATIONS ON TYPE B1 DIKE

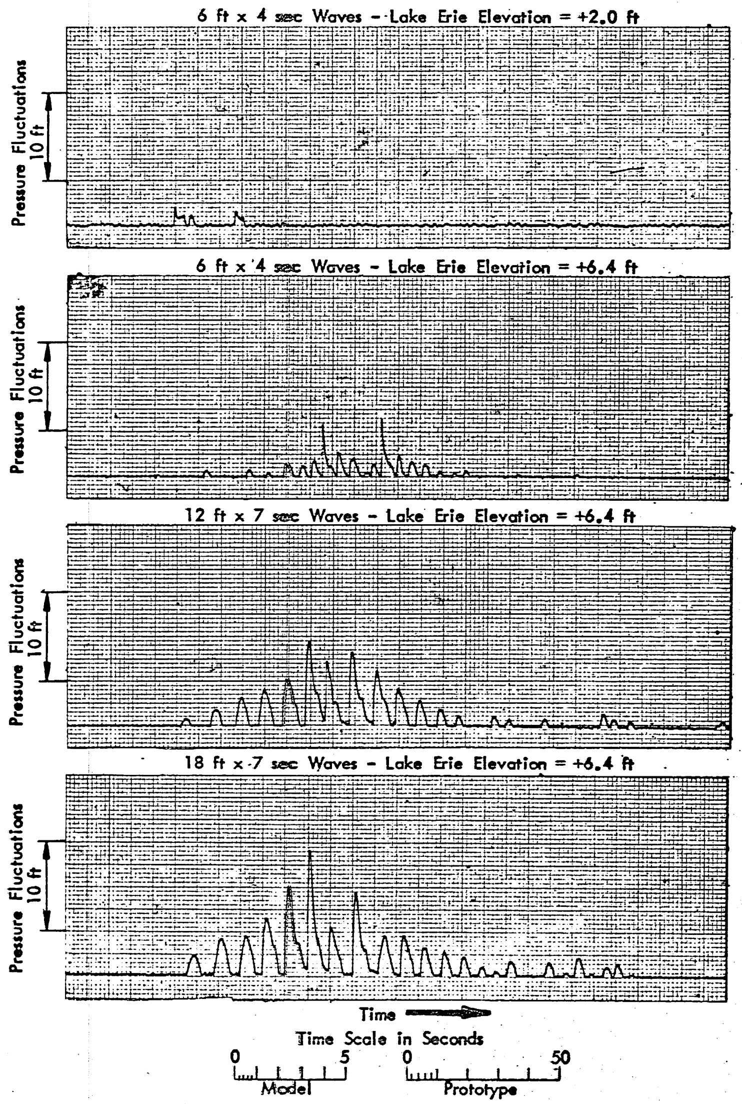
Pressure fluctuations recorded with a 5 psi pressure cell mounted on the sloping face of the bulkhead.

BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

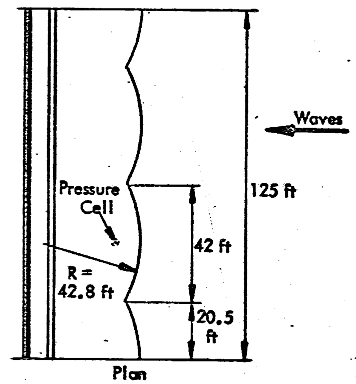
DRAWN MG	CHECKED DEF	APPROVED
SCALE	DATE 7-31-70	NO. 1838482-99

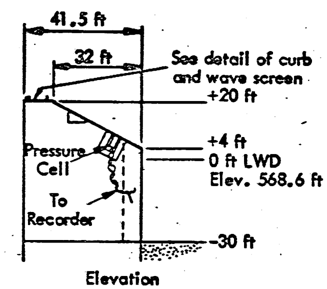
CHART 16

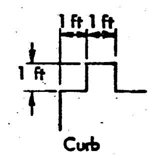


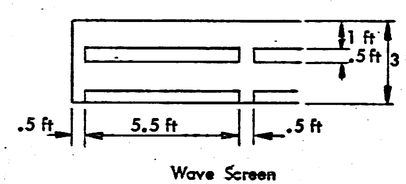
MAXIMUM PRESSURE FLUCTUATIONS ON BULKHEAD

Wave Height ft	Wave Period sec	Lake Elev. ft	Max. Pressure Fluctuations ft
6	4	+2.0	2.0
6	4	+6.4	6.4
12	7	+6.4	9.5
18	7	+6.4	14.0









PRESSURE FLUCTUATIONS ON TYPE B2 DIKE

Pressure fluctuations recorded with a 5 psi pressure cell mounted on the sloping face of the bulkhead.

BETHLEHEM STEEL CORPORATION
Lackawanna Plant
Lackawanna, New York
LAKE ERIE DIKE

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CHART 17