CORPS OF ENGINEERS, U. S. ARMY

MISSISSIPPI RIVER COMMISSION

PLANS FOR REDUCTION OF SHOALING AT THE ENTRANCE TO UMPQUA RIVER, OREGON

MODEL INVESTIGATION

TECHNICAL MEMORANDUM NO. 2-277

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

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PREFACE

The model study of the Umpqua River entrance was conducted by the Hydraulics Division of the Waterways Experiment Station, during the period June 1946 to May 1948, for the Portland District, CE. During the course of the study engineers of the Portland District visited the Experiment Station and took an active part in the planning of the test program.

Engineers of the Experiment Station directly connected with the investigation were Messrs. E. P. Fortson, C. B. Fenwick, K. B. Simmons, and I. C. Tallant.

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PLANS FOR REDUCTION OF SHOALING AT THE ENTRANCE TO UMPQUA RIVER, OREGON

Model Investigation

PART I: INTRODUCTION

1. The Umpqua River rises on the western slope of the Cascade Mountains in southwestern Oregon and flows in a general westerly direction about 111 miles to the Pacific Ocean. The mouth of the river is approximately 180 mi south of the mouth of the Columbia River and about 465 mi north of San Francisco Bay. The existing project provides for: (a) a north jetty 8,000 ft long and a south jetty 4,200 ft long terminating 1,800 ft south of the seaward end of the north jetty; and (b) for dredging to secure and maintain an entrance channel 26 ft deep at mllw and of suitable width, and a river channel 22 ft deep at mllw and 200 ft wide to Reedsport, 11 mi above the mouth.

2. Construction of the north jetty was undertaken by local interests in 1917, and the jetty was extended to its present length by the Corps of Engineers during the period 1924-1931. It was rehabilitated in 1931-1932, and reconstructed with a concrete superstructure during 1940-1941. A short south jetty was constructed in 1933, and was extended 1,790 ft to its present terminus in 1937-1938. The north jetty is now in excellent condition, but the outer end of the south jetty has been lowered by wave and current action to approximately low water elevation.

3. At the entrance to Umpqua River the ocean bar has been moved

seaward since completion of the jetties. Comparative surveys of June 1935 and June 1943 show the 18, 30, 48, and 60-ft depth contours to have moved seaward distances of approximately 1,300, 1,400, 1,100, and 1,000 ft, respectively. Controlling depth over the outer bar increased slightly after extension of the south jetty in 1937-1938, but was only 17 ft on the entrance range in June 1943, with a maximum depth of 20 ft available south of the range. In 1943, the controlling depth on the range between the jetties was 11 ft, and the greatest depth available south of the range was 15 ft.

4. The alignment of the existing south jetty does not correspond with that of the main ebb currents from the river; instead, the ebb currents strike the jetty at an abrupt angle. The result is a deeply scoured channel against the outer end of the jetty and a large area of shoal water to the north. The wide separation of the jetties at the shore end causes eddies and reverse shore currents. Periodic hydrographic surveys made since completion of the south jetty indicate that a large amount of erosion has taken place in the triangular area adjacent to the south jetty near the shore end and north along the shore line. Heavy wave action in this area stirs up the bottom material and the currents move it northerly along the shore toward the channel.

5. Much of this material apparently is moved seaward by the ebb currents and is deposited in the bar area between the outer ends of the jetties and on the ocean bar seaward from the jetties. It is probable that additional material is being supplied to the bar area between the jetty ends by sand movement through the rubble-stone south jetty, and by movement over both the north and south jetties during storms. The large

accumulation of sand on the north side of the north jetty indicates that a considerable volume of littoral drift has been trapped by this jetty since its construction. It is considered likely that some material is being carried southward past the outer end of the north jetty and deposited on the ocean bar seaward from the ends of the jetties.

6. The problem at Umpqua River entrance was therefore that of determining whether realignment of the south jetty, or the construction of spur jetties appurtenant to the existing south jetty, would realign ebb currents from the river in such manner that a navigation channel would be maintained through the outer bar without excessive dredging. To assist in resolving this problem an investigation of four proposed improvement plans was conducted on a model of the critical area. This report presents the results of the tests of these plans.

PART II: THE MODEL

7. The model was constructed to linear scale ratios of 1:400 horizontally and 1:80 vertically, and reproduced approximately 47 sq mi of the Pacific Ocean and the Umpqua River to a point about 2 mi upstream from the mouth. Provisions were made for reproducing waves from any direction between northwest and southwest, tides of any type, and littoral currents either up or down the coast.

Model Operating Technique

8. Originally, the model was of the movable-bed type, the lower river and offshore areas being molded in sand. The period between prototype surveys of June 1945 and June 1946 was selected for the verification period, and the model was successfully adjusted to reproduce prototype changes in bed configurations which occurred between the above-mentioned dates. With the model adjusted to reproduce changes which occurred during this one-year period, however, it was found that the results of a five-year or ten-year test in the model did not produce changes in bed configurations comparable to changes which took place during similar periods of time in the prototype. A more detailed examination of hydrographic changes which occurred in the prototype between the surveys of June 1945 and June 1946 revealed that very unusual changes in underwater configurations took place during this period and that the trend of bed movement during the period did not conform to the long-time trend, thus rendering that period useless for model adjustment and verification purposes.

9. A conference was held at the Waterways Experiment Station on

1 and 2 December 1947 between representatives of the Portland District Office and the Waterways Experiment Station for the purpose of selecting a new verification period which would be representative of the normal trend of bed movement. The decision was reached by representatives of the District Office, however, that the movable-bed study would be abandoned and that the proposed improvement plans would be tested to determine only their effects on current directions and velocities. It was later decided by District Office representatives that a thin layer of crushed coal would be placed over the problem area during tests of the plans in order to obtain some qualitative indication of the comparative scour and fill tendencies of each plan. The exact operating technique established by representatives of the Portland District for the model tests is outlined in the following paragraphs.

a. Tides and Currents. The model tide-control apparatus was adjusted to reproduce the tide which occurred on 19-20 August 1945 (plate 4). This tide was of approximately mean range. Current velocities in the river entrance were adjusted to prototype observations obtained on 11-12 June 1945, corrected to the tide of 19-20 August 1945 (plate 4).

b. Model bed. The model bed was first molded in concrete to elevations slightly lower (about 1.6 ft prototype) than the prototype survey of 1945. The bed was then molded exactly to the 1945 survey in crushed coal, placed on top of the concrete, thus providing a thin layer of crushed coal over the problem area. The model was operated through five complete tidal cycles, representing 24.84 hours each in the prototype, during the bed-movement phase of each test.

c. Waves and littoral currents. Waves generated in the model during the bed-movement phase of each test were 7.0 ft high and about 290 ft long. This wave was selected as being the average of all waves observed in the prototype during the one-year period June 1945-June 1946. The sequence of wave directions reproduced, and the directions of approach to the river mouth, are shown in table 1. No alongshore littoral current, except that resulting from the angularity of waves striking the shore, was reproduced during the tests herein reported.

Method of Testing

10. The first step in conducting a test in the model was to mold the bed (crushed coal) exactly to the survey of 1943. The model was then operated through five complete tidal cycles, reproducing waves as shown in table 1. On completion of the fifth cycle of operation, the model bed was stopped and photographed to record the scour and fill which occurred during the test. Current velocity measurements were then obtained at velocity stations shown on plate 1 to determine velocities for the condition being tested. Velocity measurements were obtained at the surface and at three-fourths depth. Timed photographs were then made at strengths of flood and ebb to record the directions of surface currents at such times. Confetti was scattered over the water surface while the photographs were being made, and the resulting white streaks made by the confetti show the directions and relative strengths of surface currents.

PART III: NARRATIVE OF TESTS

11. Four improvement plans were tested which, for identification purposes, are designated plans 1, 1-A, 6, and 8. The accompanying plates 1-14 show locations of current velocity stations, elements of plans tested, measurements of current velocities obtained for existing conditions and for tests of the various improvement plans, and scour and fill patterns for existing conditions and for each plan. Photographs 1-25 show scour and fill patterns for existing conditions and for each plan tested, and the directions of surface currents at strengths of ebb and flood for existing conditions and for each plan. Tables 1-4 show the height, length, sequence, and direction of waves reproduced during the model tests, and the effects of the various plans on maximum current velocities

Base Test

12. The first test made in the model was a base test, or test of existing prototype conditions. The purpose of the base test was to provide current velocity, current direction, and bed scour and fill data for existing conditions which, when compared to similar data obtained during subsequent tests incorporating proposed improvement plans, would indicate the changes from existing conditions effected by each plan tested. Accordingly, the model bed was molded to the 1945 prototype survey and, with the existing jetties installed, the model was operated through a five-cycle bed-movement test to determine scour and fill tendencies for existing conditions. Current velocity observations and

current direction photographs were then made.

13. Plate 1 and photograph 1 show the scour and fill pattern obtained at the end of the bed-movement phase of the base test. The bare concrete areas on photograph 1 indicate that all of the crushed coal, which was molded to a depth of about 1.6 ft (prototype), has been swept away. The contours and shaded areas on plate 1 indicate the areas of scour and fill and, in general, the extent of fill which occurred during the test. Photographs 6 through 9 show surface current directions at strengths of flood and ebb. It will be noted on these photographs that the strongest flood and ebb currents flow alongside or over the outer end of the south jetty instead of following the alignment of the channel between the jetties. A slow-moving eddy formed in the angle between the shore and the inner end of the south jetty during ebb, while a larger eddy formed on the south side of the outer end of the north jetty during flood.

Dredging Plan

14. Each of the improvement plans tested, which are described subsequently in this report, incorporated removal of the point on the south side of the river a short distance downstream from Boathouse Cape, and dredging of adjacent areas to the hydrography shown by contours on the cross-hatched area of plate 1. Since this dredging was common to all plans tested, the dredge cut was made in the model following completion of the base test, and velocity measurements were obtained at stations 1, 2 and 3 to determine the effects on velocities of the dredging alone. Flood and ebb velocities obtained with the dredge cut installed, but without any jetties other than the existing jetties, are presented on

plates 5 and 6 and in table 2. It will be noted by comparing these velocities with those measured during the base test that the increased cross-sectional area effected by the dredging caused material decreases in maximum ebb velocities, particularly at stations 2 and 3. Current direction photographs were not obtained for this condition; however, it was noted that the alignment of ebb currents was improved considerably throughout the area affected by the dredging.

Plan 1

15. Plan 1 (plate 2) consisted of a slightly curved impermeable jetty, 1930 ft in length, located on the south side of the river mouth just downstream of the dredged area. The crest elevation of the jetty was +15 ft mllw.

16. The scour and fill effected by plan 1 are shown on plate 2 and photograph 2; current directions at strengths of flood and ebb are shown on photographs 10-13; and measurements of current velocities are shown on plates 7 and 8 and in table 2. The over-all scour pattern effected by plan 1 was about the same as for the base test. A considerable volume of bed material was deposited on the south side of the plan-1 jetty, and indications were that deposition in that area would continue until the angle formed by the jetty was filled. Comparison of current direction photographs for plan 1 with those of the base test indicates that the strongest ebb currents were deflected slightly north and away from the outer end of the existing south jetty by the plan. Maximum flood currents were increased slightly and maximum ebb currents were decreased slightly from those measured during the base test; however, both

maximum flood and ebb velocities were increased over those obtained for the dredging alone (see table 4).

Plan 1-A

17. Plan 1-A (plate 2) consisted of extending the plan-1 jetty 1700 ft oceanward, thus making the total length of the structure 3360 ft. The extension was of impermeable construction and had the same top elevation (+15 ft mllw) as the plan-1 jetty.

18. The scour and fill effected by plan 1-A are shown on plate 2 and photograph 3; surface current directions at strengths of flood and ebb are shown on photographs 14-17; and current velocity observations with the plan installed are shown on plates 9 and 10 and in table 2. The scour and fill pattern at the end of the test of plan 1-A was substantially the same as that at the end of the base test. Some local scour occurred along the north side of the plan 1-A jetty, and a considerable deposit of material formed on the south side of the jetty in the angle between the jetty and the shore. There were general increases in maximum flood velocities and general decreases in maximum ebb velocities from those of the base test. When compared to the velocities observed during the test of the dredging plan, however, plan 1-A indicated general increases in both maximum flood and maximum ebb velocities (see table 4). The jetty of plan 1-A shifted the main current away from the outer end of the existing south jetty, thus bringing the current alignment closer to that of the navigation channel. A small eddy formed just south of the outer end of the existing north jetty during the flood period, but was not noticeable during the ebb. There was no current or eddy action in the

area between the plan 1-A jetty and the existing south jetty at any time during the tidal cycle.

Plan 6

19. Plan 6 (plate 3) consisted of a spur jetty 1350 ft long, beginning at a point approximately 1400 ft from the shore end of the existing south jetty and extending northward toward the navigation channel. The spur jetty was of impermeable construction with a top elevation of +15 ft mlw.

20. The scour and fill patterns for plan 6 are shown on plate 3 and photograph 4; current directions at strengths of flood and ebb are shown on photographs 18-21; and current velocity measurements are shown on plates 11 and 12 and in table 2. The pattern of scour and fill over the problem area was generally similar to that which occurred during the base test; however, the extent of scour in the area between the existing jetties was less than that which occurred during the base test or during tests of plans 1 and 1-A. The plan-6 jetty was subjected to heavy broadside wave action for all wave directions reproduced. Current velocities in the channel were generally reduced from those of the base test, but were about the same or slightly higher than those measured during the test of the dredging plan (see table 4). The plan-6 jetty caused a considerable northward shift in the alignments of flood and ebb currents in the jetty channel; however, there were changes in the alignments of both flood and ebb currents in the vicinity of the structure. During the flood period, eddies formed in the jetty channel just south of the outer end of the north jetty and in the area between the plan-6 jetty

and the shore. During the ebb an eddy formed just seaward of and in line with the existing south jetty.

Plan 8

21. Plan 8 (plate 3) consisted of a slightly curved jetty, 1050 ft long, located along the same alignment as plans 1 and 1-A. The jetty was of impermeable construction with a top elevation of +15 ft mllw. In addition, the outer 1380-ft section of the existing south jetty was raised to elevation +15 ft mllw.

22. The scour and fill pattern for the test of plan 8 is shown on plate 3 and photograph 5; current directions at strengths of flood and ebb are shown on photographs 22-23; and current velocity measurements are shown on plates 13 and 14 and in table 2. The scour and fill pattern for the test of plan 8 was almost identical to that of the base test, the only difference being that slightly less scour occurred in the outer portion of the jetty channel. The plan effected general decreases in maximum flood velocities from those of the base test, and general increases in maximum velocities from those of the dredging plan. The alignments of flood and ebb currents were shifted northward an appreciable distance, bringing the current alignments closer to that of the navigation channel. During the flood tide period, a large eddy formed in the jetty channel just south of the outer end of the existing north jetty, and a smaller eddy formed between the plan-8 jetty and the existing south jetty. No eddies of appreciable size were noted during the ebb tide period.

PART IV: DISCUSSION OF RESULTS

23. The shoal condition which now prevails in the Umpqua River jetty channel is believed to be attributable to three causes: (a) the faulty alignment of the south jetty which permits the concentration of ebb currents along its north face, where they maintain a narrow scoured gut, rather than deflecting them northward into the navigation channel; (b) the low elevation and high permeability of the shore end of the south jetty which permits wave action to transport large volumes of sand from the southern beach over and through the south jetty and into the jetty channel; and (c) the scouring of material from the receding beach lying between the river mouth and the south jetty, including material moving northward over and through the south jetty, into the river channel by wave and current action. It appears, therefore, that the above three factors should be taken into consideration in selecting a plan for alleviation of shoaling in the jetty channel.

24. Model tests indicate that plans 1-A, 6, and 8 would be about equally effective in realigning ebb currents to conform more closely to the alignment of the navigation channel, but that plan 1 would have little effect on existing current alignments. Plan 6 appeared to shift the alignment of ebb currents slightly farther north than did plans 1-A and 8; however, it is believed that plan 6 has four undesirable features as follows: (a) the plan would not halt the northerly movement of material along the shore and into the river channel; (b) the plan-6 jetty would be subjected to severe broadside wave action, which would probably damage the structure; (c) the north end of the structure would

probably be undermined and damaged by river currents; and (d) the deflection of both flood and ebb currents around the north end of the structure would probably cause the channel to develop some curvature in that vicinity.

25. Since the detached (inshore) structure of plan 8 was considerably shorter than plan 1, which had very little effect on existing current patterns, it is believed that practically all of the effects of plan 8 on current directions can be attributed to raising the outer end of the existing south jetty. It is understood that the outer end of the existing south jetty was originally constructed to about +15 ft mlw, and that the jetty has gradually deteriorated because of the direct attack of waves and ebb currents. It appears, therefore, that only a temporary benefit would result from repairing and raising the outer portion of this jetty unless, at the same time, provisions were made for protecting the jetty from direct attack and undermining.

26. Plan 1-A effected considerable improvement in the alignment of ebb currents in the jetty channel; furthermore, this plan would halt the northerly movement of material along the shore and into the river channel. Current velocities along the channel side of the structure did not appear to be sufficiently strong to cause appreciable damage to the jetty. It is also pointed out that plan 1-A is located almost entirely in shallow water; therefore, the cost of its construction would probably be appreciably less than would be the cost of plan 8.

27. The results of shoaling tests for existing conditions and for each proposed plan indicate for all practical purposes about the same general patterns of scour and fill for all conditions tested. It is

pointed out that the results of tests of this type can, at best, only be evaluated qualitatively. Since no verification of the model with respect to movement of coal was obtained, it is recommended that little if any significance be attached to the results of these tests.

28. Maximum current velocities in the entrance channel with the various jetty plans installed indicate that velocities would be generally decreased from those measured during the base test. However, since the dredging downstream from the Boathouse Cage was common to all jetty plans tested, it is believed that a better indication of the effects of the plans on current velocities can be obtained by comparing the plan velocities to those measured for the dredging plan (table 4) rather than to those measured during the base test (table 3). Data presented in table 4 indicate that each jetty plan would provide some increase in maximum velocities in the entrance channel, with plan 1-A effecting the greatest over-all increase.

PART V: CONCLUSIONS

29. It is the opinion of the Waterways Experiment Station that the results of tests presented herein are largely qualitative, and do not show conclusively that any one of the plans tested would solve the shoaling problems in the entrance channel. Based upon the effects of the various plans on current directions and velocities, it is believed that plan 1-A would be the most effective of the plans tested in reducing shoaling in the channel. It is also believed that extension of the plan-1-A jetty seaward would make the structure more effective; however, such extension would probably increase the cost of the jetty appreciably, since relatively deep water would be encountered a short distance beyond the outer end of the structure as tested in the model.

30. A study of the results of the model test of plan 1-A indicates that consideration should be given to testing the following two additional jetty plans in the model: (a) a plan similar to plan 1-A except that the proposed south jetty would be exactly parallel to the existing north jetty, the distance between these two jetties to be the same as the distance from the north jetty to the shore end of the plan 1-A south jetty; and (b) a test of the above proposed plan with the proposed south jetty extended 1000 ft seaward, still parallel to the existing north jetty. It is believed that the curvature of either of these proposed jetties would be such as to deflect ebb currents more nearly into alignment with the navigation channel than did the plan 1-A jetty.

Table 1

WAVE DATA

Direction of Approach	Height Prototype	Length Prototype	Duration Prototype
340°	7 ft	290 ft	1 day (1 cycle model)
293°	7 ft	290 ft	"
272°	7 ft	290 ft	"
255°	7 ft	290 ft	"
306°	7 ft	290 ft	"

Table 2

VELOCITY OBSERVATIONS

Test	Velocity Observation Stations											
	Station 1				Station 2				Station 3			
	Surface		3/4 Depth		Surface		3/4 Depth		Surface		3/4 Depth	
	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood
Base	3.2	2.6	3.1	1.6	5.5	1.5	3.9	1.6	3.8	1.4	3.7	1.4
Dredging Plan	3.0	2.4	---	---	3.9	1.7	3.3	1.5	3.2	1.4	2.6	1.2
Plan 1	3.5	2.1	3.3	1.6	3.9	2.7	3.4	2.1	4.1	1.4	3.5	1.4
Plan 1-A	3.4	2.1	3.4	1.4	4.5	2.8	3.6	2.0	4.3	1.2	3.4	1.1
Plan 6	3.4	2.2	3.2	1.5	3.6	2.2	3.2	2.1	3.8	1.2	4.6	1.4
Plan 8	3.5	2.2	3.5	1.5	4.0	2.1	2.8	1.5	3.4	1.8	3.0	1.5

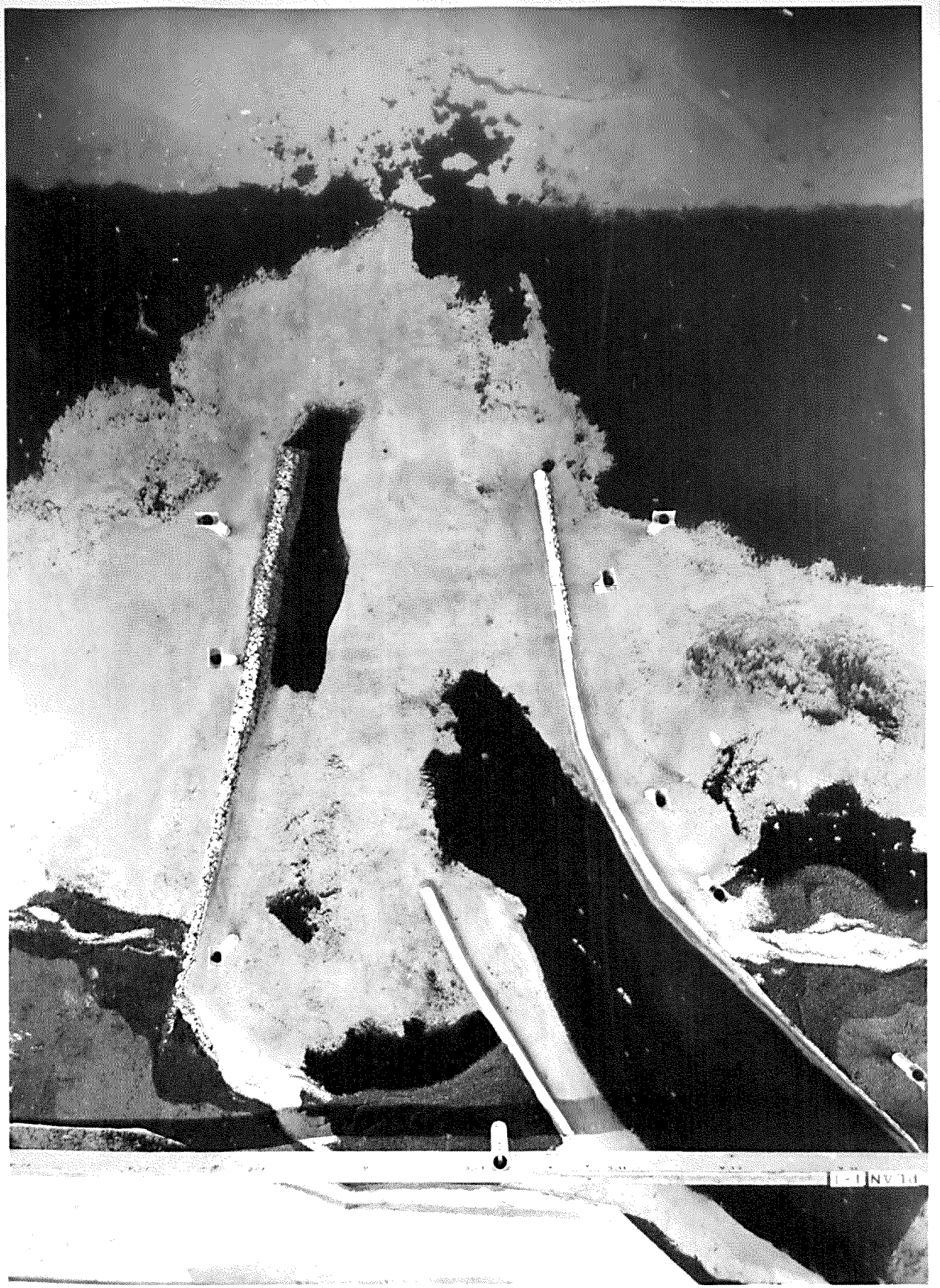
Table 3

EFFECTS OF PLANS ON MAXIMUM CURRENT VELOCITIES*

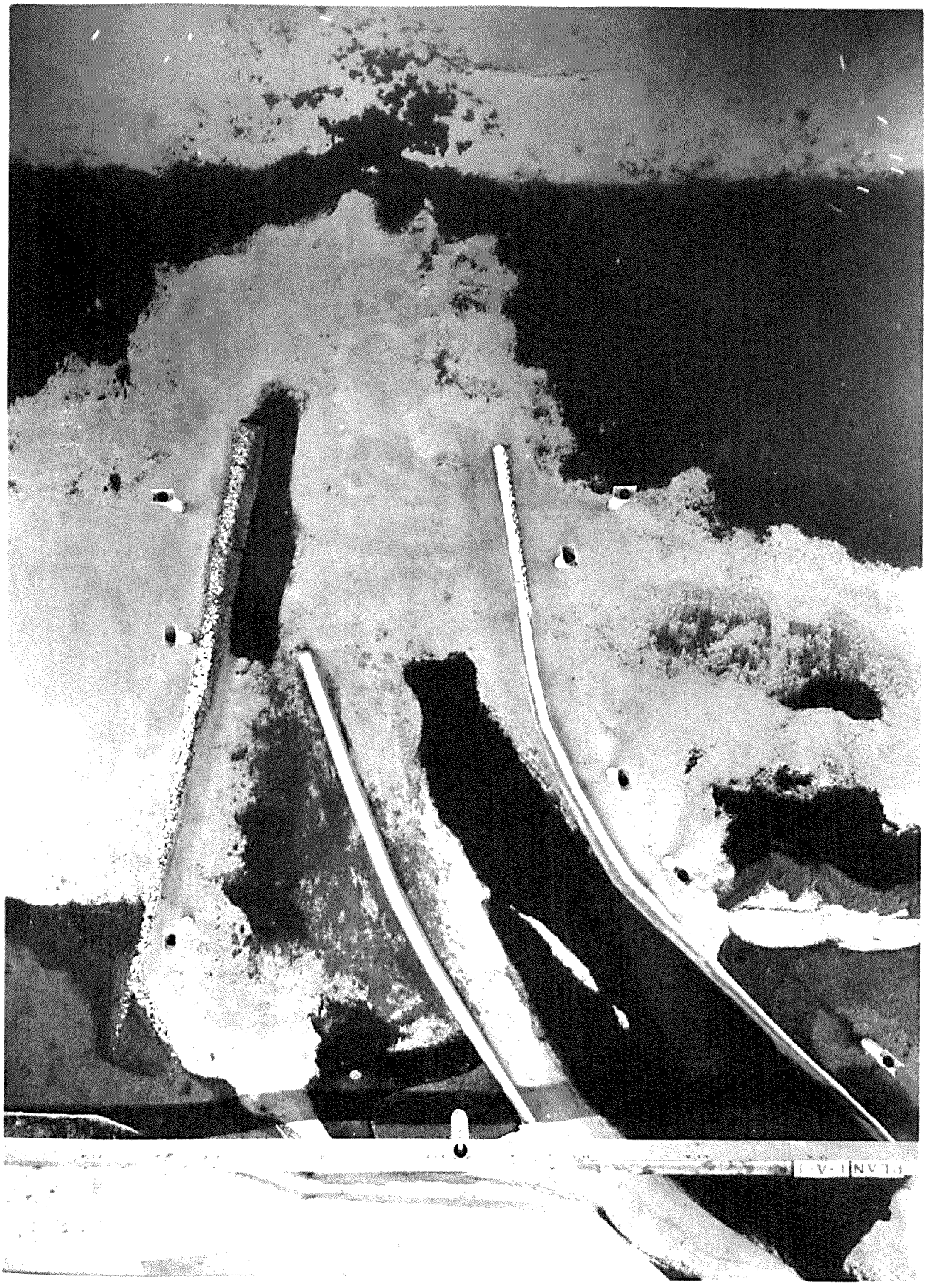
Test	Velocity Observation Stations											
	Station 1				Station 2				Station 3			
	Surface		3/4 Depth		Surface		3/4 Depth		Surface		3/4 Depth	
	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood
Dredging Plan	-0.2	-0.2	---	---	-1.6	+0.2	-0.6	-0.1	-0.6	0.0	-1.1	-0.2
Plan 1	+0.3	-0.5	+0.2	0.0	-1.6	+1.2	-0.5	+0.5	+0.3	0.0	-0.2	0.0
Plan 1-A	+0.2	-0.5	+0.3	-0.2	-1.0	+1.3	-0.3	+0.4	+0.5	-0.2	-0.3	-0.3
Plan 6	+0.2	-0.4	+0.1	-0.1	-1.9	+0.7	-0.7	+0.3	0.0	-0.2	+0.6	0.0
Plan 8	+0.3	-0.4	+0.4	-0.1	-1.5	+0.6	-1.1	-0.1	-0.4	+0.4	-0.7	+0.1

*NOTE: Base Test velocities used as basis for indicated increases or decreases

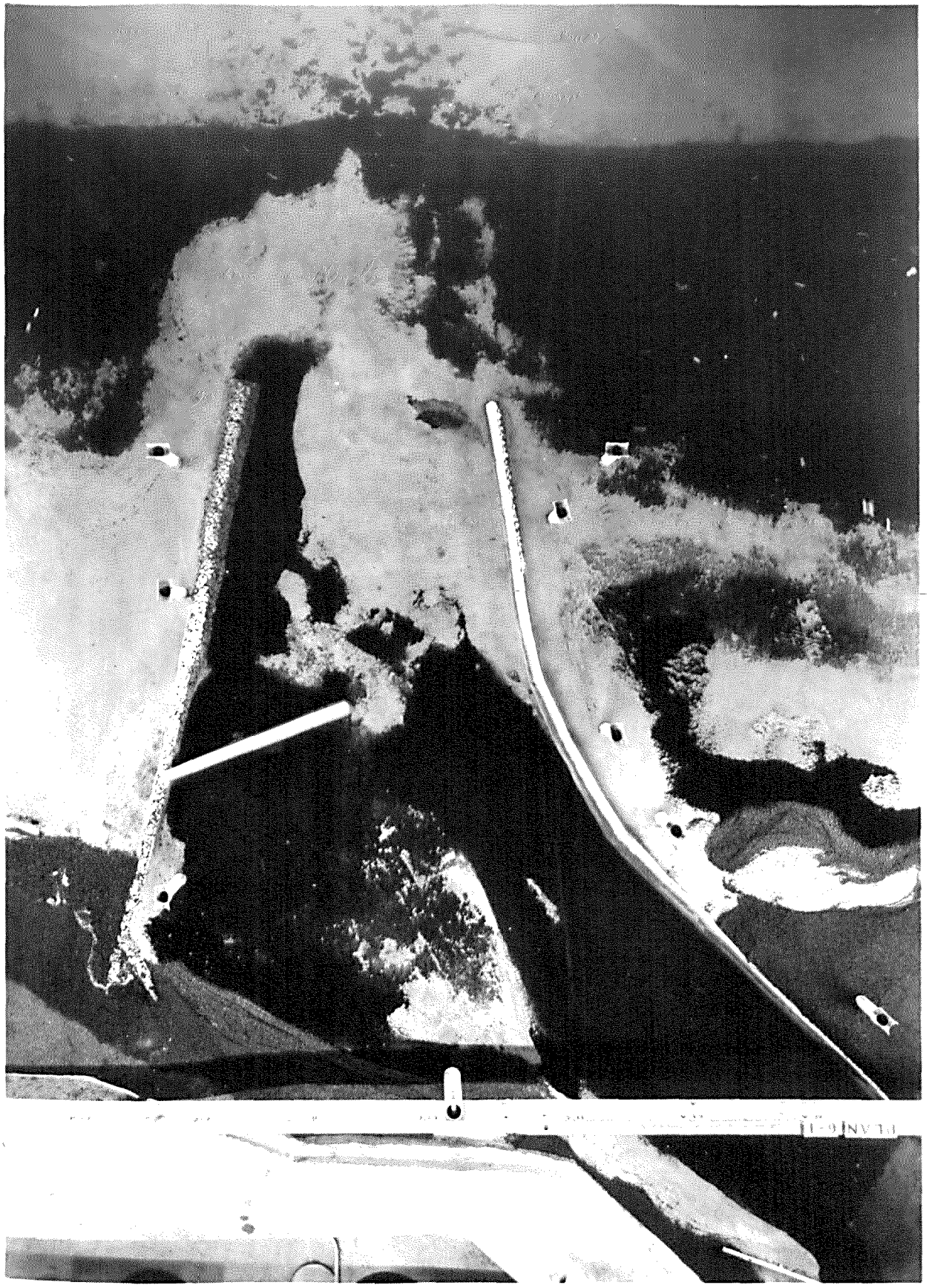
PHOTOGRAPH 1. Base Test - Bed condition after 5 cycles of operation.



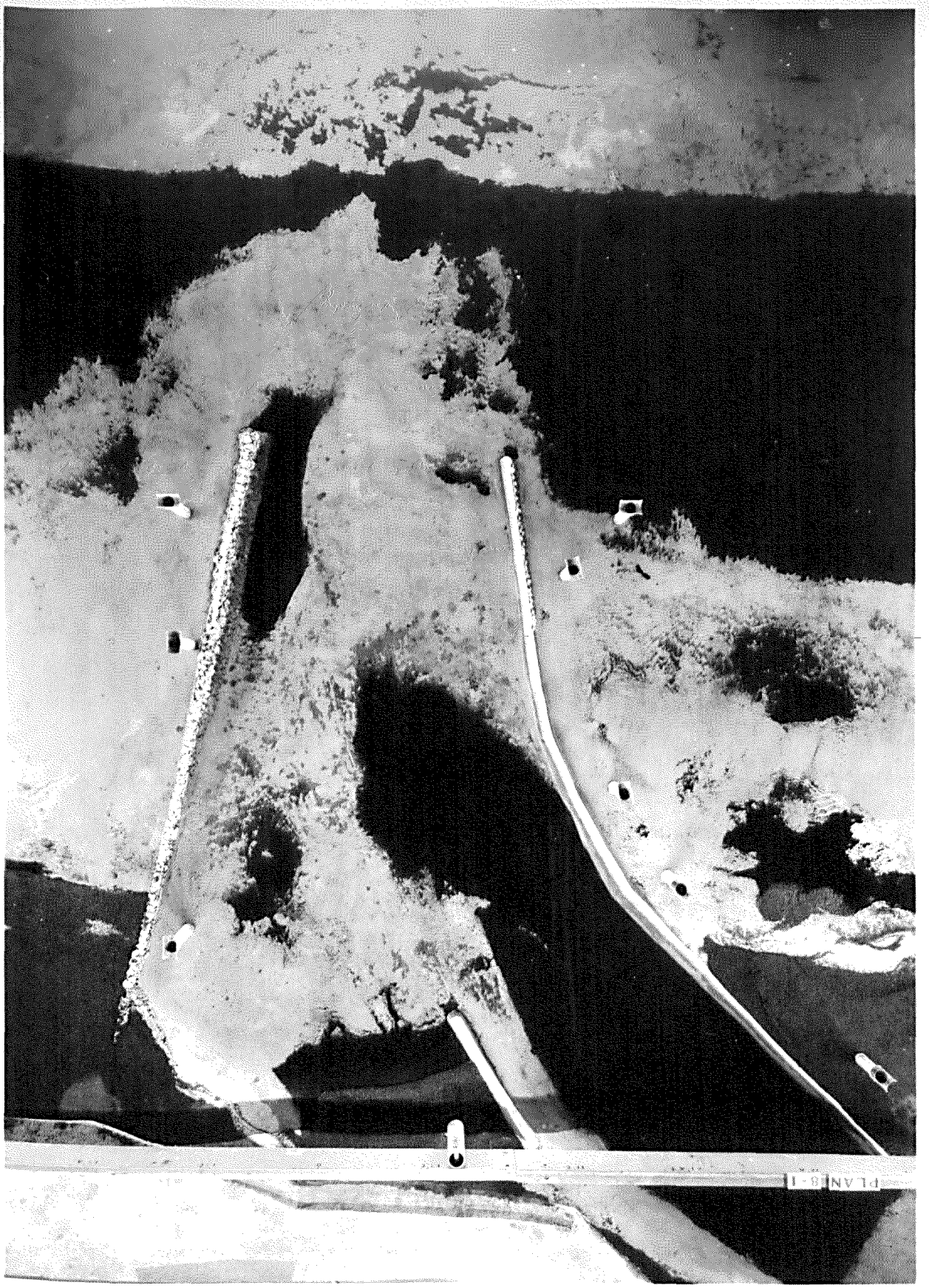
PHOTOGRAPH 2. Plan 1 - Bed condition after 5 cycles of operation.



PHOTOGRAPH 3. Plan 1-A - Bed condition after 5 cycles of operation.



PHOTOGRAPH 4. Plan 6 - Bed condition after 5 cycles of operation.



PHOTOGRAPH 5. Plan 8 - Bed condition after 5 cycles of operation.

PHOTOGRAPH 6. Base Test - Current directions at strength of flood before HHW (hr. 10.5)

PHOTOGRAPH 7. Base Test - Current directions at strength of ebb after HHW (hr. 16.5)

PHOTOGRAPH 8. Base Test - Current directions at strength of flood before LHW (hr. 23.0)

PHOTOGRAPH 9. Base Test - Current directions at strength of ebb after LHW (hr. 4.0).

PHOTOGRAPH 10. Plan 1 - Current directions at strength of flood before HHW (hr. 10.5).

PHOTOGRAPH 11. Plan 1 - Current directions at strength of ebb after HHW (hr. 16.5).

PHOTOGRAPH 12. Plan 1 - Current directions at strength of flood before LHW (hr. 23.0)

PHOTOGRAPH 13. Plan 1 - Current directions at strength of ebb after LHW (hr. 4.0)

PHOTOGRAPH 14. Plan 1-A - Current directions at strength of flood before HHW (hr. 10.5)

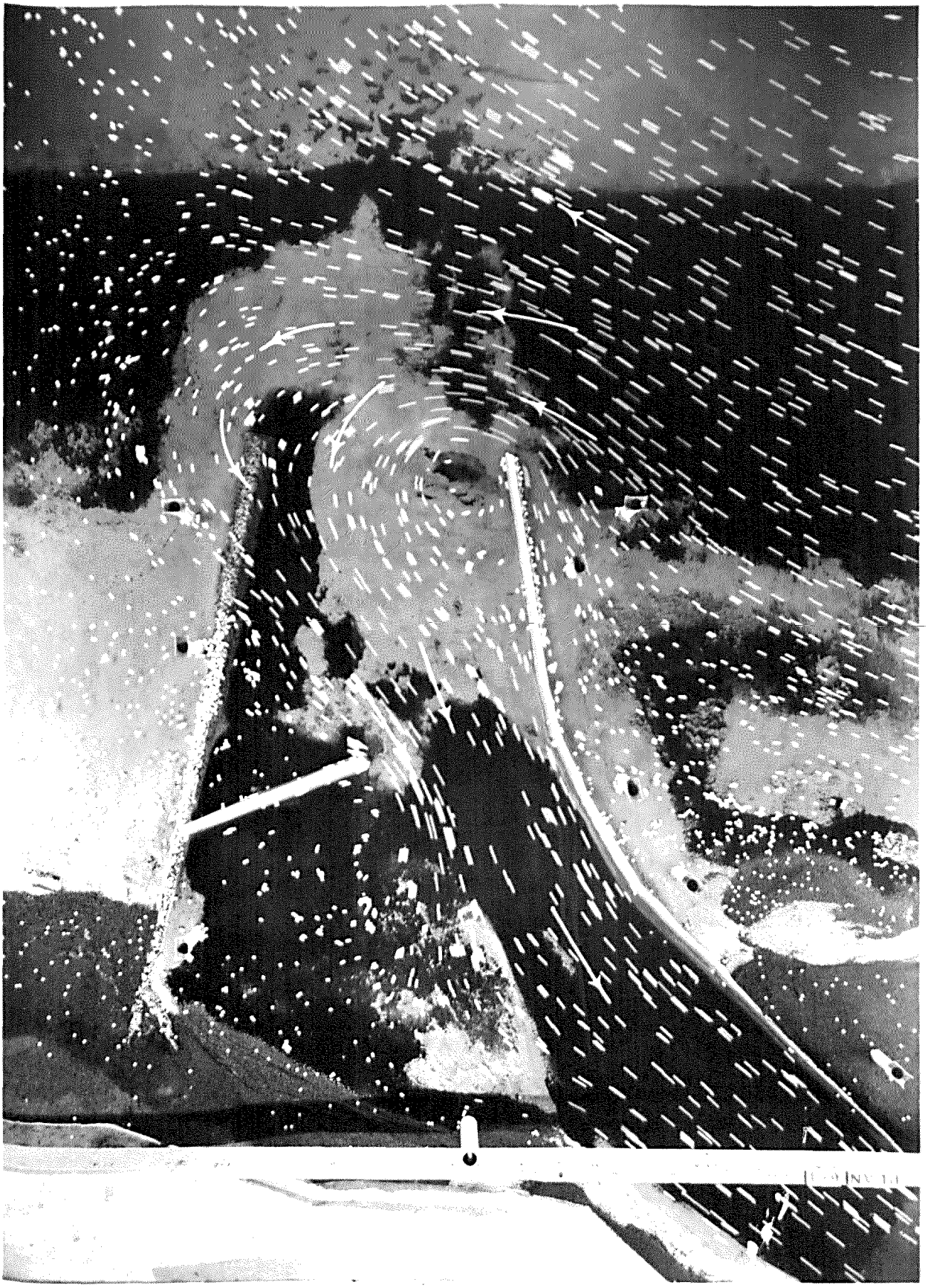
PHOTOGRAPH 15. Plan 1-A - Current directions at strength of ebb after HHW (hr 16.5)

PHOTOGRAPH 16. Plan 1-A - Current directions at strength of flood before LHW (hr. 23.0)

PHOTOGRAPH 17. Plan 1-A - Current directions at strength of ebb after LHW (hr. 4.0)

PHOTOGRAPH 18. Plan 6 - Current directions at strength of flood before HHW (hr. 10.5)

PHOTOGRAPH 19. Plan 6 - Current directions at strength of ebb after HHW (hr. 16.5)



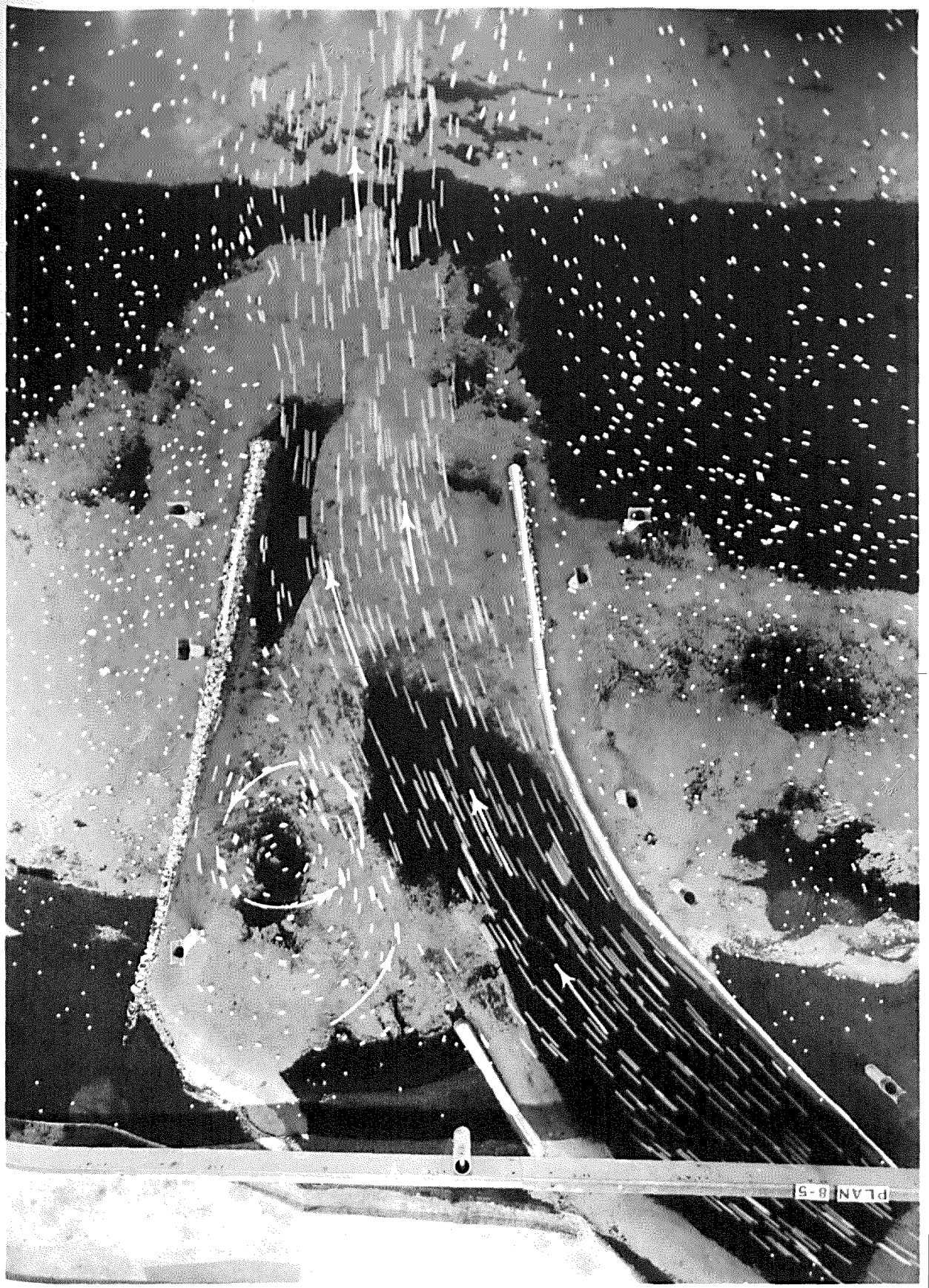
PHOTOGRAPH 20. Plan 6 - Current directions at strength of flood before LHW (hr. 23.0)

PHOTOGRAPH 21. Plan 6 - Current directions at strength of ebb after LHW (hr. 4.0)

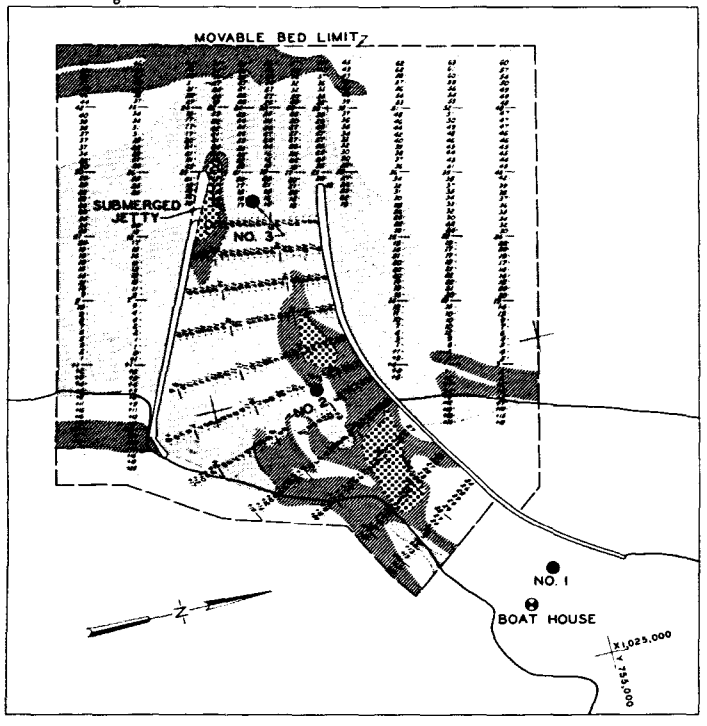
PHOTOGRAPH 22. Plan 8 - Current directions at strength of flood before HHW (hr. 10.5)

PHOTOGRAPH 23. Plan 8 - Current directions at strength of ebb after HHW (hr. 16.5)

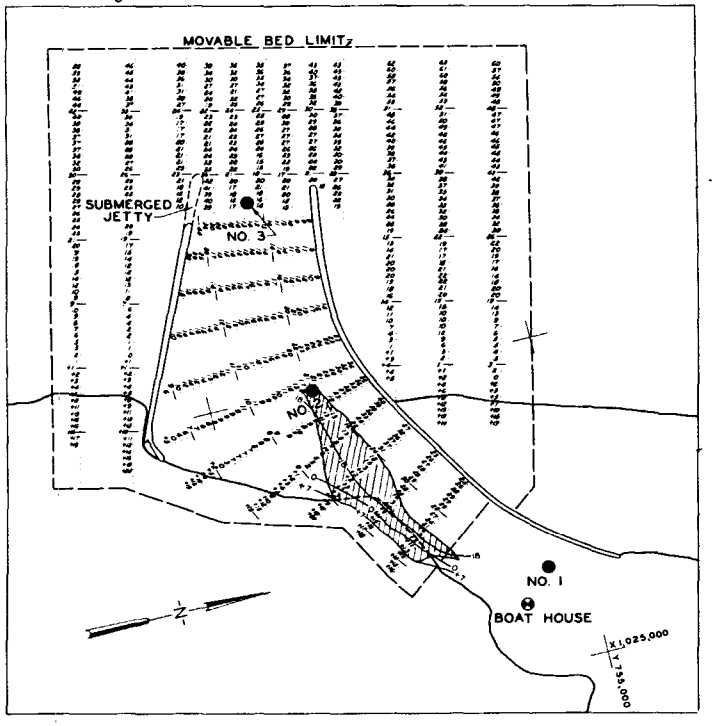
PHOTOGRAPH 24. Plan 8 - Current directions at strength of flood before LHW (hr. 23.0)



PHOTOGRAPH 25. Plan 8 - Current directions at strength of ebb after LHW (hr. 4.0)



BASE TEST



DREDGING PLAN

LEGEND

- EXISTING JETTY
- PROPOSED JETTY
- TIDE GAGE
- VELOCITY STATION
- SCOUR
- LIGHT FILL (0-6 FT)
- HEAVY FILL (6-14 FT)
- PROPOSED DREDGING

NOTE: GRID COORDINATES ARE OREGON STATE COORDINATES (SOUTH ZONE).

LOCATION OF MODEL VELOCITY STATION NO. 1 IS THE SAME AS THE LOCATION OF PROTOTYPE VELOCITY STATION NO. 2.

SOUNDINGS ARE REFERRED TO MEAN LOWER LOW WATER AT BOAT HOUSE GAGE WHICH IS 4.46 BELOW MEAN SEA LEVEL OF THE 1929 DATUM.

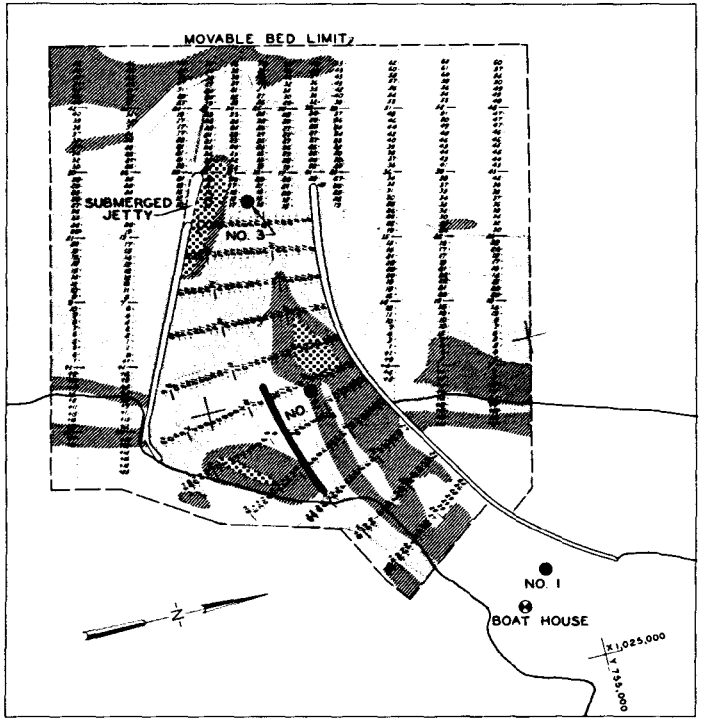
BASE TEST SCOUR AND FILL DREDGING PLAN

SCALES

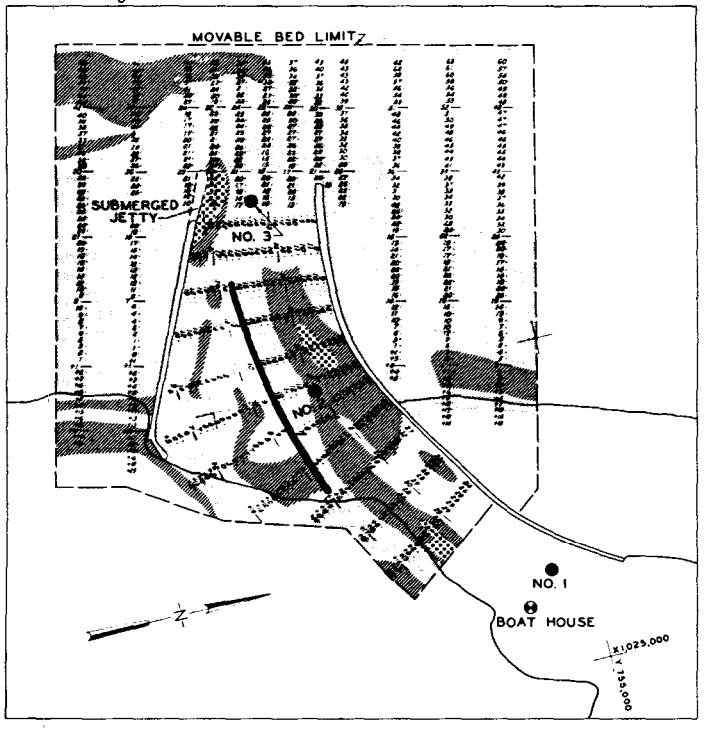
PROTOTYPE 1000 0 1000 2000 3000 4000 FT

MODEL 2 1 0 1 2 3 4 5 6 7 8 9 10 FT

PLATE 1



PLAN I



PLAN I-A

LEGEND

- EXISTING JETTY
- PROPOSED JETTY
- TIDE GAGE
- VELOCITY STATION
- SCOUR
- LIGHT FILL (0-6 FT)
- HEAVY FILL (6-14 FT)

NOTE: GRID COORDINATES ARE OREGON STATE COORDINATES (SOUTH ZONE).

LOCATION OF MODEL VELOCITY STATION NO. 1 IS THE SAME AS THE LOCATION OF PROTOTYPE VELOCITY STATION NO. 2.

SOUNDINGS ARE REFERRED TO MEAN LOWER LOW WATER AT BOAT HOUSE GAGE WHICH IS 4.46 BELOW MEAN SEA LEVEL OF THE 1929 DATUM.

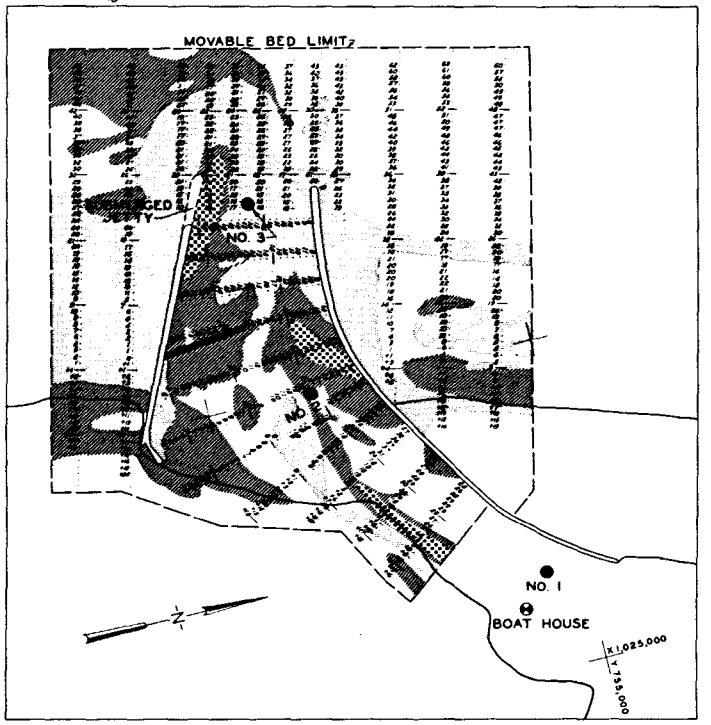
SCOUR AND FILL, PLANS I AND I-A

SCALES

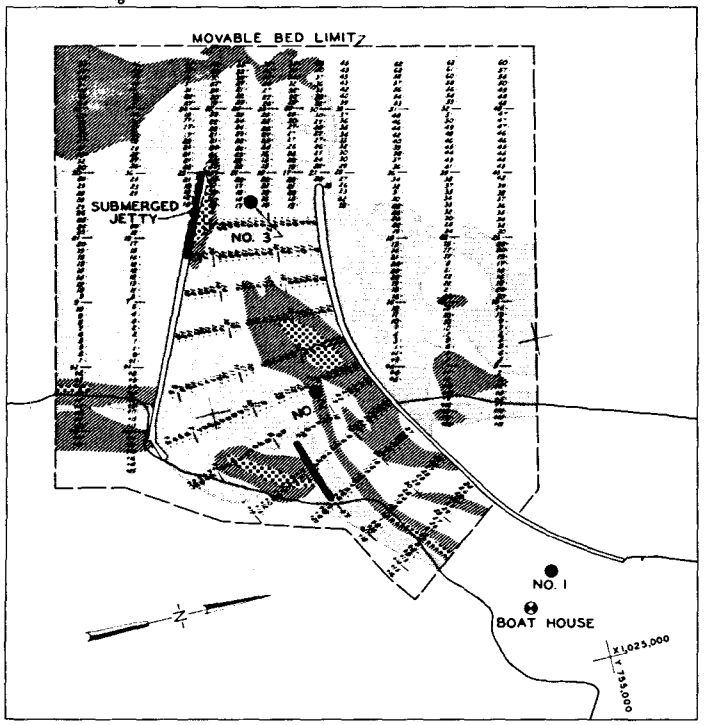
PROTOTYPE 1000 0 1000 2000 3000 4000 FT

MODEL 2 1 0 1 2 3 4 5 6 7 8 9 10 FT

PLATE 2



PLAN 6



PLAN 8

LEGEND

- EXISTING JETTY
- PROPOSED JETTY
- TIDE GAGE
- VELOCITY STATION
- SCOUR
- LIGHT FILL (0-6 FT)
- HEAVY FILL (6-14 FT)

NOTE: GRID COORDINATES ARE OREGON STATE COORDINATES (SOUTH ZONE).

LOCATION OF MODEL VELOCITY STATION NO. 1 IS THE SAME AS THE LOCATION OF PROTOTYPE VELOCITY STATION NO. 2.

SOUNDINGS ARE REFERRED TO MEAN LOWER LOW WATER AT BOAT HOUSE GAGE WHICH IS 4.46 BELOW MEAN SEA LEVEL OF THE 1929 DATUM.

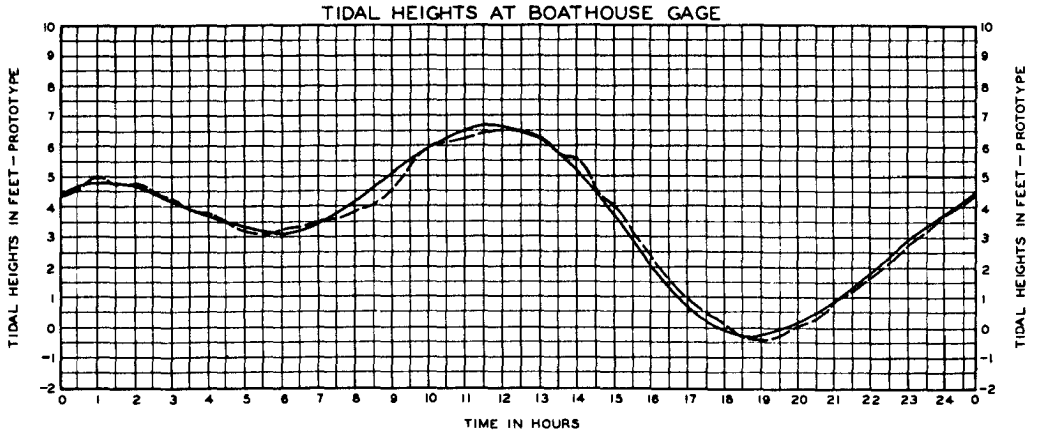
SCOUR AND FILL, PLANS 6 AND 8

SCALES

PROTOTYPE 1000 0 1000 2000 3000 4000 FT

MODEL 2 1 0 1 2 3 4 5 6 7 8 9 10 FT

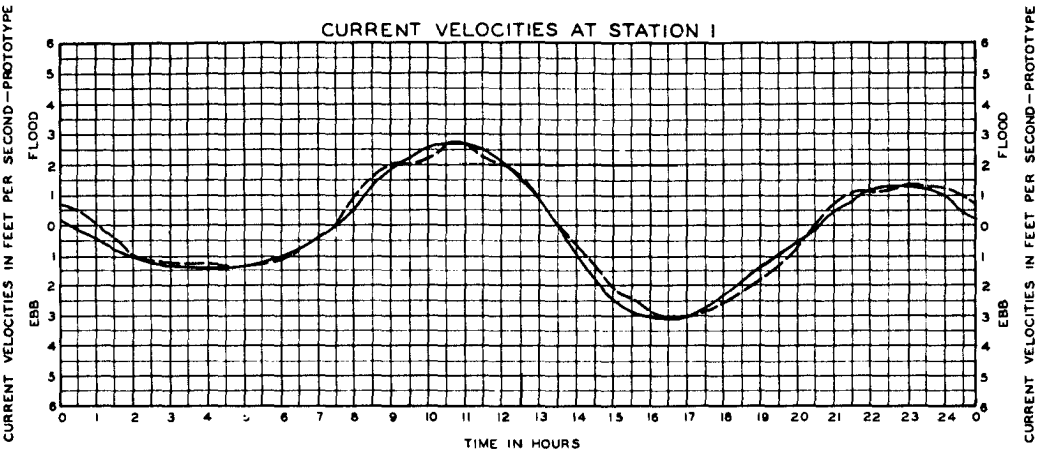
PLATE 3



LEGEND

PROTOTYPE TIDAL HEIGHTS

MODEL TIDAL HEIGHTS



LEGEND

PROTOTYPE VELOCITIES

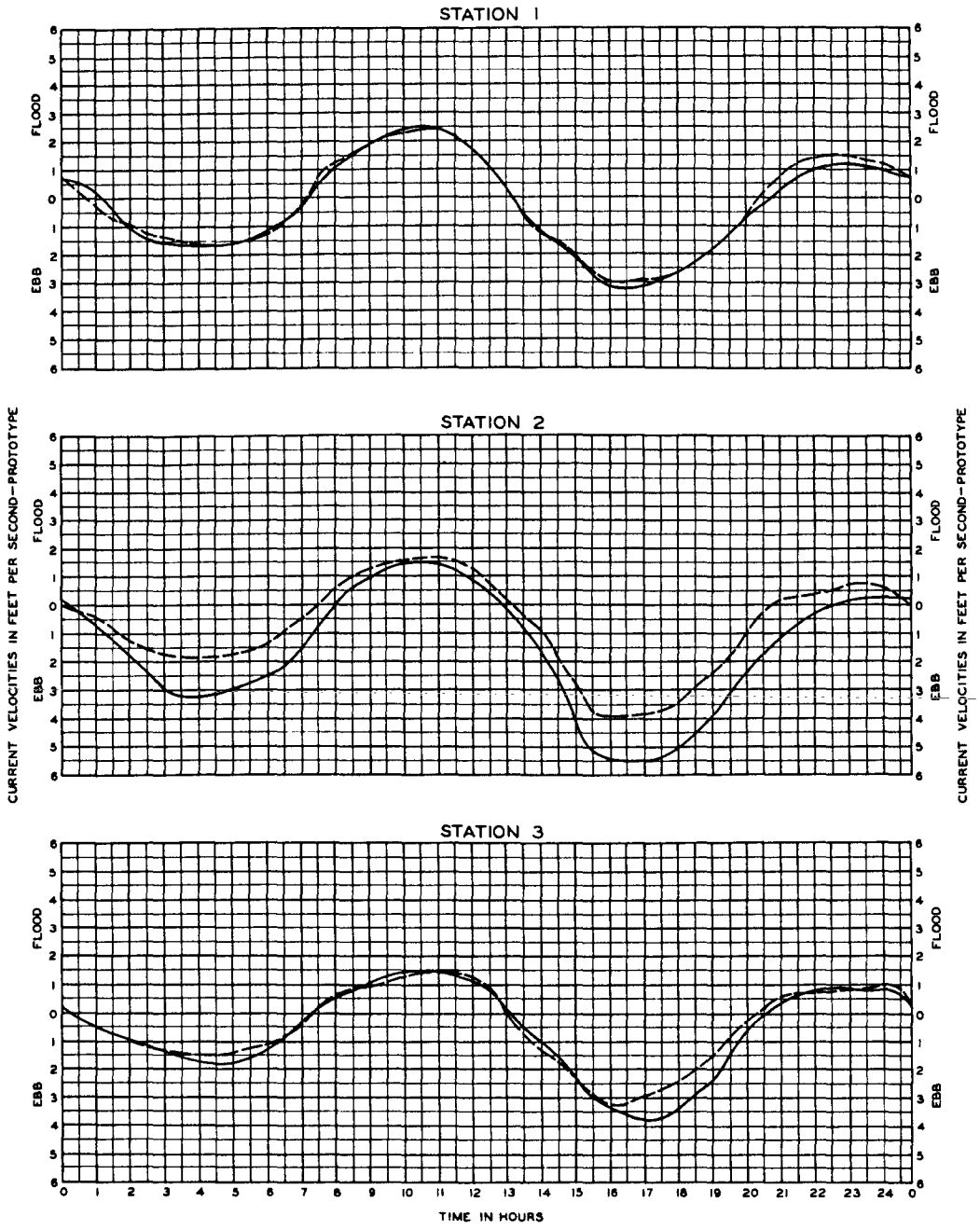
MODEL VELOCITIES

NOTE: SEE PLATE 1 FOR LOCATION OF TIDE AND VELOCITY STATIONS.

TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF BOATHOUSE GAGE.

ELEVATIONS REFER TO MLLW AT BOATHOUSE GAGE.

HYDRAULIC VERIFICATION



LEGEND

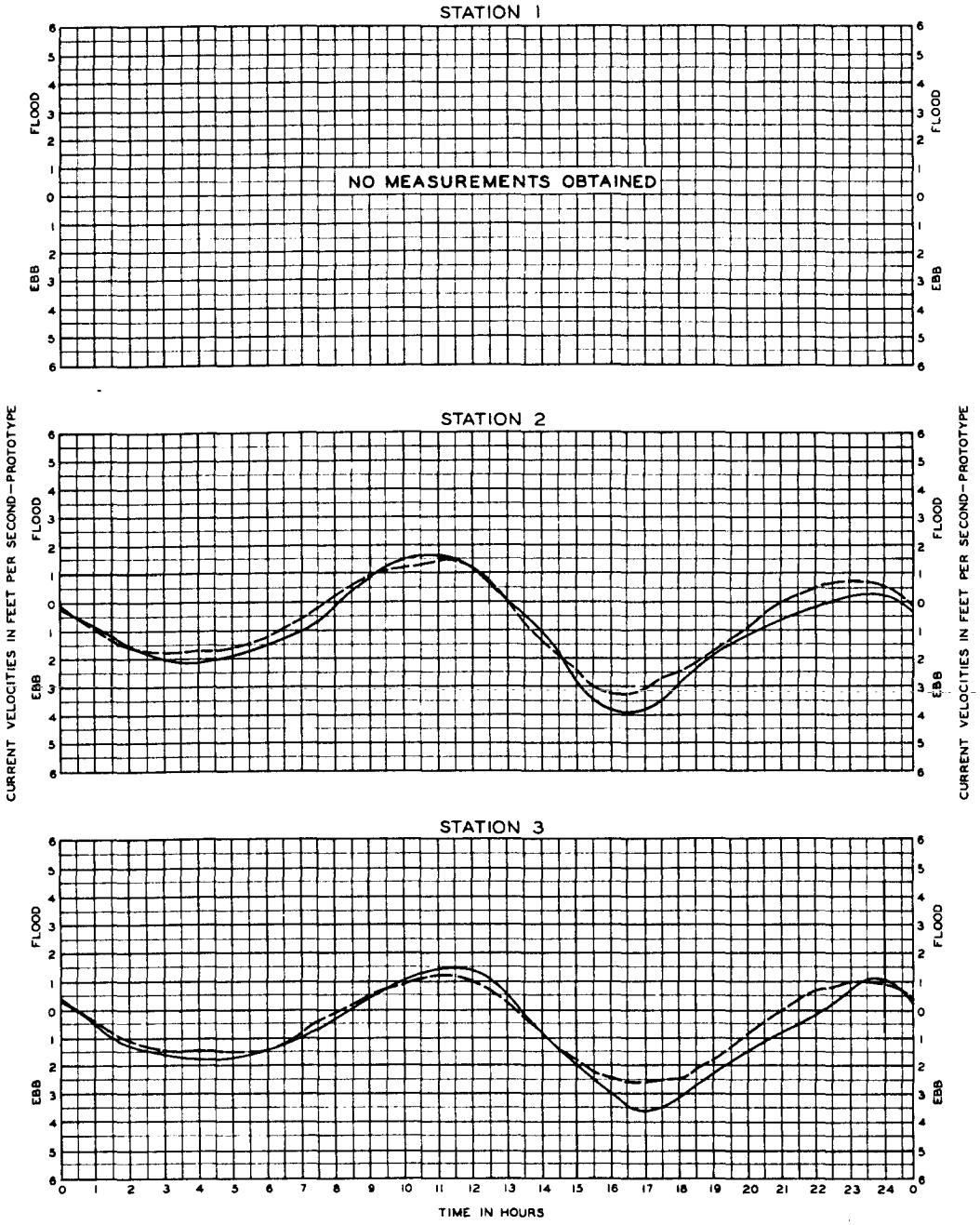
——— BASE TEST VELOCITIES

– – – – PLAN TEST VELOCITIES

NOTE: SEE PLATE 1 FOR ELEMENTS OF PLAN AND FOR LOCATION OF VELOCITY STATIONS.

TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF BOATHOUSE GAGE.

VELOCITY CURVES
DREDGING PLAN
SURFACE



LEGEND

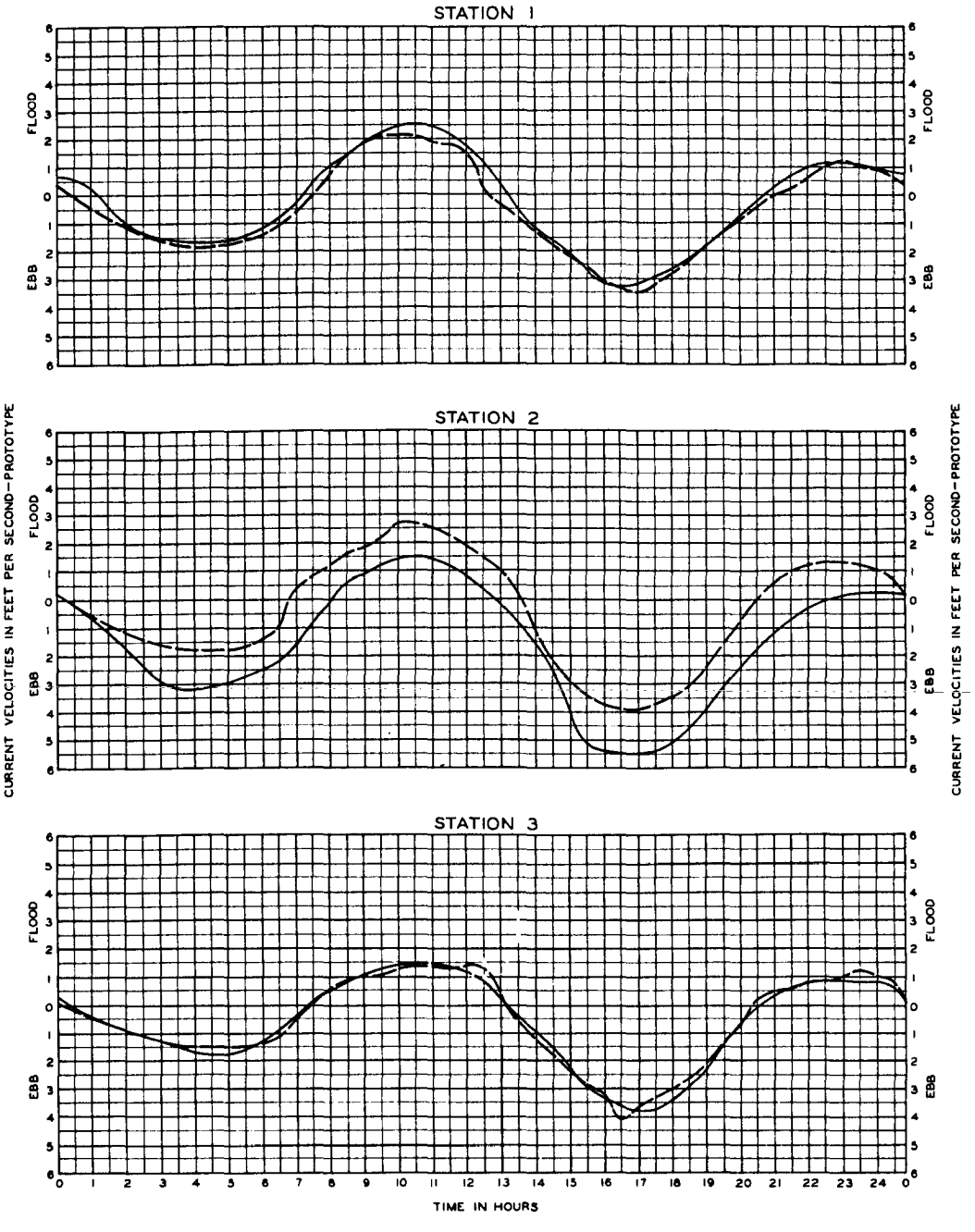
——— BASE TEST VELOCITIES

– – – – PLAN TEST VELOCITIES

NOTE: SEE PLATE 1 FOR ELEMENTS OF PLAN AND FOR LOCATION OF VELOCITY STATIONS.

TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF BOATHOUSE GAGE.

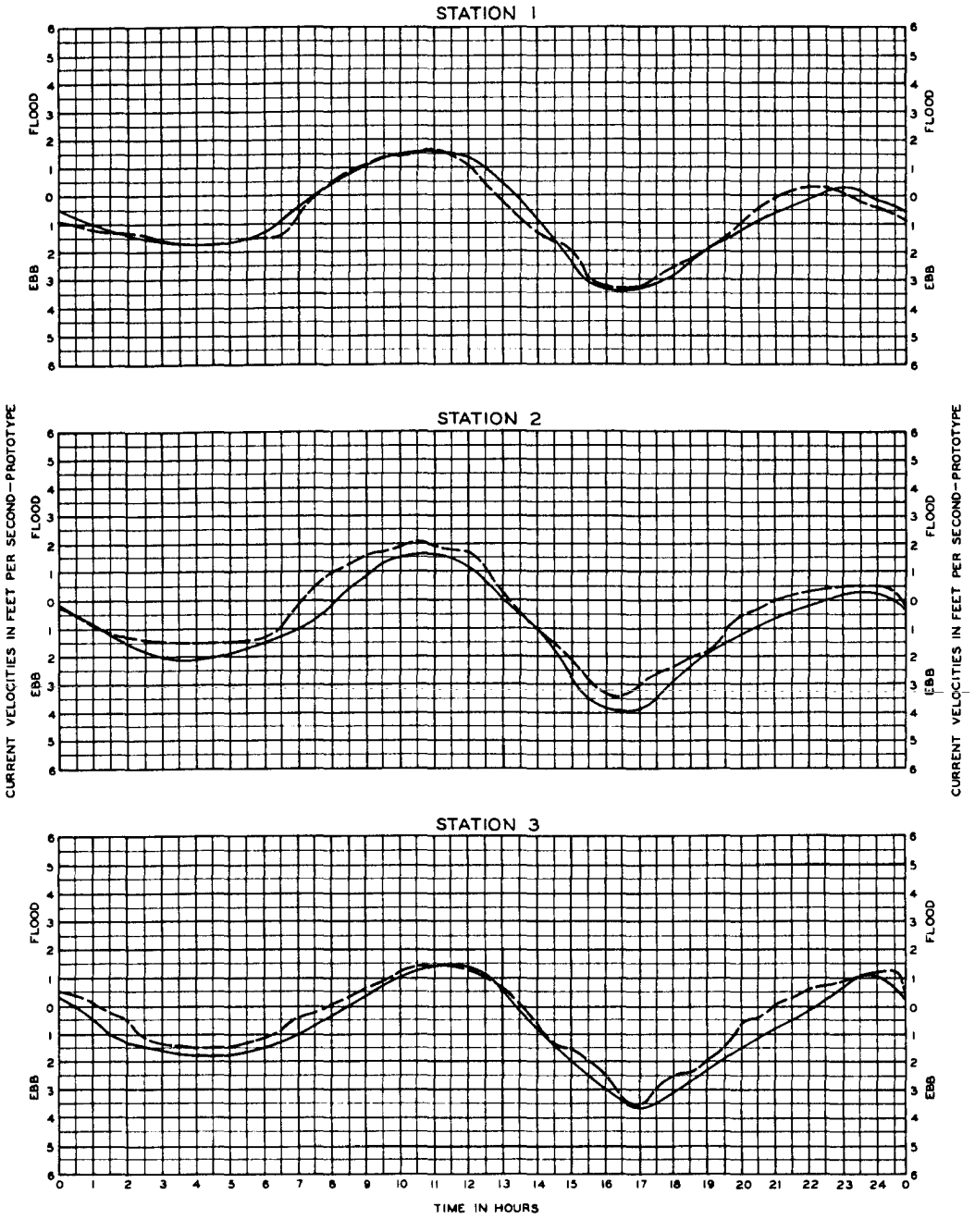
VELOCITY CURVES
DREDGING PLAN
THREE-FOURTHS DEPTH



NOTE: SEE PLATE 2 FOR ELEMENTS OF PLAN AND FOR LOCATION OF VELOCITY STATIONS.

TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF BOATHOUSE GAGE.

VELOCITY CURVES
PLAN 1
SURFACE



LEGEND

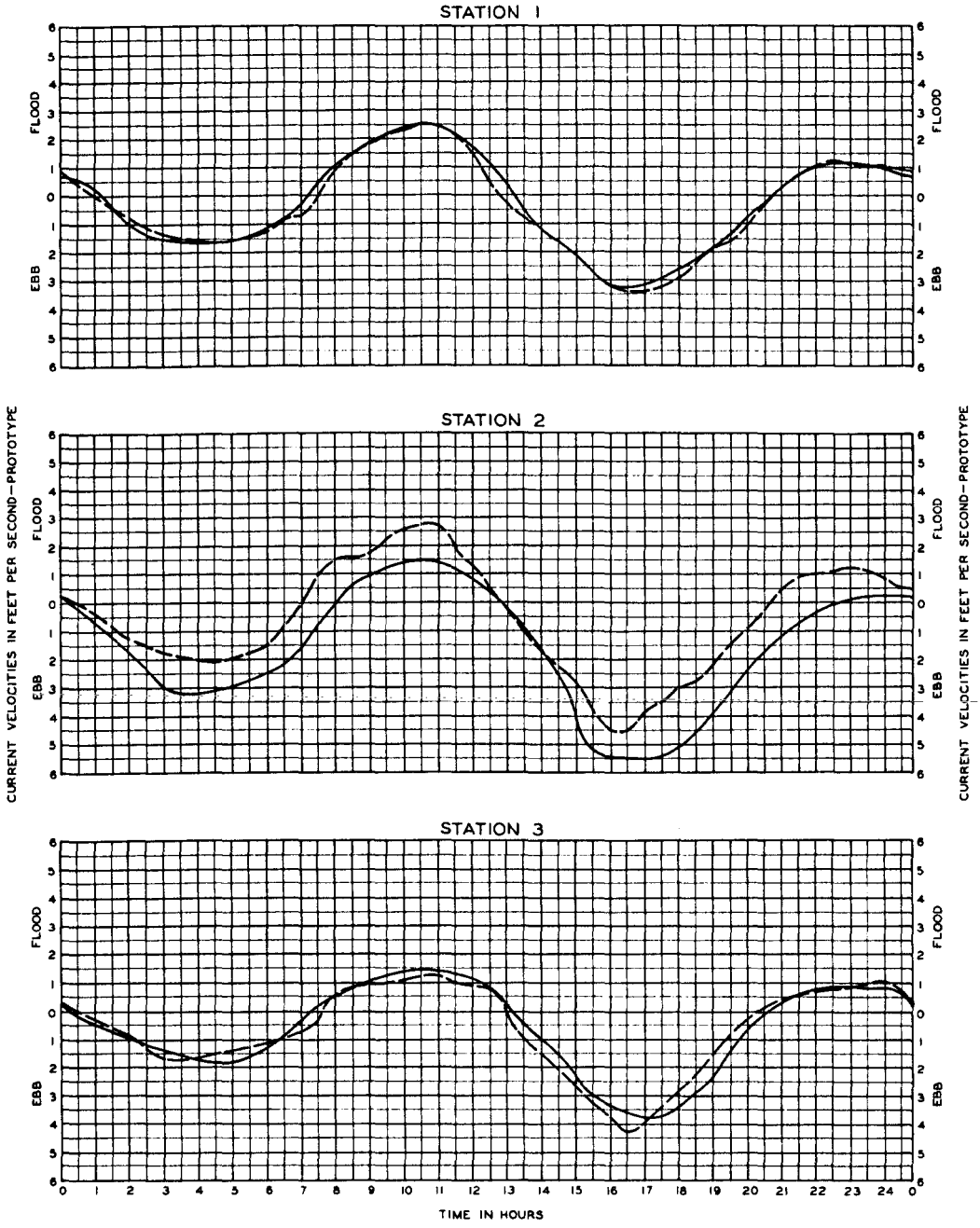
BASE TEST VELOCITIES

PLAN TEST VELOCITIES

NOTE: SEE PLATE 2 FOR ELEMENTS OF PLAN AND FOR LOCATION OF VELOCITY STATIONS.

TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF BOATHOUSE GAGE.

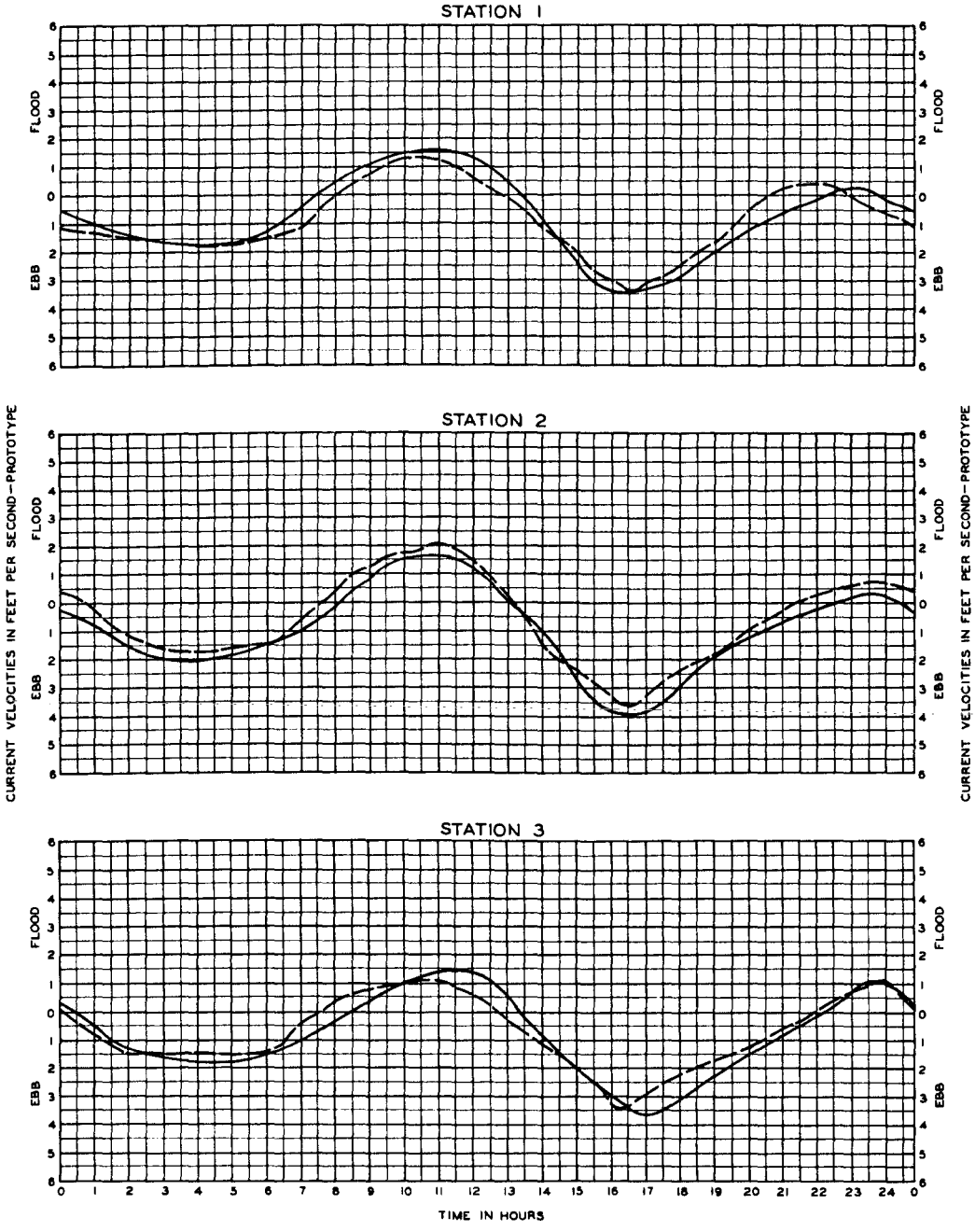
VELOCITY CURVES
PLAN 1
THREE-FOURTHS DEPTH



NOTE: SEE PLATE 2 FOR ELEMENTS OF PLAN AND FOR LOCATION OF VELOCITY STATIONS.

TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF BOATHOUSE GAGE.

VELOCITY CURVES
PLAN 1-A
SURFACE



LEGEND

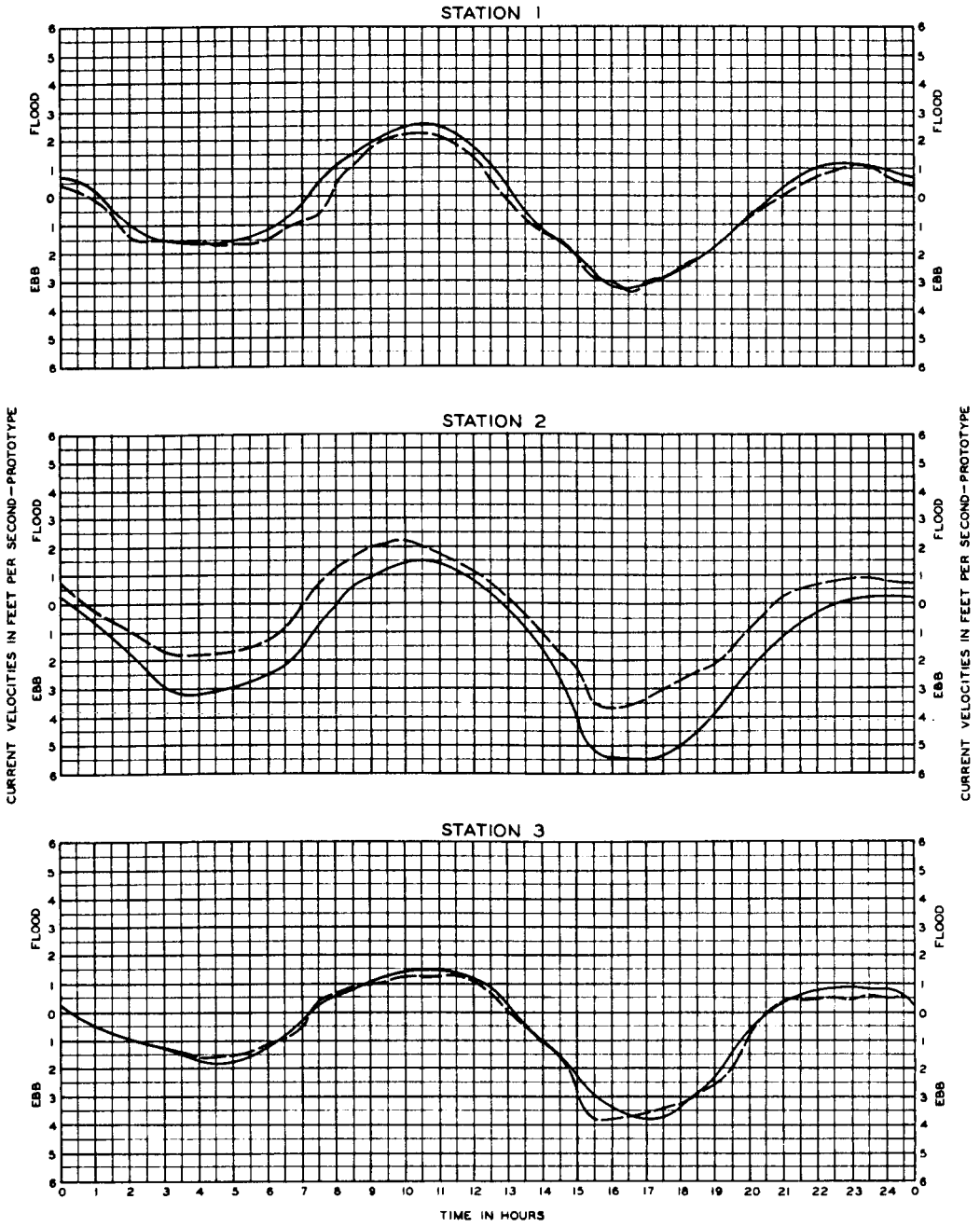
BASE TEST VELOCITIES

PLAN TEST VELOCITIES

NOTE: SEE PLATE 2 FOR ELEMENTS OF PLAN AND FOR LOCATION OF VELOCITY STATIONS.

TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF BOATHOUSE GAGE.

VELOCITY CURVES
PLAN 1-A
THREE-FOURTHS DEPTH



LEGEND

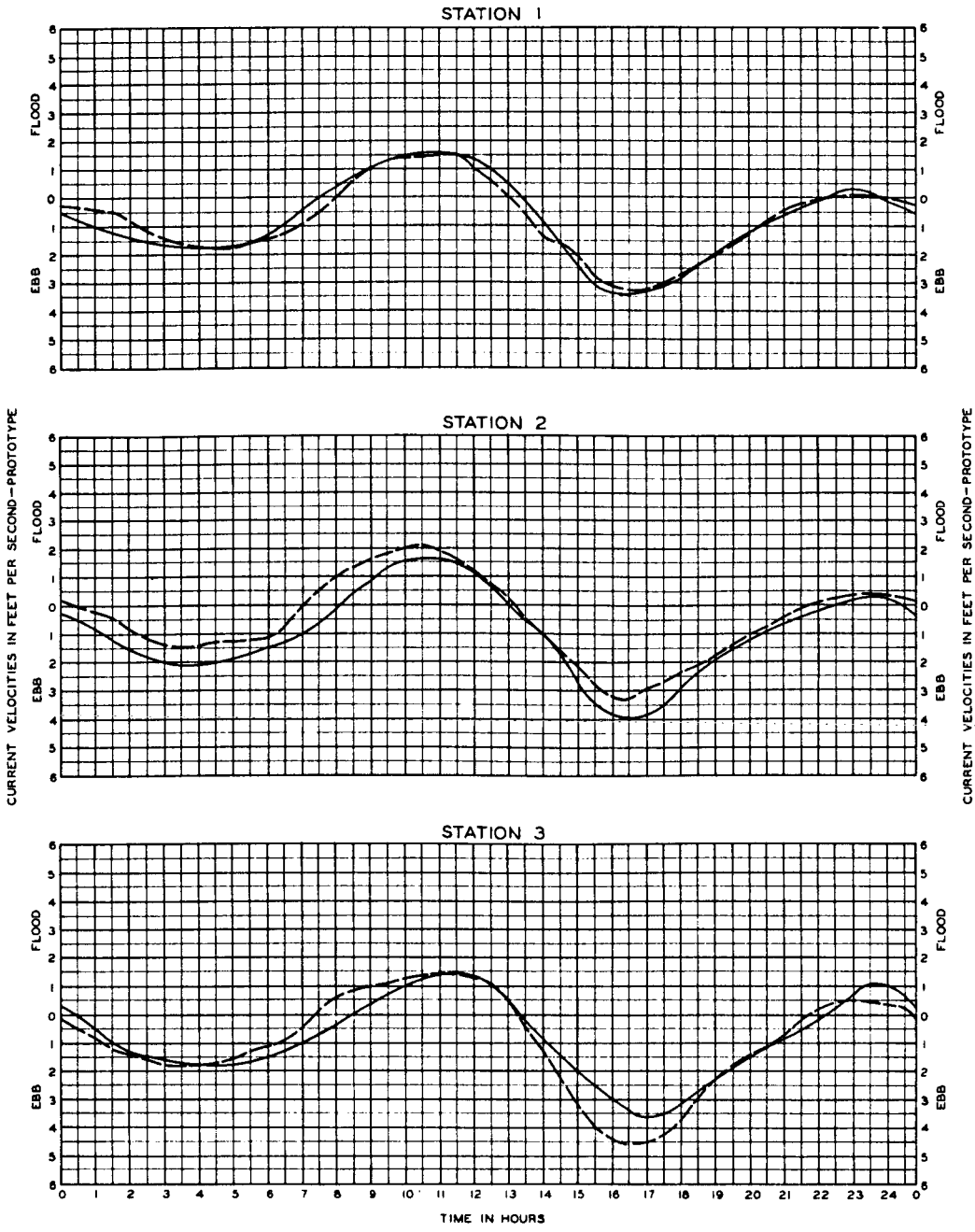
BASE TEST VELOCITIES

PLAN TEST VELOCITIES

NOTE: SEE PLATE 3 FOR ELEMENTS OF PLAN AND FOR LOCATION OF VELOCITY STATIONS.

TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF BOATHOUSE GAGE.

VELOCITY CURVES
PLAN 6
SURFACE



LEGEND

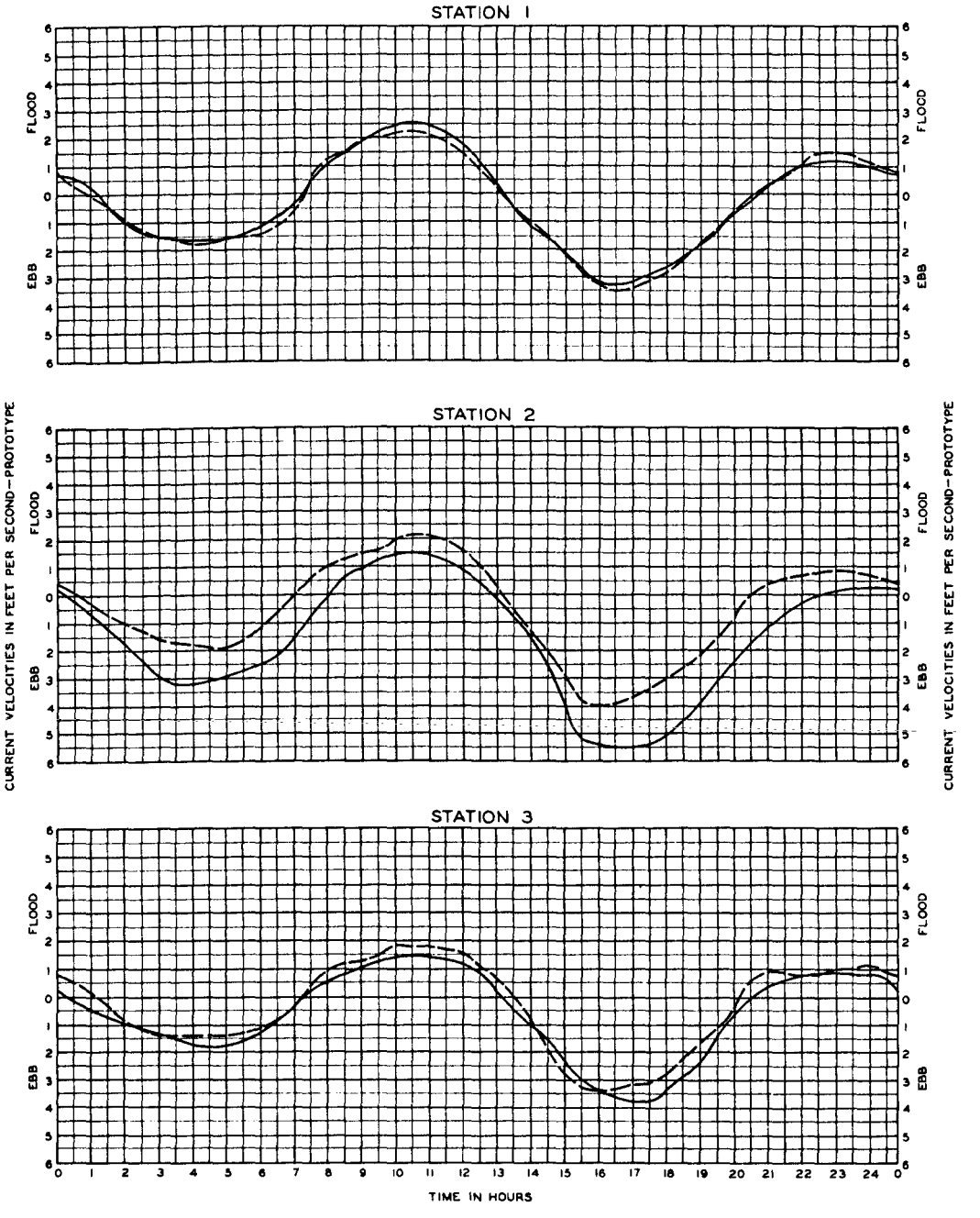
——— BASE TEST VELOCITIES

– – – – PLAN TEST VELOCITIES

NOTE: SEE PLATE 3 FOR ELEMENTS OF PLAN AND FOR LOCATION OF VELOCITY STATIONS.

TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF BOATHOUSE GAGE.

VELOCITY CURVES
PLAN 6
THREE—FOURTHS DEPTH



LEGEND

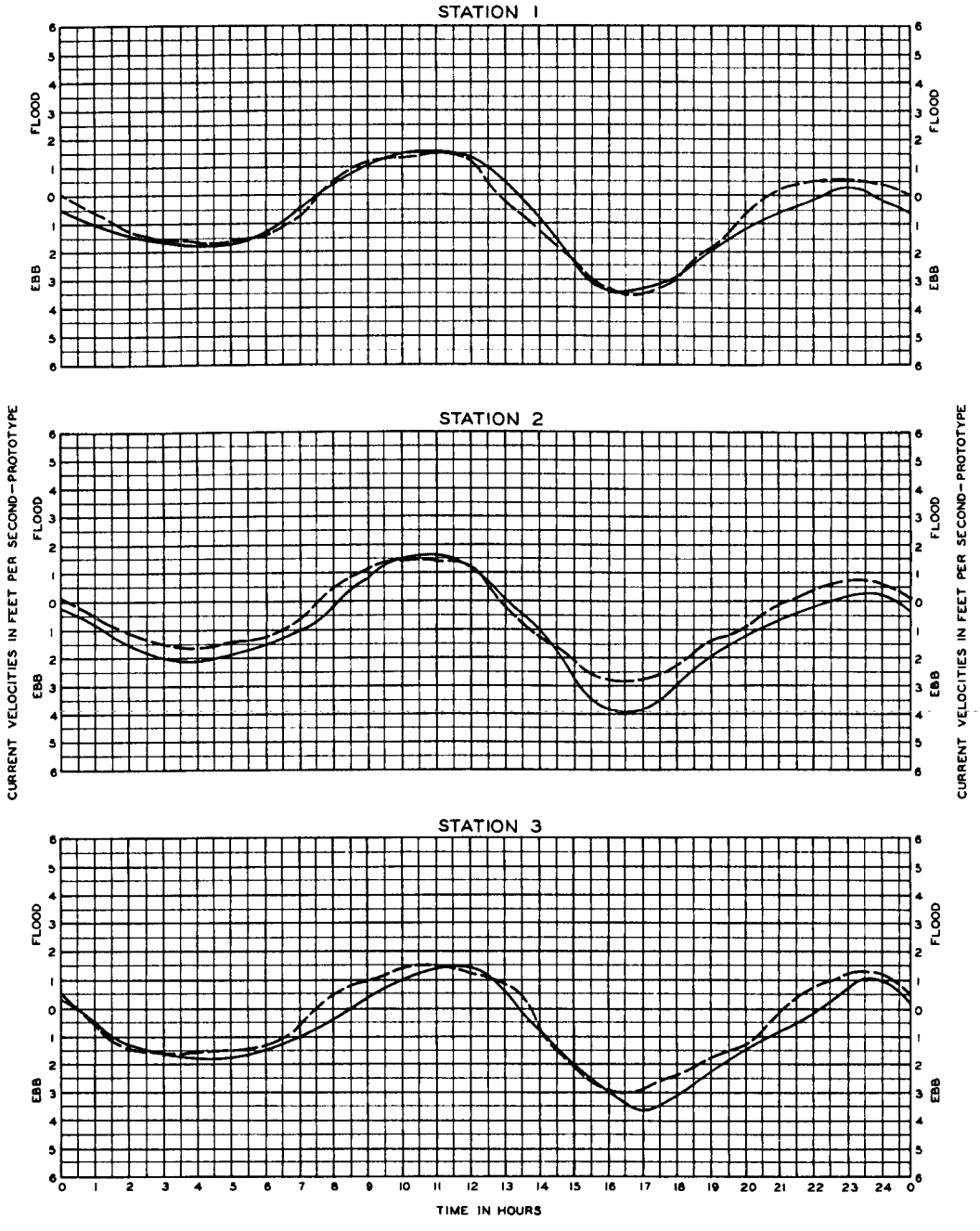
——— BASE TEST VELOCITIES

– – – – PLAN TEST VELOCITIES

NOTE: SEE PLATE 3 FOR ELEMENTS OF PLAN AND FOR LOCATION OF VELOCITY STATIONS.

TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF BOATHOUSE GAGE.

VELOCITY CURVES
PLAN 8
SURFACE



LEGEND

——— BASE TEST VELOCITIES

– – – – PLAN TEST VELOCITIES

NOTE: SEE PLATE 3 FOR ELEMENTS OF PLAN AND FOR LOCATION OF VELOCITY STATIONS.

TIME IS EXPRESSED IN HOURS AFTER MOON'S TRANSIT OF BOATHOUSE GAGE.

VELOCITY CURVES
PLAN 8
THREE-FOURTHS DEPTH