TECHNICAL REPORT H-69-12

GALVESTON BAY HURRICANE SURGE STUDY

Report 2

EFFECTS OF PROPOSED BARRIERS ON TIDES, CURRENTS, SALINITIES, AND DYE DISPERSION FOR NORMAL TIDE CONDITIONS

APPENDIX B: CALIBRATION TESTS

Hydraulic Model Investigation

by

R. A. Sager, E. C. McNair, Jr.

March 1973

Sponsored by U. S. Army Engineer District, Galveston

Conducted by U. S. Army Engineer Waterways Experiment Station
Hydraulics Laboratory
Vicksburg, Mississippi

GALVESTON BAY HURRICANE SURGE STUDY REPORTS

Report No.	Appendix	Title	Publication Date or Status
1		Effects of Proposed Barriers on Hurricane Surge Heights	Sept 1969
	A	Calibration Tests	Mar 1973
2		Effects of Proposed Barriers on Tides, Currents, Salinities, and Dye Dispersion for Normal Tide Conditions	July 1970
	A	Dye-Time Concentration Curves	July 1970
	B	Calibration Tests	Mar 1973
3		Effects of Plan 2 Alpha and Plan 2 Gamma Barriers on Tides, Currents, Salinities, and Dye Dispersion for Normal Tide Conditions	July 1970
	A	Dye-Time Concentration Curves	July 1970

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ARMY-MRC VICKSBURG, MISS

FOREWORD

The model investigation reported herein was requested by the U. S. Army Engineer Division, Southwestern, in a letter to the Director, U. S. Army Engineer Waterways Experiment Station (WES), dated 31 March 1964. Permission of the Office, Chief of Engineers, to conduct the study was subsequently requested by the Southwestern Division and was granted. WES was granted authority to proceed with the investigation by letter from the Galveston District dated 21 January 1965.

The study was conducted in several phases using two separate hydraulic models and four flume facilities. The portion of the study described herein was the development of distorted-scale models to allow effective tests to be conducted in the Houston Ship Channel model. Reports 2 and 3 in this series describe tests conducted in the Houston Ship Channel model to determine the effects of two Alpha and two Gamma barrier plans on tides, currents, salinities, and dye dispersion for normal tide conditions. The portion of the study to define the hydraulic characteristics of the Galveston Harbor Entrance and barrier beaches associated with the bay and the development of distorted-scale models to allow effective tests to be conducted in the Galveston Bay hurricane surge model is described in Report 1, Appendix A, of this series of reports. The tests conducted in the Galveston Bay hurricane surge model to define the effects of the Alpha and Gamma barrier plans on hurricane surge heights are described in Report 1 of this series of reports.

The portion of the study reported herein was conducted in the Hydraulics Laboratory of WES during the period March 1967 through October 1967, under the direction of Messrs. E. P. Fortson, Jr. (retired), Chief of the Hydraulics Laboratory, and H. B. Simmons, present Chief of the Hydraulics Laboratory and former Chief of the Estuaries Branch. The test program was completed under the supervision of Messrs. R. A. Sager and E. C. McNair, Jr.

Personnel of the Galveston District who were principally responsible for planning the course of the study included Messrs. A. B. Davis, Chester Pawlik, and Earl Howard; however, other Southwestern Division and Galveston District personnel frequently participated in conferences on the model study and visited the models from time to time.

Directors of WES during the testing phase of the study and the preparation and publication of this appendix were COL John R. Oswalt, Jr., CE, and COL Ernest D. Peixotto, CE. Technical Directors were Messrs. J. B. Tiffany and F. R. Brown.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
cubic feet per second	0.02831685	cubic meters per second

SUMMARY

This appendix is one of a series of reports presenting results of a model test program conducted to evaluate two proposed hurricane protection systems for the Galveston Bay, Texas, complex. Development of model structures to allow the effects of two barrier plans (Alpha and Gamma) on normal tide conditions to be evaluated in a distorted-scale model (1:60 vertically and 1:600 horizontally) is discussed. A model structure of a 400-ft-wide by -55 ft msl navigation opening was developed for each plan. Model structures of a total of 108 60-ft-wide tidal passages varying in depth from -10 to -40 ft msl were developed for the Alpha plan and a total of 160 60-ft-wide tidal passages at depths of -6 and -12 ft msl were developed for the Gamma plan. The results of the tests to evaluate the plans are presented in Report 2 of this series of reports.

GALVESTON BAY HURRICANE SURGE STUDY

EFFECTS OF PROPOSED BARRIERS ON TIDES, CURRENTS, SALINITIES, AND DYE DISPERSION FOR NORMAL TIDE CONDITIONS

APPENDIX B: CALIBRATION TESTS

Hydraulic Model Investigation

PART I: INTRODUCTION

Background

1. The recent growth and the potential for future development of the Texas gulf coast have led the Galveston District to consider protecting this entire area from flooding by storm-induced surges that often occur in the Gulf of Mexico. Because of the many complexities and great expenses involved in protecting the entire coastline, a pilot protection system directed toward the problems surrounding the Galveston Bay complex is planned initially. After observing the Galveston protection system in operation and the problems created by its installation, the Galveston District will be able to evaluate the feasibility of the protection plan in its entirety. However, before the pilot plan can be installed at Galveston, such factors as the effects of the protection system on salinity and pollution of the bay, navigation requirements, flooding within the protection system from upland drainage, and reduced storm-surge water heights in the bay must be considered.

Purpose of Overall Investigation

2. The purpose of the overall "Galveston Bay Hurricane Surge Study" conducted by the U. S. Army Engineer Waterways Experiment Station (WES) was to aid the Galveston District in evaluating the effects of possible

barrier designs on present and future hydraulic and environmental conditions throughout the bay complex.

Approach to Overall Investigation

3. Two basic approaches were undertaken to provide information on the effectiveness of the proposed protection plan in reducing the water heights of the bay area when the water in the Gulf of Mexico increases in height as a hurricane approaches and moves inland at or near Galveston. Tests were conducted using both a fixed-bed, small-scale physical model and a mathematical model developed for use on a digital computer. Both models represented the entire Galveston Bay complex. Details of the physical model study are presented in Report 1 and Appendix A to Report 1 of this series of reports.* The mathematical model** was developed by Texas A&M University under contract to the Galveston District.

4. Efforts to simulate the effects of the possible barrier plans on details of tides, currents, salinities, and dye dispersion for normal tides are presently limited to tests in physical models, if useful results are to be expected. Therefore, an existing physical model of a major portion of the Galveston Bay complex, known as the Houston Ship Channel model, was used to conduct these tests. Details of this aspect of the study are presented in Reports 2 and 3 of this series and their appendixes, which includes this appendix.

Purpose of Calibration Tests

5. Successful tests in the Houston Ship Channel model are dependent on, among other items, model structures with hydraulic characteristics that properly simulate expected prototype conditions. The purpose of the calibration tests described in this appendix was to develop model

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* See back of front cover for list of reports in this series.

** R. O. Reid and B. R. Bodine, "Numerical Model for Storm Surges in Galveston Bay," Journal, Waterways and Harbors Division, American Society of Civil Engineers, Vol 94, No. WW1, Feb 1968, p 33.

structures that allowed the hydraulic characteristics of proposed prototype structures to be accurately reproduced in the Houston Ship Channel model.

Scope of Calibration Tests for Normal Tides

6. The features of the hurricane protection plans that were required for proper tests in the Houston Ship Channel model were the navigation openings and tidal passages for each plan of interest, i.e. Alpha and Gamma plans. Tests to define the hydraulic characteristics were conducted in undistorted-scale models of each structure of interest. Distorted-scale models for use in the Houston Ship Channel model were then developed. The appropriate models were installed in the Houston Ship Channel model to allow the Alpha and Gamma plans to be evaluated as discussed in Reports 2 and 3 of this series.

The Plans

7. Two hurricane protection plans were submitted by the Galveston District for evaluation of the degree of protection provided by each plan and the effects of each plan on environmental regimes. The first system, called the Alpha plan, would be located in the Galveston Harbor Entrance and, with a dike and levee system, would provide protection for the entire bay complex. The alternate proposed system, the Gamma plan, would be located within Galveston Bay and would cross the bay from Smith Point on the east to Dollar Point on the west. The Gamma system would thus provide protection from storms for the inner bay areas only. The location of each plan is shown in plate B1. The basic designs of both plans consist of a system of overland levees, dikes in which gated structures are installed to permit tidal interchange between the gulf and the bay, and a navigation opening to permit passage of ship traffic. The arrangement of the tidal passages and navigation structure for the Alpha plan is shown in photo B1, and similar information is provided in photos B2 and B3 and plate B2 for the Gamma plan. During periods of high-water

levels, the tidal interchange passages will be closed, and only through the navigation openings can water enter the bay. When extremely high-water levels are predicted, such as those associated with hurricanes, gates with crests 5 ft* above msl can be floated into place across the navigation opening, if an ungated opening will not provide the desired degree of surge protection.

* A table of factors for converting British units of measurement to metric units is presented on page vii.

PART II: THE NAVIGATION OPENINGS

8. In models whose horizontal and vertical scale ratios are different (distorted-scale models), the characteristics of the model are so changed that a mere geometric scaling of the prototype structure does not result in a model that has scaled hydraulic characteristics. Since the Houston Ship Channel model was constructed with scales of 1:60 vertically and 1:600 horizontally, equivalent openings developed to the scales of the model and with the proper hydraulic characteristics were required.

The Models

9. Two 1:100 undistorted-scale models of the 400-ft-wide by -55 ft msl navigation openings were constructed at WES, one representing the Alpha plan structure and the other representing the Gamma plan structure (see photos B4 and B5). All hydrography in the vicinity of each of the structures was molded in concrete to sheet metal templates previously placed to control model elevations. Each model extended approximately 1500 ft gulfward and approximately 1200 ft bayward from the axes of the openings, and the total reproduction of width in the models, including the openings, was approximately 1900 ft (see plate B3). The structure proper was fabricated of sheet metal caissons with plywood forming the gate recesses.

10. The distorted-scale models of the navigation structures were fabricated of metal stock and the surrounding areas were molded of concrete and putty (see photos B6 and B7 for Alpha plan structure and photos B8 and B9 for Gamma plan structure). The limits of the models extended approximately 12,000 ft gulfward and 9000 ft bayward from the openings and the model widths were about 15,000 ft.

11. The distorted-scale structures were constructed by maintaining horizontal and vertical scale relations, with the exceptions that the widths of the opening were adjustable and vertical slots were placed in each sidewall to allow vertical restriction plates to be placed in the structures. The purpose of the restriction plates was to allow the

slopes of the curves defining the hydraulic characteristics of the distorted-scale structures to be modified by changing the shapes and sizes of the restriction plates.

Calibration Test Procedure

12. The testing procedure followed in the calibration tests of the navigation opening was the same for each navigation opening. A constant discharge was introduced into the end of the model representing the Gulf of Mexico and was maintained until stabilized flow conditions existed throughout the model. Water-surface elevations were then monitored at each of the gages (gage locations are shown in plate B3). Subsequently, the water level of the bay was lowered by an adjustment to the tailgate, and the procedure was repeated for the same constant discharge until the range of water levels above high water and below low water had been defined. A new constant discharge was then introduced and the entire procedure repeated.

13. All tests conducted in the model were completed with a flow direction from the gulf to the bay. During normal tidal conditions, flow must pass through the structures in opposite directions depending on the phase of the tide. However, since the structures were symmetrical in design and approach conditions to the structures were similar, results of tests with flow in one direction apply to the appropriate reverse flow conditions.

Calibration Test Results

14. Plates B4 and B5 show the relations between gulf and bay water-surface elevations for various constant discharges through the Alpha and Gamma plan navigation openings. The gulf water-surface elevations include a correction for the approach velocity. The discharges shown are the total flow rates in cubic feet per second passing the openings.

15. An alternate, though less direct, method of presenting the data from the model is that of determining the coefficients of discharge for

the openings. This method of presentation allows a quick and direct comparison of the efficiencies of alternate plans in passing all flows. The selection of an appropriate equation defining the flow is necessary, and since the flow conditions at the navigation openings are such that contracted flow exists, the orifice equation

$$Q = C_d A \sqrt{2g\Delta h}$$

was chosen. In this equation, Q is the discharge through the opening, C_d is the coefficient of discharge, A is the area of the navigation opening below water level, g is acceleration due to gravity, and Δh is the difference between the gulf elevation including velocity head and the bay elevation. The variations of submergence versus the coefficients of discharge for the Alpha and Gamma plan navigation structures are shown in plates B6 and B7, respectively. The submergence of the openings is defined as the ratio of the bay water depth above -55 ft msl to the gulf water depth above -55 ft msl.

Development of Distorted-Scale Openings

16. The development of model structures with the proper hydraulic characteristics to accurately reproduce total losses of these structures in the distorted-scale Houston Ship Channel model was accomplished by a trial-and-error test procedure. All tests were conducted in the distorted-scale models described in paragraphs 10 and 11.

17. Initially, the widths of the openings were fixed at distances greater than the scaled distances, and the structures were subjected to a series of steady-state flow tests following the procedure described in paragraph 12 for the undistorted-scale models. The head differentials from the gulf side of the structures to the bay side of the structures were then compared with appropriate test results for the undistorted-scale models. If the comparison indicated a generally smaller head difference, the widths of openings of the structures were decreased. The procedure was then repeated until the comparison of the test results indicated that the

results from tests of the distorted-scale structures showed all head differential measurements to be slightly smaller than the comparable results from the undistorted-scale structure tests. The vertical restriction plates were then installed in the slots provided in the two sidewalls of each structure. Steady-state tests were again conducted and the results compared with the data from the undistorted-scale models. Modifications to the vertical restriction plates were then made as dictated by the comparison of the results. This procedure was repeated until results from the distorted-scale models duplicated the results from the undistorted-scale models. The test data from the final distorted-scale structures for the Alpha and Gamma plan navigation openings are shown in plates B8 and B9.

Discussion of Results

18. Although the results of the tests conducted are considered to be sufficiently accurate to meet the basic purpose, i.e. provide sufficiently accurate data to allow effective comparison of possible protection plans, these results must be used only with recognition of the associated limitations of the data. All tests were conducted in fixed-bed models; therefore, effects of changes of bed form or gross bed configuration were not simulated. These models were not of sufficient size to allow detailed evaluation of scouring effects around the structures to be evaluated or to allow precise definition of flow patterns to aid in defining possible scouring effects.

19. Application of the test data must also include consideration of the effects of structural changes that might be made to the navigation structure. Any significant modification of the structure, such as the addition of guide walls to the approach, would modify the hydraulic characteristics of the structure.

PART III: THE TIDAL PASSAGES

20. As was the case for the navigation openings, distorted-scale models of the tidal passages with the proper hydraulic characteristics were also required for successful testing in the Houston Ship Channel model.

The Models

21. Inspection of the proposed Alpha and Gamma plans (see photo B1 and plate B2) indicated that tidal passages with design depths varying from -6 to -40 ft msl were incorporated into the plans. Each plan had a specified number of tidal passages, i.e. 108 60-ft-wide passages for the Alpha plan and 160 60-ft-wide passages for the Gamma plan. If the smallest hydraulic model feasible (1:100 undistorted scale) to allow definition of the hydraulic characteristics of the tidal passages were to be incorporated into the test program, an undistorted-scale model 80 ft wide would be required for the Alpha plan and a model approximately 100 ft wide would be required for the largest group of tidal gates for the Gamma plan. In addition, the distinct possibility existed that results from tests of the plans might dictate changes in the design and number of tidal passages required. Because of the high costs which would have been required for an investigation utilizing undistorted-scale models of the entire structures and the possibility of changes in design, the best approach appeared to be to define the hydraulic characteristics of the structure with a section model.

22. The undistorted-scale section model of the tidal passages consisted of six complete bays and two half bays on each end as shown in photo B10. The model reproduced seven 60-ft-wide bays and seven 12-ft-wide piers for a total width of 504 ft. Approximately an 800-ft approach from the gulf and a 700-ft approach from the bay were reproduced in the section model at a uniform elevation equal to the invert elevation of the tidal passage. This model was used to represent all tidal passages.

23. The Alpha plan distorted-scale models were developed in a flume with each group of tidal passages with the same invert elevation developed during a particular series of tests. The width of the flume allowed a maximum of 10 tidal passage bays to be reproduced; therefore, two different procedures were required to develop the structures. Inspection of the details of the Alpha plan (see photo B1) shows that each group of navigation passages with invert elevations of -10, -30, and -40 ft msl (Galveston Island side of navigation opening) has a total number of passages exceeding the 10 that could be reproduced in the flume. The distorted-scale models for each of these groups were developed by initially developing a distorted-scale section model representing 10 bays. The final distorted-scale model structure representing each of the three sets of tidal passages was then fabricated by adding the appropriate number of additional openings to each model. The remaining groups of tidal passages were developed by modifying the width of the flume as necessary to simulate the number of tidal passages required, i.e., five with -15, five with -20, five with -25, three with -35, and eight with -40 ft msl invert elevations. The width of each group of tidal passages varied in accordance with the horizontal scale of the Houston Ship Channel model (1:600).

24. The Gamma plan tidal passages were developed following similar procedures. The tidal passages included in the design of the Gamma plan are shown in plate B2. Since two sets of tidal passages with a -6 ft msl invert elevation and 11 gates each were identical, it was necessary to develop a distorted-scale model for only one of these sets. The four sets of tidal passages with a -12 ft msl invert elevation were developed by initially developing a distorted-scale section model representing 10 bays and separating piers. The final distorted-scale model structure representing each of the four sets of tidal passages was then fabricated by adding the appropriate number of tidal openings to each model.

Test Procedure and Results

25. All undistorted-model tests were conducted in the single

1:100-scale section model of the tidal passages. Since all of the tidal passages (regardless of invert elevations) were identical in plan throughout the wetted portion of the structure, results for each depth of structure could be obtained from one family of curves defining gulf elevation versus bay elevation by assigning the proper invert depth to the data. The single family of curves was developed by introducing a constant discharge to the gulf side of the section model and adjusting the tailgate in the bay until the gulf total depth was 44 ft above the invert elevation. This depth was established by adding the depth of the deepest tidal passage (-40 ft msl) and a depth somewhat greater than the largest spring tide amplitude (4 ft). After stabilized flow was established throughout the section model, water-surface elevations in the gulf and the bay were defined. The water level in the bay was then incrementally lowered and water-surface data were obtained until free flow occurred or the flow simulated conditions for the tidal passages with an invert elevation of -6 ft msl. This procedure was then repeated until data for a total of 10 discharges were obtained. The test results adjusted for each group of tidal passages of a specific depth are represented by the curves in plates B10-B18.

26. As discussed for the navigation openings, tests were limited to one-direction flow. Because the structures and approach conditions are essentially identical for either direction, results of the tests apply to flow in either direction through the tidal passages.

Development of Distorted-Scale Openings

27. Similar to the procedure used for the navigation openings, a trial-and-error procedure was followed to develop the distorted-scale tidal passage structures for the Houston Ship Channel model. The tests were conducted in the distorted-scale models described in paragraphs 23 and 24.

28. The models of each group of tidal passages were constructed with the depth properly scaled to the 1:60 vertical scale of the Houston Ship Channel model and the width properly scaled to the 1:600 horizontal

scale of the Houston Ship Channel model. Vertical copper strips were installed in the openings to simulate the piers between each tidal passage. The structure was then subjected to a series of steady-state tests following the same test procedure used for the undistorted model as described in paragraph 25. The resulting water-surface levels were compared with the appropriate test results from the undistorted-scale model. If agreement was achieved, the model configuration was installed in the Houston Ship Channel model for testing. If the results did not agree, the number or width of the vertical strips was modified as indicated by a comparison of the results. The steady-state tests were repeated and results again compared. This procedure was repeated until satisfactory comparison was achieved. Data from distorted-scale model tests as well as the curves developed from the undistorted-scale model for each depth of tidal passages are shown in plates B10-B18. The final distorted-scale model configurations are shown in photo B1 for the Alpha plan and in photos B2 and B3 for the Gamma plan.

Discussion of Results

29. The distorted-scale tidal passages are sufficient to produce accurate data to meet their basic purpose, i.e., allow effective comparison of possible protection plans. However, as with the navigation structure data, these results must be used only with recognition of the associated limitations of the data. All tests were conducted in fixed-bed models; therefore, effects of changes of bed form or gross bed configuration were not simulated. These models were not of sufficient size to allow detailed evaluation of scouring effects around the structures to be evaluated or to all precise definition of flow patterns to aid in defining possible scouring effects.

30. Application of the test data must also include consideration of the effects of structural changes that might be made to the navigation structure. Any significant modification of the structure, such as redesign of the piers or changes in invert depth, would modify the hydraulic characteristics of the structure.

PART IV: CONCLUSIONS

31. Based on the results of the test program discussed in this appendix, the following conclusions have been reached:

- a. The distorted-scale navigation openings and tidal passages developed for the Alpha and Gamma plans allowed tidal flows to be reproduced in the Houston Ship Channel model with sufficient accuracy to be compatible with the overall ability of the model to reproduce the normal tidal conditions.
- b. The results from the tests in the undistorted-scale models were not of sufficient accuracy to evaluate the effects of erosional characteristics or changes in bed form. Additional analysis and laboratory tests are required to evaluate these effects.
- c. Additional laboratory tests will be required to establish final design of the navigation openings and tidal passages.

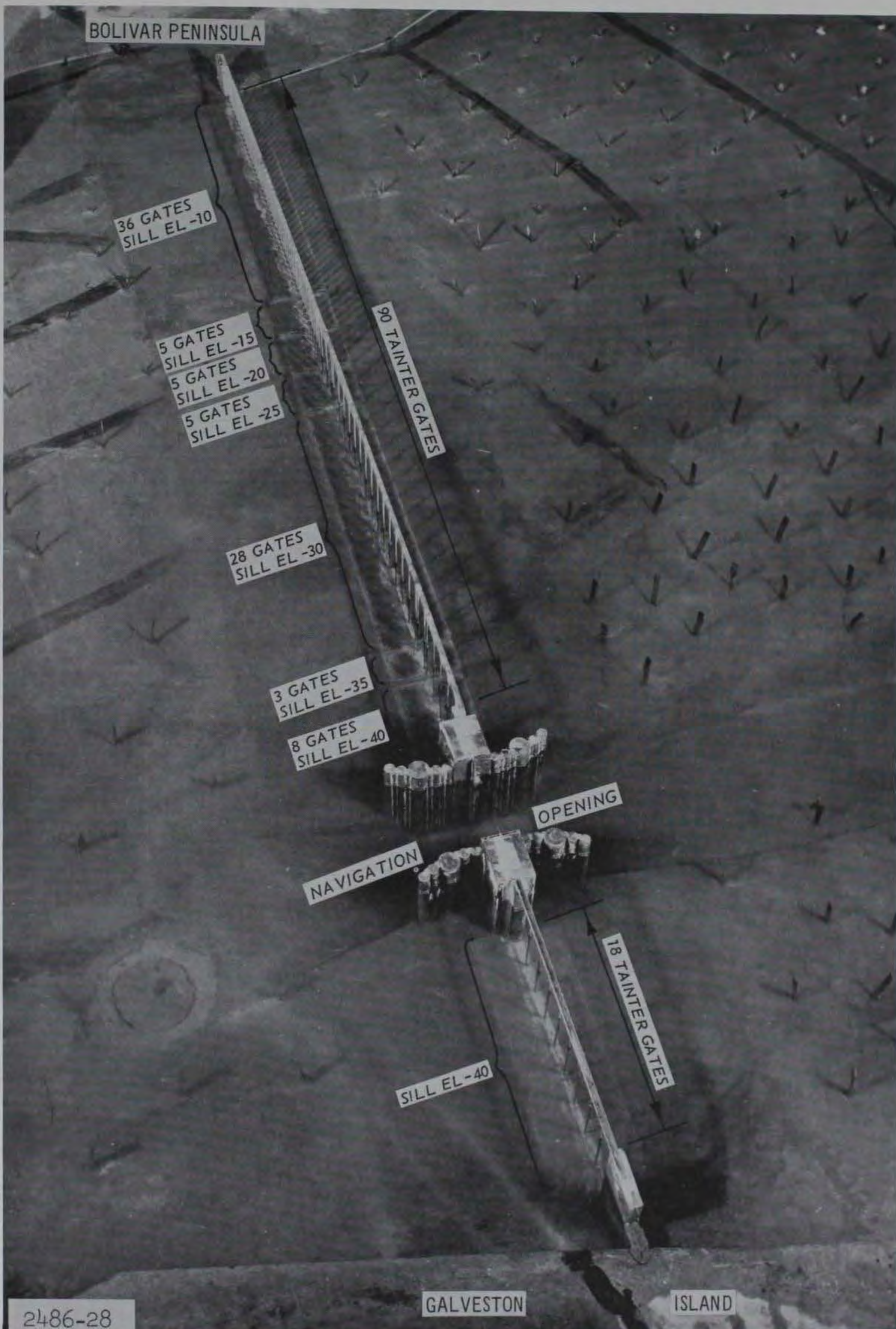


Photo B1. General view of plan 1 Alpha barrier from Galveston Island

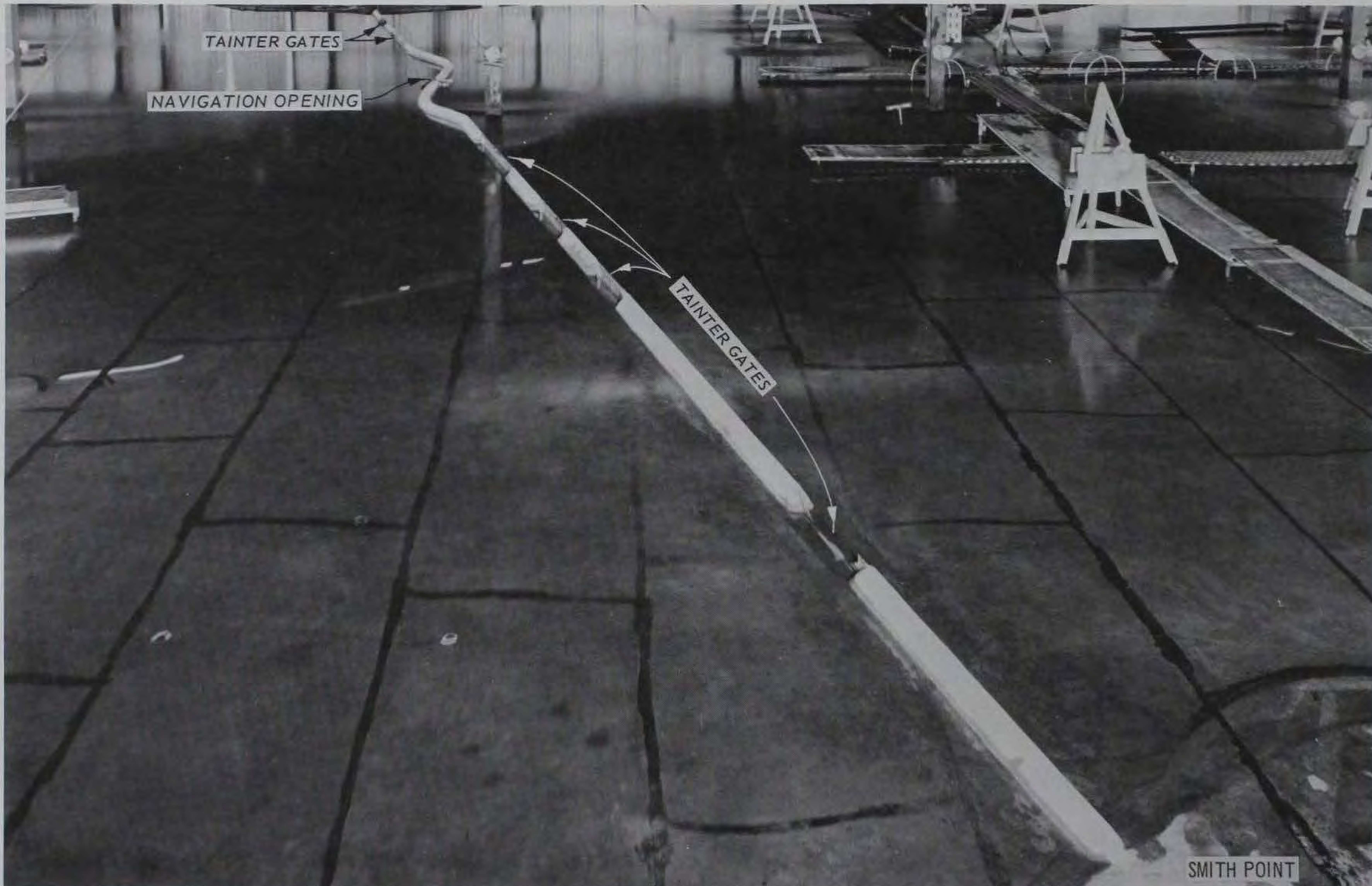


Photo B2. General view of plan 1 Gamma barrier from Smith Point

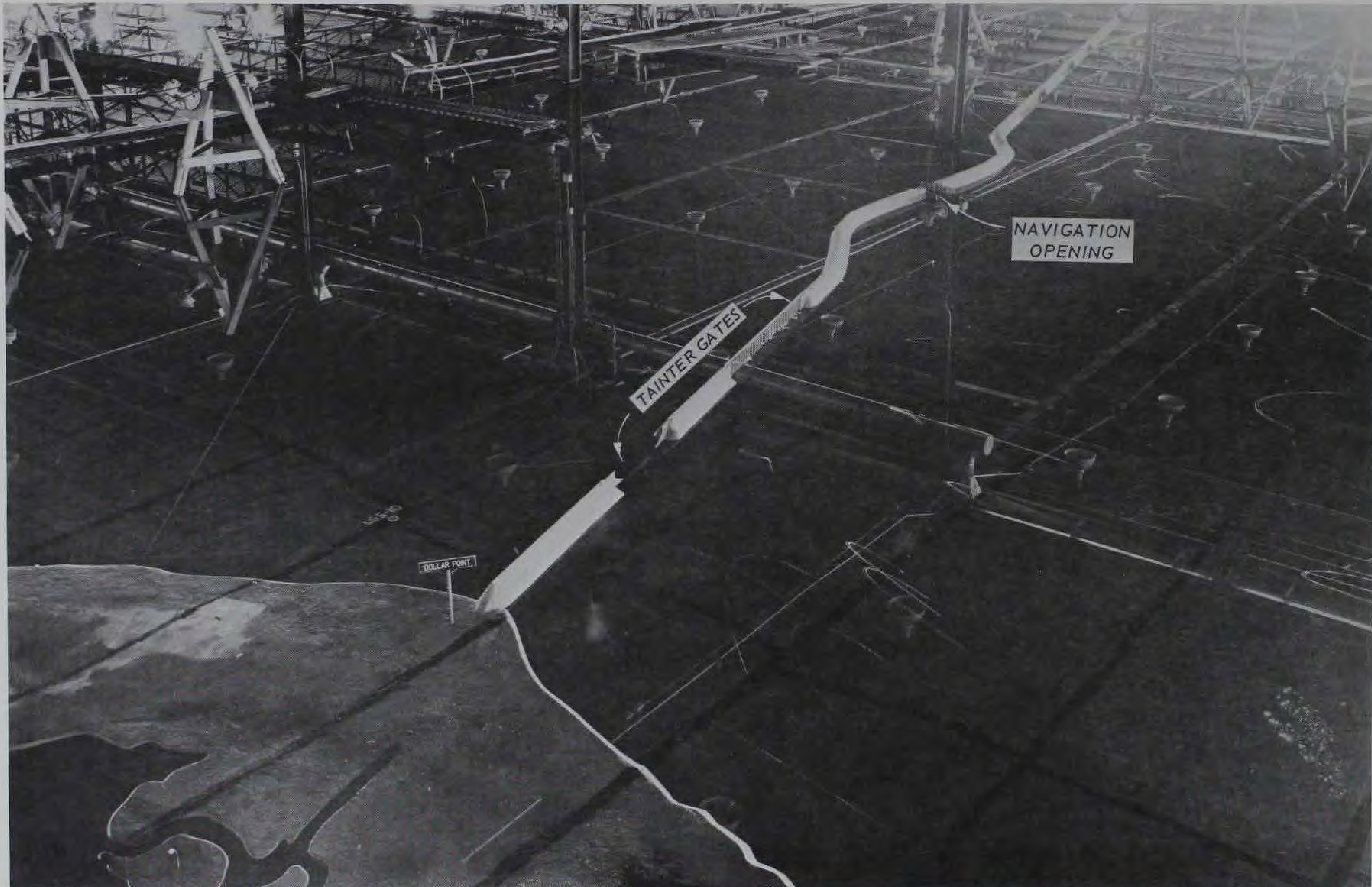


Photo B3. General view of plan 1 Gamma barrier from Dollar Point

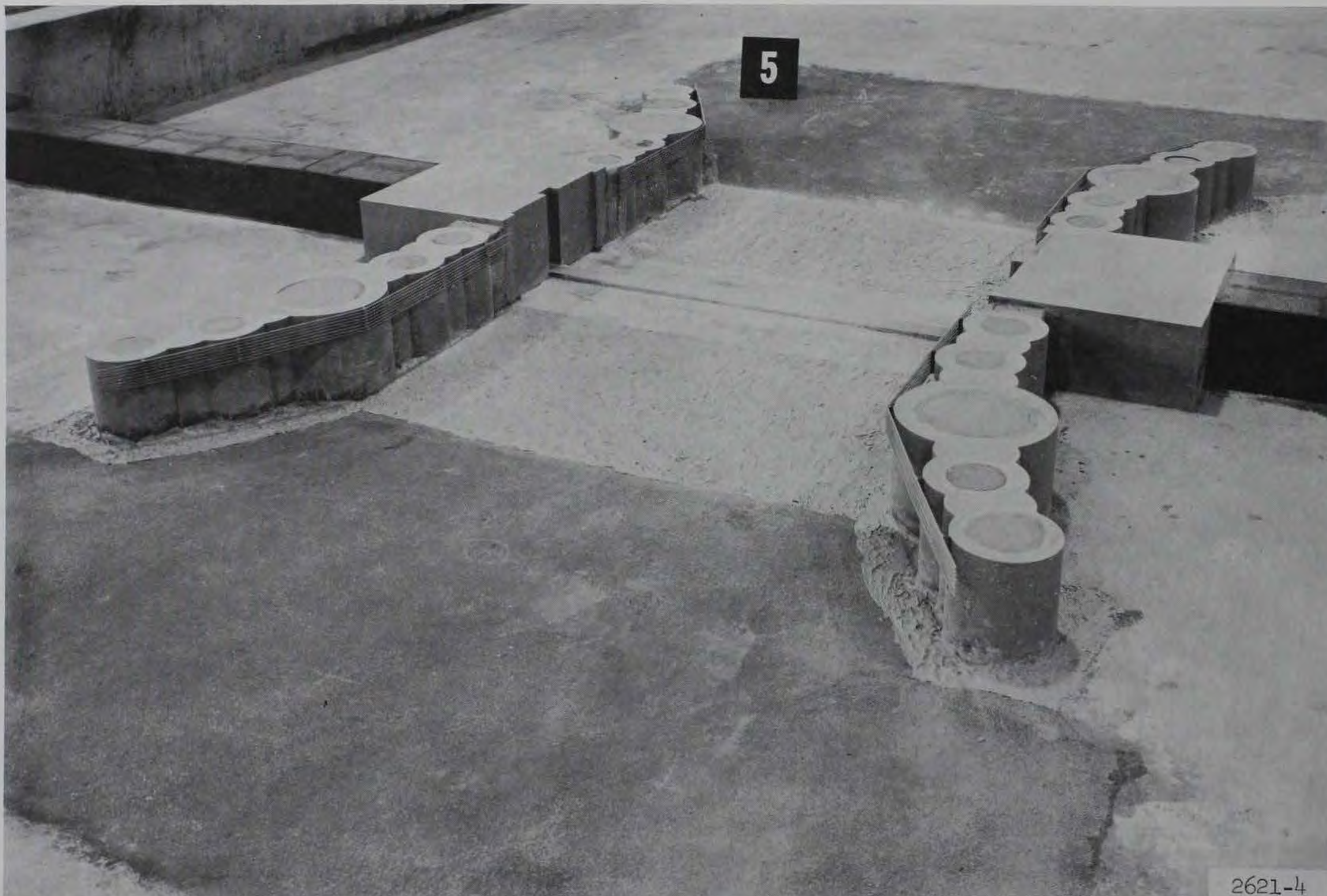


Photo B4. Alpha plan, undistorted-scale model of the navigation structure

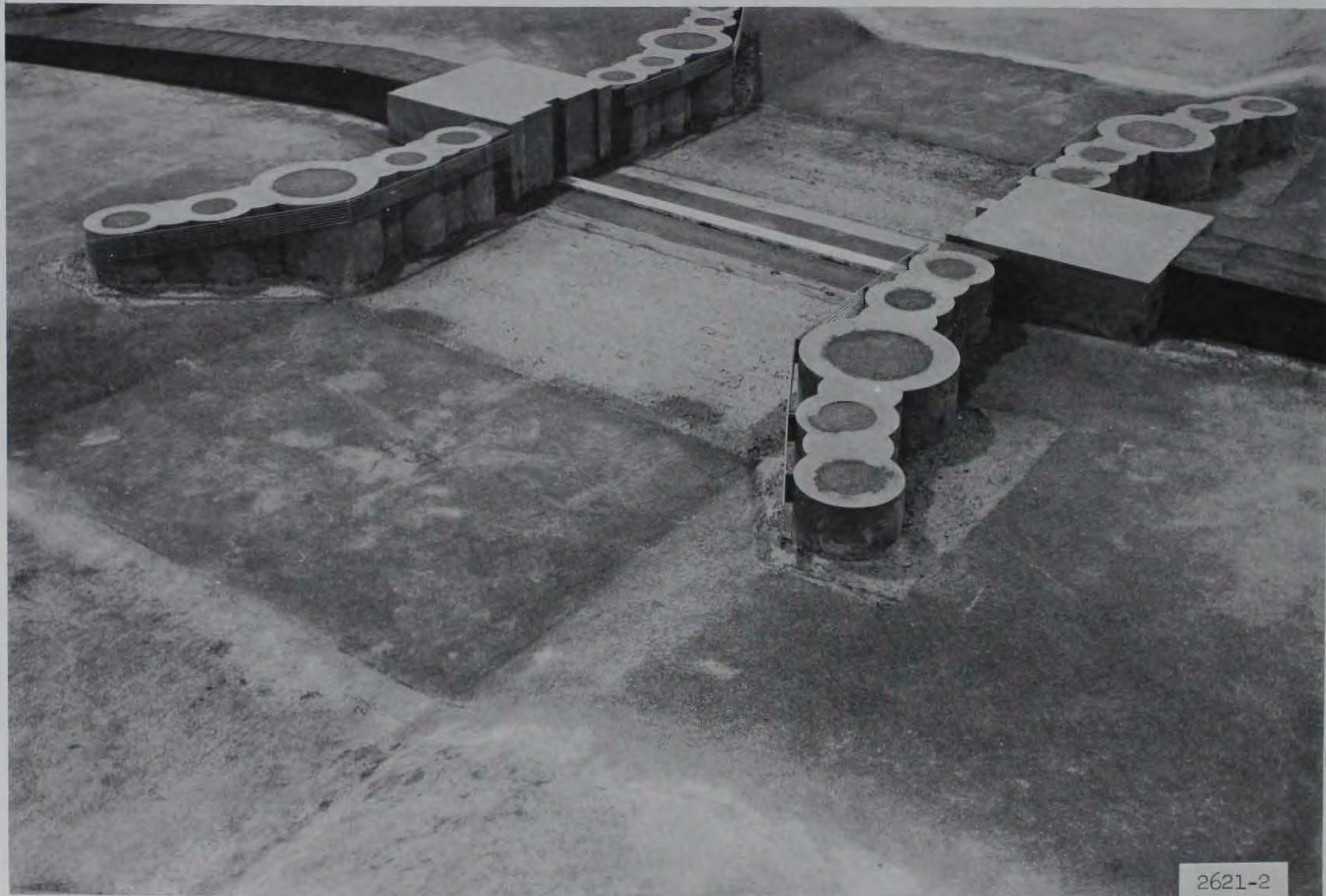


Photo B5. Gamma plan, undistorted-scale model of the navigation structure

Photo B6. Alpha plan, distorted-scale model of the navigation structure, overhead view from the gulf

Photo B7. Alpha plan, distorted-scale model of the navigation structure, water-level view from the bay

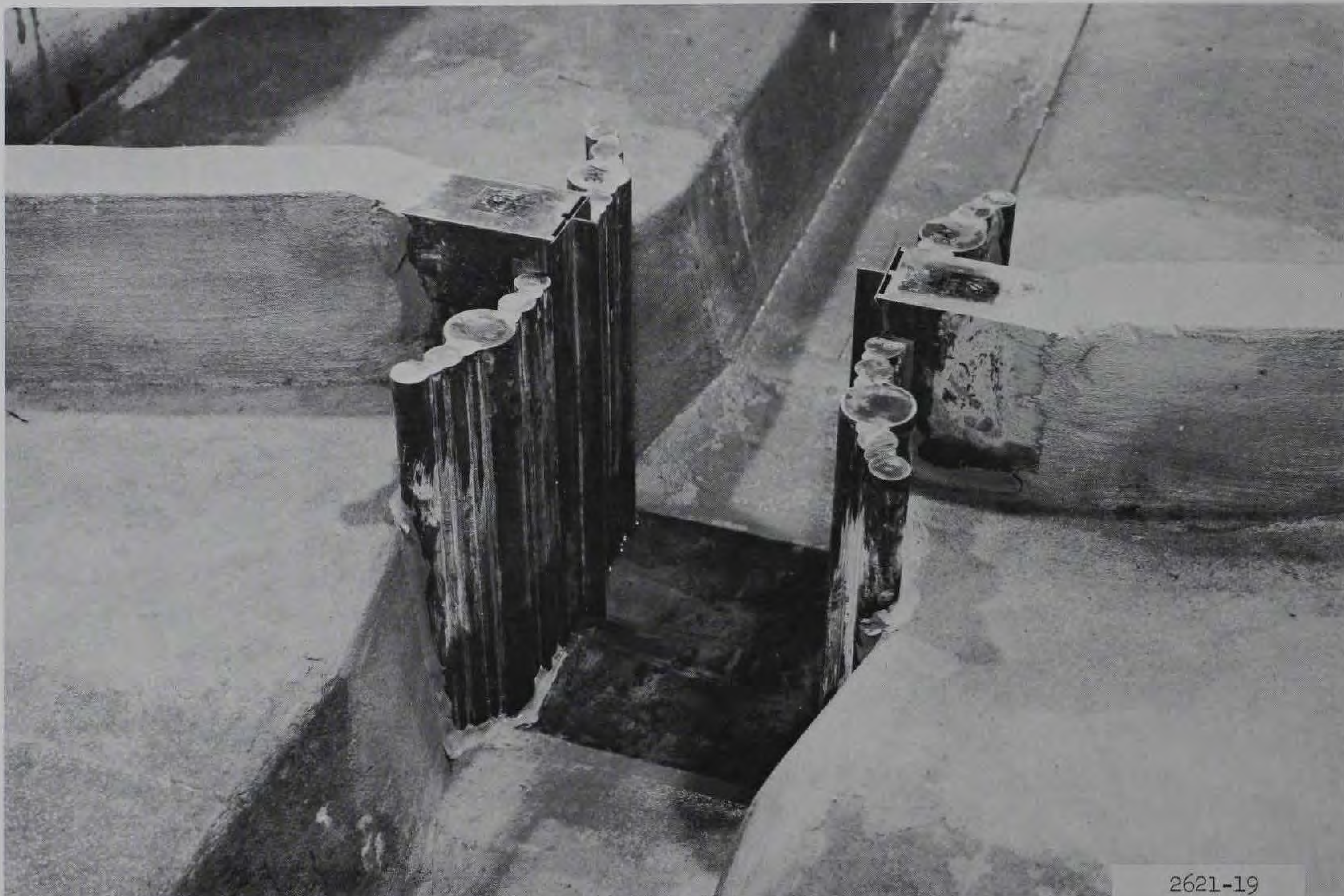


Photo B8. Gamma plan, distorted-scale model of the navigation structure, overhead view

Photo B9. Gamma plan, distorted-scale model of the navigation structure, water-level view

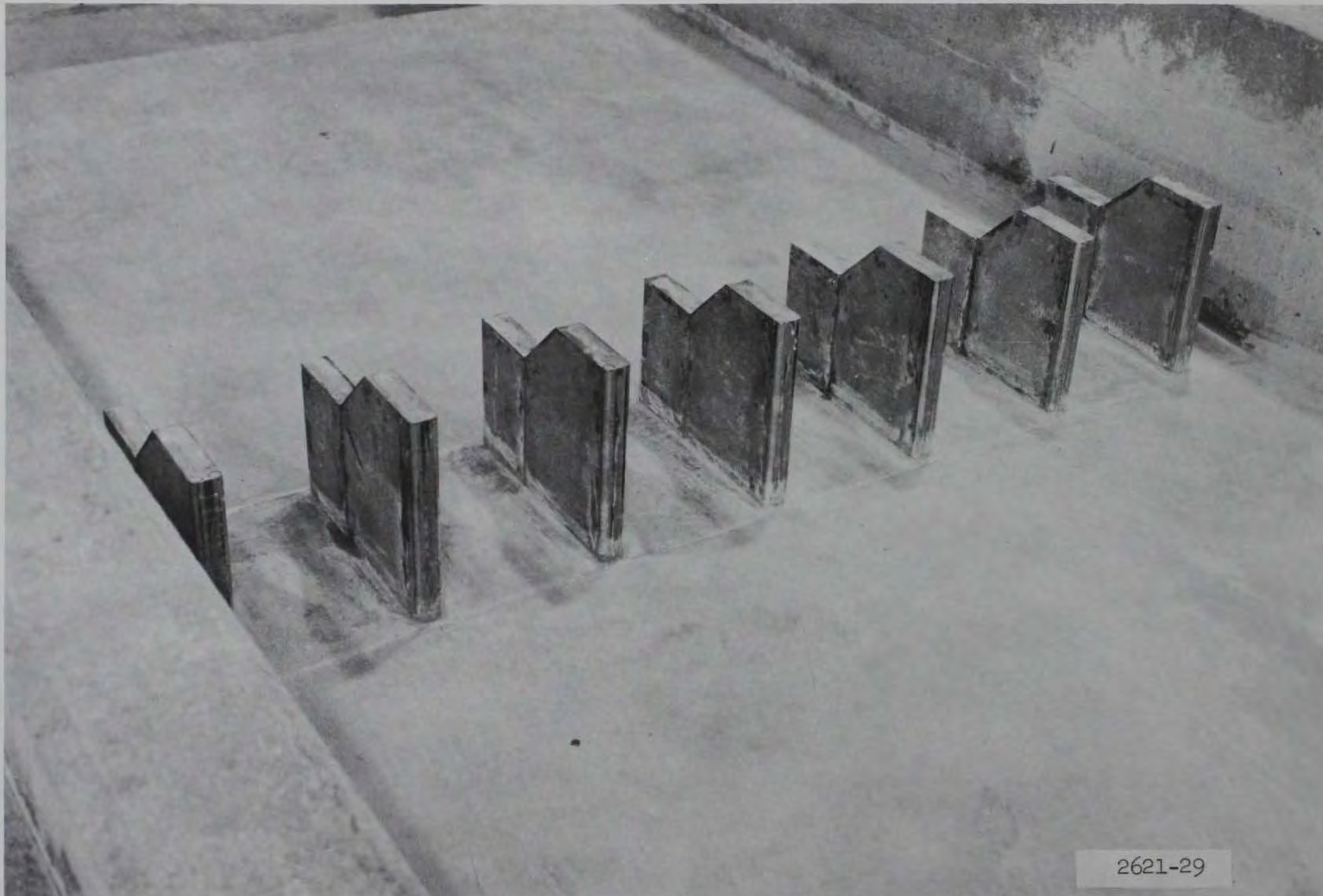
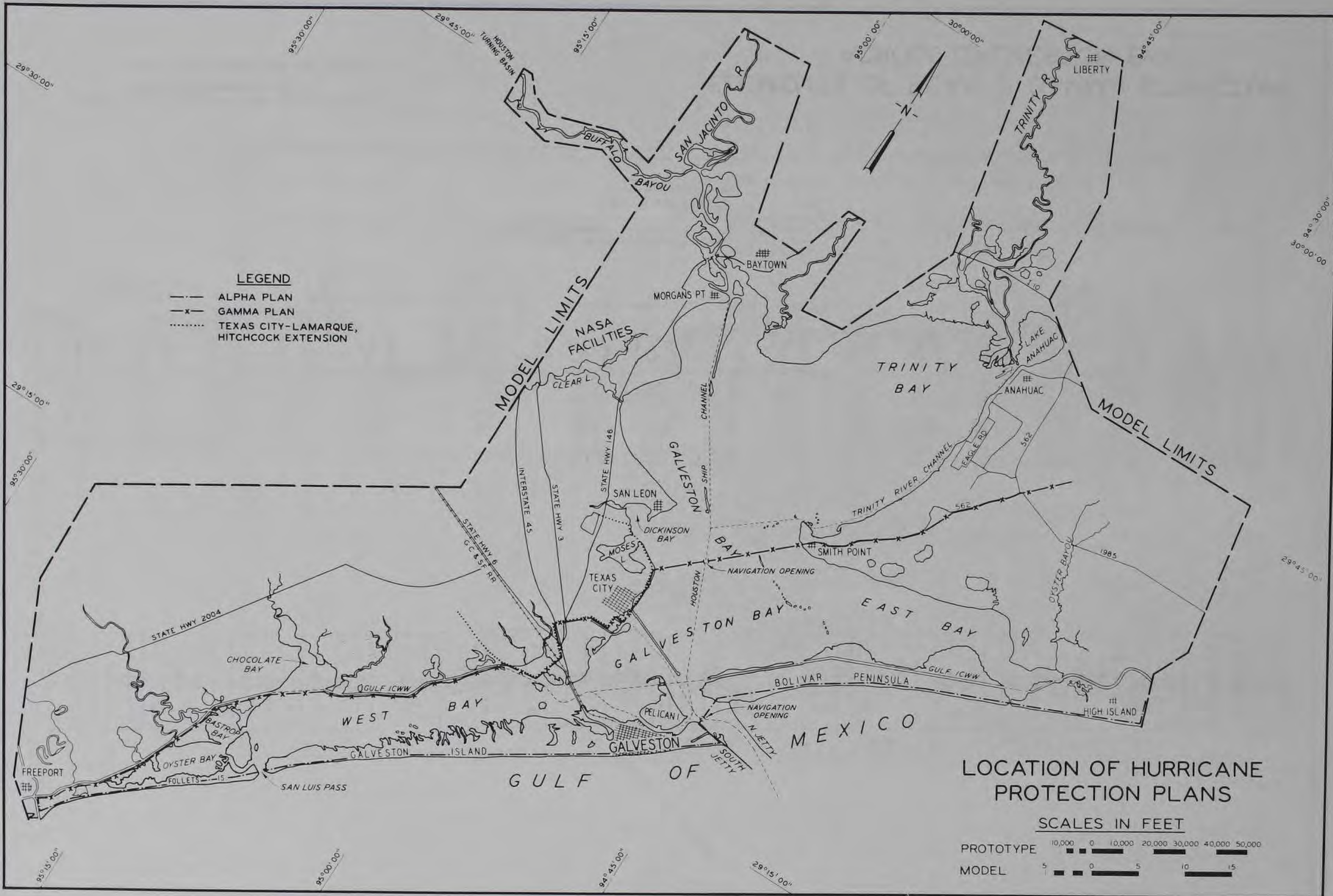
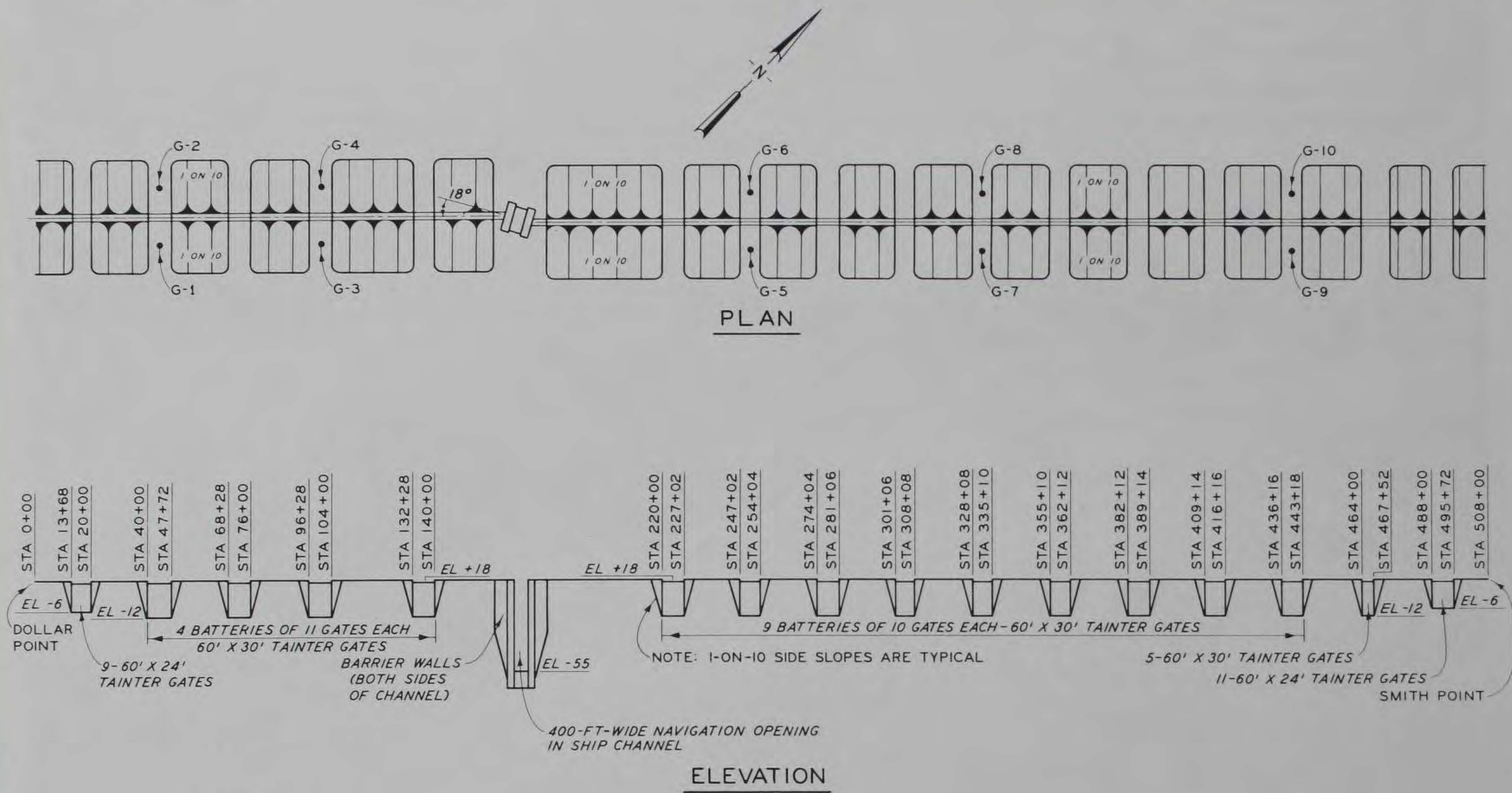


Photo B10. Undistorted-scale section model of seven tidal passages



LOCATION OF HURRICANE PROTECTION PLANS

PLATE B1

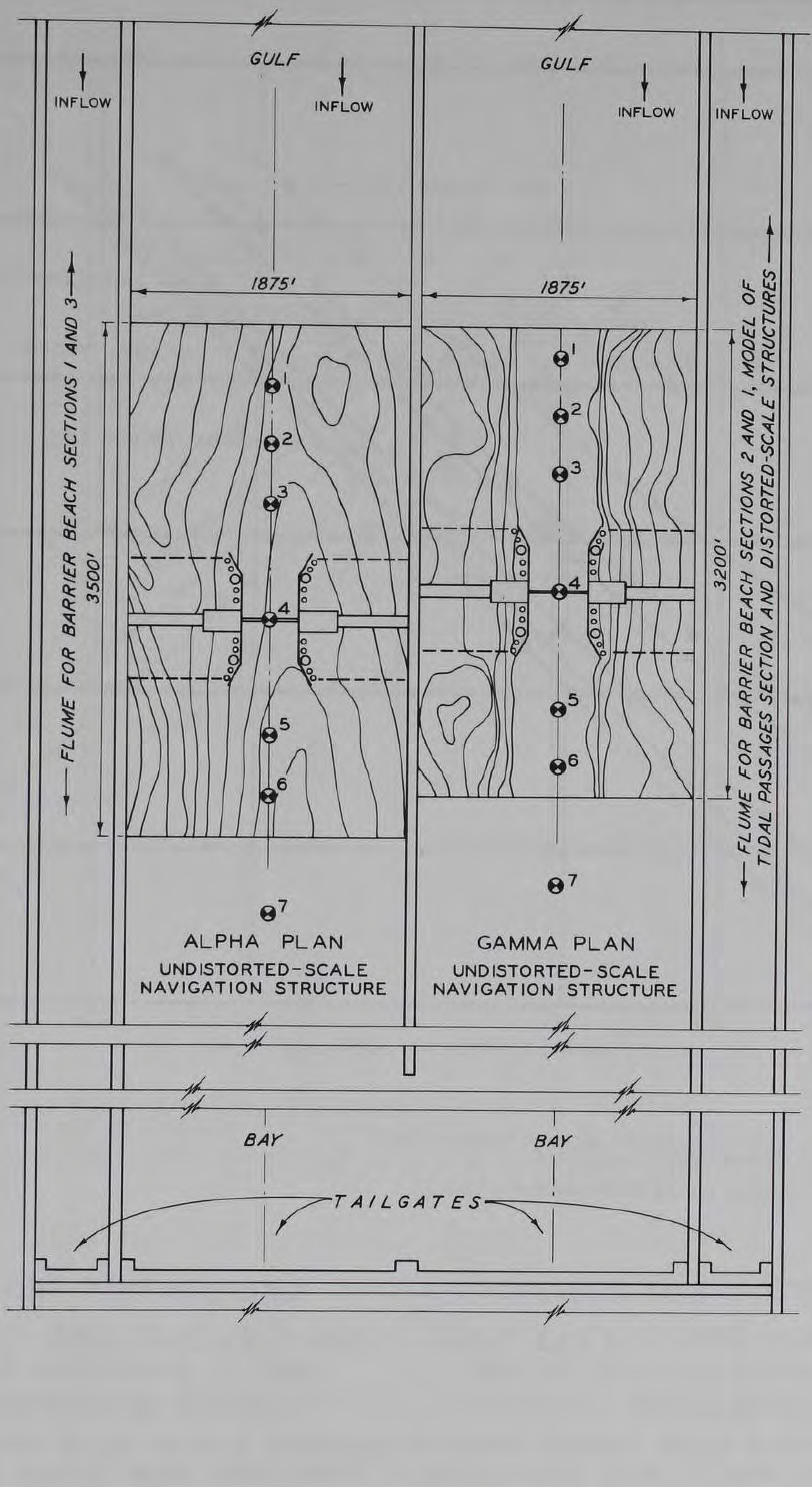


LEGEND

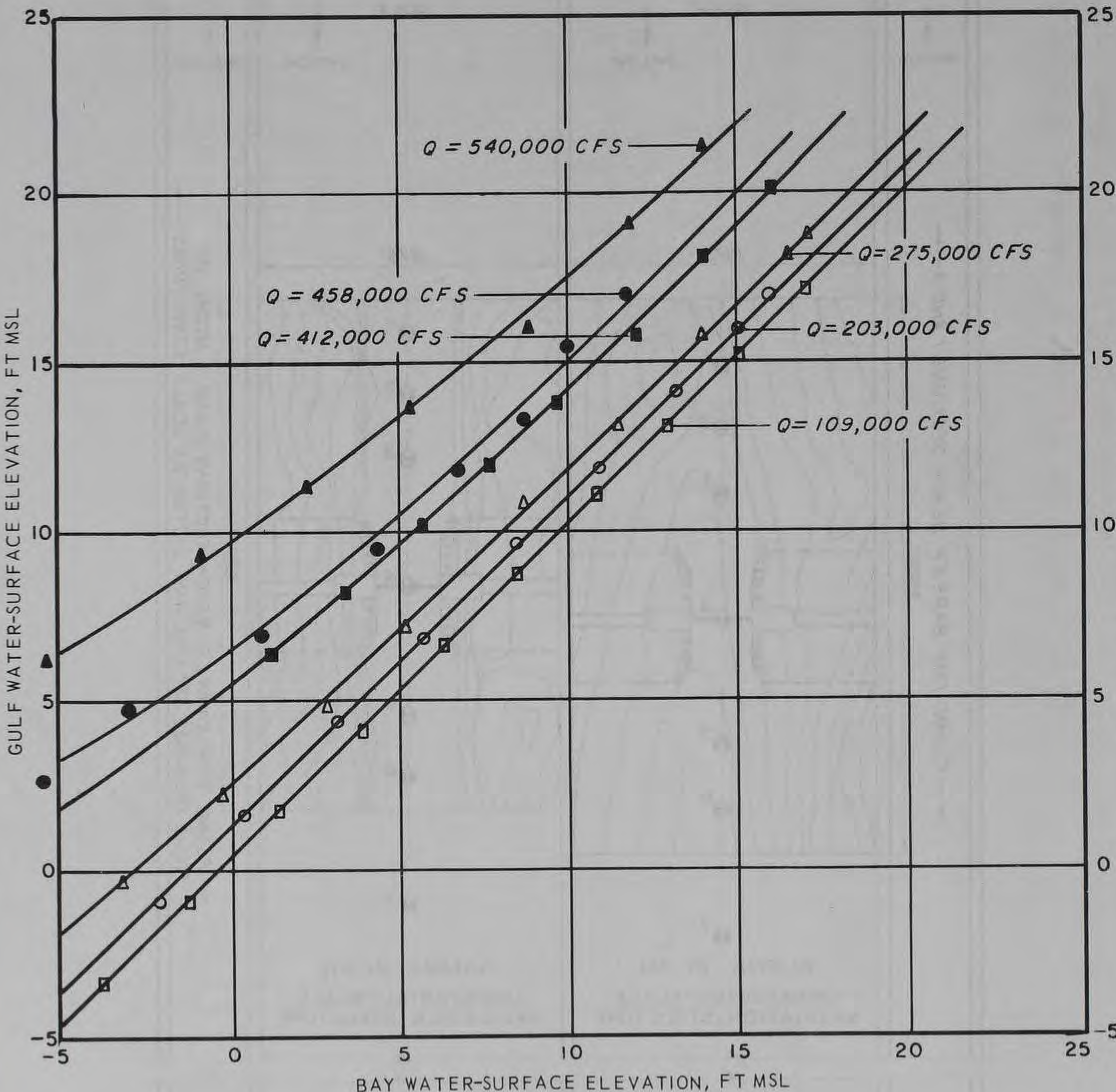
• VELOCITY STATION

NOTE: GATE PIER WIDTHS ARE 10' EXCEPT
END PIERS WHICH ARE 6'
ALL GATE SLABS ARE 10' THICK

ELEMENTS OF PLAN 2 GAMMA STRUCTURE
ACROSS GALVESTON BAY



FLUMES FOR SECTION MODELS



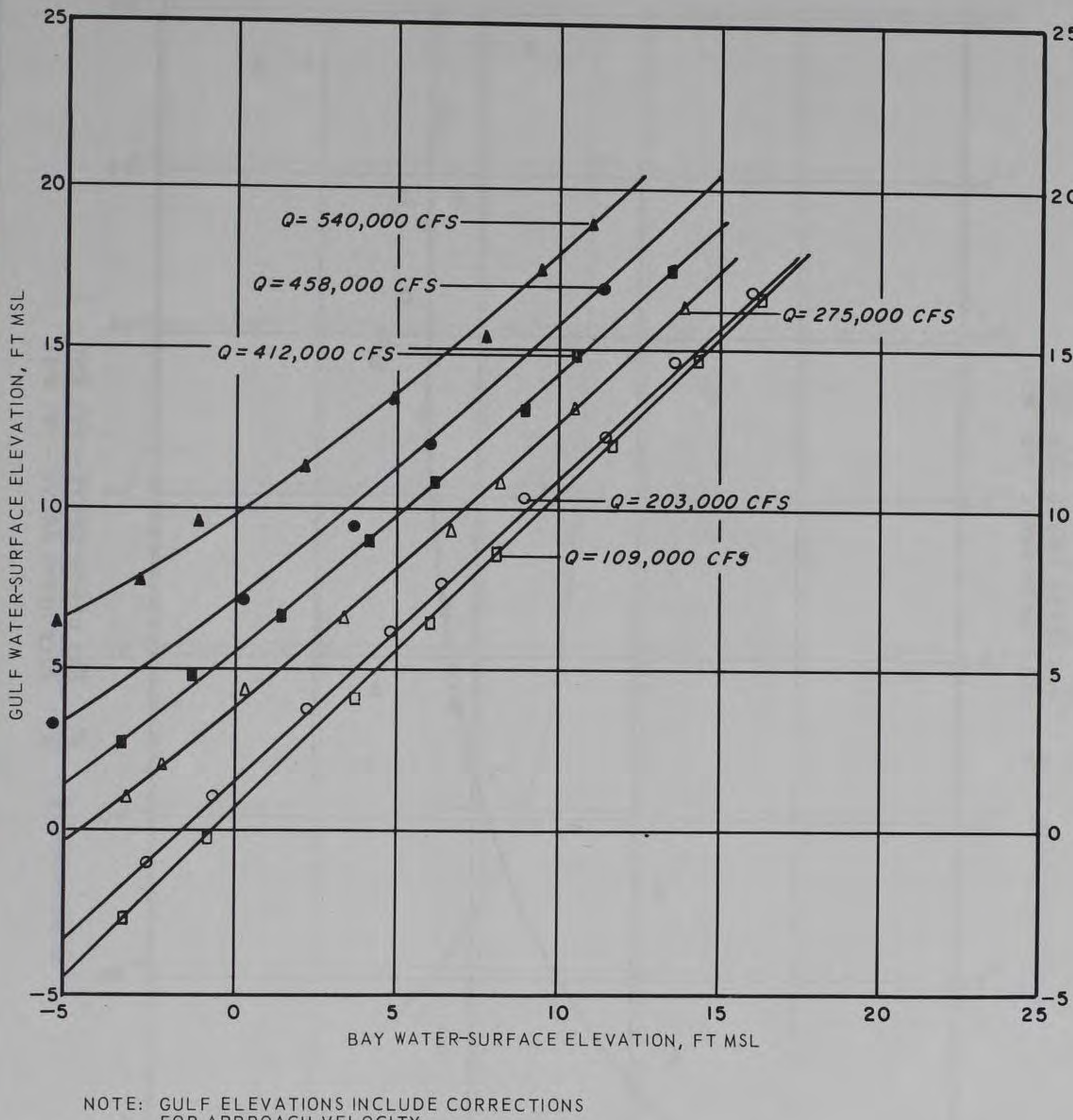
NOTE: GULF ELEVATIONS INCLUDE CORRECTIONS FOR APPROACH VELOCITY.

UNDISTORTED MODEL SCALE = 1:100

CALIBRATION TESTS

GULF ELEVATIONS VERSUS BAY ELEVATIONS FOR VARIOUS DISCHARGES

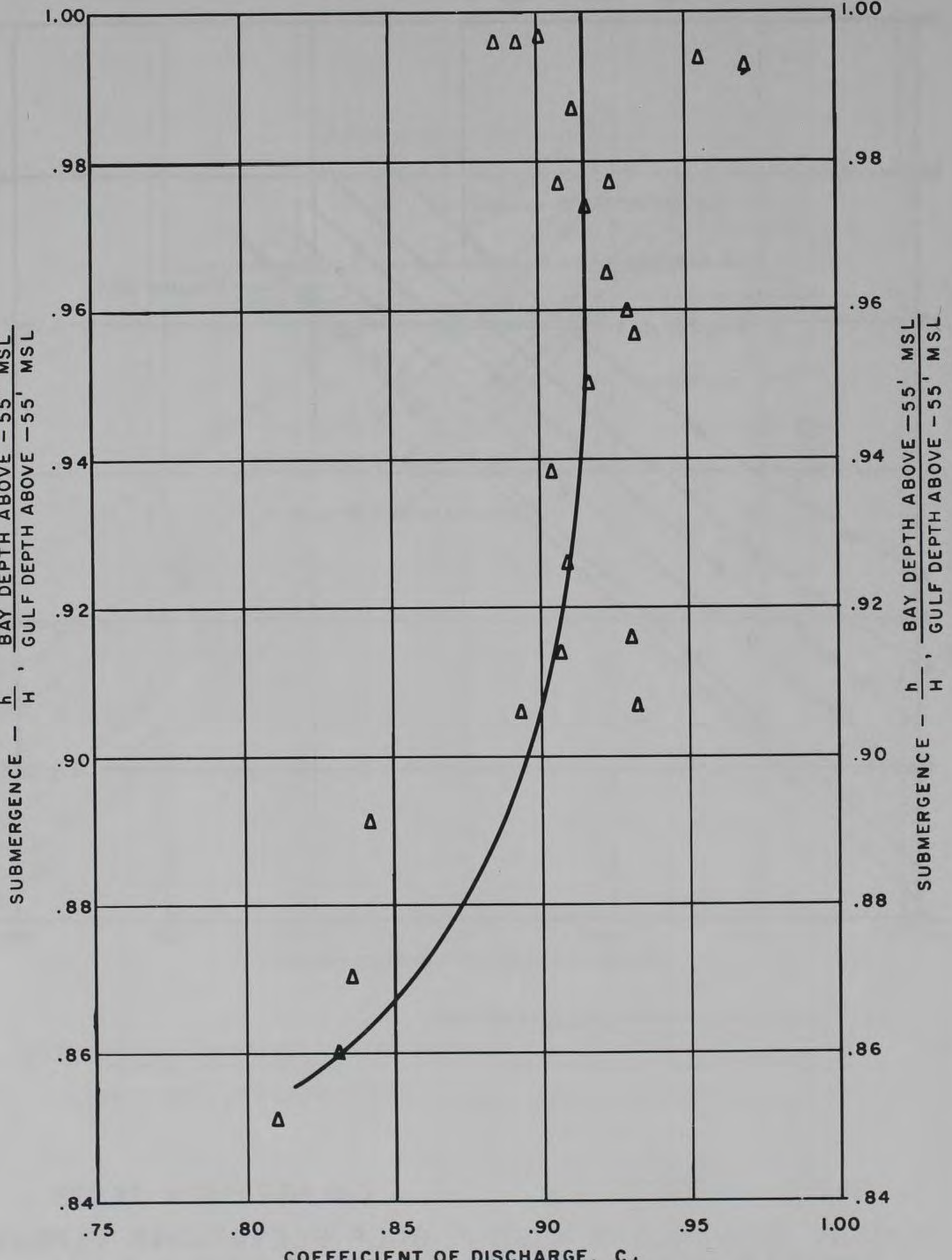
UNGATED ALPHA PLAN NAVIGATION STRUCTURE FOR TEXAS COAST HURRICANE SURGE STUDIES



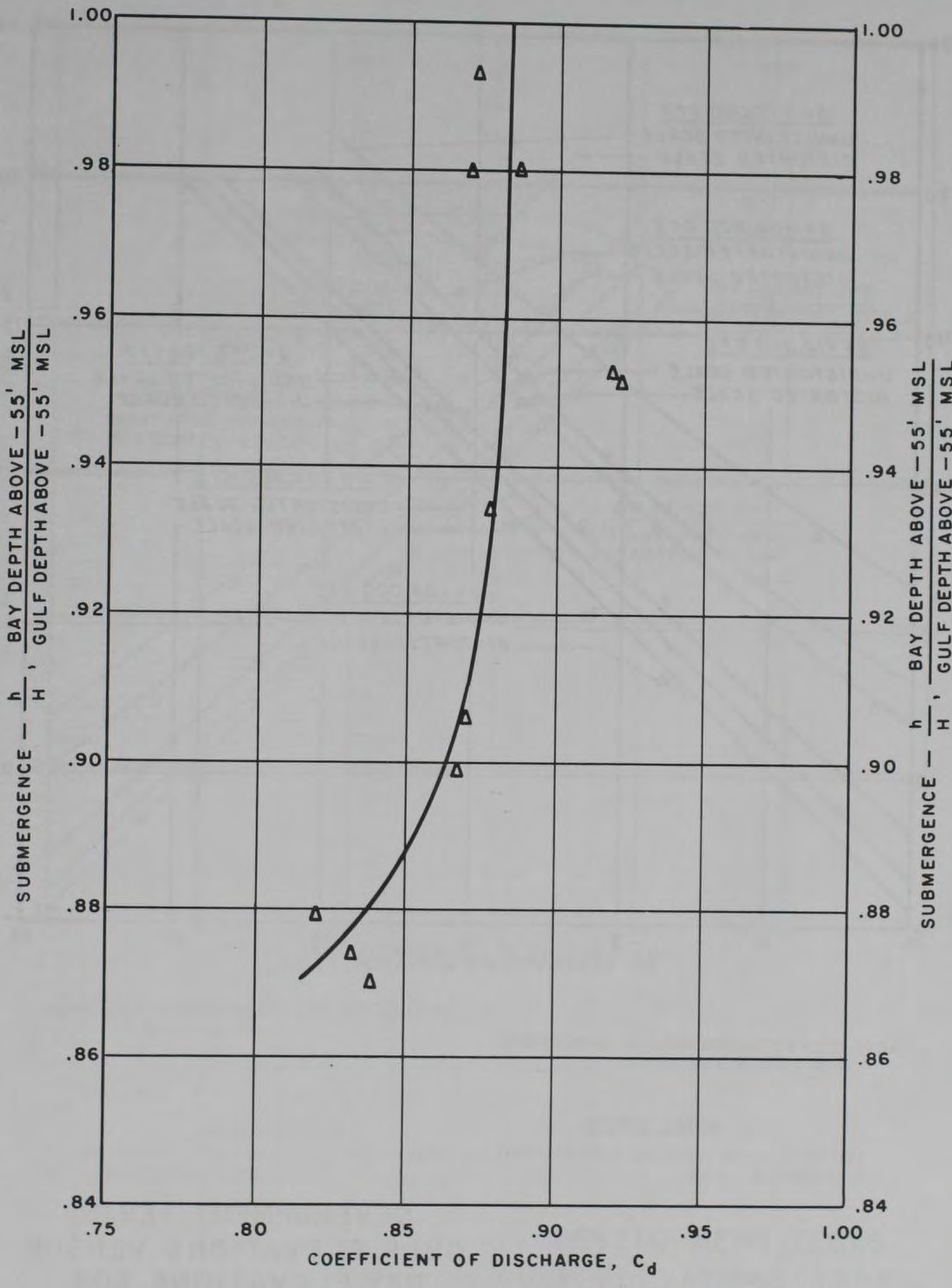
NOTE: GULF ELEVATIONS INCLUDE CORRECTIONS FOR APPROACH VELOCITY.

UNDISTORTED MODEL SCALE = 1:100

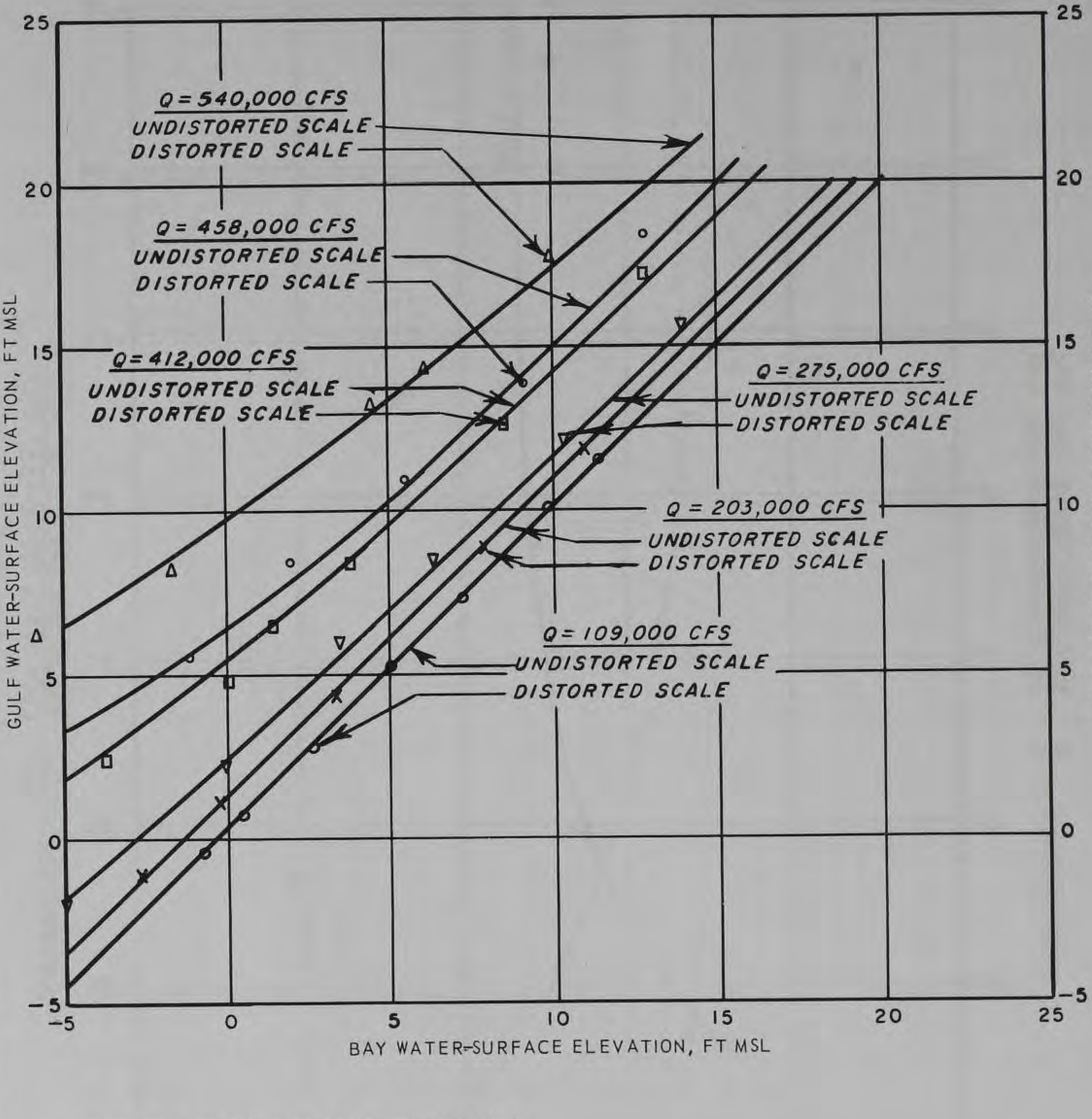
CALIBRATION TESTS
GULF ELEVATIONS VERSUS BAY ELEVATIONS FOR VARIOUS DISCHARGES
UNGATED GAMMA PLAN NAVIGATION STRUCTURE FOR TEXAS COAST HURRICANE SURGE STUDIES



SUBMERGENCE VERSUS
COEFFICIENT OF DISCHARGE
ALPHA PLAN NAVIGATION STRUCTURE FOR
TEXAS COAST HURRICANE SURGE STUDIES



SUBMERGENCE VERSUS
COEFFICIENT OF DISCHARGE
GAMMA PLAN NAVIGATION STRUCTURE FOR
TEXAS COAST HURRICANE SURGE STUDIES

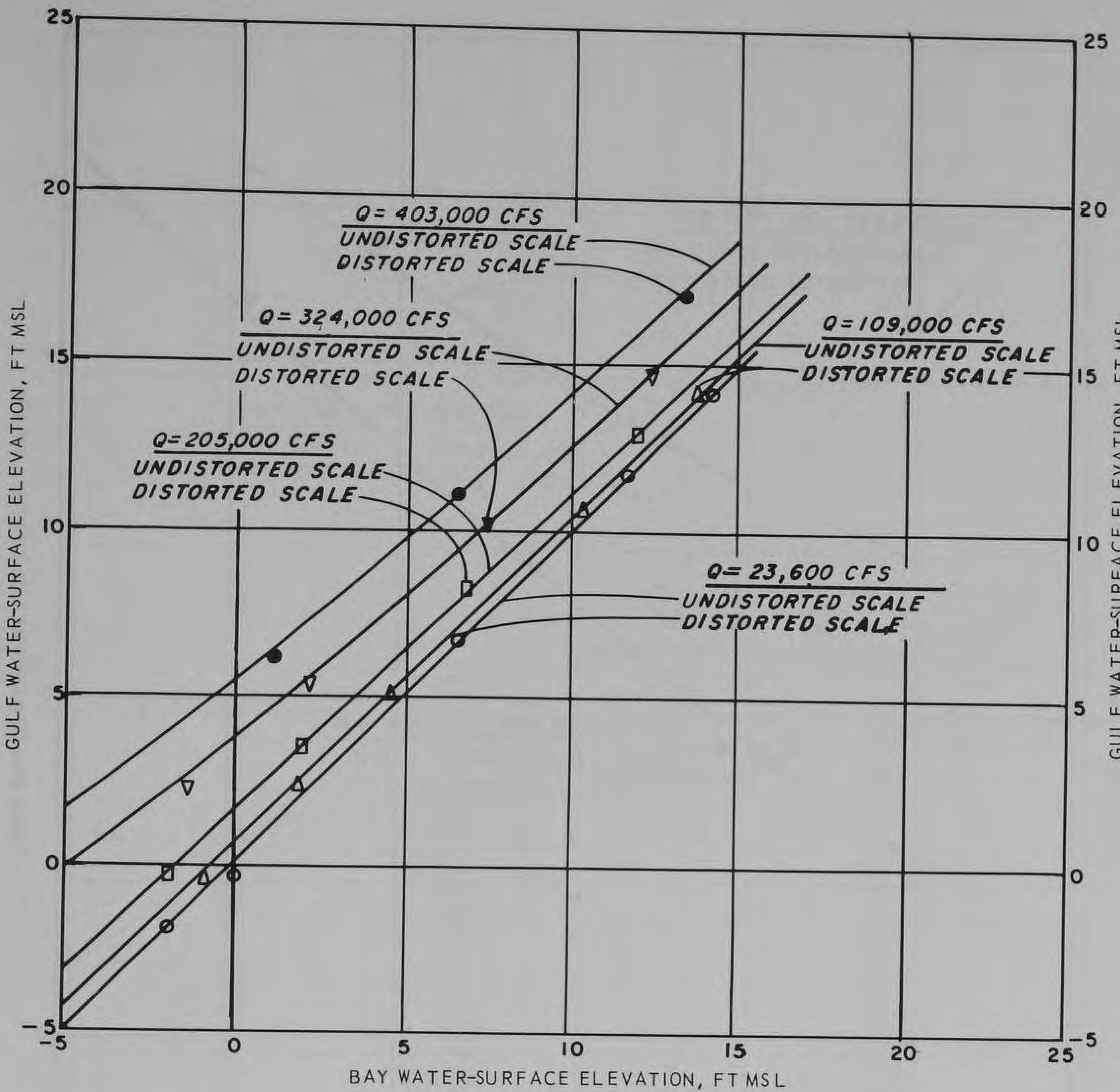


NOTE: GULF ELEVATION INCLUDE CORRECTIONS FOR APPROACH VELOCITY.

MODEL SCALES

DISTORTED – 1:60 VERTICAL; 1:600 HORIZONTAL
UNDISTORTED – 1: 100

DEVELOPMENT TESTS
GULF ELEVATIONS VERSUS
BAY ELEVATIONS FOR
VARIOUS DISCHARGES
ALPHA PLAN NAVIGATION STRUCTURE
FOR HOUSTON SHIP CHANNEL STUDIES

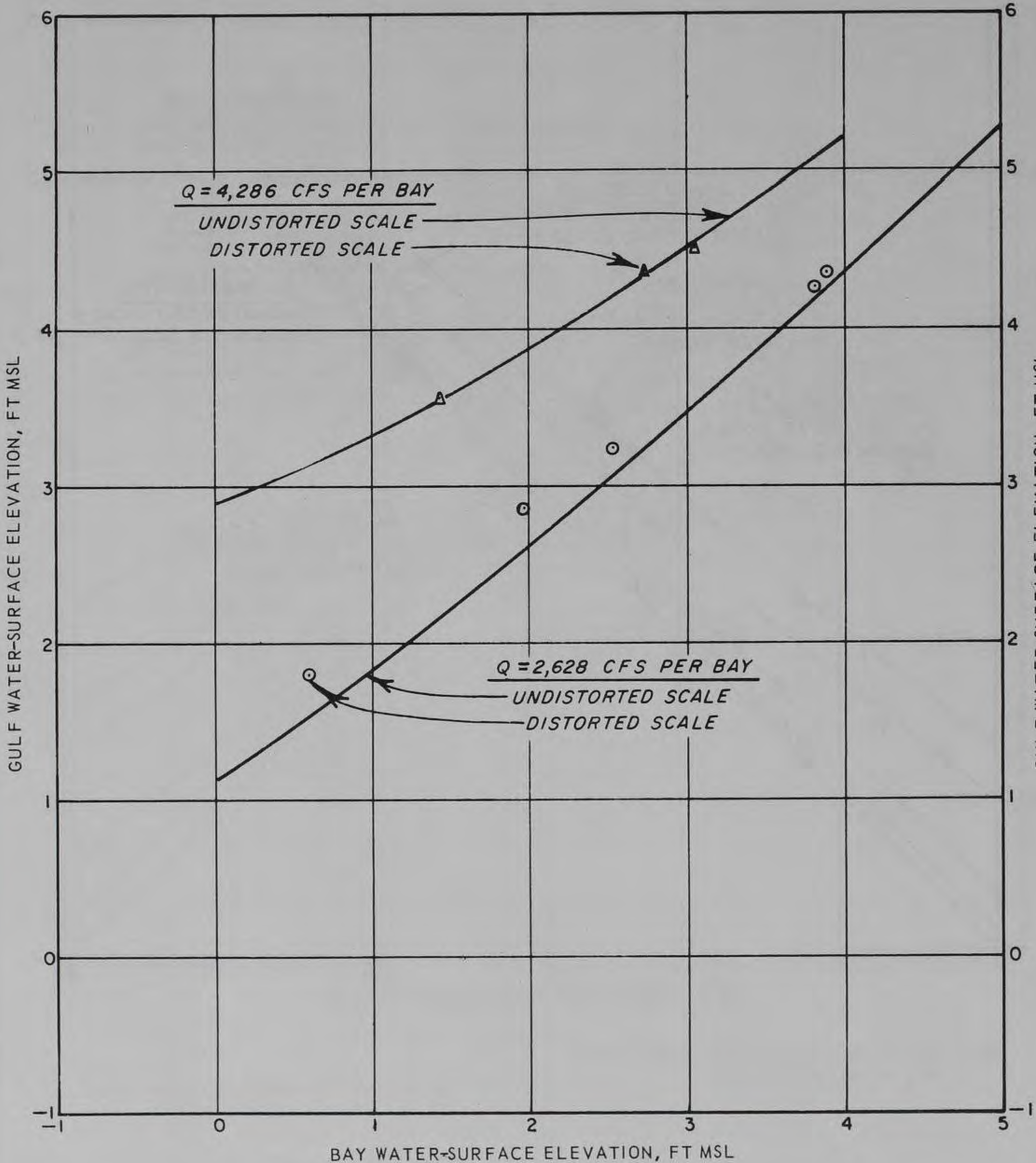


NOTE: GULF ELEVATIONS INCLUDE CORRECTIONS FOR APPROACH VELOCITY.

MODEL SCALES

DISTORTED – 1:60 VERTICAL; 1: 600 HORIZONTAL
UNDISTORTED – 1:100

DEVELOPMENT TESTS
GULF ELEVATIONS VERSUS BAY ELEVATIONS FOR VARIOUS DISCHARGES
GAMMA PLAN NAVIGATION STRUCTURE FOR TEXAS COAST HURRICANE SURGE STUDIES

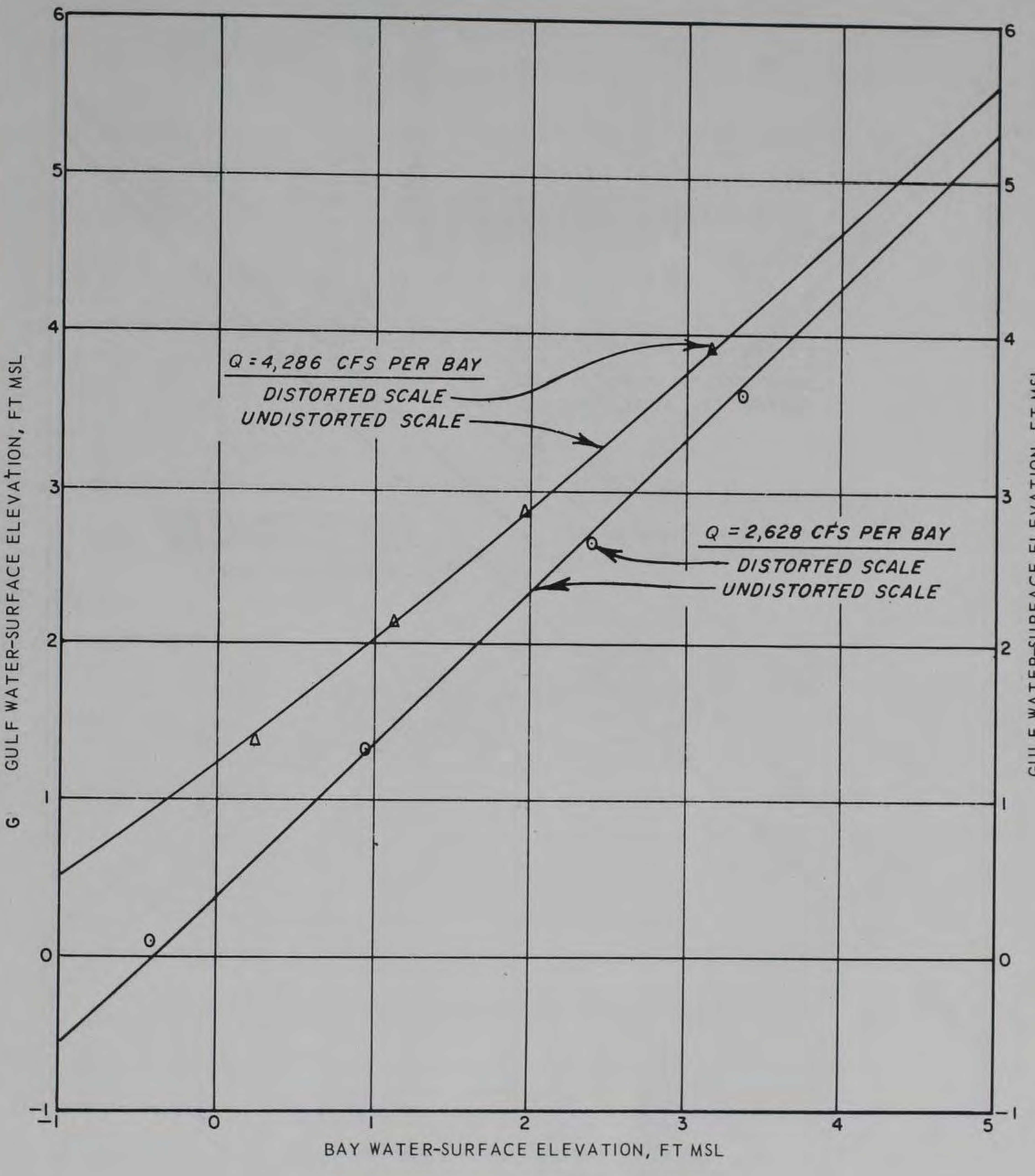


NOTE: GULF ELEVATIONS INCLUDE CORRECTIONS FOR APPROACH VELOCITY.

DISCHARGES ARE EXPRESSED IN CUBIC FEET PER SECOND PER BAY.

GULF ELEVATIONS VERSUS BAY ELEVATIONS FOR VARIOUS DISCHARGES

PASSAGE INVERT SUBMERGENCE = 6 FT

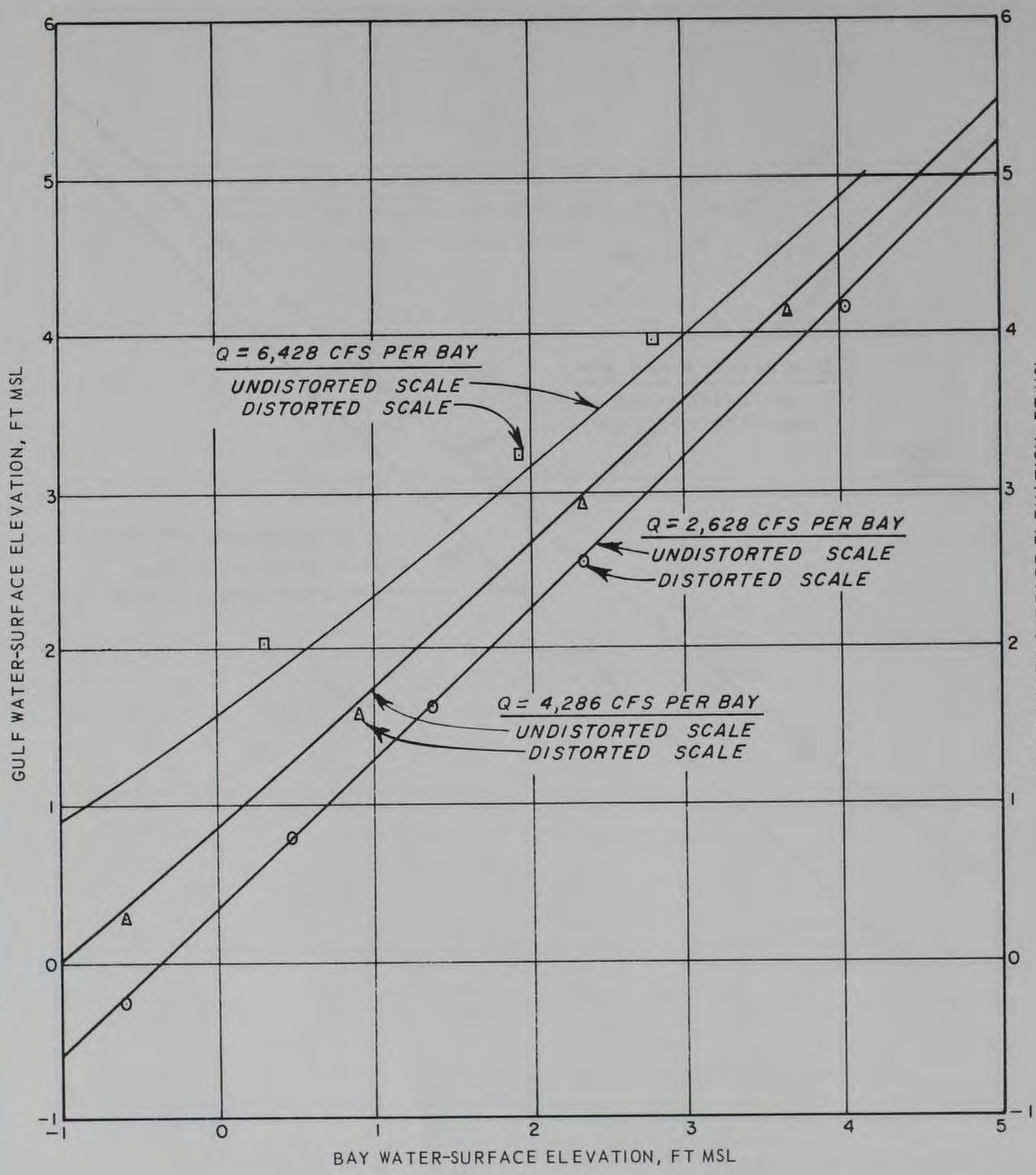


NOTE: GULF ELEVATIONS INCLUDE CORRECTIONS FOR APPROACH VELOCITY.

DISCHARGES ARE EXPRESSED IN CUBIC FEET PER SECOND PER BAY.

GULF ELEVATIONS VERSUS BAY ELEVATIONS FOR VARIOUS DISCHARGES

PASSAGE INVERT SUBMERGENCE = 10 FT

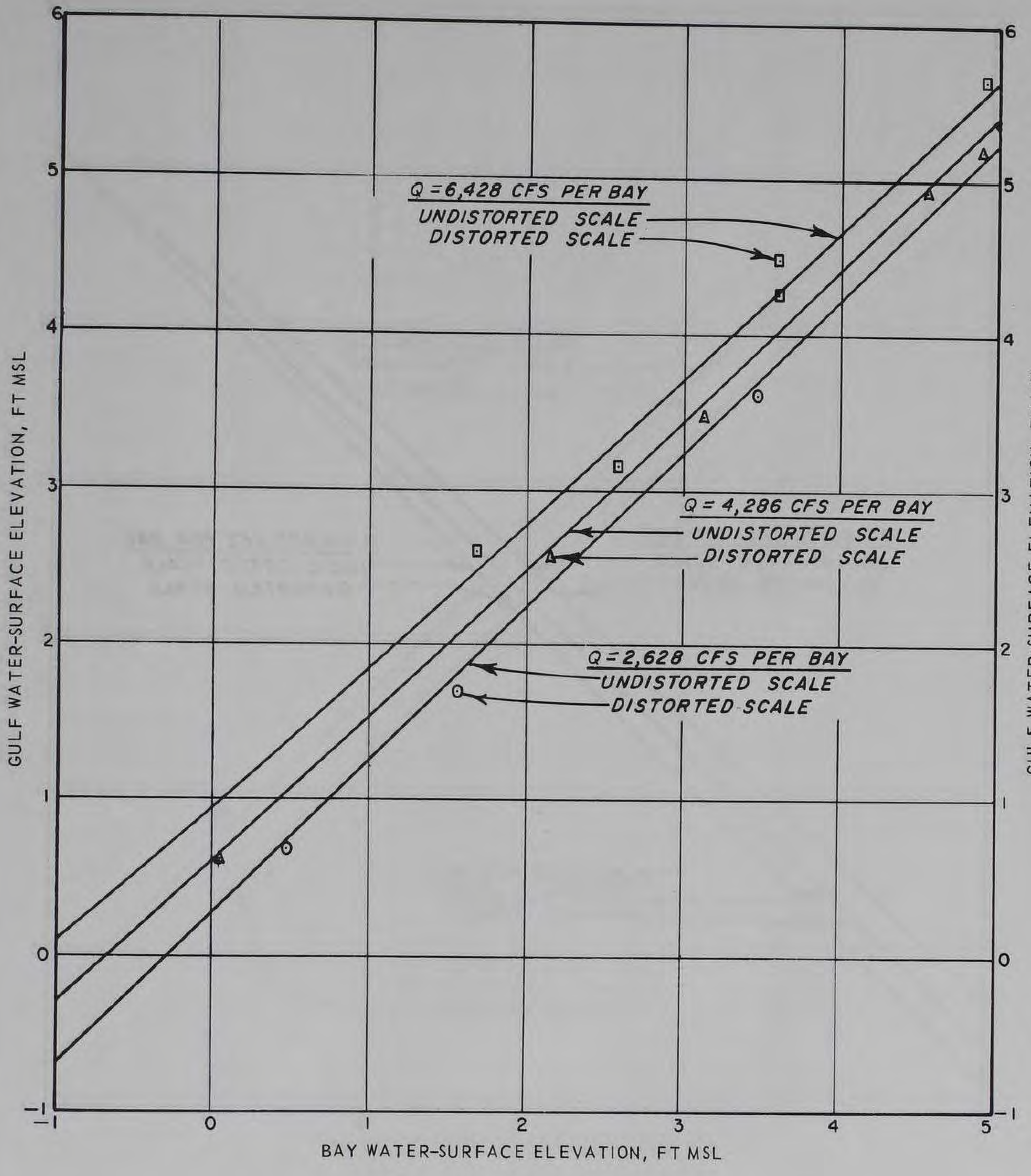


NOTE: GULF ELEVATIONS INCLUDE CORRECTIONS FOR APPROACH VELOCITY.

DISCHARGES ARE EXPRESSED IN CUBIC FEET PER SECOND PER BAY.

GULF ELEVATIONS VERSUS BAY ELEVATIONS FOR VARIOUS DISCHARGES

PASSAGE INVERT SUBMERGENCE = 12 FT

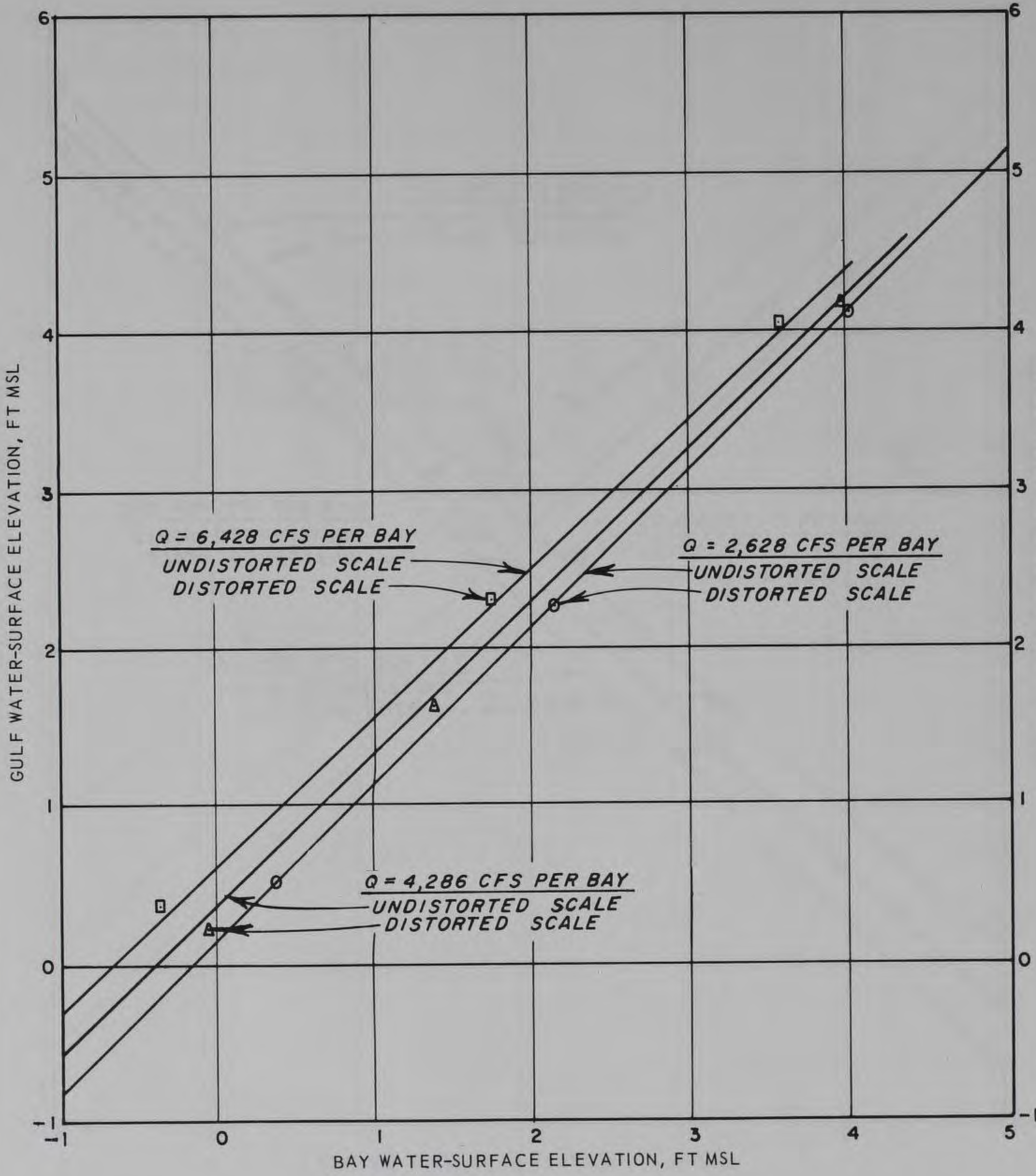


NOTE: GULF ELEVATIONS INCLUDE CORRECTIONS FOR APPROACH VELOCITY.

DISCHARGES ARE EXPRESSED IN CUBIC FEET PER SECOND PER BAY.

GULF ELEVATIONS VERSUS BAY ELEVATIONS FOR VARIOUS DISCHARGES

PASSAGE INVERT SUBMERGENCE = 15 FT

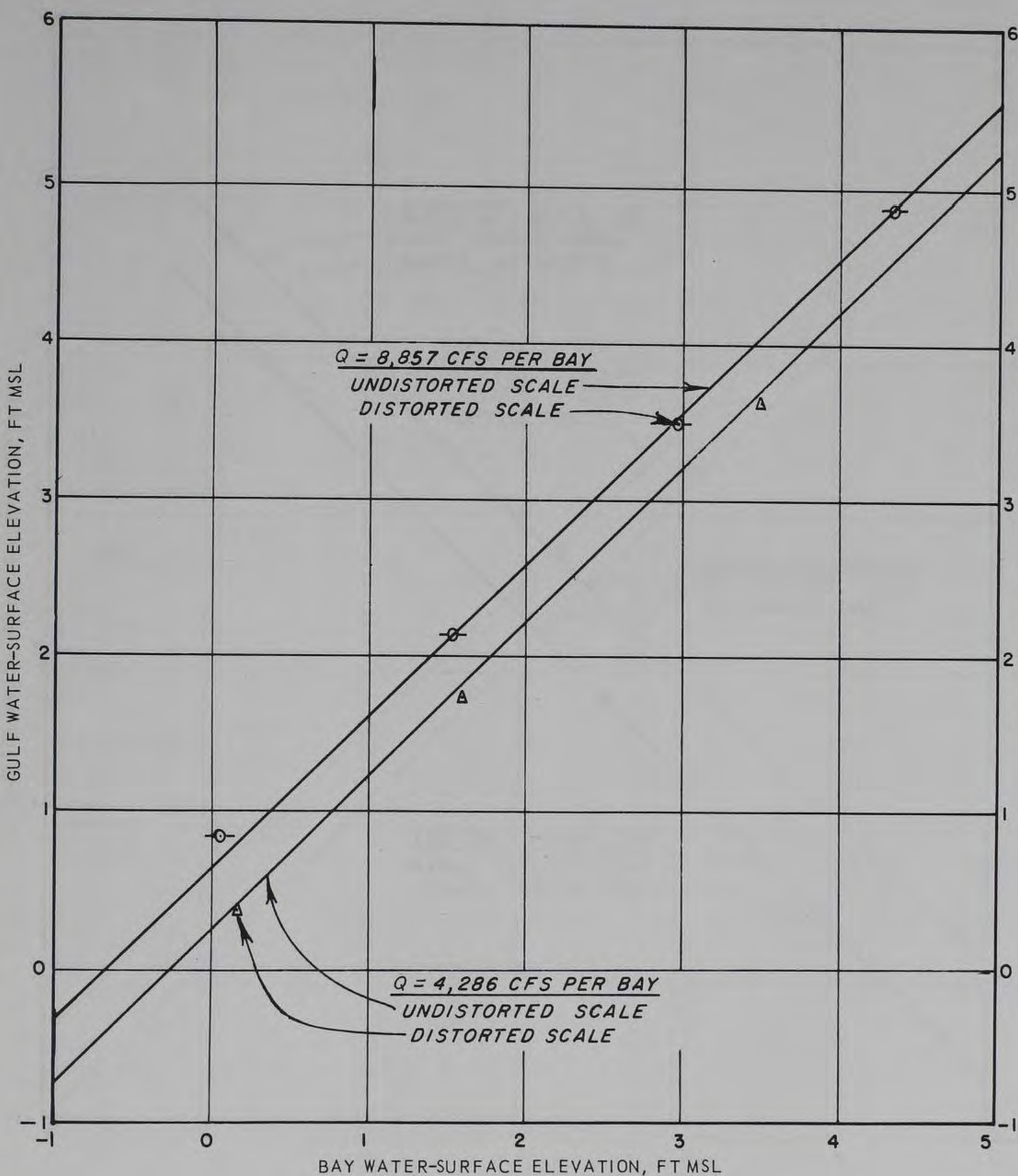


NOTE: GULF ELEVATIONS INCLUDE CORRECTIONS FOR APPROACH VELOCITY.

DISCHARGES ARE EXPRESSED IN CUBIC FEET PER SECOND PER BAY.

GULF ELEVATIONS VERSUS BAY ELEVATIONS FOR VARIOUS DISCHARGES

PASSAGE INVERT SUBMERGENCE = 20 FT

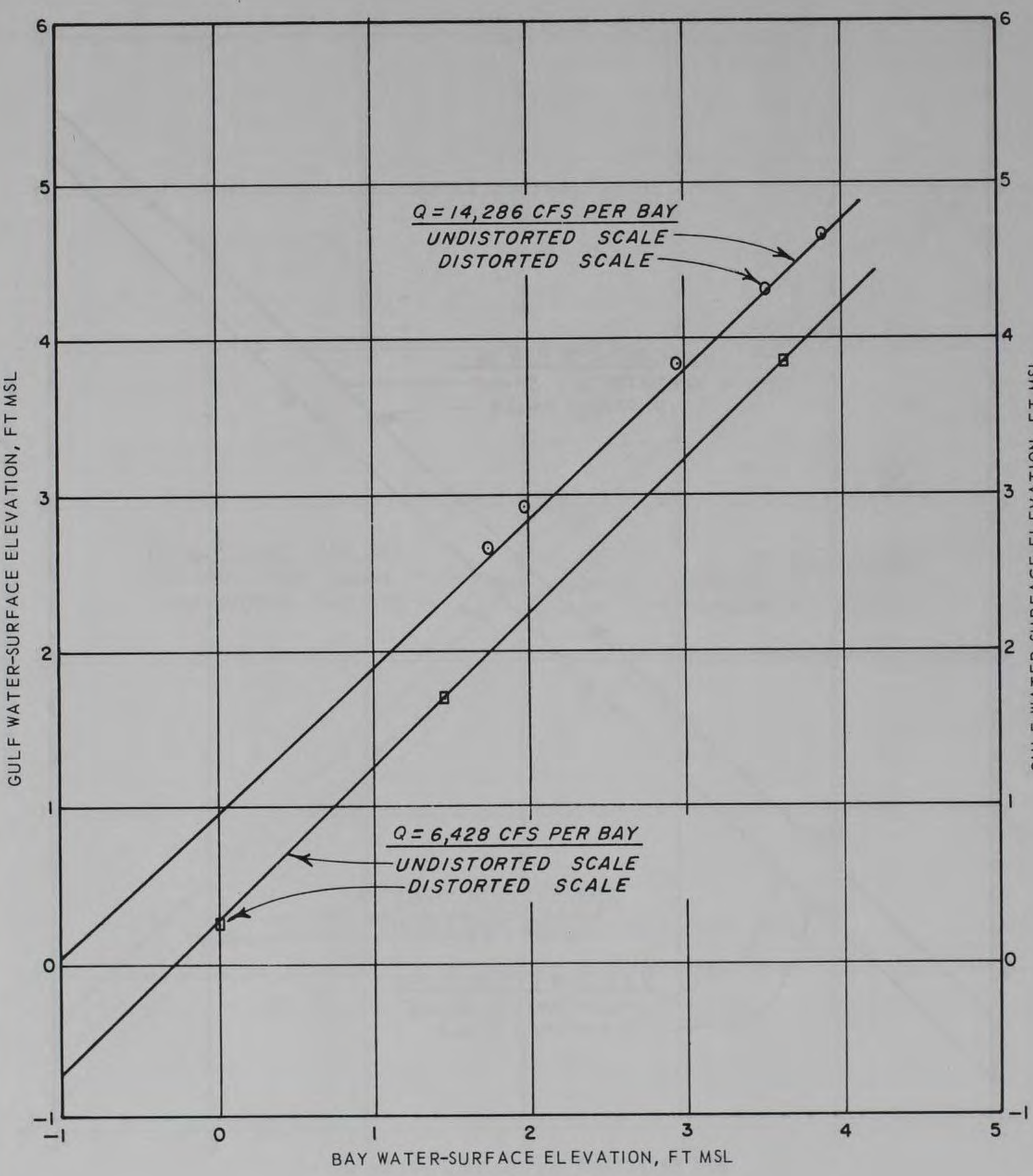


NOTE: GULF ELEVATIONS INCLUDE CORRECTIONS FOR APPROACH VELOCITY.

DISCHARGES ARE EXPRESSED IN CUBIC FEET PER SECOND PER BAY.

GULF ELEVATIONS VERSUS BAY ELEVATIONS FOR VARIOUS DISCHARGES

PASSAGE INVERT SUBMERGENCE = 25 FT

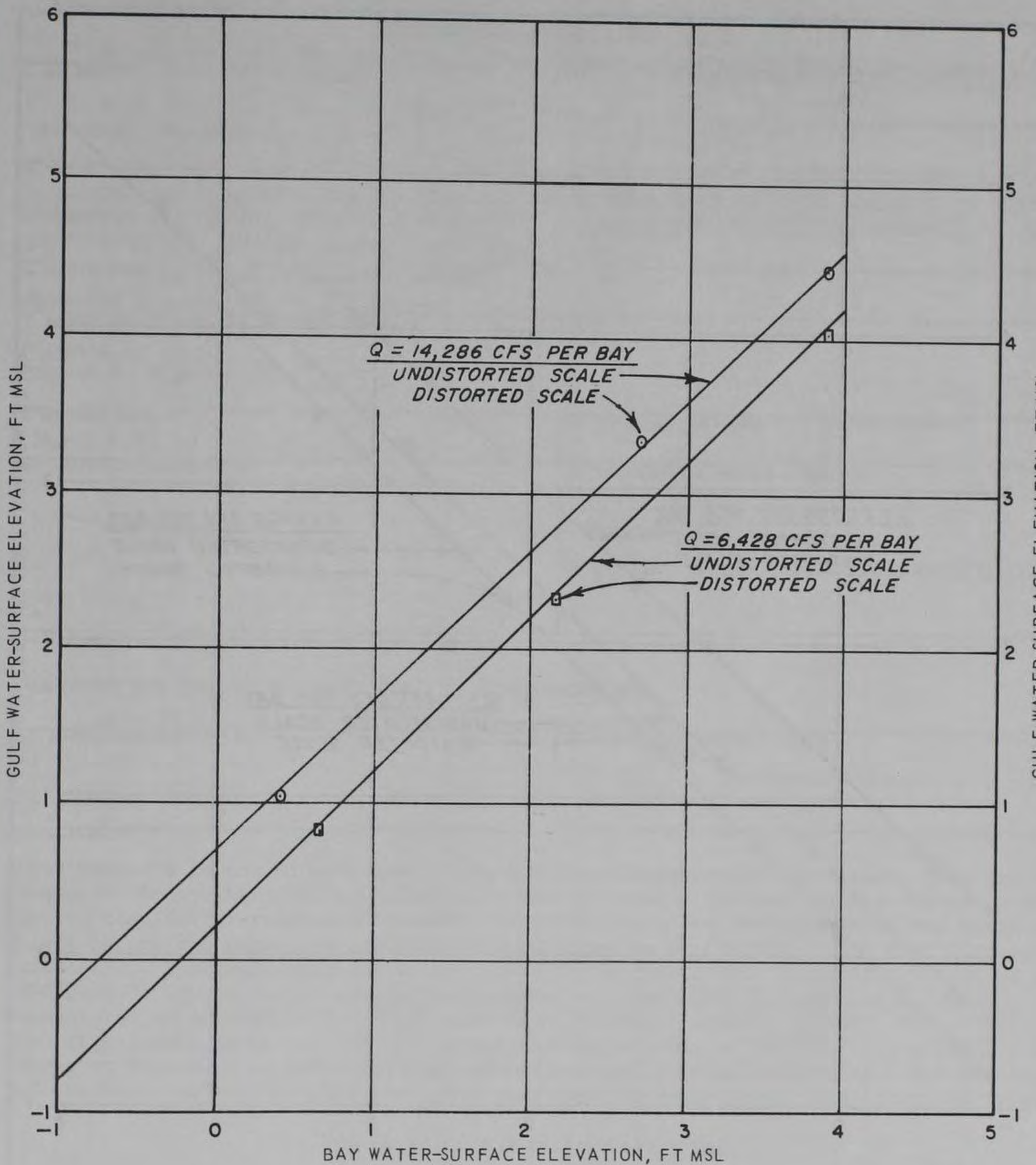


NOTE: GULF ELEVATIONS INCLUDE CORRECTIONS FOR APPROACH VELOCITY.

DISCHARGES ARE EXPRESSED IN CUBIC FEET PER SECOND PER BAY.

GULF ELEVATIONS VERSUS BAY ELEVATIONS FOR VARIOUS DISCHARGES

PASSAGE INVERT SUBMERGENCE = 30 FT

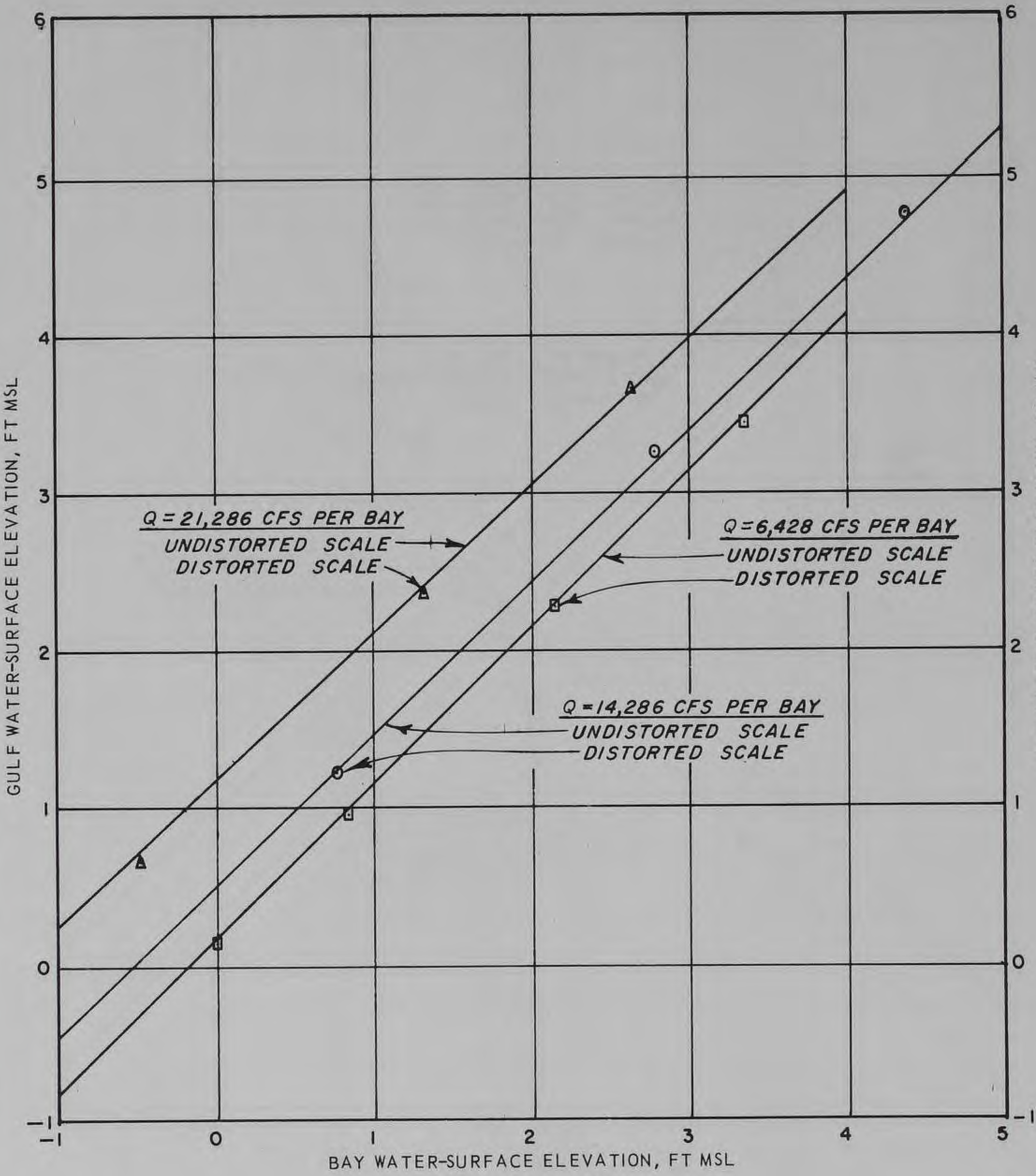


NOTE: GULF ELEVATIONS INCLUDE CORRECTIONS FOR APPROACH VELOCITY.

DISCHARGES ARE EXPRESSED IN CUBIC FEET PER SECOND PER BAY.

GULF ELEVATIONS VERSUS BAY ELEVATIONS FOR VARIOUS DISCHARGES

PASSAGE INVERT SUBMERGENCE = 35 FT



NOTE: GULF ELEVATIONS INCLUDE CORRECTIONS FOR APPROACH VELOCITY.

DISCHARGES ARE EXPRESSED IN CUBIC FEET PER SECOND PER BAY.

GULF ELEVATIONS VERSUS BAY ELEVATIONS FOR VARIOUS DISCHARGES

PASSAGE INVERT SUBMERGENCE = 40 FT

Unclassified
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13. ABSTRACT

This appendix is one of a series of reports presenting results of a model test program conducted to evaluate two proposed hurricane protection systems for the Galveston Bay, Texas, complex. Development of model structures to allow the effects of two barrier plans (Alpha and Gamma) on normal tide conditions to be evaluated in a distorted-scale model (1:60 vertically and 1:600 horizontally) is discussed. A model structure of a 400-ft-wide by -55 ft msl navigation opening was developed for each plan. Model structures of a total of 108 60-ft-wide tidal passages varying in depth from -10 to -40 ft msl were developed for the Alpha plan and a total of 160 60-ft-wide tidal passages at depths of -6 and -12 ft msl were developed for the Gamma plan. The results of the tests to evaluate the plans are presented in Report 2 of this series of reports.

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