MISCELLANEOUS PAPER H-74-7

STA-POD STABILITY TESTS

Hydraulic Model Investigation

by

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August 1974

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for Marine Modules, Inc.
Newburgh, New York 12550

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper H-74-7	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) STA-POD STABILITY TESTS; Hydraulic Model Investigation		5. TYPE OF REPORT & PERIOD COVERED Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) D. Donald Davidson		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Hydraulics Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Marine Modules, Inc. c/o Scales Manufacturing Corporation P. O. Box 1111, Newburgh, New York 12550		12. REPORT DATE August 1974
		13. NUMBER OF PAGES 39
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Armor units (Hydraulics)
Breakwaters
Groins (Structures)
Hydraulic models
STA-POD
Stability
Water wave action on maritime structures

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Model tests were conducted on STA-POD armor units used on selected groin-type structures, subjected to the largest waves that can attack the units when placed in the surf zone in a water depth equal to the height of the unit. One preliminary test also was conducted to obtain an indication of the stability of STA-PODS when used on a breakwater slope (1:1.5). All tests were conducted in a wave flume 110 ft long, 4 ft wide, and 4 ft deep. The surf zone tests utilized a 1:25 model to prototype scale, while the breakwater slope tests

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20. ABSTRACT (Continued)

used only model values. It was concluded from results of the surf zone tests, where the model STA-PODS were tested on a hard-surface slope, that 5-ton STA-PODS used as a groin or small jetty type structure in the prototype would be stable for wave heights in excess of the 7.5 ft tested on the model. A small area of STA-PODS tested on a 1:1.5 breakwater slope indicated that random-placed STA-PODS interlocked and provided good stability characteristics. The use of STA-PODS as a breakwater unit would be practical, provided their structural stamina were sufficient to endure forces during prototype construction and storm action, and provided additional research indicated their damage coefficient was sufficiently large to make STA-PODS economically feasible.

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Preface

The model investigation described herein was requested by Marine Modules, Inc. (formerly Gratten Marine Research Corp.) in a letter to the U. S. Army Engineer Waterways Experiment Station (WES) dated 5 June 1970. Authority to conduct the investigation was granted by the Office, Chief of Engineers (OCE) in the 1st indorsement dated 30 June 1970 to WES letter dated 23 June 1970. The tests were conducted at WES from December 1970-September 1971 under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Mr. R. Y. Hudson, former Chief of the Wave Dynamics Division. The tests were conducted in the Wave Research Branch by Mr. D. D. Davidson, Chief, and Mr. G. G. Stout, Engineering Technician. This report was prepared by Mr. Davidson under the direction of Dr. R. W. Whalin, present Chief of the Wave Dynamics Division.

Directors of WES during the conduct of this investigation and the preparation and publication of this report were BG E. D. Peixotto and COL G. H. Hilt. Technical Director was Mr. F. R. Brown.

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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
pounds per cubic foot	16.02	kilograms per cubic meter
pounds (mass)	0.4535924	kilograms
tons (2000 pounds)	907.185	kilograms
square feet	0.092903	square meters

STA-POD STABILITY TESTS

Hydraulic Model Investigation

Introduction

1. Designers of coastal and river engineering works, such as breakwaters, groins, jetties, revetments, and seawalls, are continuously looking for economical and functional armor units to use in coastal construction. Many special shaped concrete armor units have been developed over the last 20 years and have proven quite feasible. The use of concrete armor units has several advantages, especially in areas where stone costs are high and in areas of high intensity wave action. Compared with stone, concrete armor units are more complex in shape and require certain design information from both a hydraulic and structural standpoint. For example, units used on a large breakwater or jetty where they are subjected to large waves must be durable as well as functional, whereas units used on groins and toe revetments in the normal surf zone do not require as much durability but must still maintain adequate wave protection.

2. One such concrete unit proposed for construction of small groins, jetties, and toe revetments is the STA-POD,* fig. 1, developed by Marine Modules, Inc. This unit is mainly designed to be set in an upright interlocking position and consists of a main trunk section with four stabilizing legs. The stabilizing legs are slightly longer than the main trunk, which allows them to sink into the sand or bottom material for greater stability or if placed on a rock apron, additional rock material can be dumped around the legs. Basically, there is no limitation to the size that the STA-PODS can be constructed; however, to date only 2- and 5-ton** units have been installed in the prototype

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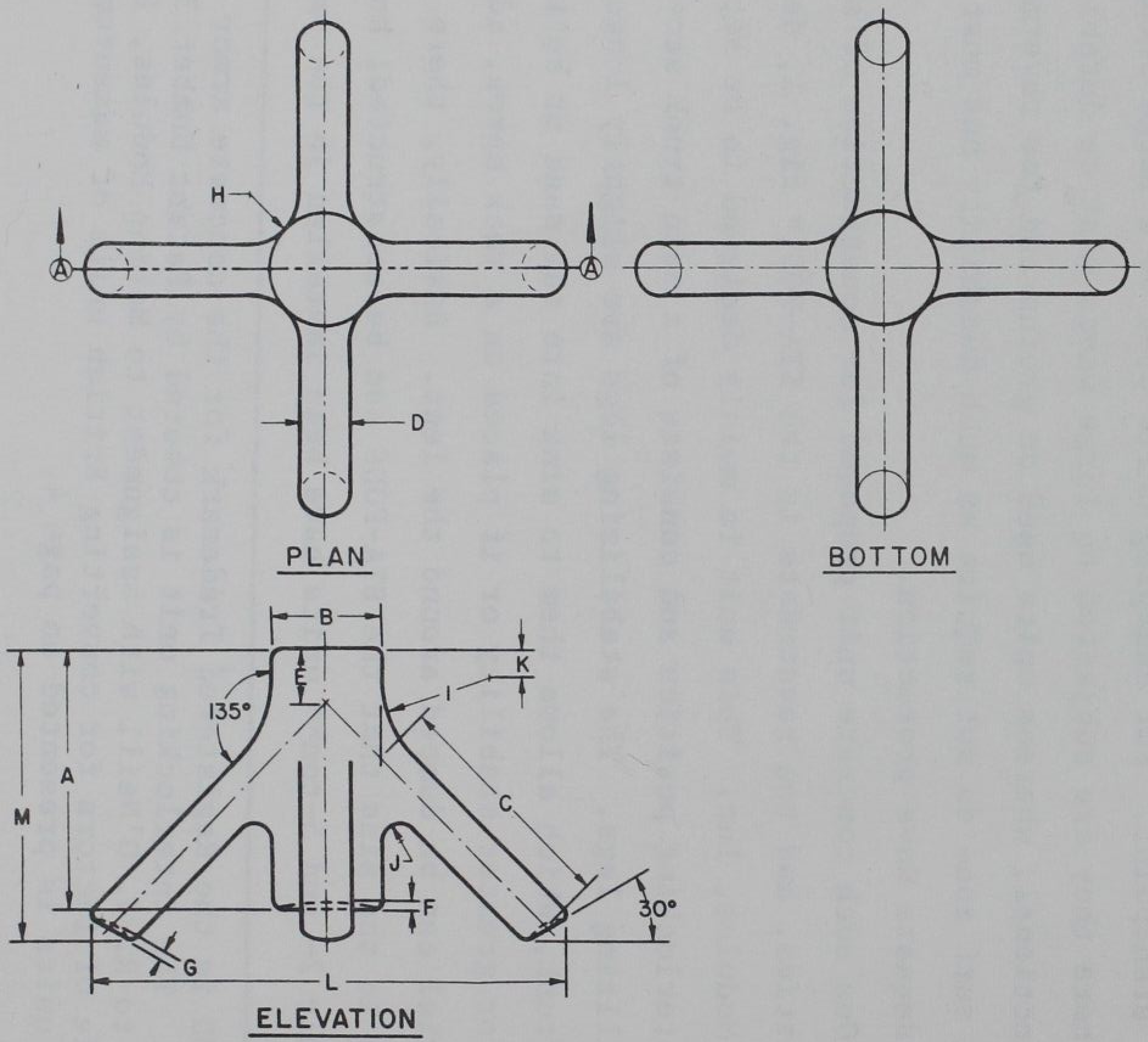
* STA-POD is the Registered Trademark for the concrete armor unit tested. The interlocking unit is covered by Patent Number 3,399,535 issued to R. J. O'Neill with assignment to Marine Modules, Inc.

** A table of factors for converting British units of measurement to metric units is presented on page 4.



	VOLUME OF INDIVIDUAL ARMOR UNITS (CU FT)										
	7.14	14.29	28.57	71.43	142.86	214.29	285.71	357.14	428.57	500.00	571.43
UNIT WEIGHT LB/CU FT	**WEIGHT OF INDIVIDUAL ARMOR UNITS (TONS)**										
140.0	0.50	1.00	2.00	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00
149.5	0.53	1.07	2.14	5.34	10.68	16.02	21.36	26.70	32.04	37.38	42.71
156.0	0.56	1.11	2.23	5.57	11.14	16.71	22.29	27.86	33.43	39.00	44.57
162.0	0.58	1.16	2.31	5.79	11.57	17.36	23.14	28.93	34.71	40.50	46.29
	AVERAGE MEASURED HEIGHT OF ONE LAYER PLACED UNIFORMLY (IN)										
	41.78	52.63	66.27	89.98	113.38	129.76	142.81	153.86	163.47	172.13	179.95
SYMBOL	**DIMENSIONS OF ARMOR UNITS (IN)**										
A	37.17	46.82	58.96	80.05	100.87	115.44	127.05	136.89	145.44	153.14	160.10
B	15.85	19.97	25.14	34.14	43.01	49.23	54.18	58.37	62.02	65.31	68.27
C	34.07	42.95	54.09	73.38	92.46	105.85	116.55	125.51	133.37	140.43	146.84
D	6.88	8.68	10.93	14.82	18.68	21.38	23.54	25.35	26.94	28.37	29.66
E	7.99	10.07	12.68	17.21	21.69	24.82	27.32	29.43	31.27	32.93	34.42
F	1.38	1.73	2.18	2.96	3.73	4.27	4.70	5.06	5.38	5.67	5.92
G	1.06	1.33	1.68	2.27	2.87	3.28	3.61	3.89	4.13	4.35	4.55
H	7.35	9.26	11.67	15.84	19.96	22.84	25.14	27.08	28.78	30.30	31.68
I	15.85	19.97	25.14	34.14	43.01	49.23	54.18	58.37	62.02	65.31	68.27
J	1.39	1.76	2.21	3.00	3.78	4.33	4.77	5.14	5.46	5.75	6.01
K	4.44	5.59	7.04	9.56	12.04	13.78	15.17	16.34	17.36	18.28	19.17
L	68.65	86.48	108.90	147.85	186.31	213.23	234.66	252.83	268.62	282.86	295.70
M	41.78	52.63	66.27	89.98	113.38	129.76	142.81	153.86	163.47	172.13	179.95

Fig. 1. STA-PODS, volume, weight, thickness of layers, and dimensions

(From Marine Modules, Inc.)

as toe revetment and as groins for beach stabilization. Photographs 1 and 2 show typical prototype installations at Queens and Fire Island, New York, respectively.

3. Since no hydraulic or structural research data exist on the STA-PODS, other than the general performance of the existing prototype structures, the sponsor requested that the Waterways Experiment Station (WES) conduct model tests to determine the performance of selected STA-POD structures under certain hydraulic conditions. The structural characteristics of the STA-POD were not considered in this study.

Purpose of Model Tests

4. The purpose of the model tests was to investigate the stability of the STA-POD unit when used in selected groin-type structures and subjected to the largest waves that can attack the unit when placed in the surf zone in a water depth equal to the height of the unit. Also, one preliminary test was desired to check the stability of STA-PODS when used on a breakwater slope.

Test Conditions

Surf zone tests

5. It was necessary to conduct the STA-POD model tests on a hard surface slope because it is not presently known how to properly scale the sinkage and settlement factors of the unit into the sand. The exact effect that such settlement would have on the stability of the units against wave action is not known, but it is reasonable to assume that the units would be more stable with a slight amount of settlement into the sand. Thus, WES model tests conducted on a hard surface where settlement is not allowed should give conservative results. The sponsor provided two sizes of STA-PODS for testing: (a) wt = 0.37 lb, sp wt = 167 lb per ft^3 and (b) wt = 0.50 lb, sp wt = 167 lb per ft^3.

6. Tests for the groin structures were conducted at a linear

scale of 1:25 and the following conditions were used: (a) prototype wave periods of 8- and 12-sec were used to simulate typical wave conditions; (b) all tests were made with a constant beach slope of 1:40, and then the tests were repeated using a compound slope (a 1:10 slope seaward of the 1:40 slope); and (c) the water depth at the seaward end of each test section was equal to the height of the armor unit being tested.

Breakwater stability test

7. Test conditions for the STA-PODS on a breakwater slope (1:1.5) did not utilize a model to prototype scale but consisted of the following model conditions: 2-ft water depth, 1.31-sec wave period, 0.25 relative depth (d/L), and 0.30- to 0.60-ft wave heights.

Test Procedures

Surf zone tests

8. The tests were conducted in a 5-ft-wide, 4-ft-deep, and 119-ft-long wave flume with a vertical-displacement type wave generator capable of producing sinusoidal waves of various periods. The model slopes were constructed of marine plywood on a wooden frame. The beach area where the STA-POD test sections were constructed was covered with one layer of burlap cloth to provide a reasonable degree of roughness for the units to sit on. Placement of the model units were by hand, approximately simulating the use of a front-end loader in the prototype. None of the model units were locked together to a degree that could not be obtained under reasonable conditions in the field.

9. The model tests used the smallest size STA-POD (0.37 lb) provided by the sponsor because, considering the selected test conditions and the WES wave generator capabilities, there was a greater possibility of obtaining displacement of the smaller units. A linear scale of 1:25 was selected for the tests based on the capabilities of the wave generator, the water depth at the seaward end of the test sections, and the weight of the model STA-POD being tested. For this

scale, the 0.37 lb (167 lb per cu ft) model STA-PODS represent 5-ton (150 lb per cu ft) units in the prototype. The water depth at the seaward end of each test section corresponded to a prototype depth of 5.7 ft. Calibration of the wave generator showed that the maximum breaking wave heights which could be made to attack the test sections at the selected scale and test conditions were as follows:

Beach Slope	Wave Period sec	Model Wave Heights ft	Prototype Wave Heights ft
1:40	8	0.23	5.7
	12	0.23	5.7
1:10; 1:40	8	0.30	7.5
	12	0.26	6.5

Wave heights are measured without the structure in place. Higher waves were possible on the compound slope because of the increase in the effective depth of the breaking waves.

Breakwater stability test

10. The breakwater stability test conducted with the STA-PODS was preliminary and gives only tentative indications as to their performance as a breakwater unit. A breakwater test section was subjected to nonbreaking waves in approximately 0.05-ft wave-height increments for each test until a height of 0.60 ft was reached. Placement of the armor units was random and the stability of the units was observed visually. Electrical wave gages and a recording oscillograph were used to measure wave heights. Selective photographs of each test were made before and after testing.

Tests and Results

Surf zone tests

11. The first series of tests were conducted with a constant beach slope of 1:40. Tests and results were as follows:

a. Plan 1, plate 1, consisted of a single row of 5-ton STA-PODS extending into the surf zone at a 90-deg angle to the beach. The test section was subjected to the maximum wave conditions of 5.7-ft, 8-sec and 5.7-ft, 12-sec waves. No damage occurred for either wave condition. Photographs 3 and 4 show this plan before and after testing with a 5.7-ft, 8-sec wave. The test section was then rebuilt and tested two more times. Results of the repeat tests were the same as the original test.

b. Plan 1A, plate 2, consisted of 5-ton STA-PODS extended into the surf zone at an angle of 45 deg to the beach. Again no damage or movement of the STA-PODS was observed for the maximum wave conditions (photographs 5 and 6). The test section was reconstructed and retested two additional times, and each repeat test confirmed results of the original test.

c. Since no damage occurred for either of the single-row test plans, it was obvious that a double row of STA-PODS with quarrystones in the middle would be stable for the selected wave conditions. Thus, this plan was not tested on the constant 1:40 slope.

12. The second series of tests was conducted with a compound beach slope of 1:10 seaward of the 1:40 slope. Each test section was positioned in reference to the break in the beach slope so that the maximum breaking waves would plunge on the first few units in the seaward end of the test section. Tests and results are as follows:

a. Plan 1, plate 3, was subjected to the maximum wave conditions of 7.5-ft, 8-sec and 6.5-ft, 12-sec waves. No damage occurred to the test section (photographs 7 and 8). Two repeat tests were conducted and their results checked those of the original test.

b. Plan 1A, plate 4, was tested for the maximum wave conditions and again no damage occurred (photographs 9 and 10). The test section was reconstructed and retested two additional times. Results of the repeat tests were the same as those of the original test.

c. Plan 2, plate 5, consists of a double row of 5-ton STA-PODS placed about 12.5 ft apart and filled with quarrystones. The stone interior consists of filler stones whose average weight was about 100 lb covered by one layer of 1000-lb cap stones (photograph 11). The test section was subjected to the maximum wave conditions of 7.5-ft, 8-sec and 6.5-ft, 12-sec waves. No movement was observed for the STA-PODS; however, the 1000-lb cap stones covering the last 12 ft of the seaward end of the test section were rolled back onto the test section or washed off the test section. The exposed filler material was then displaced down to about one-half the depth (photograph 12). The test section was then rebuilt and tested a second and third time. In the repeat tests, the cap stones and filler material were displaced similar to that of the original test. No significant movement of STA-PODS occurred.

d. Plan 2A, plate 6, was similar to plan 2 except that the cap stone weight was increased to 2000 lb (photograph 13). When tested with the 6.5-ft, 12-sec waves, no damage occurred to any part of the test section. The 7.5-ft, 8-sec waves did not move the STA-PODS, but rolled the 2000-lb cap stones covering the last 7 ft of the seaward end of the test section back onto the remaining section. A small amount of the exposed filler stones was displaced and was swept up the beach (photograph 14). The test section was reconstructed and tested two additional times. Results of the repeat tests checked those from the original test.

e. Plan 2B, plate 7, was the same as Plans 2 and 2A except that the cap stone weight was 4000 lb (photograph 15). No damage occurred for the 6.5-ft, 12-sec waves. The 7.5-ft, 8-sec waves displaced the cap stones covering the last 5 ft of the seaward end of the structures and washed out a pocket in the filler material in that portion of the test section. Once this pocket was formed, the waves plunged into the confined area with such force that the STA-PODS on the seaward toe were forced out of position allowing loss of cap stones and deterioration of the end of the test section (photographs 16 and 17). Two repeat tests gave the same results as the original test. For this plan, the breaking waves are apparently not strong enough to displace the 4000 lb stones further shoreward on the test section, which would dissipate wave energy over a large area. Instead, the force of the breaking waves is concentrated into a confined area where the increased forces cause displacement. It is possible for this situation to occur in the prototype; however, it is believed that if the units are properly founded into sandy bottom material by trenching or other methods, movement of the STA-PODS might not occur for the given test condition. To prevent loss of cap stone at the head of the structure, heavier cap stone in two layers would be required.

Breakwater stability tests

13. The third test on STA-PODS was conducted to obtain an indication of their stability when used on a breakwater slope (1:1.5).

Since there were only one hundred of the 0.37 lb model STA-PODS (sp wt = 167 lb/cu ft) available for testing, an area of approximately 1.6 sq ft in the middle of a test section was covered with two layers of random-placed STA-PODS and the rest of the test section was covered with a selected armor shape (photograph 18). Test conditions consisted of a 2-ft water depth, 1.31-sec wave period, 0.25 relative depth (d/L), and 0.30- to 0.60-ft wave heights. The wave height was increased in approximately 0.05-ft increments for each test until a height of 0.60 ft was reached. Waves higher than 0.60 ft were not tested because the concrete armor units surrounding the STA-PODS failed and left the remainder of the test section unprotected. No damage occurred to the STA-POD area. Of course this type of test is not conclusive because a sufficiently high wave height was not reached to determine the actual design wave. The STA-PODS did withstand a 0.60-ft wave; however, by substitution of this value for the wave height in the Hudson* stability formula, the damage coefficient is calculated as follows:

$$W_r = \frac{\gamma_r H^3}{K\Delta (S_r - 1)^3} \cot \alpha$$

$$K_\nabla = \frac{\gamma_r H^3}{W_r (S_r - 1)^3} \cot \alpha = 14$$

where

$\gamma_r = 167\ \text{lb/ft}^3$

$\cot \alpha = 1.5$

$W_r = 0.37\ \text{lb}$

$S_r = \gamma_r / \gamma_w = 167/62.4 = 2.66$

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* R. Y. Hudson, "Design of Quarrystone Cover Layers for Rubble Mound Breakwaters," Research Report 2-2, Jul 1958, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Based on this preliminary test, the STA-POD section exhibited good stability characteristics, and it seems that the use of STA-PODS as breakwater armor units would be practical provided they can structurally withstand forces subjected during prototype construction and storm action, and provided their damage coefficient is sufficiently large to make them economically feasible. However, before definite conclusions can be drawn relative to their stability, a sufficient number of model units must be made to construct an entire model breakwater for additional testing.

Conclusions

Surf zone tests

14. It is obvious that for the selected test conditions (water depth, wave period, beach slopes, and weight of model STA-POD), the depths in which the units were placed would not allow waves of sufficient height to attack the structure. Thus, it was not possible to determine a design-wave height for the STA-POD armor unit tested. The STA-POD's stability characteristics, even on a hard surface, are such that a 5-ton unit is certainly stable for a 7.5-ft wave height in cases where single rows of units are used and in cases where normal wave forces are not intensified. Based on performance of the model STA-PODS tested on a hard surface slope, it is estimated that, for a 5-ton unit in the prototype, where vertical settlement into the sand can occur, it should be stable for wave heights somewhat larger than those tested on the model (7.5 ft).

Breakwater stability tests

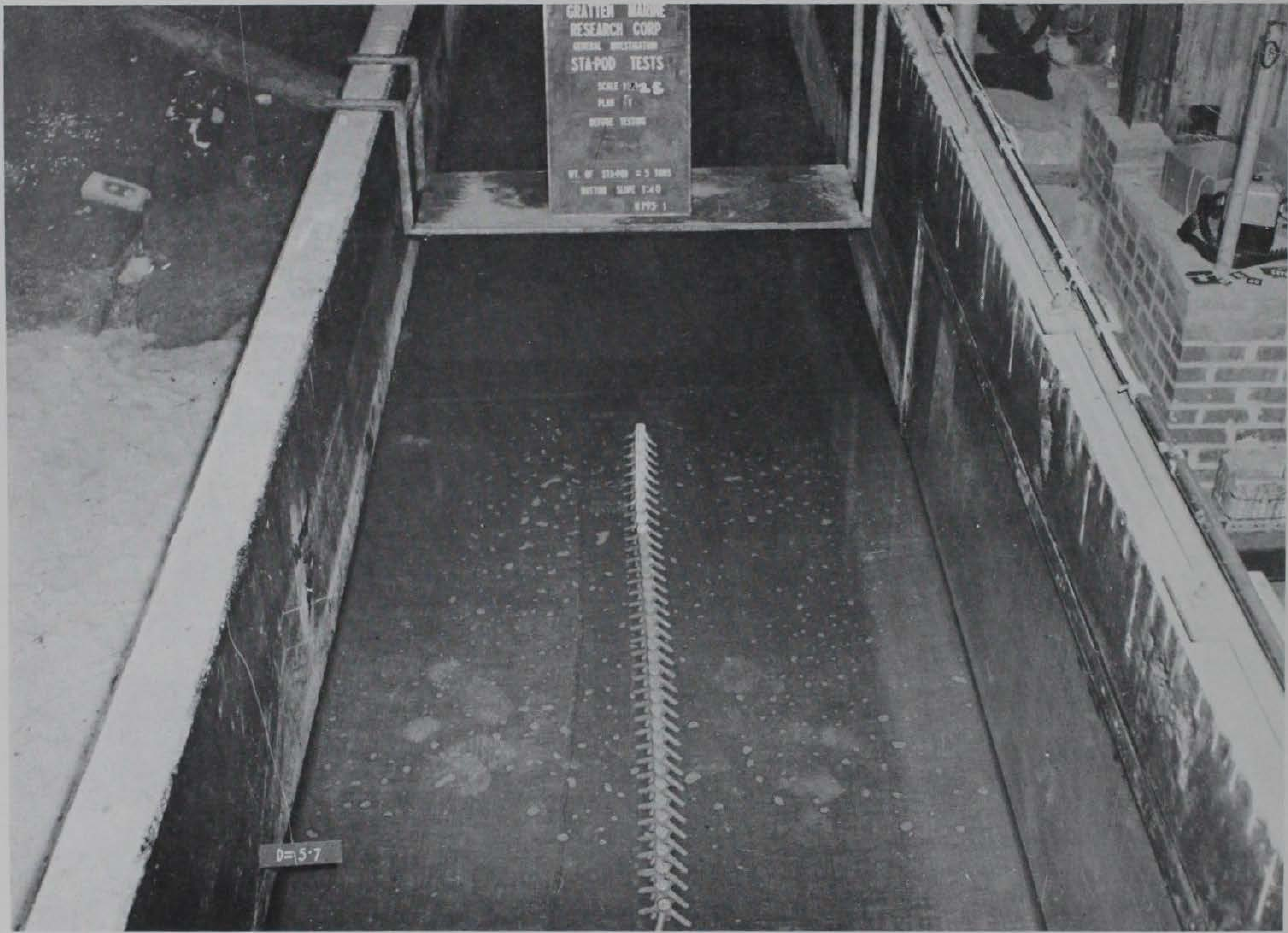
15. The STA-POD section tested showed good stability characteristics, and it seems that the use of STA-PODS as breakwater armor units would be practical provided they can structurally withstand forces induced during prototype construction and storm action, and provided their damage coefficient is sufficiently large to make them economically feasible. However, before definite conclusions can be drawn

relative to their stability, a sufficient number of model units must be made to construct an entire model breakwater for additional testing.

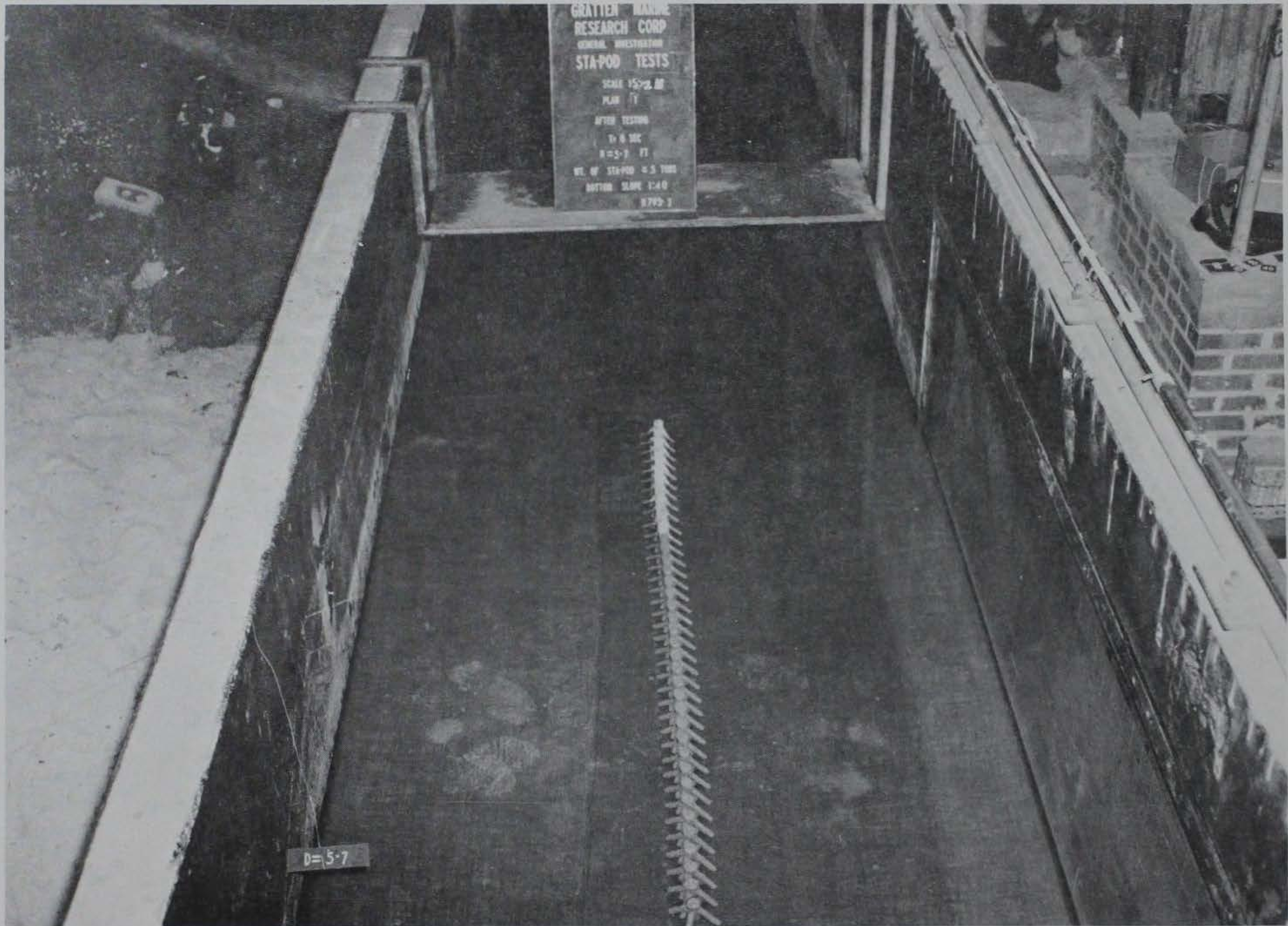
Photograph 1. Interlocking STA-PODS with entrapped stone fill for slope protection against high tides at the Cross Bay Parkway Bridge, Queens, New York

(From Marine Modules, Inc.)

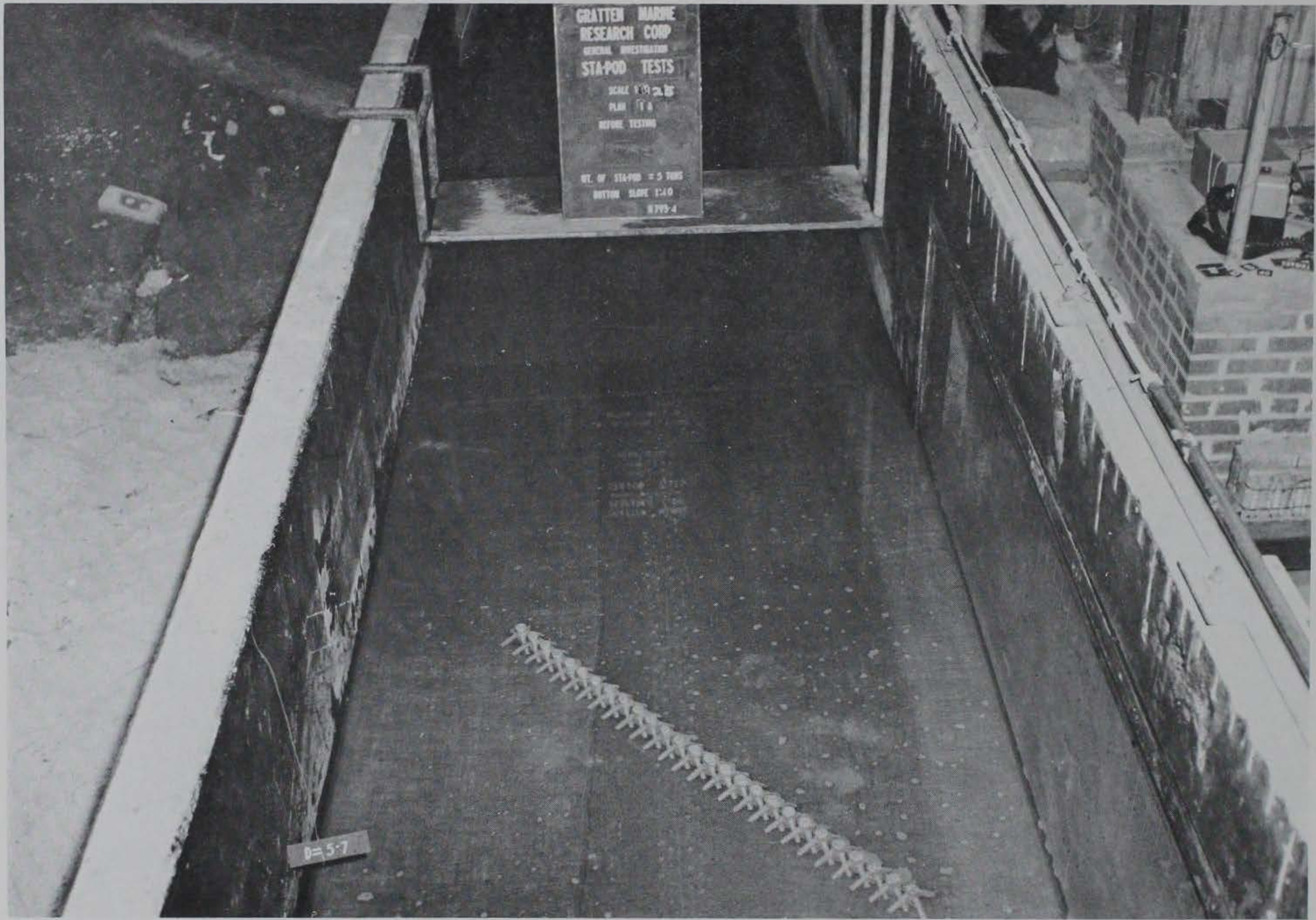
Photograph 2. Two- and five-ton STA-PODS used to stabilize the beach at Fire Island, New York
(From Marine Modules, Inc.)



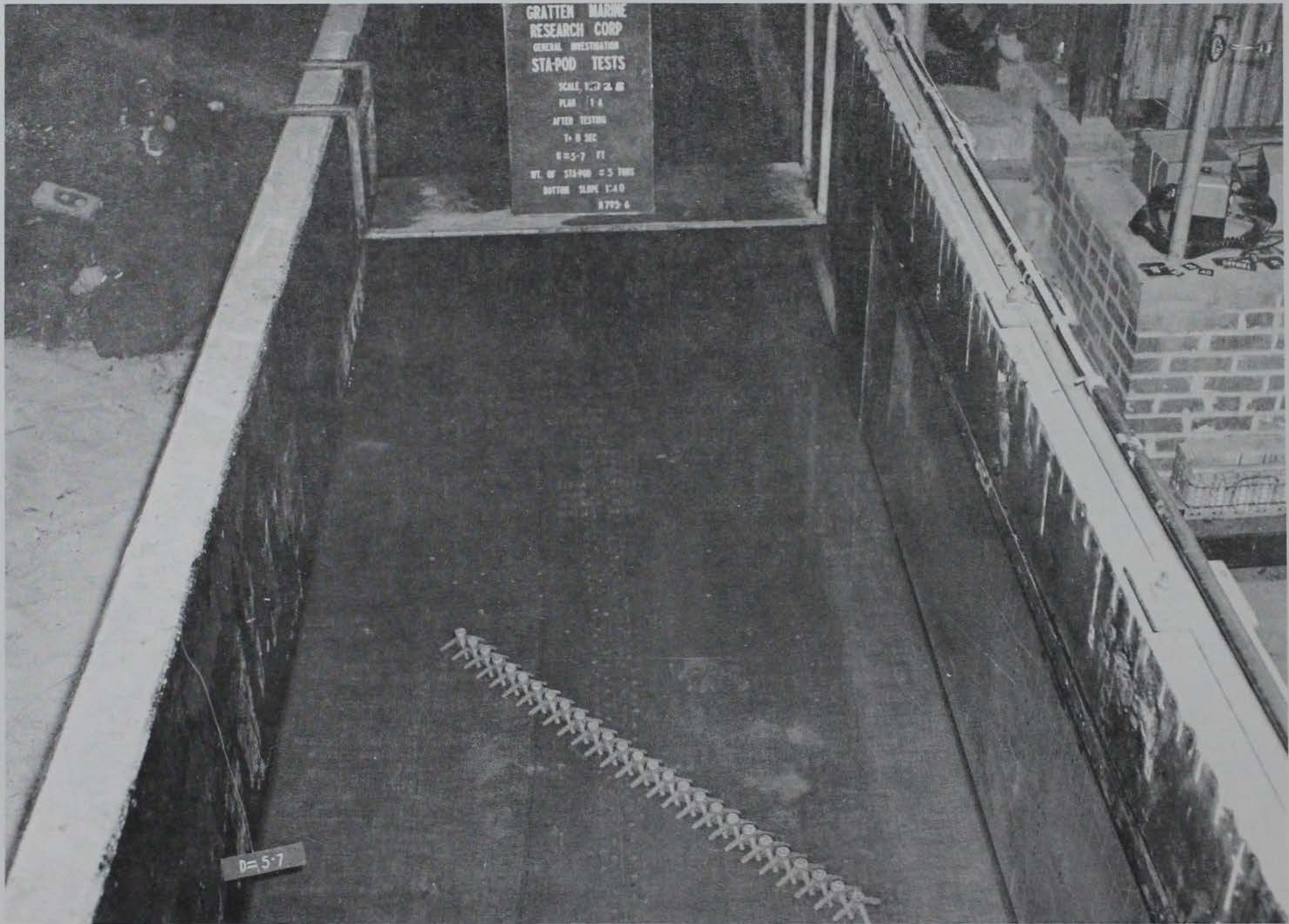
Photograph 3. Plan 1 before wave attack. Five-ton STA-PODS 90 degrees to beach; beach slope 1:40; depth = 5.7 ft



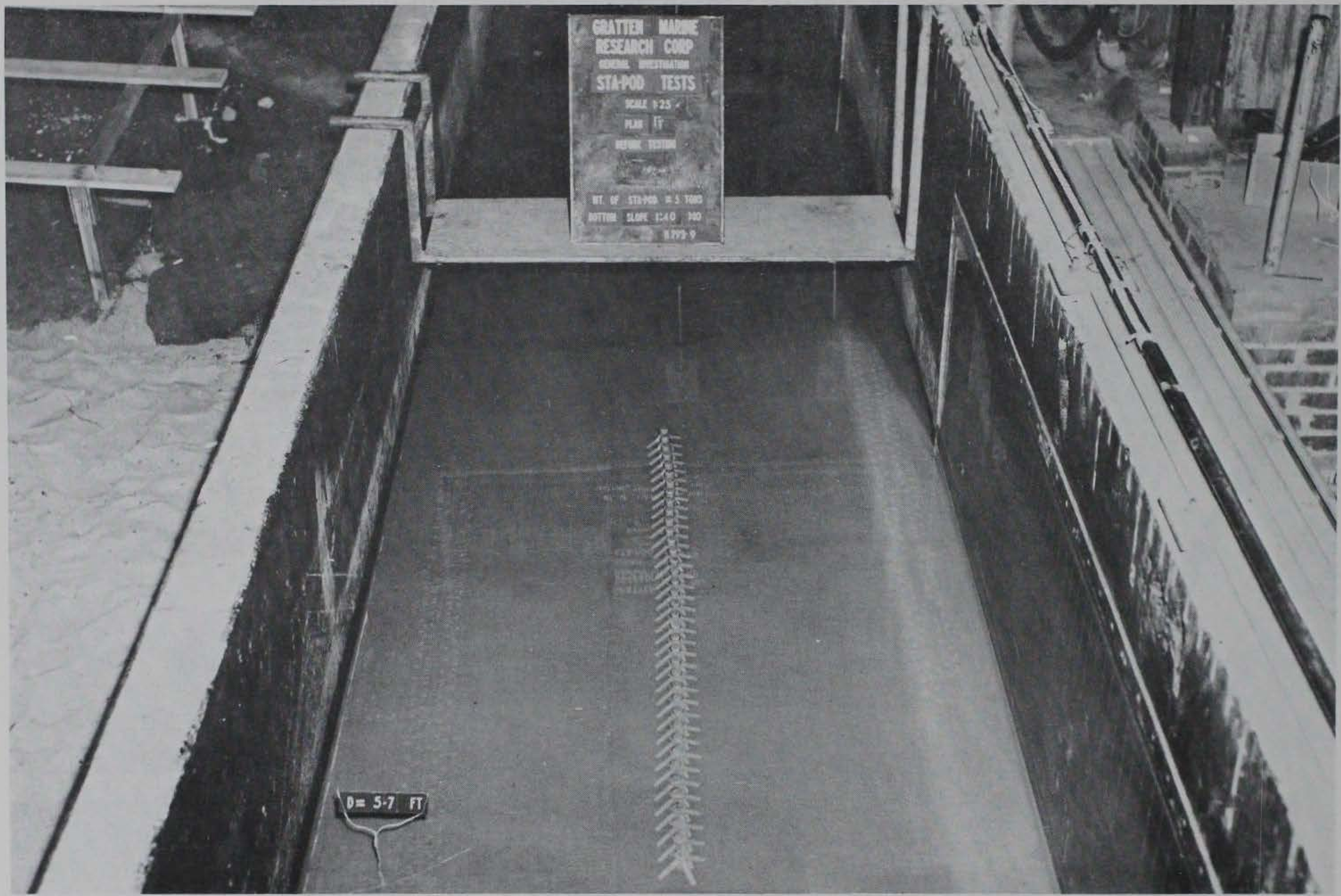
Photograph 4. Plan 1 after attack by 5.7-ft, 8-sec waves



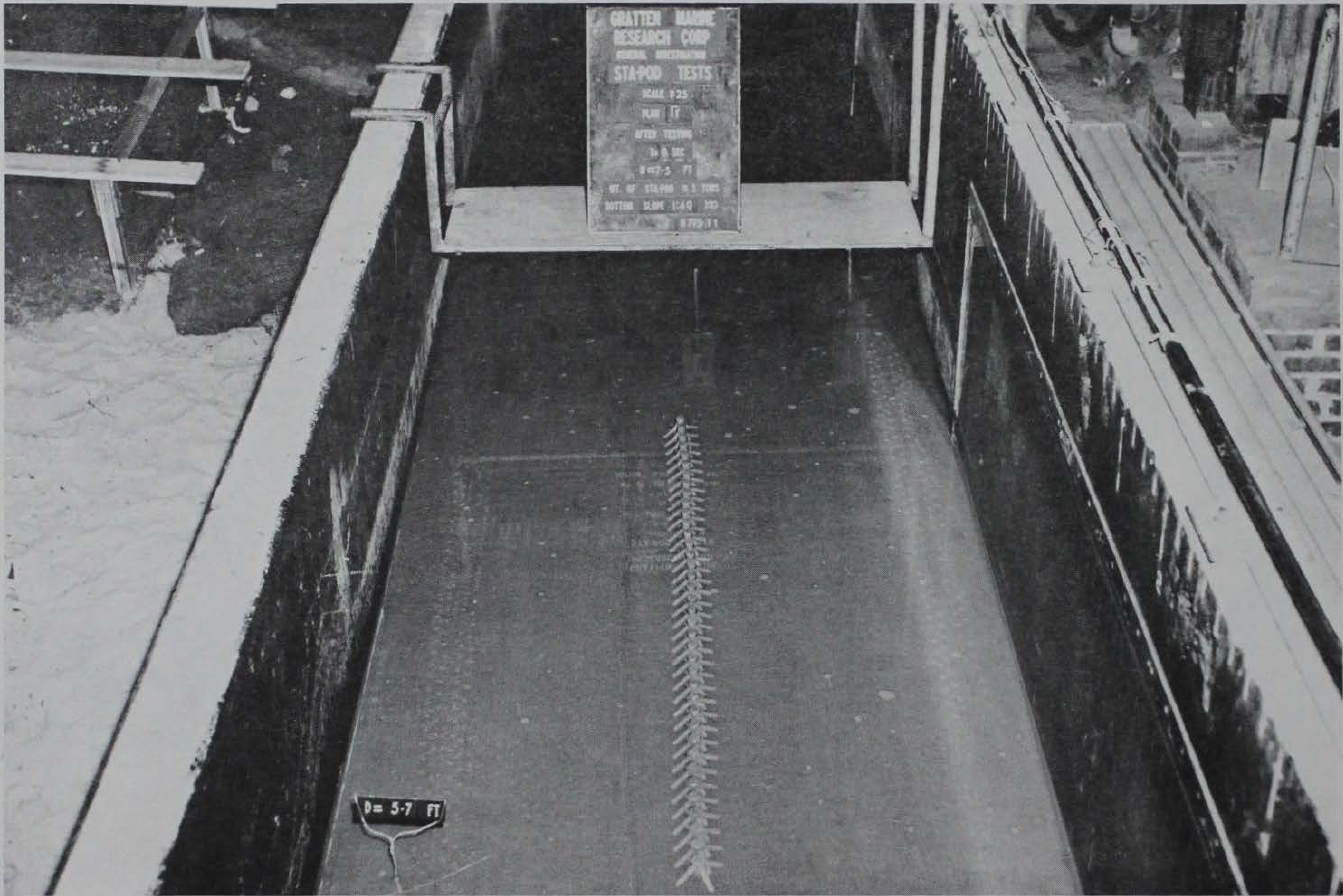
Photograph 5. Plan 1A before wave attack. Five-ton STA-PODS 45 degrees to beach; beach slope 1:40; depth = 5.7 ft



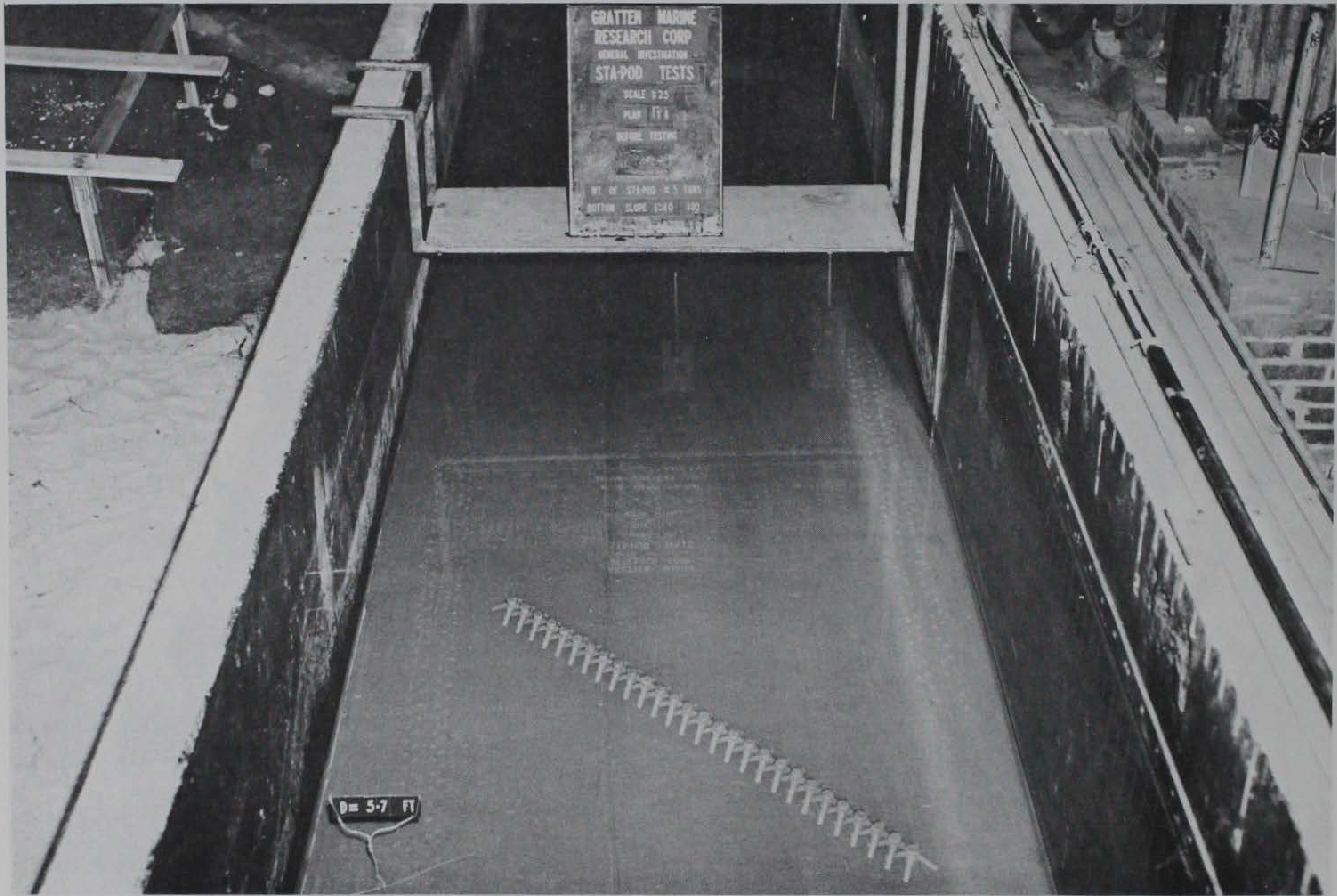
Photograph 6. Plan 1A after attack by 5.7-ft, 8-sec waves



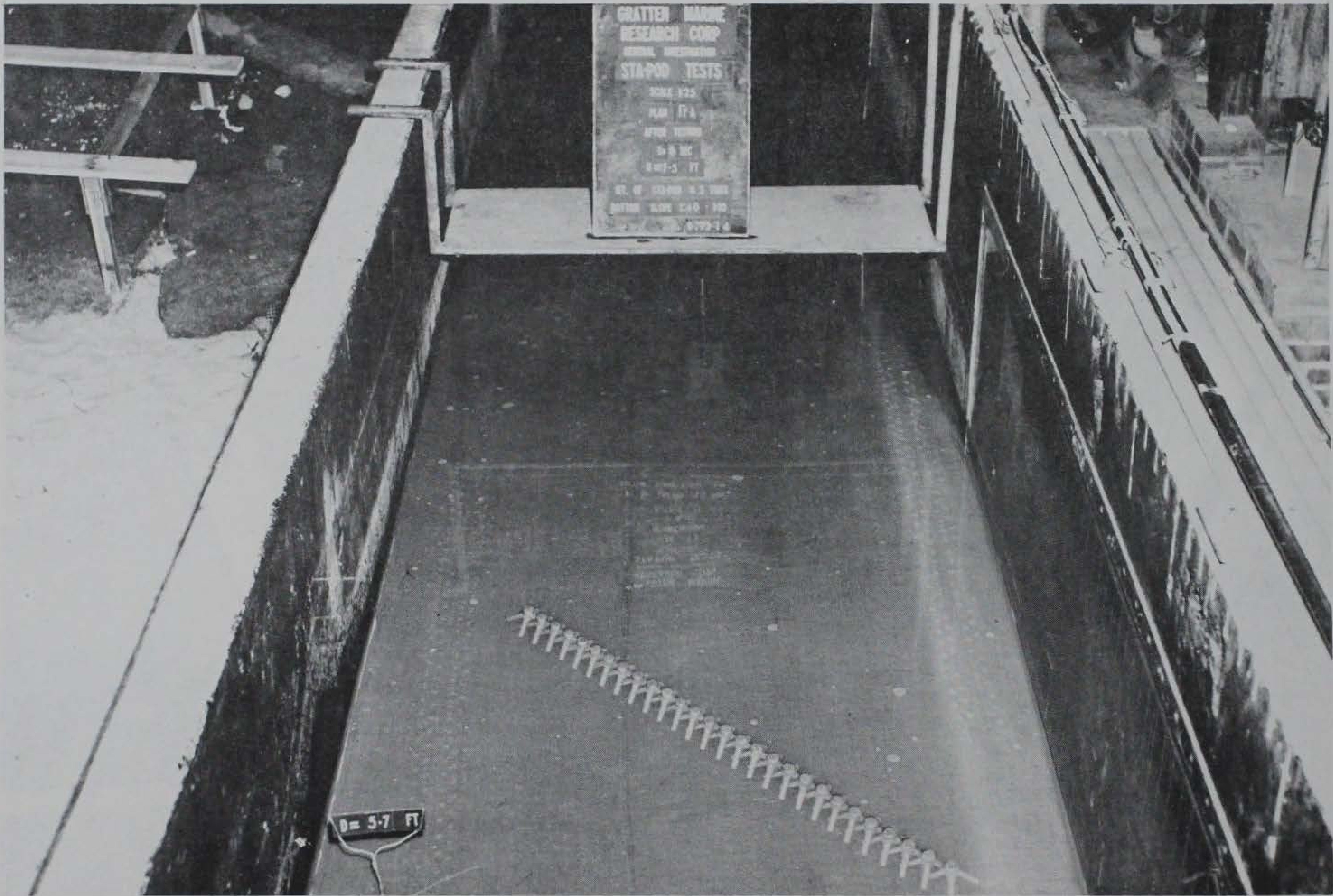
Photograph 7. Plan 1 before wave attack. Five-ton STA-PODS 90 degrees to beach; beach slope 1:10 and 1:40, depth = 5.7 ft



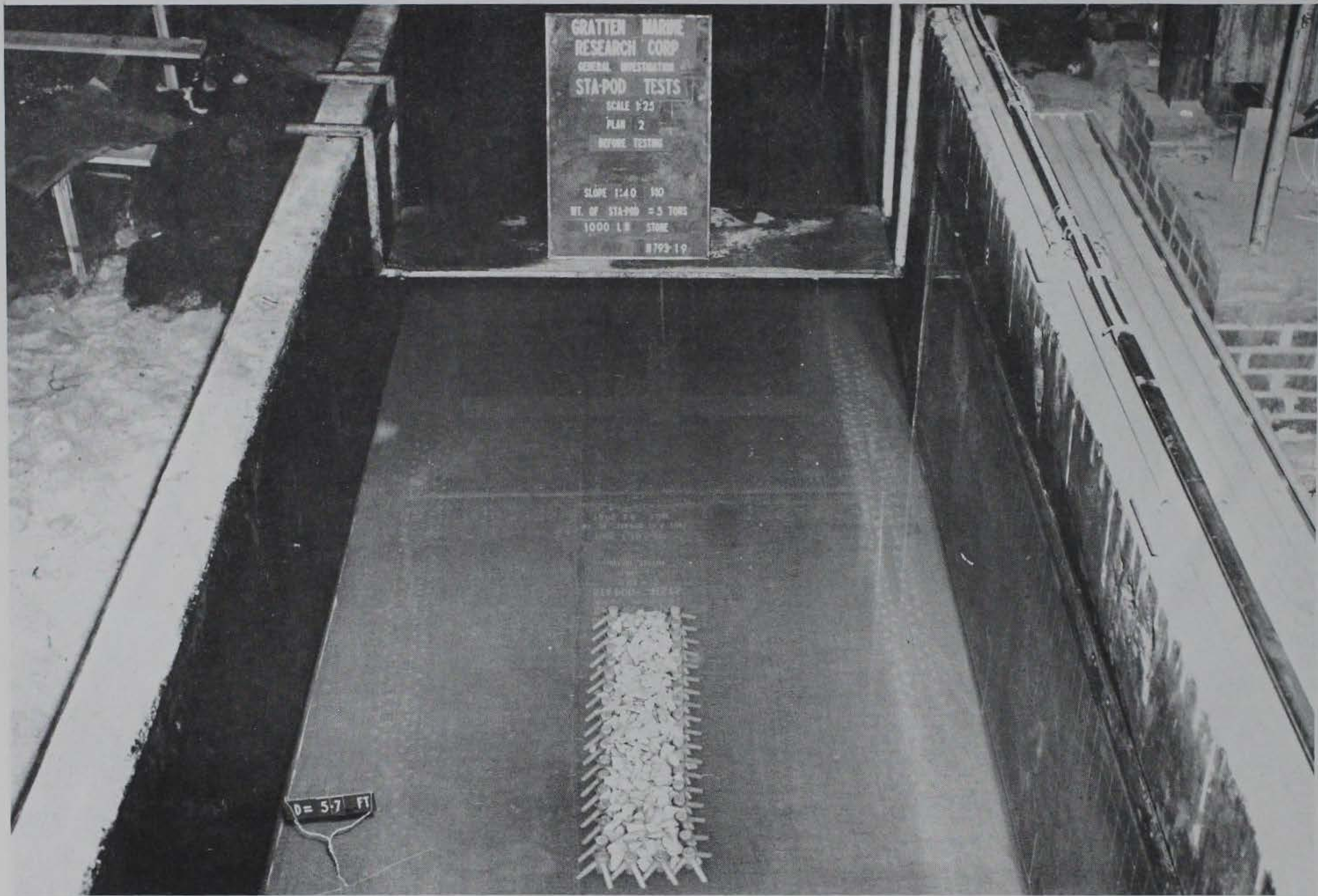
Photograph 8. Plan 1 after attack by 7.5-ft, 8-sec waves



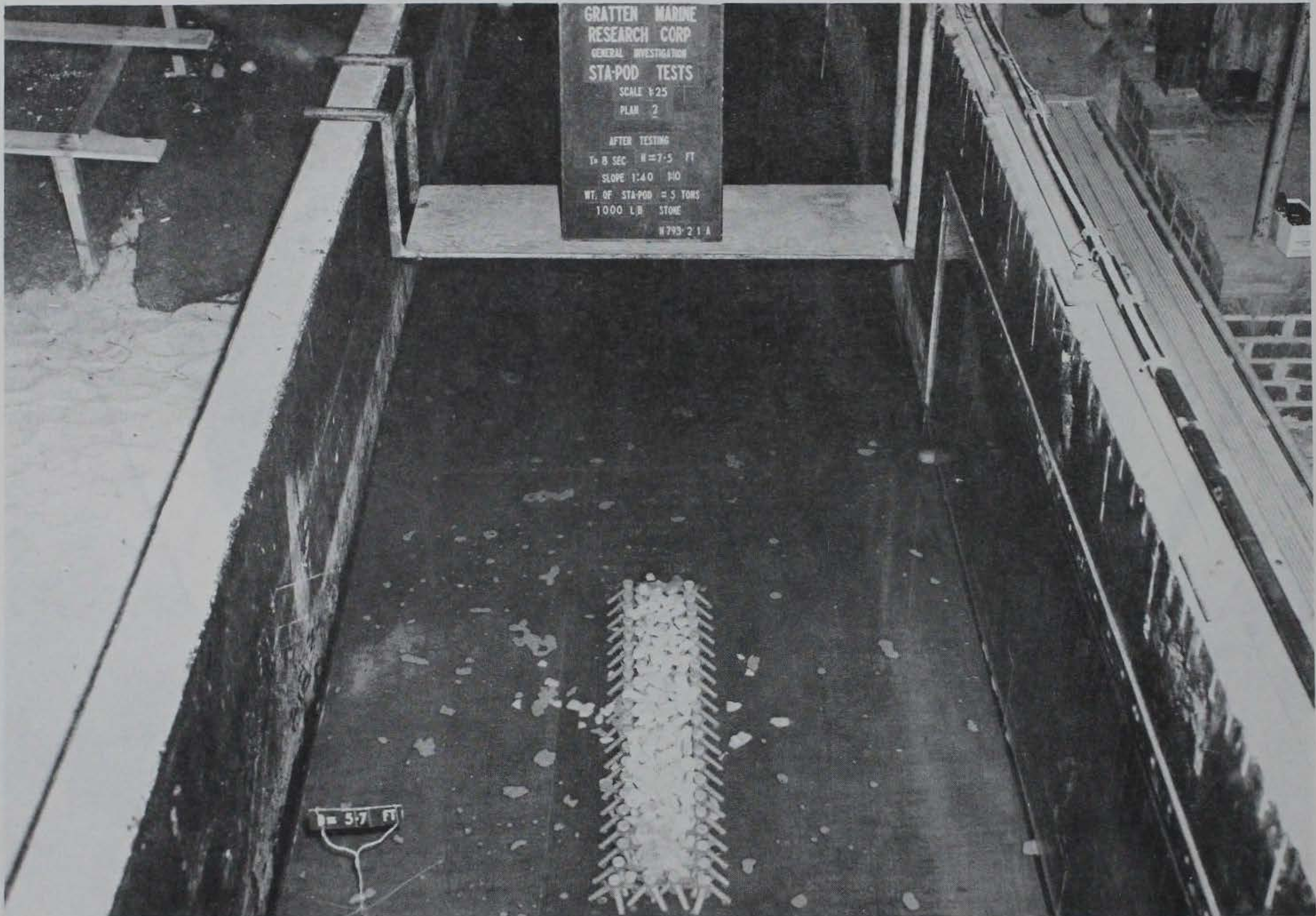
Photograph 9. Plan 1A before wave attack. Five-ton STA-PODS 45 degrees to beach; beach slope 1:10 and 1:40; depth = 5.7 ft



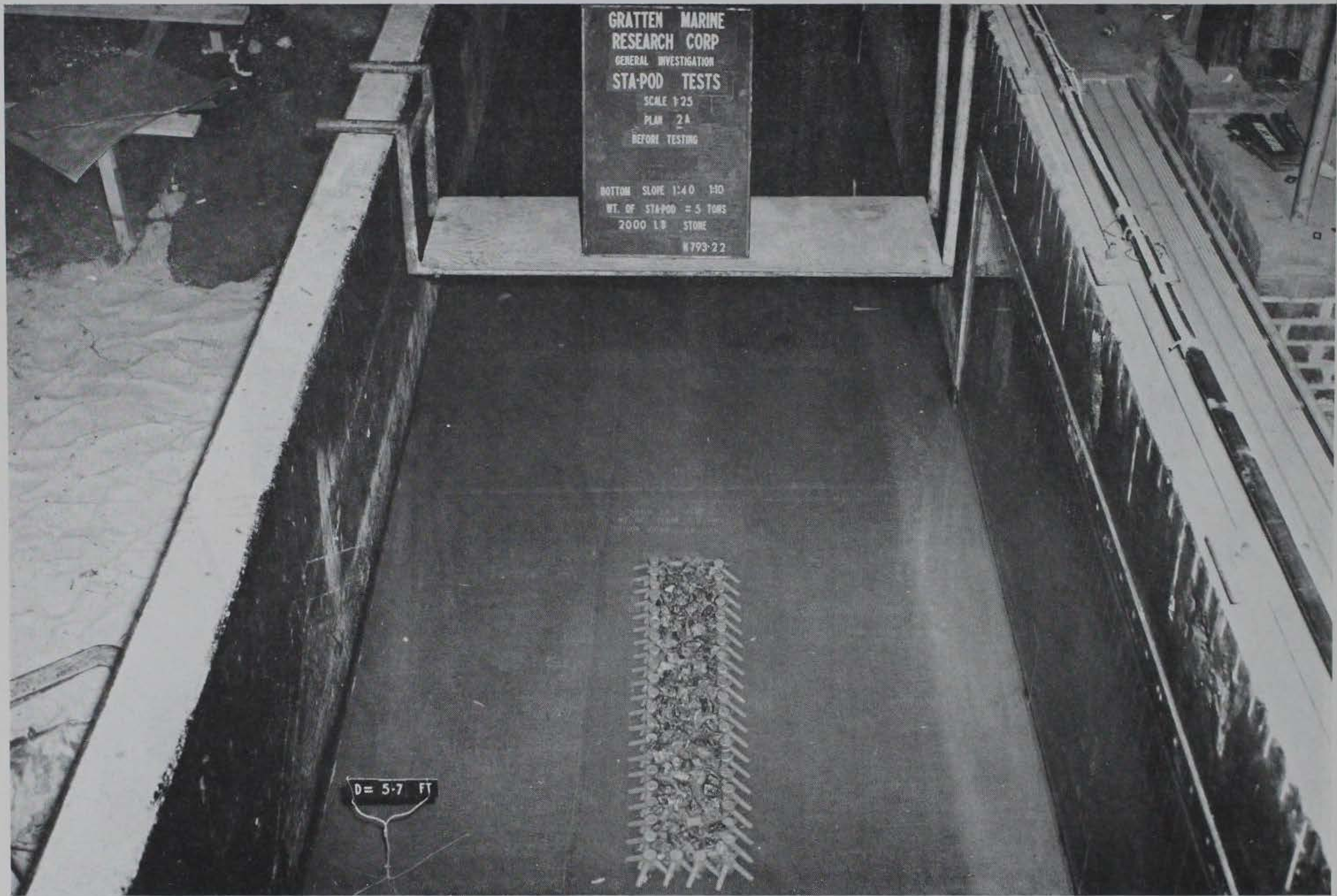
Photograph 10. Plan 1A after attack by 7.5-ft, 8-sec waves



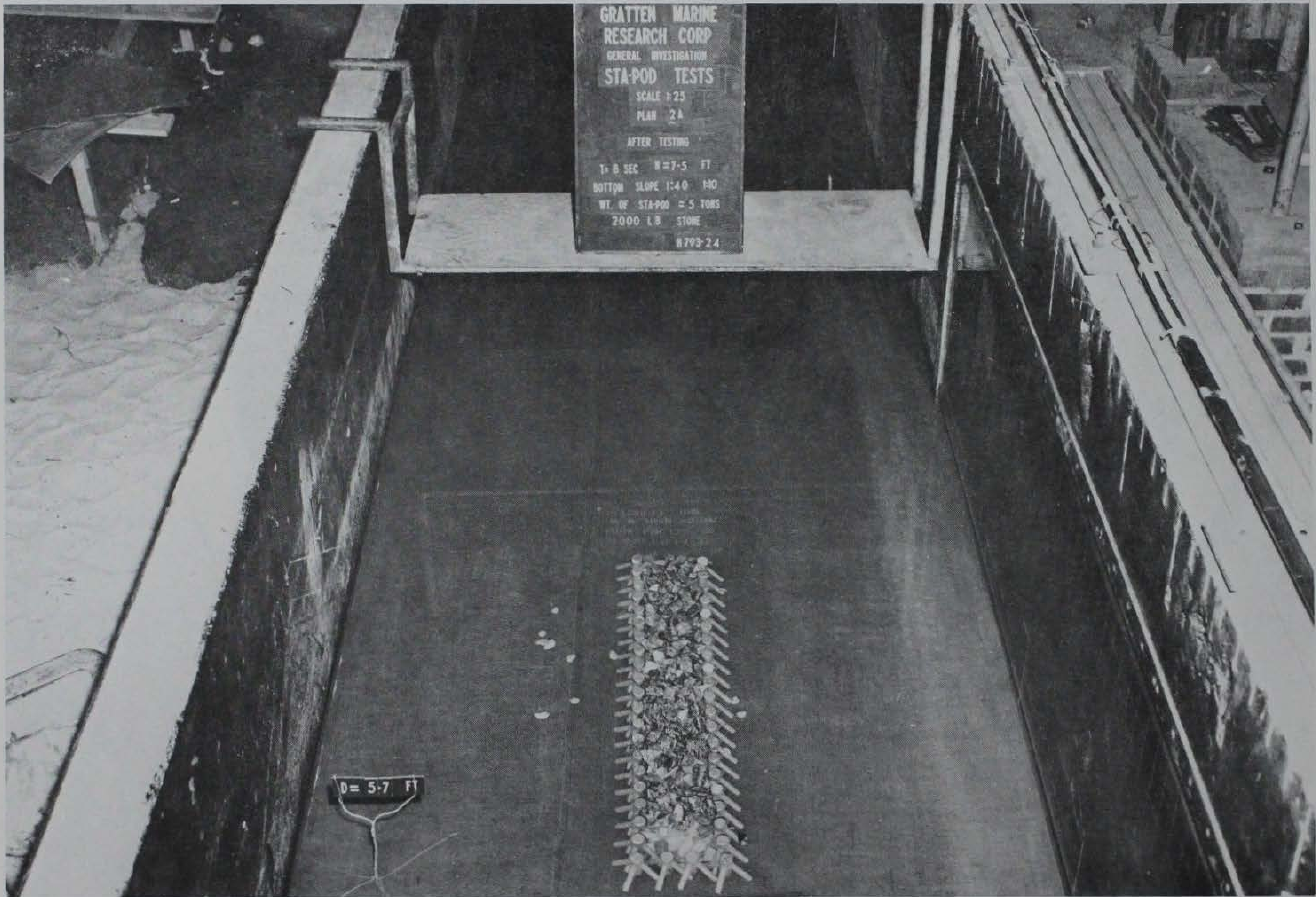
Photograph 11. Plan 2 before wave attack. Five-ton STA-PODS with 1000-lb cap stone; beach slope 1:10 and 1:40; depth = 5.7 ft



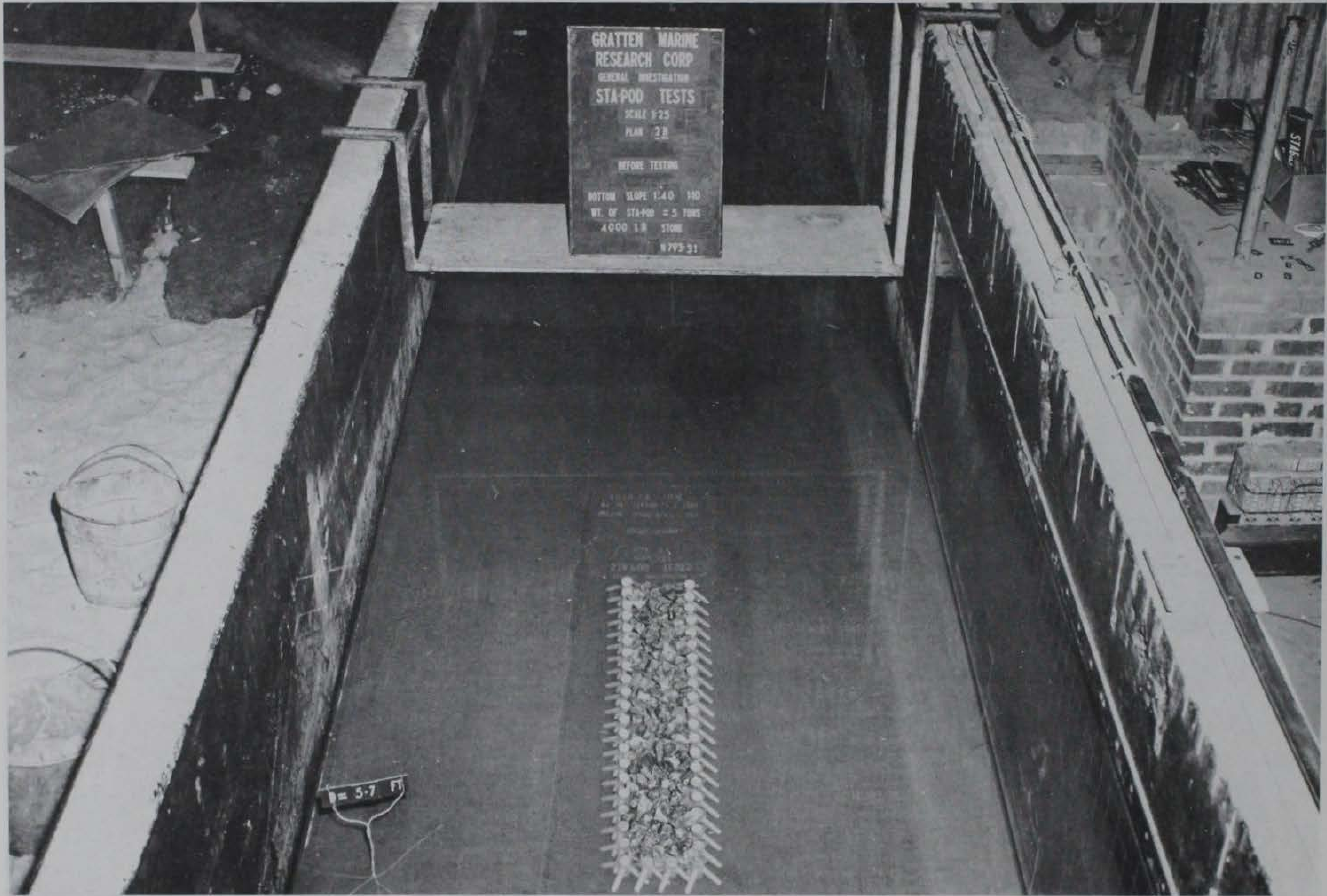
Photograph 12. Plan 2 after attack by 7.5-ft, 8-sec waves



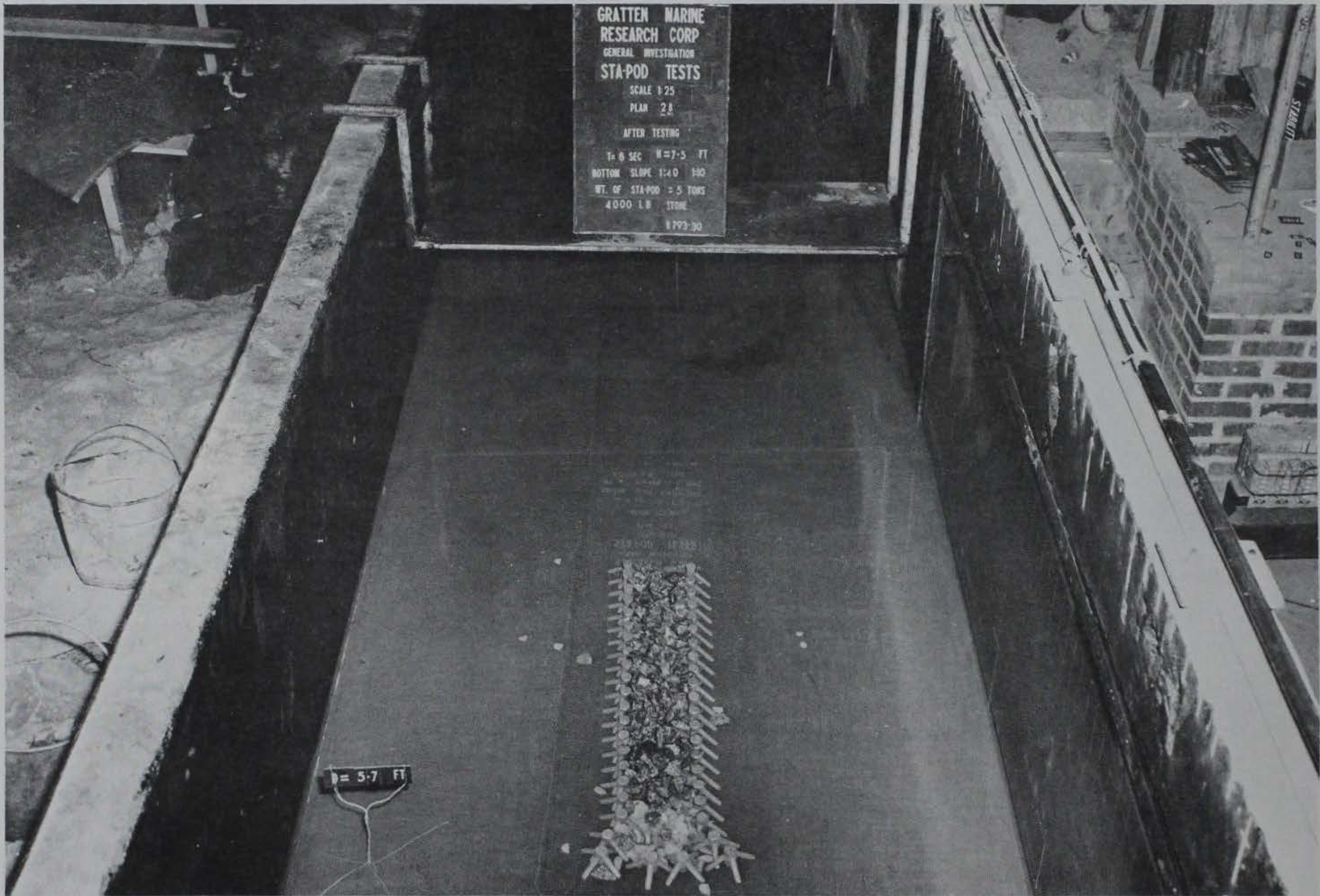
Photograph 13. Plan 2A before wave attack. Five-ton STA-PODS with 2000-lb cap stone; beach slope 1:10 and 1:40; depth = 5.7 ft



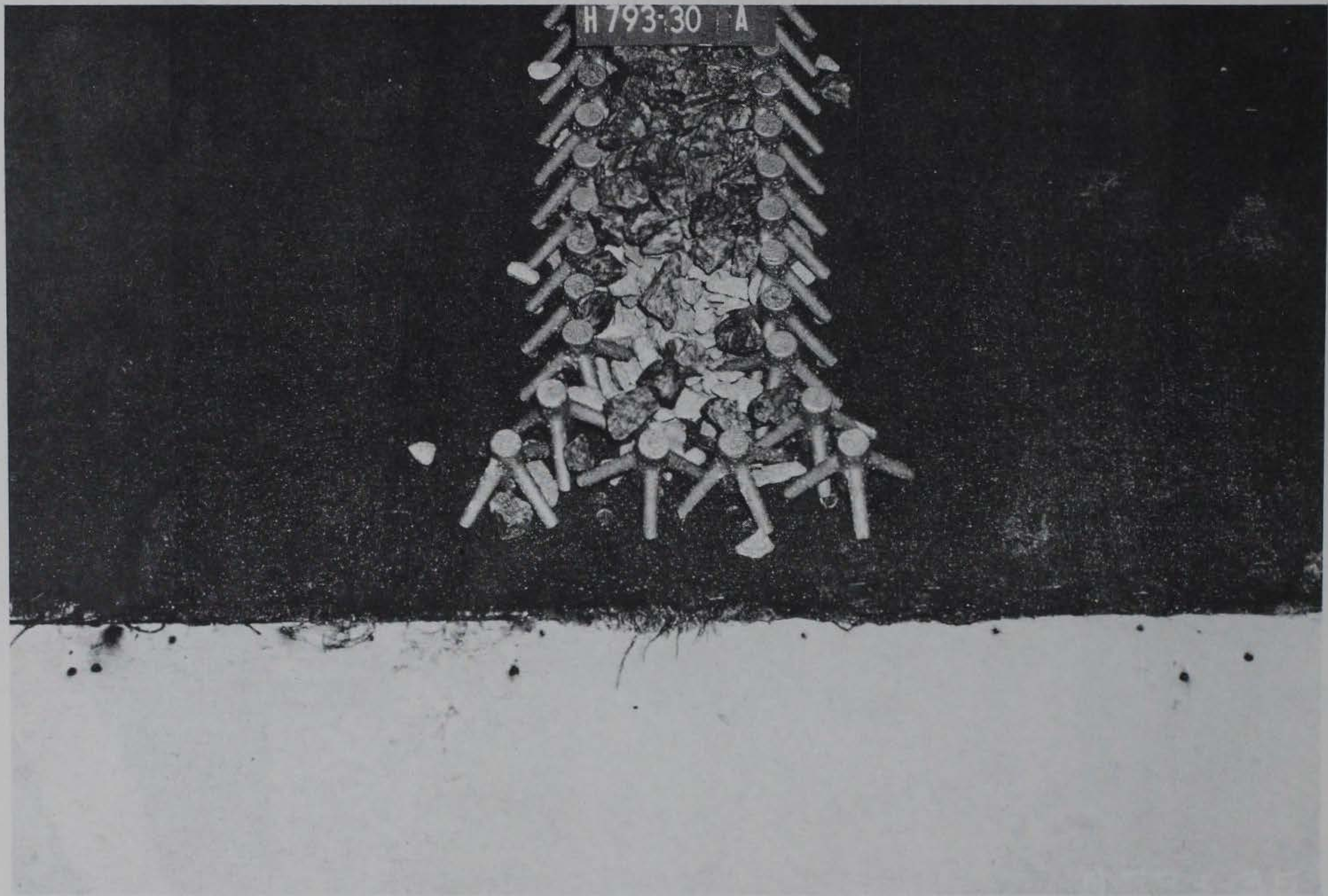
Photograph 14. Plan 2A after attack by 7.5-ft, 8-sec waves



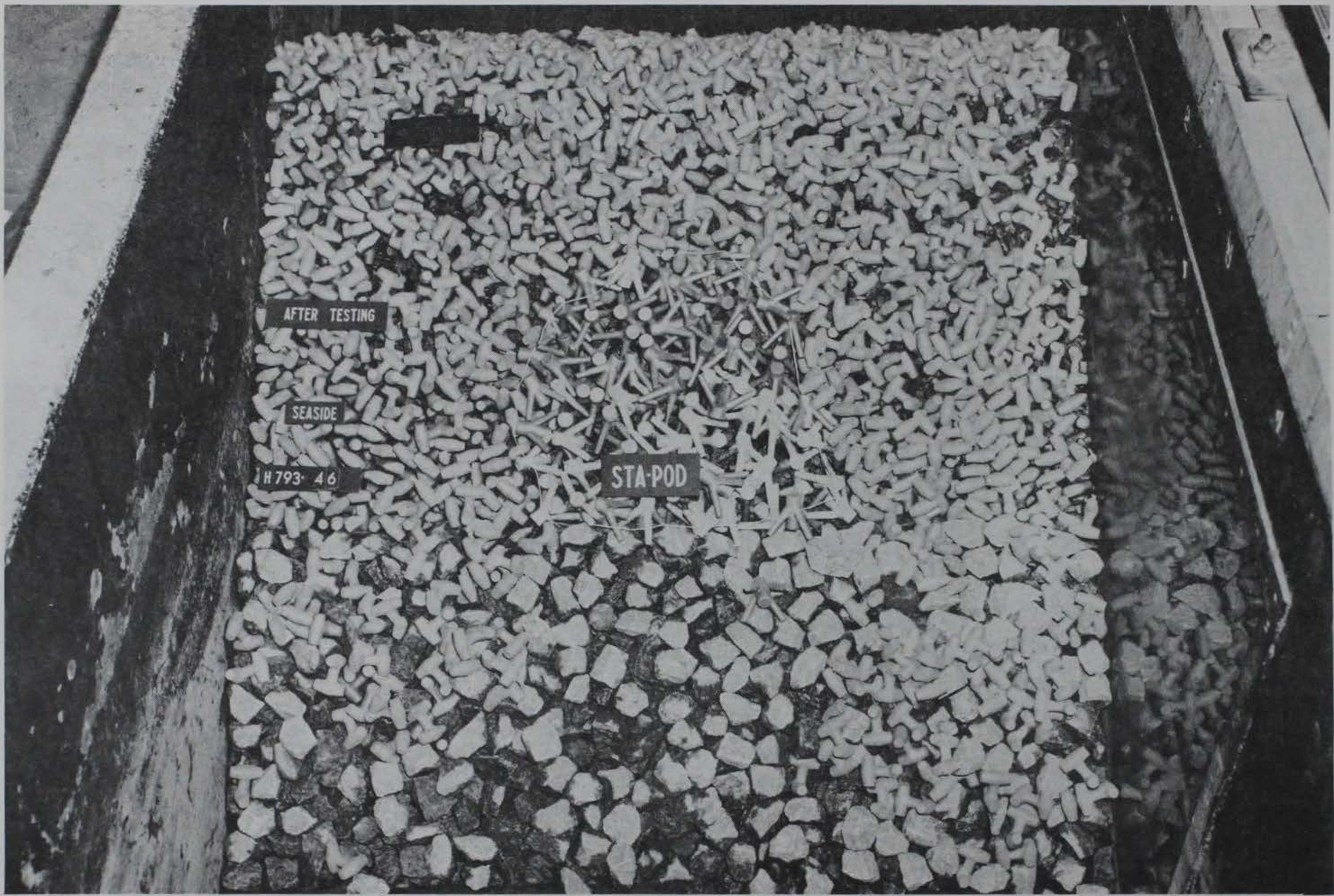
Photograph 15. Plan 2B before wave attack. Five-ton STA-PODS with 4000-lb cap stone; beach slope 1:10 and 1:40; depth = 5.7 ft



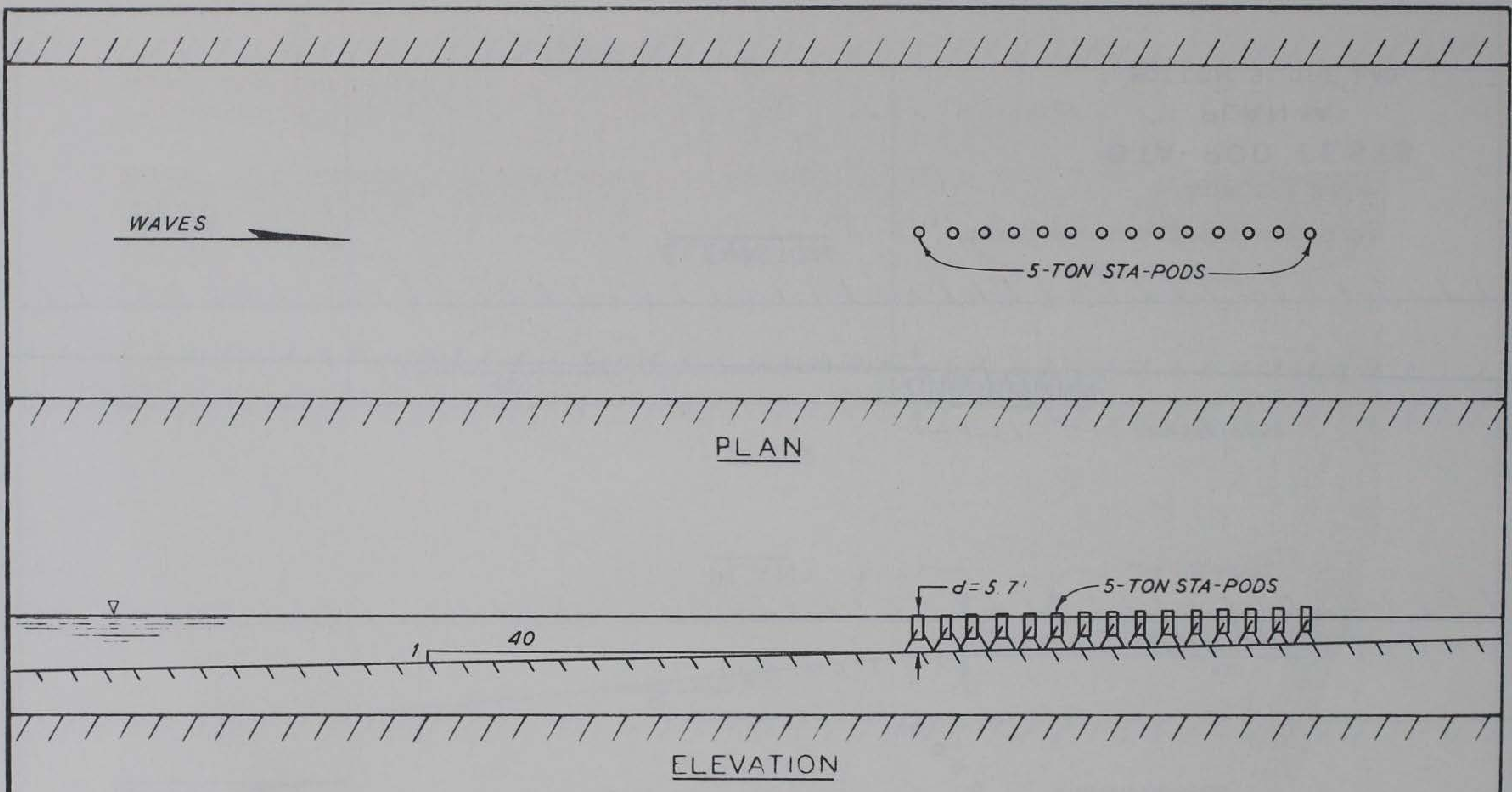
Photograph 16. Plan 2B after attack by 7.5-ft, 8-sec waves



Photograph 17. Closeup view of Plan 2B after attack by 7.5-ft, 8-sec waves



Photograph 18. After testing view of preliminary STA-POD test section. No significant damage occurred to the 0.37-lb STA-PODS for wave heights up to 0.60 ft at which the test was stopped because of failure of surrounding concrete armor units

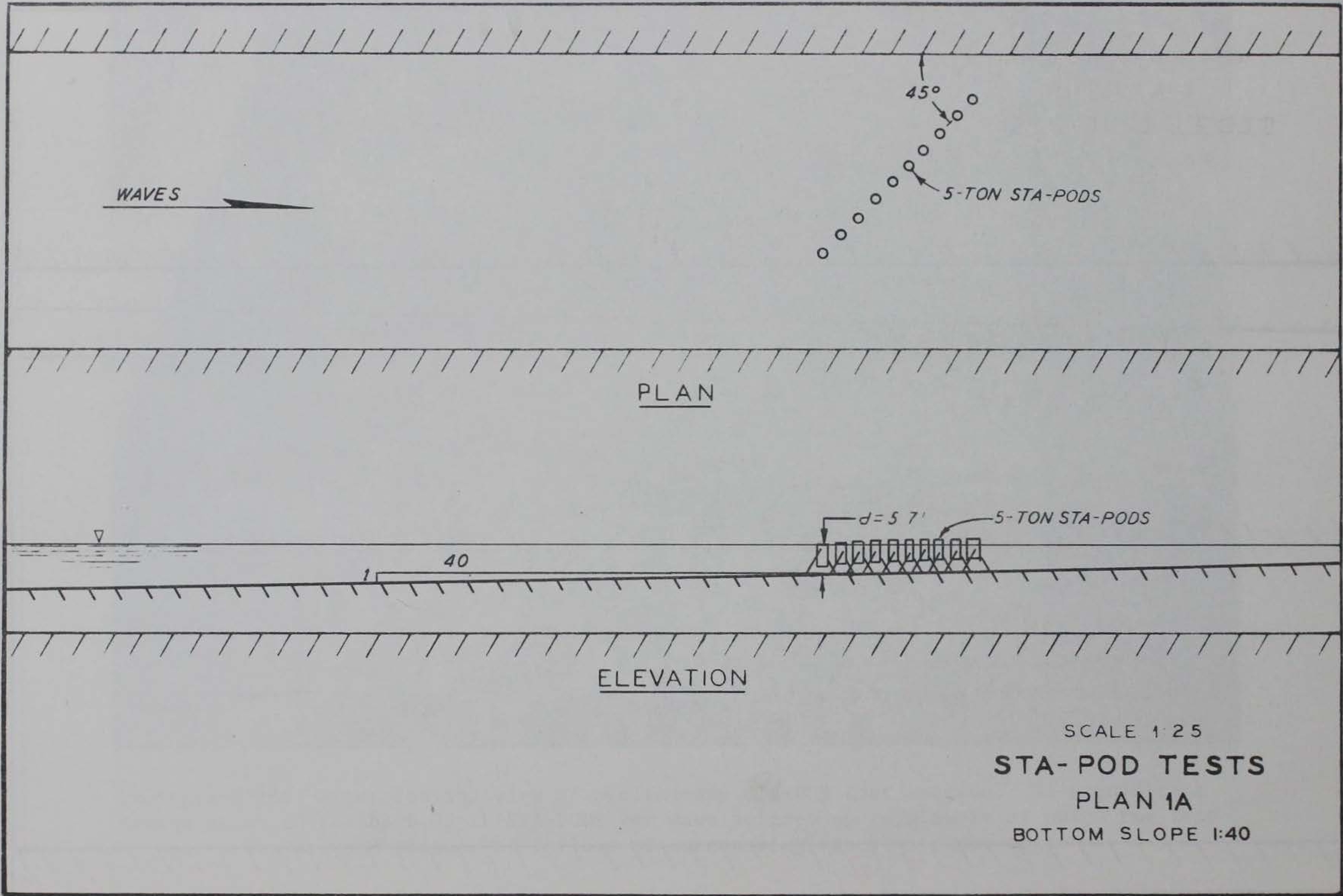


SCALE 1:25

STA-POD TESTS

PLAN 1

BOTTOM SLOPE 1:40

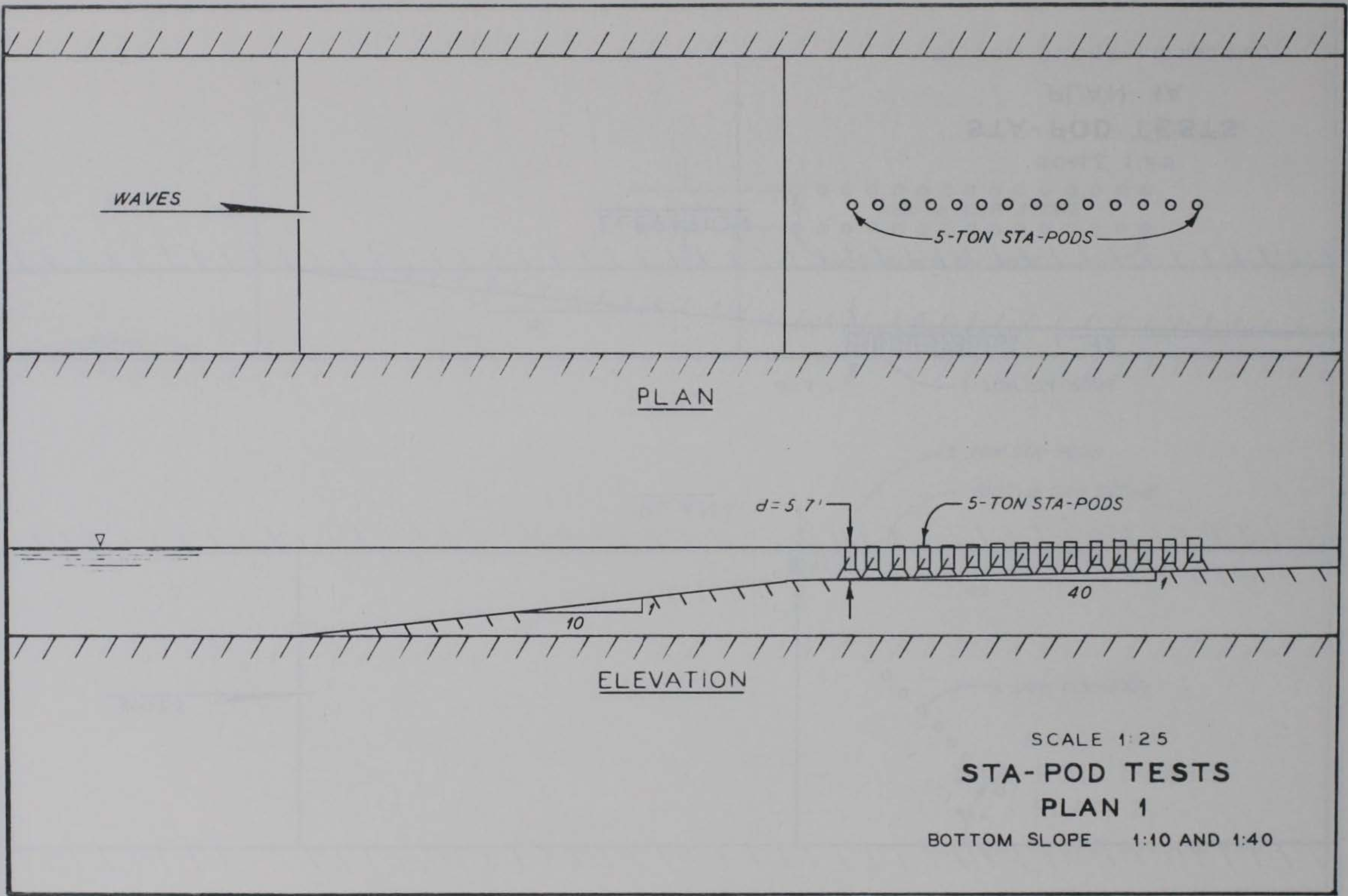


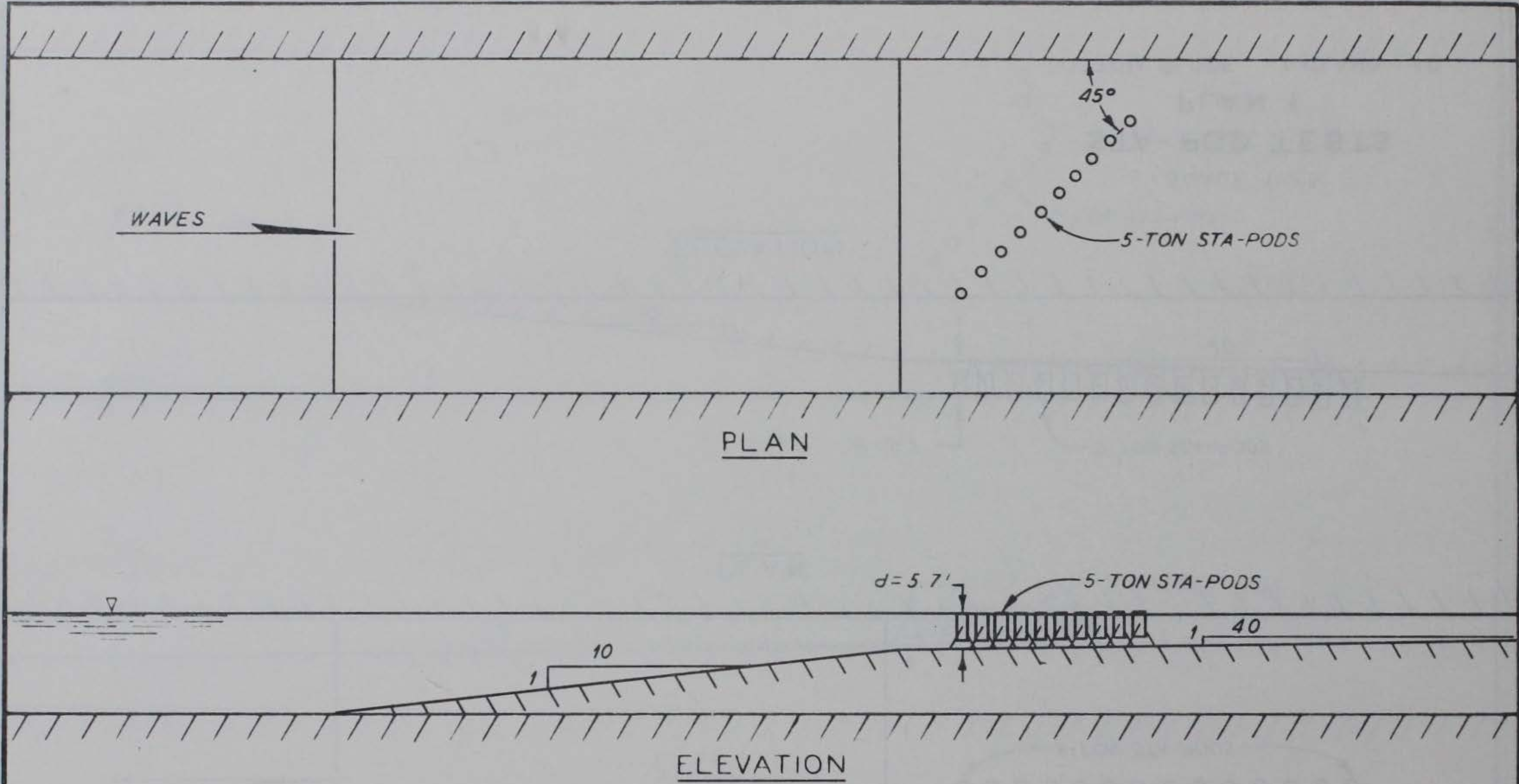
SCALE 1:25

STA-POD TESTS

PLAN 1A

BOTTOM SLOPE 1:40


WAVES
5-TON STA-PODS
PLAN
d = 5.7'
5-TON STA-PODS
10
1
40
1
ELEVATION
SCALE 1:25
STA-POD TESTS
PLAN 1
BOTTOM SLOPE 1:10 AND 1:40

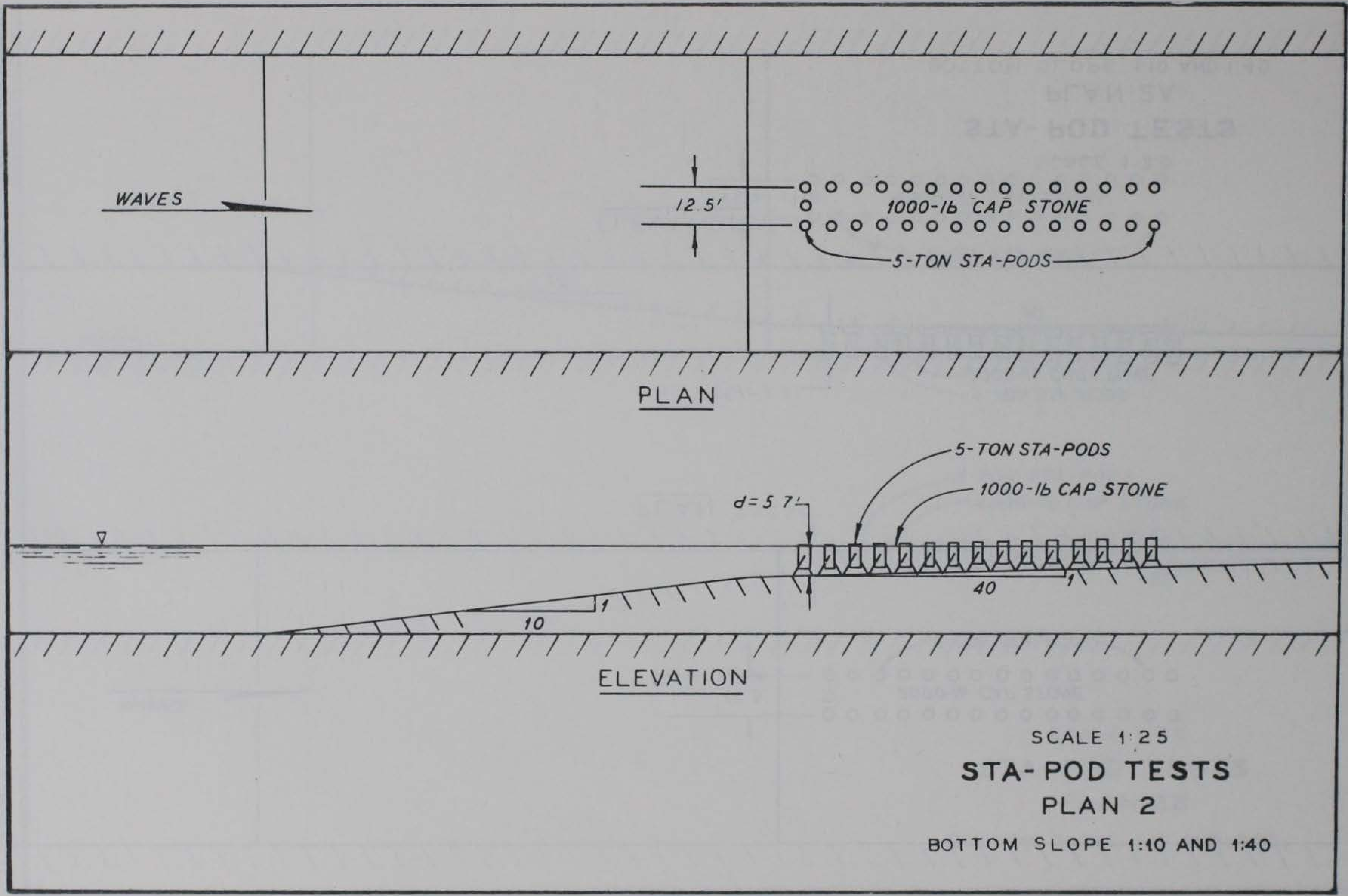


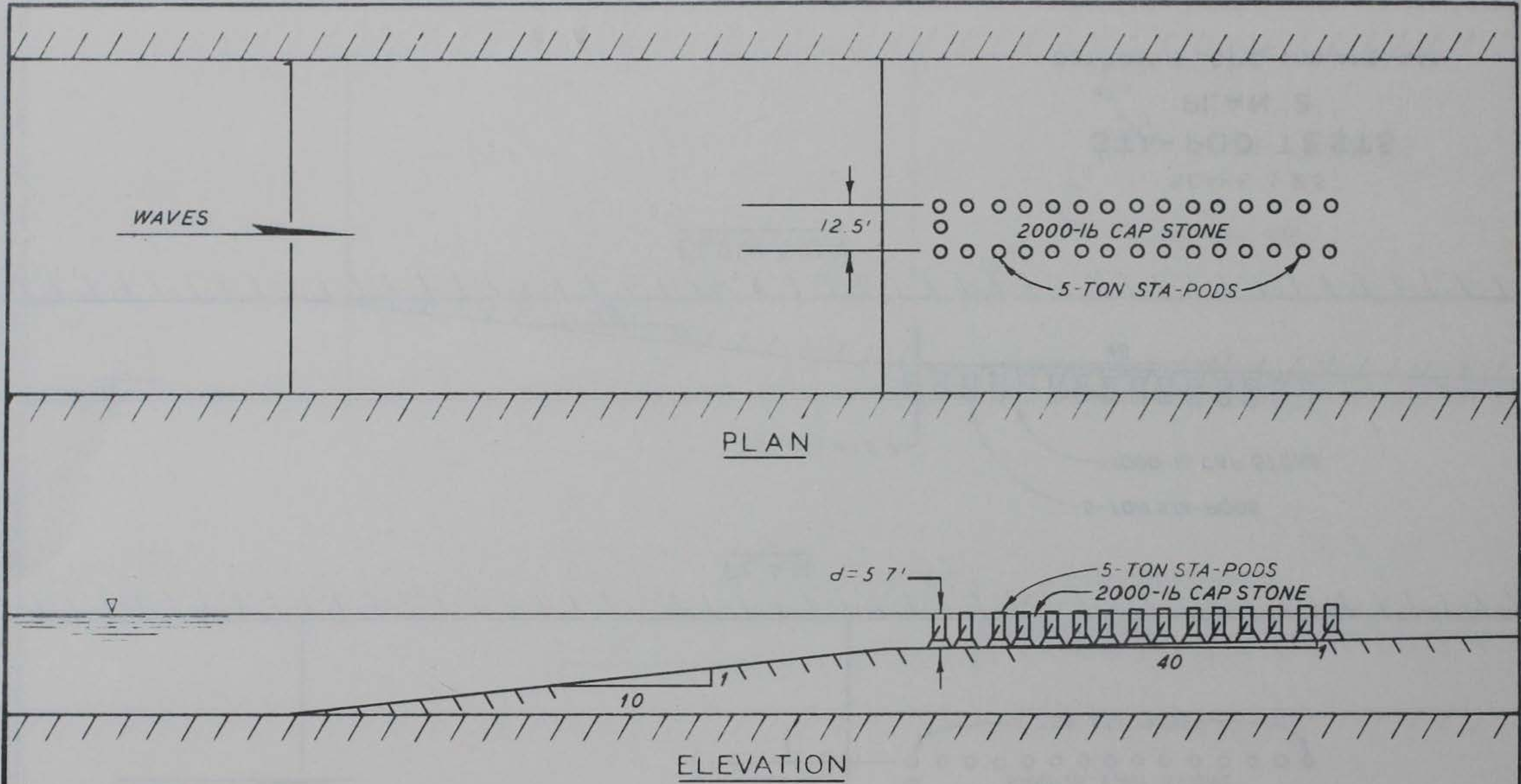
SCALE 1:25

STA-POD TESTS

PLAN 1A

BOTTOM SLOPE 1:10 AND 1:40


WAVES
12.5'
1000-lb CAP STONE
5-TON STA-PODS
PLAN
5-TON STA-PODS
1000-lb CAP STONE
d=5.7'
1
40
1
10
ELEVATION
SCALE 1:25
STA-POD TESTS
PLAN 2
BOTTOM SLOPE 1:10 AND 1:40

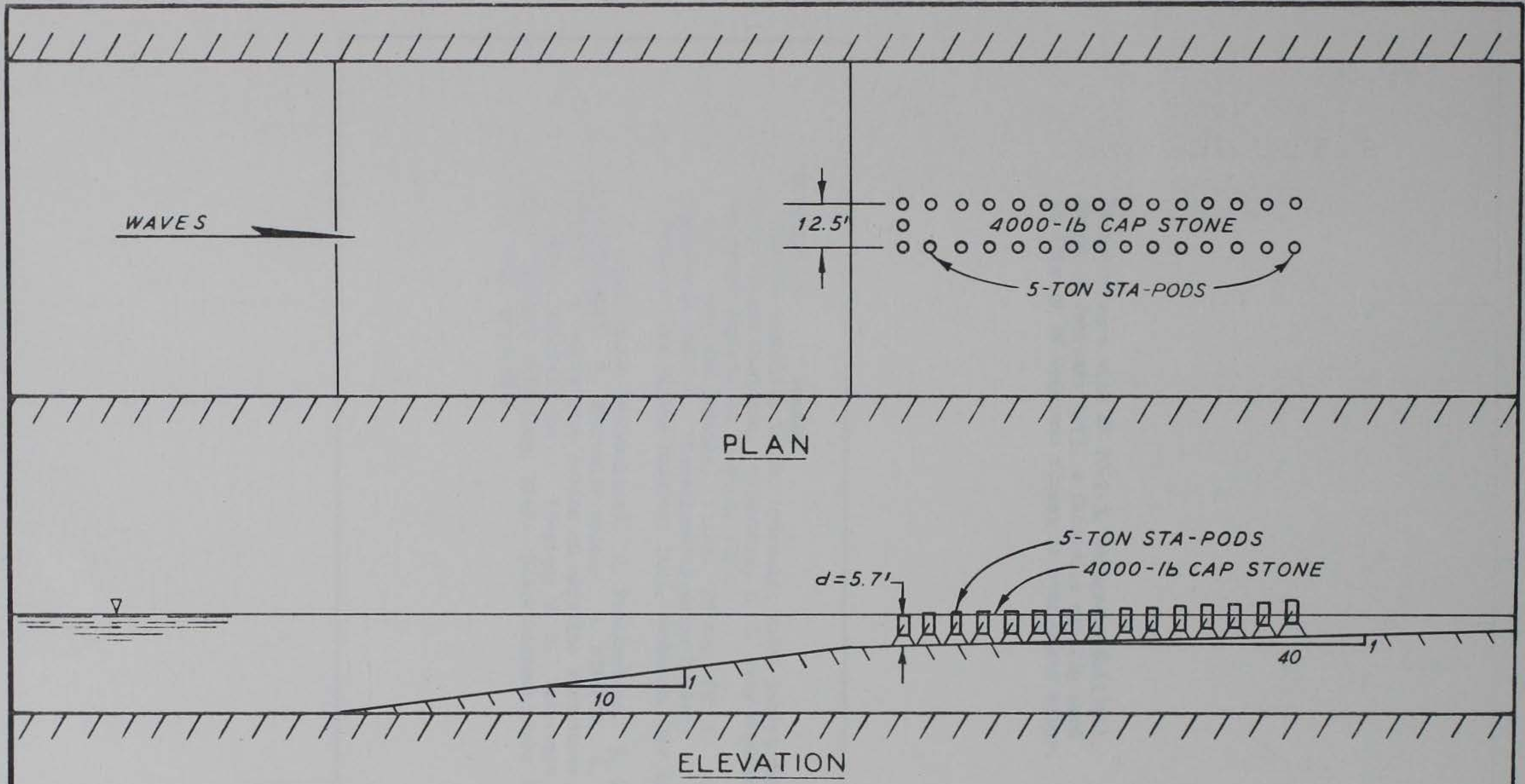


SCALE 1:25

STA-POD TESTS

PLAN 2A

BOTTOM SLOPE 1:10 AND 1:40



SCALE 1:25

STA-POD TESTS

PLAN 2B

BOTTOM SLOPE 1:10 AND 1:40