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BEACH STABILIZATION TESTS OF LANDING MATS AND PREFABRICATED MEMBRANES

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TECHNICAL REPORT NO. 3-592

February 1962

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi



FEB. 1962

BEACH STABILIZATION TESTS OF LANDING MATS & PREFABRICATED MEMBRANES

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BEACH STABILIZATION TESTS OF LANDING MATS AND PREFABRICATED MEMBRANES



TECHNICAL REPORT NO. 3-592

February 1962

**U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi**

ARMY-MRC VICKSBURG, MISS.

PREFACE

The investigation reported herein was conducted under Corps of Engineers Subproject 8-70-01-400,* "Engineering Studies and Investigations, Ground Mobility Research," and related Subprojects 8-70-03-420,** "Prefabricated Airfield and Road Surfacing Membrane," and 8-70-03-440,** "Landing Mats, Airfield, Metal." Specific authorization for the investigation was given by the Office, Chief of Engineers, in first indorsement dated 12 February 1958 to U. S. Army Engineer Waterways Experiment Station letter dated 17 January 1958, subject, "Proposed Waterways Experiment Station Test Program for Beach Operations."

Field tests of landing mats and prefabricated membranes were conducted in Europe during May-June 1959 along the Brittany coast of France. Coordination of plans for the accomplishment of the tests was effected through the Engineer Offices at Headquarters Communication Zone, Orleans, France, and Base Section, Poitiers, France. Particular acknowledgment is made to Col. G. W. Bixby, Engineer for Communication Zone, Col. I. W. Finberg, Engineer for Base Section, and members of their staffs for the excellent cooperation rendered at all echelons of command. The 89th Port Construction Company of the 83rd Engineer Battalion (Const) provided direct support in the field; transportation for the Waterways Experiment Station field party was provided by the St. Nazaire Installation commanded by Maj. W. C. McKinney.

* Now Task 01 under Project 8S70-05-001, "Trafficability and Mobility Research."

** Now Task 05 under Project 8S70-05-001.

Engineers of the Waterways Experiment Station who were actively engaged in the planning, testing, analysis, and report phases of this investigation were Messrs. W. J. Turnbull, A. A. Maxwell, W. L. McInnis, S. G. Tucker, and J. L. Garrett. This report was prepared by Messrs. Tucker and Garrett.

Col. Edmund H. Lang, CE, and Col. Alex G. Sutton, Jr., CE, were Directors of the Waterways Experiment Station during the conduct of this study and preparation of this report. Mr. J. B. Tiffany was Technical Director.

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SUMMARY

Field tests were conducted at La Turballe Beach and Suscinio Beach, on the Brittany coast of France, on three metal landing mats and three prefabricated membranes to determine their suitability and effectiveness as portable surfacing expedients for increasing the trafficability potential of unprepared beaches for emergency offshore discharge operations. Mats tested were: the PSP, a light pierced steel plank; the M8, a heavier pierced or perforated steel mat; and the T11, an extruded aluminum mat. Membranes tested were: the T1, a No. 8 cotton duck, vinyl-coated membrane; and the T12 and T14, neoprene-coated nylon membranes.

The metal mats and membranes were placed on two undisturbed beach areas subject to the action of waves and tides, and accelerated traffic was applied with typical military vehicles usually employed in emergency offshore discharge operations. In some cases, the mats were placed directly on the beach subgrade; in others, membrane was placed directly on the subgrade and mats were placed atop the membrane. One of the beach test sites consisted of a loose sand and steep slope, whereas the other test site provided a somewhat firmer sand and a flat-sloped beach.

Results of the tests indicated the following:

- a. All materials and/or combinations tested increased the trafficability potential of vehicular traffic across the beaches.
- b. Of the surfacing materials tested, the M8 steel landing mat underlain with membrane was the most satisfactory in performance.
- c. All membranes performed satisfactorily underneath the M8 steel mat.
- d. Membranes improved the performance of the PSP, but the No. 8 cotton duck (T1) sustained an appreciable number of punctures by the overlaid mat panels.
- e. All items tested can be rapidly removed and reused at various locations by field troops.

Based on results of this investigation, it is recommended that the M8 steel landing mat (either with or without membrane placed underneath) be used in emergency offshore discharge operations as a replacement for the

pierced steel plank (PSP) or pierced aluminum plank (PAP). Further, it is recommended that a study be conducted to develop a more satisfactory lightweight surfacing expedient for beach stabilization. Such study should include among other factors investigation of the effects of wave action, beach slope, tide, and variations in composition of beach materials.

BEACH STABILIZATION TESTS OF LANDING MATS

AND PREFABRICATED MEMBRANES

PART I: INTRODUCTION

Background

1. New Offshore Discharge Exercises (NODEXES) are being conducted in Europe along the west coast of France to provide logistical training in the emergency use of unprepared beaches for unloading supplies. In the conduct of these exercises, considerable difficulty has been experienced in moving heavy equipment and supplies across the beaches because of inability of the beach materials to support traffic. Pierced steel plank (PSP) and pierced aluminum plank (PAP) remaining from World War II have been utilized in various NODEXES in an attempt to stabilize the beach surfaces, but results have not been very satisfactory. At the request of the Engineer, Headquarters United States Army Communications Zone Europe, representatives of the U. S. Army Engineer Waterways Experiment Station attended NODEX 17 in October 1957 to observe the conduct of this exercise and the difficulties involved in maneuvering across beaches. Based on results of these observations and discussions with U. S. Army Corps of Engineers personnel at Communications Zone and Base Section, France, the Waterways Experiment Station (WES) prepared a program of tests of landing mats and prefabricated membranes, and recommended that the tests be conducted on beaches under field conditions. Results of these tests are presented herein.

Purpose and Scope of Test Program

Purpose

2. The test program described in this report was conducted to obtain factual information for use in evaluating the relative effectiveness of several standard and experimental metal mats and prefabricated membranes in stabilizing unprepared beach sites subject to the action of waves and tides, and thus increase the trafficability potential of beaches for use in emergency offshore discharge operations. Past experience has proved that,

for the loads involved, these mats and membranes will perform satisfactorily on dry areas or on areas not affected directly by the fluctuation (rise and fall) of water. Specifically, it was desired to determine:

- a. The effectiveness of PSP, M8 and T11 metal landing mats, and T1, T12, and T14 prefabricated membranes in stabilizing unprepared beach sites.
- b. The time and effort involved in beach site preparation when prefabricated surfacing materials are used as stabilization measures.
- c. The operational suitability (suitability for use in a military mission including movement, supply, attack, etc.) of various surfacing expedients for preventing wave erosion of beaches between high and low tides.
- d. The effects of beach vehicular traffic on the landing mats and membranes.
- e. The feasibility of removing these portable surfacing materials for reuse on other beach sites.
- f. The towing forces required on landing mats and on unsurfaced sand beaches.
- g. The need for the development of a special expedient surfacing material for beach operations.

Scope

3. Field tests were conducted at La Turballe and Suscinio Beaches along the Brittany coast of France on three metal landing mats and three prefabricated membranes. The test items were placed on two undisturbed beach areas to afford a comparison of different sand conditions and beach gradients. All items were subjected to accelerated traffic of two military vehicles usually employed in emergency offshore discharge operations.

Specifically, the following types of tests were conducted:

- a. Limited soil tests to classify the different beach materials and to determine their moisture content, density, and approximate bearing capacity.
- b. Traffic tests on lanes surfaced with mat alone and with mat-membrane combinations to determine the performance of these materials under vehicular loads.
- c. Towing tests on mat- and mat-membrane-surfaced lanes and on unsurfaced beach areas to determine relative rolling resistance.

Visual observations of all pertinent phenomena were also made throughout the investigative periods.

Definitions of Pertinent Terms

4. For clarity, the meanings of certain terms used in this report are defined below.

Beach.* The zone of unconsolidated material that extends landward from the low-water line to the place where there is marked change in material or physiographic form (usually the effective limit of storm waves). A beach includes foreshore and backshore.

Foreshore.* That part of the beach that is ordinarily traversed by the uprush and backrush of the waves as the tides rise and fall.

Backshore.* That part of the beach between the foreshore and the dune area or coastline and acted upon by waves only during severe storms.

Dune area. An area of wind-deposited sand extending along the top of the backshore or coastline. Coastal dunes may be active or partially stabilized by vegetation.

Test lane. An area with only one type of mat placed directly on the beach or with one type of mat placed over membranes.

Tracking lane. Area of the test lane in which the passes by the test vehicles were controlled so that an exact rate and pattern of traffic were obtained.

Pass. One trip of the test vehicle over the tracking area of the test lane.

Subgrade. The nonprocessed soils upon which the membranes and landing mats were placed.

In-place density. The dry weight of soil, in pounds per cubic foot, existing at a particular time in the subgrade.

Moisture content. The ratio of weight of water to weight of solid matter. It is usually expressed as a percentage.

In-place CBR. The California Bearing Ratio of soil measured in the field.

Run. A strip equal to one width of the landing mat or membrane.

Overlap. The amount, in inches, that one run of membrane covers an adjacent run of membrane.

* Extracted from Appendix A of Beach Erosion Board Technical Report No. 4, dated June 1954.

Warp direction. The direction parallel to the long axis of the runs of membrane.

Neoprene. A synthetic, rubberlike plastic formed by the polymerization of chloroprene.

Vinyl. Any of a group of thermoplastic resins formed by the polymerization of a vinyl compound. Resins of this group are resistant to chemical agents and are used for surface coatings, molded articles, etc.

Erosion. The washing away or removal of soil particles by water moving under and around portions of the landing mat or membrane placed in contact with the soil.

Towing force. The force required to tow a given vehicle under specific test conditions.

PART II: MATERIALS, TESTS, AND DATA OBTAINED

Materials Tested

5. The PSP and M8 steel mats were procured through the Engineer Office, Base Section, and the U. S. Air Force, Europe, from available stocks in France. The T11 aluminum mat and all membranes were furnished by the WES.

Landing mats

6. Landing mats used in these tests were as follows:

- a. PSP. Pierced steel plank (PSP), used in World War II and also used extensively in previous NODEX operations, was utilized in these tests for purposes of comparison. The mat conforms substantially to Corps of Engineers drawing D-2114-1. Nomenclature for this item is: mat, airplane landing, steel, pierced-plank type, 0.134-in. sheet (see fig. 1).

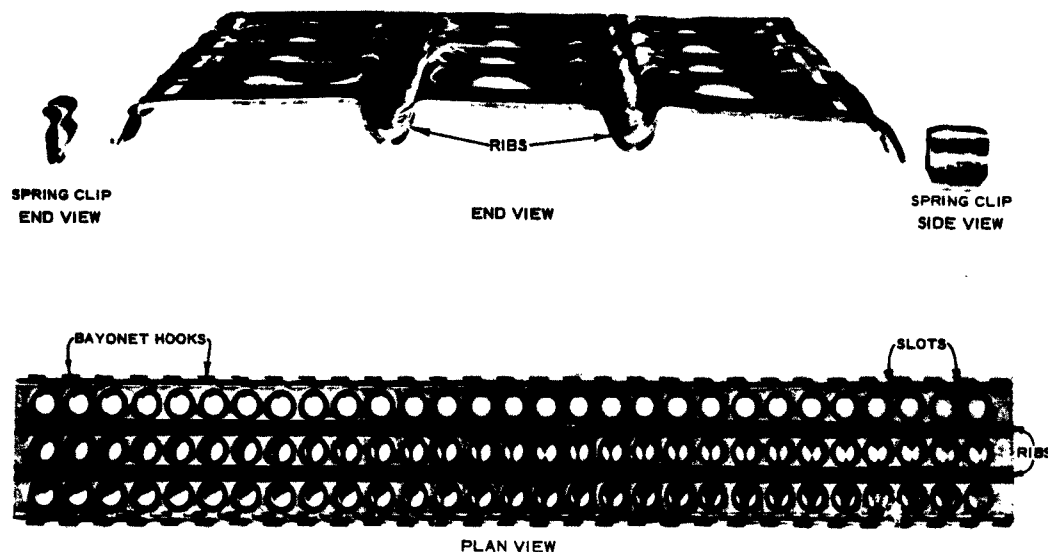


Fig. 1. Pierced steel plank (PSP)

- b. M8 steel mat. The M8 is the standard 10-gage mat conforming substantially to Military Specification MIL-M-59B* (type II, class A) and Corps of Engineers drawing M-7613-1 (see fig. 2). Nomenclature for this item is: mat, airplane landing, steel, pierced type, 50,000-lb single-wheel load, 0.134-in. sheet.

* Now Military Specification MIL-M-59C.

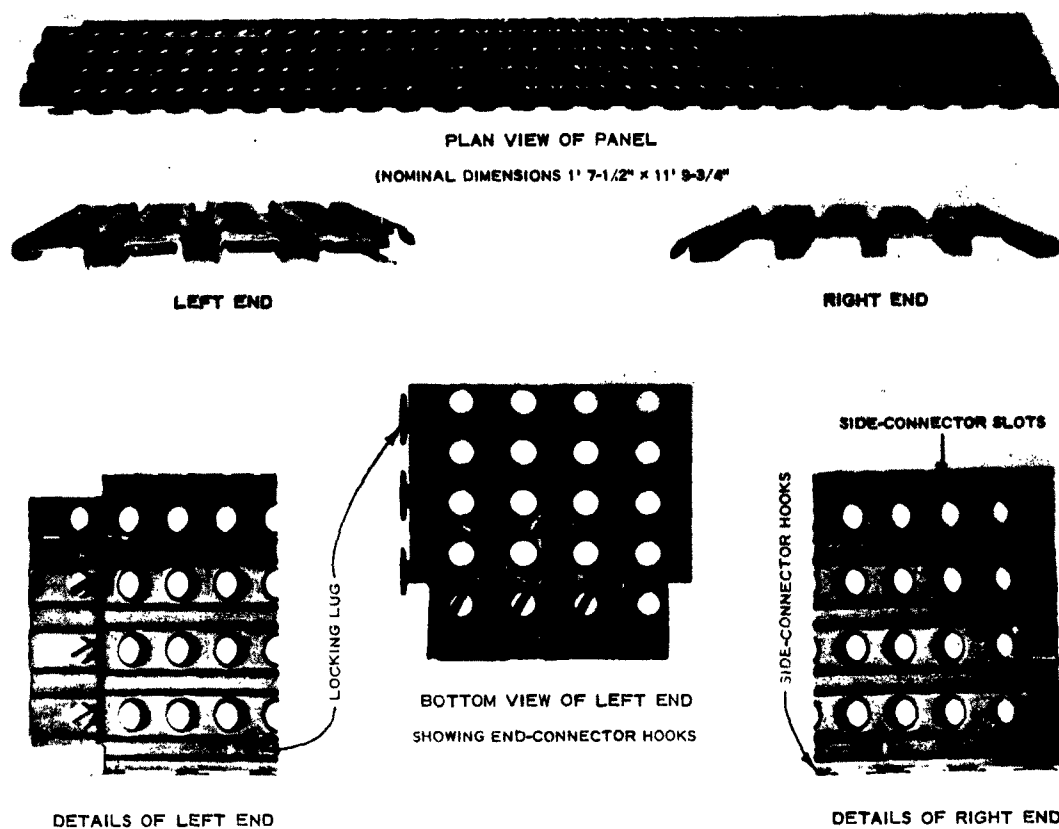


Fig. 2. M8 steel landing mat

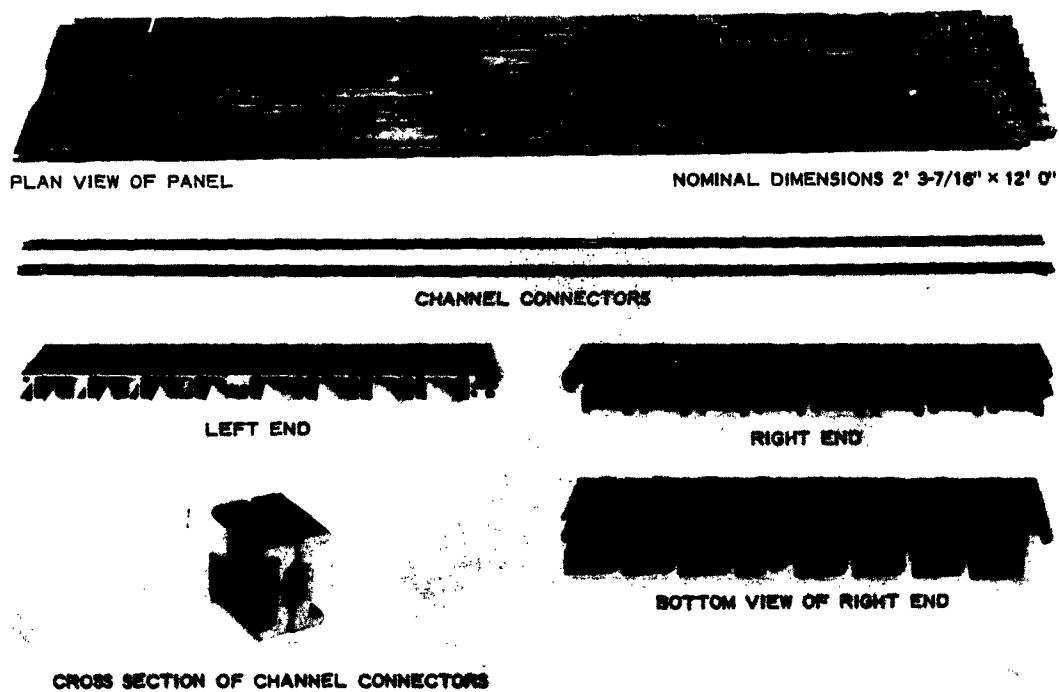


Fig. 3. T11 aluminum landing mat

- c. T11 aluminum mat. The T11 is an experimental extruded aluminum mat which is still in the development stage. Details of the design are shown in Corps of Engineers drawing E-10003-1. The mat used in these tests was extruded from 6061-T6 aluminum alloy with a solid surfacing in contrast to the pierced type of surfacing afforded by the PSP and M8 mats. The T11 mat is shown in fig. 3.

Membranes

7. Close-ups of the three experimental membranes tested are shown in figs. 4-6; the membranes are described as follows:

<u>Designation</u>	<u>Description</u>
T1	No. 8 cotton duck, balanced coating of 8-oz-per-sq-yd vinyl on each side of fabric; color, light gray; average weight, 2.2 lb per sq yd.
T12	8-oz-per-sq-yd nylon fabric, balanced coating of 16-oz-per-sq-yd neoprene on each side of fabric; color, black; average weight, 2.5 lb per sq yd.
T14	8-oz-per-sq-yd nylon fabric, balanced coating of 20-oz-per-sq-yd neoprene on each side of fabric; color, black; average weight, 3.0 lb per sq yd.

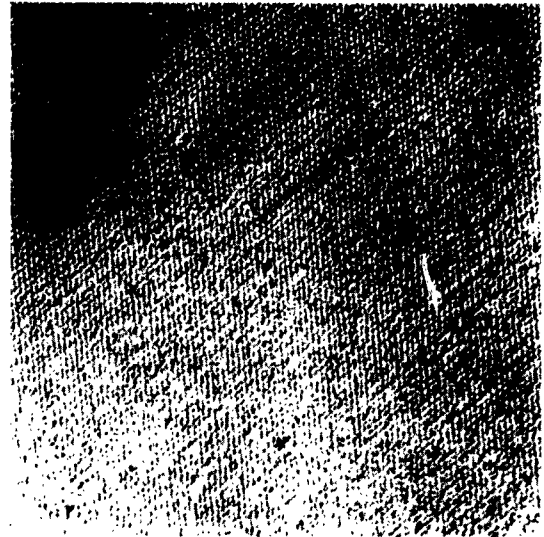


Fig. 4. T1 vinyl-coated cotton duck

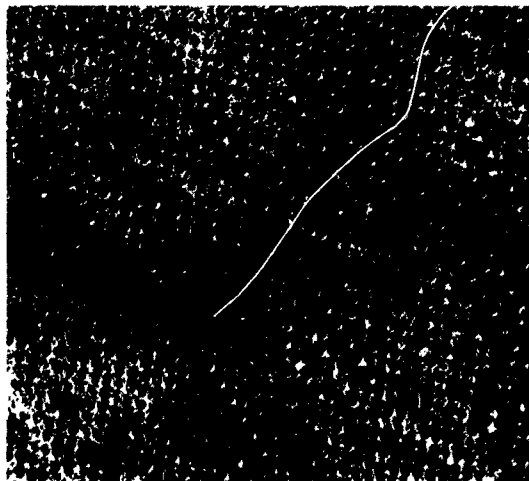


Fig. 5. T12 neoprene-coated nylon



Fig. 6. T14 neoprene-coated nylon

The T1 and T14 membranes were supplied in rolls 36 in. wide and 100 yd long; the T12 membrane was furnished as a sewn panel 30 ft wide and 30 ft long.

Test Vehicles and Method of Testing

Vehicles

8. The prime test vehicle used in the traffic tests was the M51, 5-ton, 6x6 dump truck (fig. 7). It was selected because it exerted the

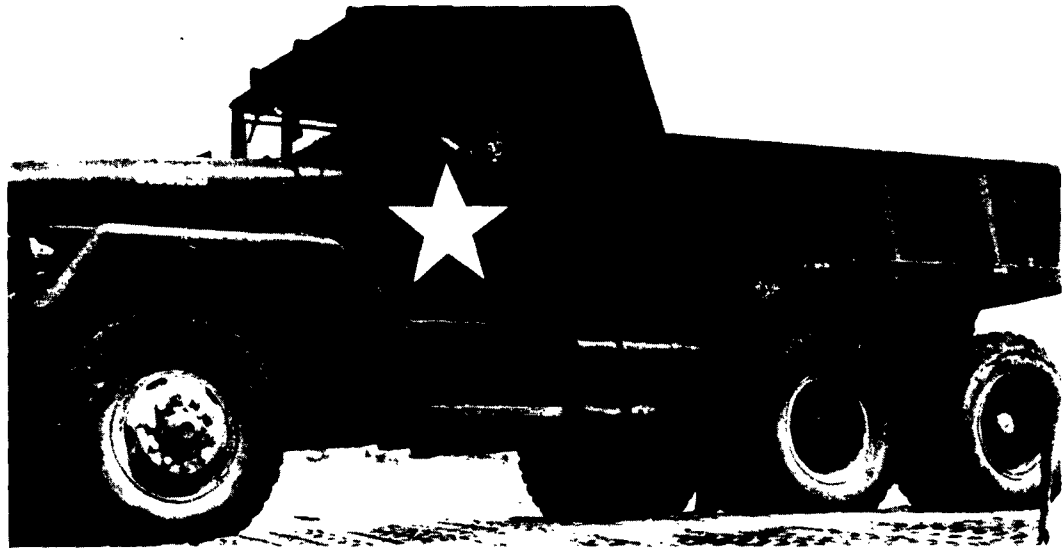


Fig. 7. M51 dump truck

most severe single-axle load of the pneumatic-tired vehicles available for test purposes. Two M51 trucks were used for traffic tests at each beach site. These trucks had standard equipment and were loaded with bundles of PSP mat to simulate loads normally transported across beaches (fig. 8).



Fig. 8. 5-ton dump truck (M51) loaded with bundles of mat

At La Turballe the trucks were loaded to gross loads of 30,000 and 34,000 lb, respectively, and at Suscinio the trucks were loaded to gross loads of 32,900 and 31,240 lb. The tire inflation pressure of the M51 trucks was maintained at 70 psi. In addition to the dump trucks, two 2-1/2-ton, 6x6 (DUKW) amphibian trucks were used for traffic tests (fig. 9). The DUKW's

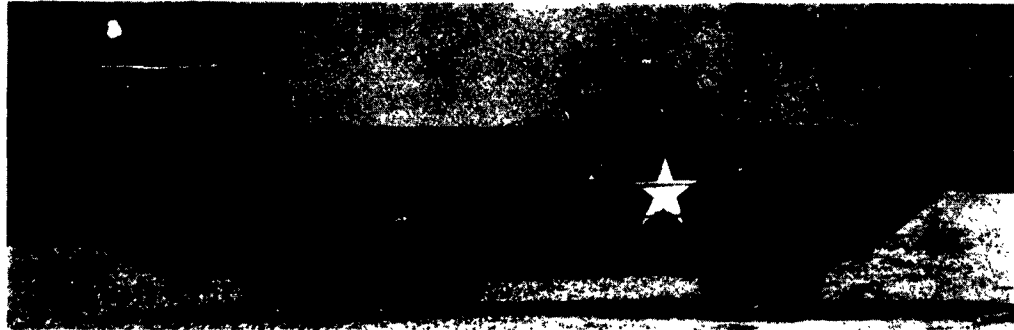


Fig. 9. 2-1/2-ton DUKW

had standard equipment and were loaded with bundles of PSP mat to gross loads of 20,000 lb at La Turballe Beach. For traffic tests at Suscinio Beach, the DUKW's were loaded to gross loads of 20,000 and 14,670 lb, respectively. Tire pressures of the DUKW's varied throughout the tests from 25 to 40 psi.

Method of testing

9. Accelerated traffic was applied in a tracking lane approximately 8 ft wide along the center line of each test lane. In applying traffic, the dump trucks were driven forward down the lanes toward the edge of the water and then backward up the lanes keeping as near as possible in the same tracks. At La Turballe, the DUKW's were driven down a lane into the water, turned around, and then driven back up the same lane. At Suscinio, the DUKW's were driven down one lane into the water and up an adjacent lane. It was found that this latter method of trafficking with the DUKW's permitted the use of both vehicles at the same time, and consequently increased the rate at which the desired number of passes could be completed.

Types of Data Obtained

10. The following information and data were obtained at each test

site: soil classification, moisture content, density, and in-place sand bearing determinations of the subgrade of the test lanes before and after traffic; profiles and permanent surface deformation along each test lane; time required for preparation of each test lane; and visual observations of the performance of the surfacing materials under the action of fluctuating tides, waves, and vehicular traffic, supplemented by still photographs and movies. In addition, the force required to tow loaded vehicles across the various landing mats and across the unsurfaced sand was determined at Suscinio Beach.

La Turballe Beach Test Site and Tests

Location and description of test site

11. La Turballe Beach is located on the Brittany coast of France approximately 15 miles northwest of St. Nazaire (see plate 1). The overall test site was about 370 ft wide and extended from the approximate point of low tide to the dune area immediately beyond the backshore. Fig. 10 shows

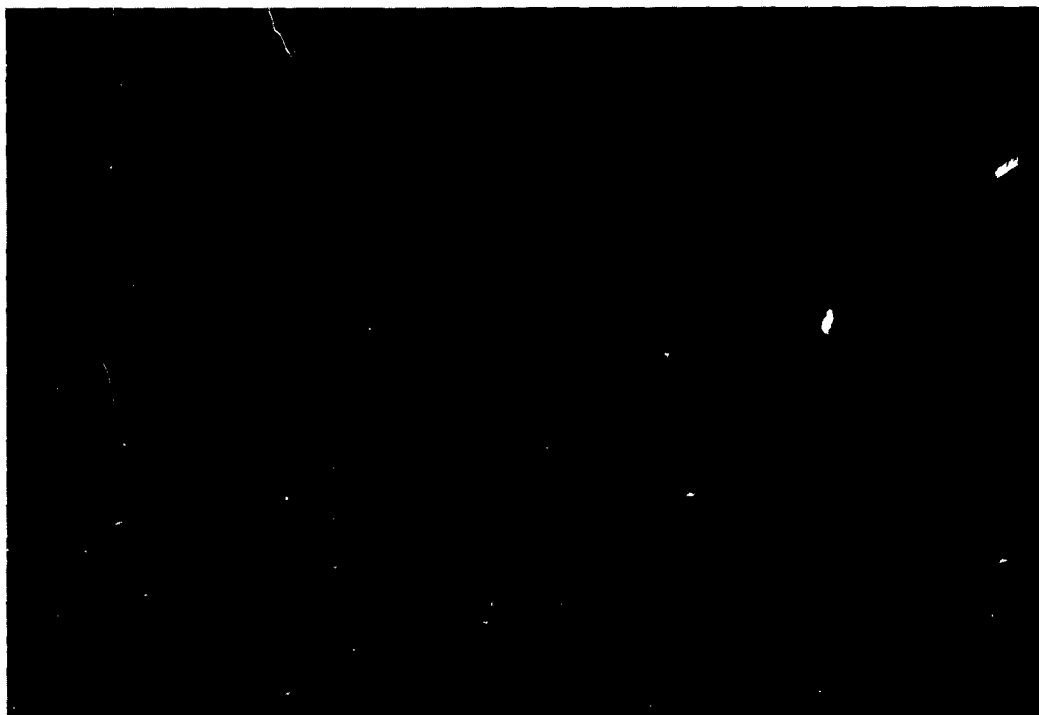


Fig. 10. La Turballe Beach test site

the test site prior to placement of membranes and landing mats. To a depth of 18 in. the beach backshore consisted of a poorly graded medium sand (SP) as shown in plate 2; the foreshore consisted of a poorly graded sand (SP) which ranged from medium to coarse as shown in plate 3. Fig. 11 illustrates rutting and the general texture of beach materials at La Turballe.

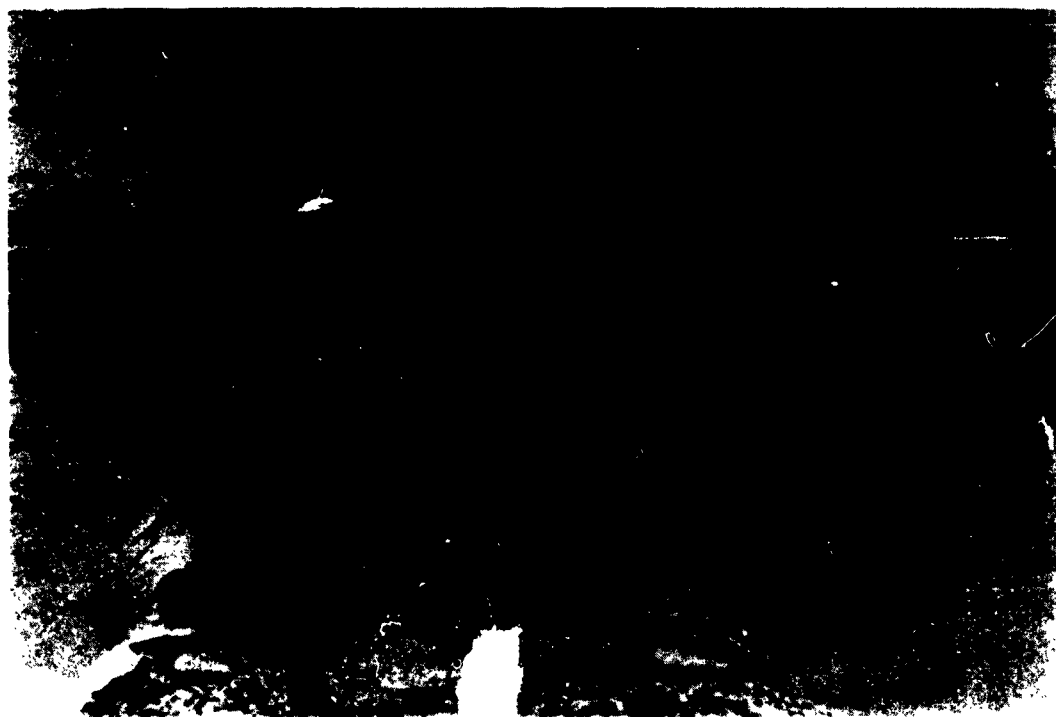


Fig. 11. Typical rutting at La Turballe Beach

The average water content of the soil at the foreshore was 4.2* percent, and the average density 92.7* lb per cu ft; on the backshore the average water content was 3.1* percent, and the average density 91.4* lb per cu ft. The average slope of the beach (along the four test lanes) was 12.2 percent.

Construction of test lanes

12. Four test lanes, approximately 30 ft wide and varying in length from 145 to 198 ft, were prepared at La Turballe as shown in plate 4. Lane 1 was surfaced with T11 aluminum mat, lane 2 with PSP steel mat,

* These data were obtained at low tide.

lane 3 with PSP steel mat underlain with T1 and T14 membranes, and lane 4 with M8 steel mat underlain with T1, T12, and T14 membranes. All mats were placed with the long axis of the panels perpendicular to the center line of the test lane, whereas each run of membrane was placed parallel to the center line of the lane.

13. All surfacing materials were placed by troops of the 89th Port Construction Company of the 83rd Engineer Battalion (Const) with WES engineers and technicians directing operations as required. The size of the placing crew varied continuously throughout construction of the lanes, and all data shown in reference to the placing rate of membrane and mat are based on the average size placing crew. A majority of the military personnel used for placing the surfacing materials were experienced in placing the PSP mat; however, they were completely unfamiliar with the M8 and T11 mats and the membranes. On the test lanes where landing mat only was used, it was placed directly upon the natural in-place subgrade. However, when membrane was also used, the membrane was placed directly on the subgrade and then landing mat was placed over the membrane. All materials were placed by hand and carried into position from a storage area beyond the backshore. Data concerning construction of all lanes at La Turballe Beach are presented in table 1.

14. Lane 1. Lane 1 was approximately 166 ft long and surfaced with the T11 panels (plate 4). Placement of this mat was started on the backshore at sta 0+00 (an arbitrary selection) and was carried down the slope of the beach to sta 1+66, near the point of low tide. Considerable difficulty was experienced in placing the mat because of binding in the side and end connections which was aggravated further by sand which entered the connecting slots and by irregularities in the beach surface. The sand along the backshore was very loose, and in the sliding of the panels together to make the end connection, the sand clogged the connectors and made it necessary to use considerable force to drive the panels into position. The drive rivets normally used to prevent separation of the end joints were not installed since the end connections were so tight. It rained almost constantly throughout the preparation of this test lane, and members of the placing crew tracked more sand onto the panels as they were placed. As mat placement progressed down the beach, the placing rate increased somewhat

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14. Lane 1. Lane 1 was approximately 166 ft long and surfaced with the T11 panels (plate 4). Placement of this mat was started on the backshore at sta 0+00 (an arbitrary selection) and was carried down the slope of the beach to sta 1+66, near the point of low tide. Considerable difficulty was experienced in placing the mat because of binding in the side and end connections which was aggravated further by sand which entered the connecting slots and by irregularities in the beach surface. The sand along the backshore was very loose, and in the sliding of the panels together to make the end connection, the sand clogged the connectors and made it necessary to use considerable force to drive the panels into position. The drive rivets normally used to prevent separation of the end joints were not installed since the end connections were so tight. It rained almost constantly throughout the preparation of this test lane, and members of the placing crew tracked more sand onto the panels as they were placed. As mat placement progressed down the beach, the placing rate increased somewhat

because the sand was firmer and the beach surface smoother. In an effort to further increase the placing rate, the two outer end-connector bars and the center end-connector bar were omitted from all panels beginning at sta 0+24. The mat was placed on lane 1 at an average rate of 63.3 sq ft per man-hour.

15. Lane 2. Lane 2 was 198 ft long and surfaced with panels of PSP (plate 4). Mat placement was started on the backshore at sta 0+00 and continued down the slope of the beach to sta 1+98. The PSP supplied for this investigation was very difficult to place as it was in extremely poor condition. The mat had been used extensively in previous NODEX operations and many panels were bent and bowed; also, a large number of the bayonet side connectors were bent or broken. In addition, the overall size of a number of panels had been affected by corrosion. It was necessary to straighten the panels with hand labor, wherever possible, in order to interlock them. Inclement weather also reduced the placing efficiency of the crew, but no other unusual difficulties were experienced in placing the mat, and the irregularity of the beach surface did not affect placement of the mat. Since the PSP has no end connectors, the panels were staggered about 8 in. on alternate runs so that the end joints would not be in line throughout the length of the lane. The PSP was placed at an average rate of 103.7 sq ft per man-hour.

16. Lane 3. Lane 3 was 145 ft long and surfaced with PSP. The west half of the lane was underlain with T1 vinyl-coated cotton duck, and the east half with T14 neoprene-coated nylon (see plate 4). Prior to placement of the membrane directly on the sand, ditches approximately 2 ft deep were constructed across the ends of the lane at about the point of low tide (sta 2+00) and high tide (sta 0+50). As the membranes were placed they were extended into the ditches, and the ditches were backfilled to anchor the membrane at each end of the lane. At the sides of the lane, sand was shoveled onto the membranes to anchor them in place. Fig. 12 shows a portable rack constructed at the WES and shipped to France especially for use in these tests. A roll of membrane was placed in the rack on a steel rod which permitted the roll to rotate freely above the surface of the beach, facilitated removal of the membrane from the roll, and at the same time accelerated the rate at which it was placed on the beach. The



Fig. 12. Portable membrane rack

membrane was positioned to allow the edges of each run to overlap by 12 in. so that a continuous surfacing was formed, as shown in fig. 13. A crew of

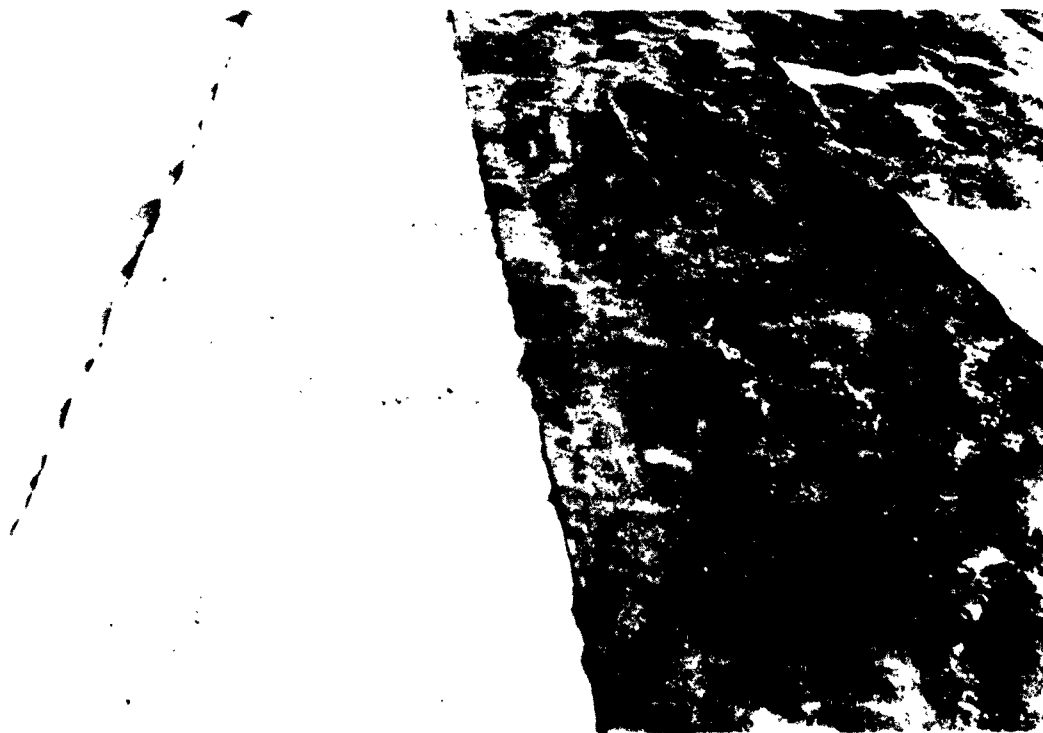


Fig. 13. Membrane runs overlapped 12 in. on lane 3, La Turballe, prior to placement of PSP

eight men placed the membranes at an average rate of 1638 sq ft per man-hour. Immediately after placement of the membrane on the subgrade, PSP mat was placed directly upon the membrane. Mat placement began on the fore-shore at approximately low tide elevation and continued up the slope of the beach to sta 0+50 (fig. 14). As mentioned earlier, the PSP was in very



Fig. 14. PSP being placed on membranes, lane 3, La Turballe

poor condition because of use in previous NODEX operations. Some panels were bowed and the bayonet side connectors were bent to such an extent that it was necessary to straighten them before the panels could be placed satisfactorily. Again it was necessary to stagger the panels so that the panel ends would not be in line throughout the length of the lane. A crew of 10 men placed the PSP at an average rate of 158.2 sq ft per man-hour. The entire operation of placing mat and membrane on lane 3 was accomplished at a rate of 144.3 sq ft per man-hour.

17. Lane 4. Lane 4 was 150 ft long and surfaced with M8 steel mat underlain with T1 vinyl-coated cotton duck and T12 and T14 neoprene-coated nylon (plate 4). The T1 material was placed on the west half of the lane

between sta 0+50 and 1+70, and the T14 was placed on the east half between the same stations. The 30-ft-square sewn panel of T12 membrane was placed on the offshore end of the lane. Prior to placement of the membrane, ditches approximately 2 ft deep were constructed across the ends of the lane at sta 0+50 and 2+00, and after placement of membrane they were back-filled to anchor the membrane. Sand was shoveled onto the membrane along the sides of the lanes for additional anchorage. Membrane placement began at sta 2+00 and progressed up the slope of the beach to sta 0+50. The 30-by 30-ft sewn panel of the T12 membrane first was unfolded and positioned along the test lane between sta 2+00 and 1+70. Runs of T1 and T14 membranes then were placed directly on the subgrade between sta 1+70 and 0+50, with the edges overlapped a distance of 12 in. Each membrane run also overlapped the sewn T12 section by 12 in. to form a continuous surfacing. The sewn section and runs of membrane are shown in fig. 15. A crew of eight men placed the membrane at an average rate of 1913.4 sq ft per man-hour. The M8 mat then was placed directly upon the membrane beginning at sta 2+00

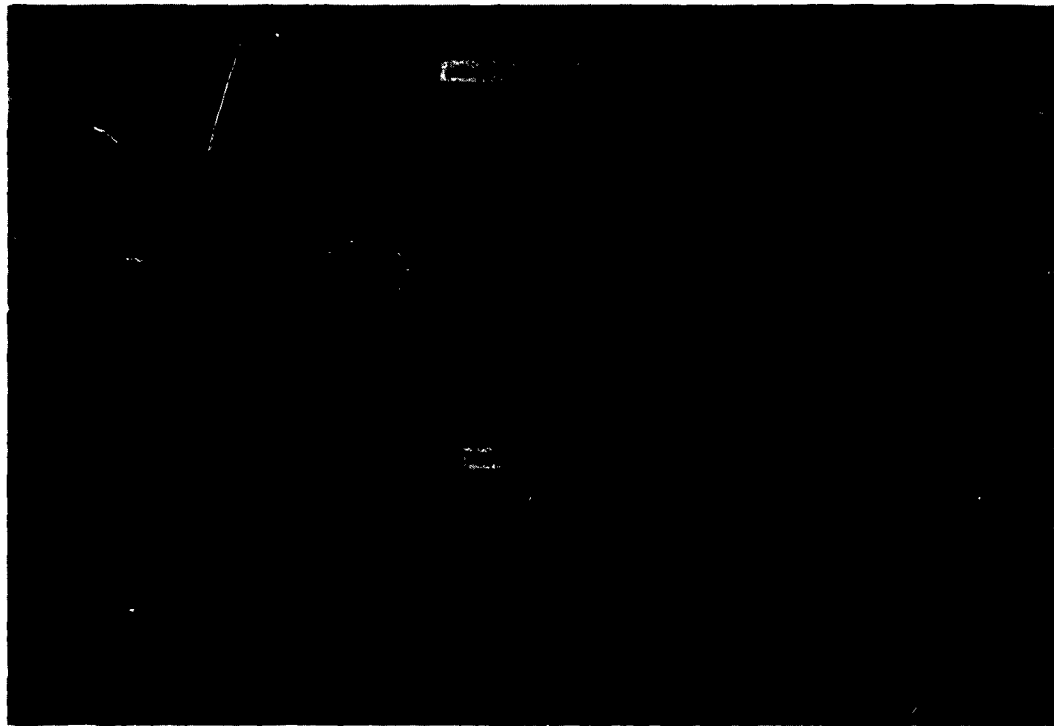


Fig. 15. Sewn membrane panel and membrane runs on lane 4, La Turballe, prior to placement of M8 mat

and continuing up the slope of the beach to sta 0+50. This mat was obtained from an Air Force depot in France and was received in good condition, but the inexperience of the crew in placing this type of mat resulted in a slower rate initially than expected. However, as the crew gained experience, the rate of placement increased appreciably. The number of half panels available was insufficient to permit staggering the end joints of the mat throughout the test lane, and it was necessary to stagger full panels a distance of approximately 6 ft. Eight men placed the M8 mat at an average rate of 162.2 sq ft per man-hour. The complete test lane was constructed at an average rate of 149.0 sq ft per man-hour.

Traffic tests and performance of test materials

18. Curves showing airfield cone penetrometer readings and corresponding CBR values in each lane before and after traffic are shown in plates 5 and 6; center-line profiles along the mat- and membrane-surfaced lanes before and after traffic are shown in plates 7-10. Examination of the CBR curves shows that the initial average bearing capacity varied appreciably along each lane and that the CBR increased considerably under the accelerated traffic. Inspection of the center-line profiles shows the overall compaction effect of traffic on the test lanes. It will be noted that in most instances compaction of subgrade occurred along the inshore portions of the lanes.

19. Lane 1. Preparation of lane 1 was completed on 21 May 1959, at which time traffic was started. A total of 1000 passes with the DUKW and the M51 dump truck were completed by the end of 26 May (see table 2). At the beginning of traffic, the mat surface was generally smooth (photograph 1), but the mat was bridging some irregularities in the beach surface, since no attempt had been made to grade the beach or seat the mat. In addition, during high tide on the night of 20 May some erosion had occurred along the western edge of the lane between sta 0+84 and 0+91 where the last run of mat had been placed that day.

20. After 14 passes on 21 May with the DUKW loaded to 20,000 lb, it was noted that a number of the mat end joints which were under water at the offshore end of the lane had separated from 1 to 2 in. Traffic was stopped

to close the end joints and to insert two drive rivets,* which had been omitted purposely to expedite mat placement (paragraph 14). Traffic was resumed on this lane on 22 May with the 5-ton dump truck loaded to 30,000 lb and with a tire inflation pressure of 70 psi; 390 passes were applied on this date, and no further distress in the mat or subgrade developed at this time. The T11 mat provided good traction for the test vehicle at this time, as the truck was able to operate without difficulty on the offshore end of the lane which was under 2 to 3 ft of water. During the afternoon the rising tide produced waves about 3 ft high. The waves caused the runs of mat on the offshore end of the lane to flex and partially float.

21. On the morning of 23 May (after 404 passes), it was observed that the outer seven runs of panels had become disengaged from the other mats during the night. Three of the runs were partially buried in the sand at the lower end of the test lane, and two of these had flipped over as shown in photograph 2. The other four runs of panels were found at low tide scattered over an area about 40 to 60 ft from the offshore end of the lane and partially buried in the sand. In addition to the displacement of these mats, considerable other damage was also noted at this time. A number of the drive rivets which had been inserted in the end joints after 14 passes of traffic had sheared in the offshore portion of the lane, and about 12 end joints between sta 0+90 and 1+20 had separated as much as a foot. Sand had also been scoured under these separated end joints for a depth of 8 to 10 in. (see photograph 3). All of the test lane below about sta 0+60 was sloping from north to south (see plate 4) as sand had been displaced under the south edge of the lane and deposited under the north edge. Along the south edge of the lane near sta 0+65, sand was scoured to a depth of about 2 ft (photograph 4). The general condition of the tracking lane at this time is shown in photograph 5.

22. Traffic was resumed on 23 May with the M51 truck loaded to 30,000 lb. The first mat failure under traffic occurred on the 48th pass

* A blind-type rivet used to prevent separation of end joints of the T11 mat when this mat is used as airfield surfacing. Described in Waterways Experiment Station Technical Report No. 3-461, Engineering Tests of Experimental T7 Magnesium and Modified Standard Steel Airplane Landing Mat (Vicksburg, Miss., July 1957).

that day (total of 452 passes) at an end joint which had opened about 5 in. This allowed the splice-joint rivets along the middle of the panel to shear at the separated end, causing the splice joint to fail and producing an upward concavity in the mat (photograph 6). Similar failures of the splice-joint rivets occurred later at several other end joints.

23. During the remainder of the trafficking period, which ended on 26 May after a total of 1000 passes, the extent of separation increased at partially open end joints, although there was no noticeable increase in the number of joints so affected; also one additional run of mat had worked loose at the offshore end of the lane. Photograph 7 shows the general condition of the lane at completion of 1000 passes. Overall, the lane was in poor condition, although it was not considered failed, and traffic could have continued longer by avoiding the separated end joints. Erosion along each edge of the foreshore portion of the lane extended under the mat for 6 to 8 ft; however, in general, the mat in the center portion was in contact with the beach throughout the lane as there had been little erosion in this center area except where the end joints were separated. End joints on the backshore portion of the lane did not separate at any time during traffic, and the mat in this area was relatively undamaged with a smooth surface appearance. Examination of plate 7 shows uniform settlement of most of the mat, either from embedment of the mat or compaction of the subgrade or a combination of both.

24. Lane 2. This lane was surfaced with PSP mat to afford a direct comparison with the materials used on the other lanes. Preparation of lane 2 was completed on 19 May, at which time traffic was started. A total of 1000 passes with the M51 dump truck and the DUKW were completed by the end of 25 May (see table 2). At the beginning of traffic, the mat surface was generally smooth (photograph 8), and the lane was in good condition although some of the individual panels were deformed from previous use as described in paragraph 15. The mat was bridging irregularities in the beach surface since no attempt had been made to grade the beach or seat the mat, but the bridging was less pronounced on this lane than on lane 1 because the PSP mat is more flexible than the T11 mat and tends to conform better to the contour of the subgrade.

25. During the early stages of traffic, the mat began to deform and

buckle at the ends (the PSP has no end connectors) and some of the bayonet hooks were torn loose. In addition, sand was eroded from the upper foreshore portion of the lane and from under the extreme offshore end of the mat. Much of the sand eroded from the upper foreshore appeared to be deposited on the lower portion of the lane. As more traffic was applied, the mat continued to deform and after a total of about 600 passes, shallow ruts had formed in the wheel paths. Also, a considerable number of spring clips, used in the bayonet slots to prevent lateral slippage and disengagement, had worked loose. Several panels at the offshore end of the lane had become disengaged and partially overturned as a result of wave action (see photograph 9). In addition, a considerable quantity of sand had eroded from the upper foreshore, and from 8 to 10 in. of sand had been deposited throughout the lower portion of the lane, except on the outermost runs (see photograph 10). The erosion of sand under the mat caused slack in the panels, and at several locations the mat had rolled or buckled up and was bridging the subgrade. Photograph 11 shows the most pronounced example of this condition which occurred at about sta 0+95 where the mat was bridging the subgrade a maximum of about 10 in. along the edge of the lane. The buckled panels tended to flatten under traffic.

26. At the conclusion of 1000 passes on 25 May, lane 2 was in poor condition but it was not considered failed and traffic could have continued. Photograph 12 shows the general condition of the lane at the end of the test. The surface was much rougher than lane 1, primarily because of areas where the end joints had buckled or the mat had rolled up, but there were no holes in the mat surface in lane 2 as had developed on lane 1 where the end joints separated. Examination of plate 8 shows generally uniform settlement of the mat on the backshore, whereas considerable sand had deposited on the lower portion of the lane (between sta 1+00 and 1+55). The sharp rise shown in plate 8 at about sta 0+95 is at the point of extreme mat buckling described in paragraph 25.

27. Lane 3. This lane was surfaced with PSP mat placed over T1 cotton duck and T14 nylon membranes. Preparation of the lane was completed on 20 May, at which time traffic started. A total of 1000 passes with the M51 dump truck and the DUKW were completed on 26 May. The surface of the mat was fairly smooth at the beginning of traffic (photograph 13) and the

lane was in good condition, although some panels were deformed from previous use. As traffic was applied, the panels in the tracking lane deflected considerably, and since this mat has no end connectors, the ends of these panels curled up above the adjoining panels. The combined effect of traffic, tide, and wave action soon bowed and removed several panels near the offshore end of the lane (photograph 14). Minor erosion occurred along the southeast edge of the lane (photograph 15) but did not extend very far under the mat as the underlying membrane protected the subgrade. As traffic continued, the end curl of panels became more pronounced, and sand was deposited on the lane during the rise and fall of the tide. Photograph 16 shows the lane after 450 passes and an exposure of four days to tidal and wave action. The condition of the lane at the end of the test is shown in photograph 17. Approximately 6 in. of sand had been deposited on the surface of the mat at various locations, and near sta 1+00 the lane was completely buried for a depth of 6 to 8 in. across the full width of the lane. Lane 3 was considered in better condition at the end of the test than lane 2, and traffic could have continued indefinitely.

28. The mat was removed from the lane on 27 May 1959, and the membranes were inspected for possible damage. The T14 membrane was not damaged by the overlaid PSP mat, and there were no indications of puncture by the bayonet side connectors (photograph 18). The T1 membrane was not torn, but the bayonet side connectors had punctured the material at several locations (photograph 19). These punctures were not severe as the membrane did not fail completely nor was the subgrade eroded beneath the membrane. Examination of plate 9 shows that little change occurred in the elevation of the inshore portion of the lane, but that considerable sand had been deposited on the offshore portion.

29. Lane 4. This lane was surfaced with M8 steel mat placed over the T1, T12, and T14 membranes. Preparation of the lane was completed late on 21 May, and traffic was started the next morning. A total of 1000 passes with the M51 truck and the DUKW were completed on 26 May. The surface of the mat was very smooth at the beginning of traffic (photograph 20), and the lane was in excellent condition. As traffic was applied, there was no appreciable deflection of the mat panels under the vehicle wheel load as was observed with the PSP mat on lanes 2 and 3. The end connectors of the

M8 mat prevented development of end curl. After 450 passes, the riding surface remained smooth and there were no significant changes in the condition of the lane, nor had wave action overturned or disengaged any of the mat panels. Photograph 21 shows the lane after 1000 passes. Approximately 2 to 6 in. of sand had been deposited on the mat surface between sta 1+00 and 0+50, but all mat was considered to be still in very good condition.

30. The membranes were inspected immediately after removal of the mat on 29 May, and there was no visible evidence of puncture or failure thereof. Light crease marks were visible on the membrane surfaces where the mat had been in contact (photographs 22 and 23). Anchorage of the membranes was satisfactory as there were no indications of lateral slippage of the membrane runs. Examination of plate 10 shows that except for the compaction of the sand and settlement of the mat caused by vehicular traffic toward the inshore end of the lane and upward displacement of panels at the extreme offshore end, the test lane remained stable throughout the traffic period.

Suscínio Beach Test Site and Tests

Location and description of test site

31. Suscínio Beach is located on the Brittany coast of France approximately 35 miles northwest of St. Nazaire (plate 1). The overall test site was about 370 ft wide and extended from the approximate point of low tide to the dune area immediately beyond the backshore. Fig. 16 is a general view of the test site prior to placement of membranes and landing mats. Soil samples were taken at three locations at the test site (plates 11 to 13) and indicated that to a depth of 18 in. the beach material consisted of a well-graded gravelly sand (SW). The average water content of the soil at the foreshore was 3.4* percent, and the average density 104.4* lb per cu ft; on the backshore the average water content was 1.4* percent, and the average density 104.6* lb per cu ft. The average slope of the beach (along the four test lanes) was 7.5 percent. Compared to La Turballe Beach, the Suscínio Beach has a firmer sand and flatter slope.

* Data obtained at low tide.



Fig. 16. Suscinio Beach test site

Construction of test lanes

32. All surfacing materials were removed from La Turballe Beach upon completion of tests there and transported to Suscinio Beach for additional tests. Four test lanes, approximately 30 ft wide and varying in length from 140 to 165 ft, were prepared at Suscinio as shown in plate 14. Again all mats were placed with the long axis of the panels perpendicular to the center line of the test lane, and each run of membrane was placed so as to be parallel to the center line of the test lane.

33. All the surfacing materials were placed on this beach by essentially the same troops and WES personnel utilized at the La Turballe test site (see paragraph 13). Again the size of the placing crew varied continuously throughout the construction of the lanes, and all data shown in reference to the placing rate of membrane and mat are based on the average size placing crew. In construction of the Suscinio test lanes, the same procedures were used as had been used at La Turballe; i.e., where only landing mat was used, it was placed directly upon the natural in-place

subgrade, and when membrane was used also, it was first placed directly upon the subgrade and then the mat was placed over the membrane. All materials used in the construction of the test lanes at this site had been used during the previous investigation at La Turballe; they were placed by hand and carried into position from a storage area beyond the backshore. Data concerning construction of all lanes at Suscinio Beach are presented in table 3.

34. Lane 1. Lane 1 was approximately 140 ft long and surfaced with relatively undamaged panels of the experimental T11 aluminum mat used in the tests at La Turballe Beach (except for one panel as described in paragraph 42). Placement of the landing mat began at sta 0+00 (an arbitrary selection) at the approximate point of high tide, and progressed down the slope of the beach to sta 1+40, thus allowing the entire test lane to be subjected to the action of waves and fluctuating tide. Even though the mat used on this lane had been used previously at La Turballe Beach and difficulty was still experienced because of binding in the side and end connections, it was much easier to place at Suscinio and the placing rate was much higher. The major factors contributing to the increased ease and rate of mat placement were: (a) a more experienced placing crew, (b) a flatter longitudinal slope of the beach surface, (c) a relatively firmer and smoother beach surface throughout the lane, and (d) improved weather conditions during construction of the lane with a corresponding increase in the efficiency of the placing crew. As at La Turballe Beach, the beach surface on the foreshore at this site was firmer and smoother than that on the backshore. All the mat on this lane was placed on the foreshore, and although loose soil was encountered, it did not clog the connectors and it was easier to maintain the opposing panels in the same datum plane to complete the side connections. There was a light covering of gravel on the surface of the foreshore of this beach, but it caused no major interference. Drive rivets were placed in the end joints during the mat placement as follows: four rivets at each end joint in the runs from sta 0+80 to 1+40, and two rivets at each end joint in the runs from sta 0+45 to 0+80. End-joint rivets were not placed in any of the mat runs from sta 0+00 to 0+45 because of a shortage of rivets. This mat was placed on the lane at an average rate of 100 sq ft per man-hour.

35. Lane 2. Lane 2 was surfaced with the old PSP mat removed from La Turballe Beach and was approximately 143 ft long (plate 14). Mat placing was started at sta 0+00 and continued down the slope of the beach to sta 1+43. The PSP mat was even more difficult to place on this lane than at La Turballe Beach because a large number of panels had sustained considerable additional* deformation during the tests at La Turballe. However, the characteristics of the beach surface at Suscinio appeared to have little effect in either increasing or detracting from the ease of placement of the PSP. The panels on this lane were staggered about 8 in. in alternate runs, as for the La Turballe tests, so that the end joints would not be in line throughout the length of the lane. The PSP was placed on this lane at an average rate of 89.4 sq ft per man-hour.

36. Lane 3. Lane 3 was 150 ft long and surfaced with PSP underlain with T1 vinyl-coated cotton duck on the south half of the lane and T14 neoprene-coated nylon on the north half (see plate 14). The same procedures were used to place and anchor the membranes as were used at La Turballe. A crew of six men placed the membrane from sta 0+00 to 1+50 at an average rate of 1750 sq ft per man-hour. Immediately after placement of the membranes was completed, the PSP was placed directly upon these materials. Mat placement began at the offshore end of the lane and extended up the slope of the beach to sta 0+00. The PSP mat was in extremely poor condition because of use in previous NODEX operations and in the tests at La Turballe Beach. During the latter tests, numerous panels had become bowed and bent, and it was necessary to straighten them before they could be placed satisfactorily. When the mat was placed, several panels were discovered to be damaged excessively and it was necessary to discard them and carry additional panels onto the lane before placing could continue. The panels were staggered approximately 6 to 8 in. to prevent the ends being in line throughout the lane. A crew of six men placed the PSP at an average rate of 166.7 sq ft per man-hour. The entire operation of placing mat and membrane on the lane was accomplished at an average rate of 152.1 sq ft per man-hour.

37. Lane 4. Lane 4 was 165 ft long and surfaced with M8 steel mat

* Panels were already in poor condition prior to their initial use at La Turballe (see paragraph 15).

underlain with T1 vinyl-coated cotton duck and T12 and T14 neoprene-coated nylon (see plate 14). The T1 membrane was placed on the south half of the lane and the T14 on the north half of the lane between sta 0+65 and 2+00. The 30-ft-square panel (sewn) of T12 nylon was placed at the inshore end of the lane between sta 0+35 and 0+65. The membranes were placed and anchored by the same procedures used at La Turballe Beach (paragraph 16). The sewn panel was carried onto the center of the lane and unfolded first across and then along the lane. All membranes were placed by an eight-man crew at an average rate of 1863 sq ft per man-hour. Fig. 17 shows the sewn panel and membrane runs prior to placement of the M8 mat on the lane. Immediately after the lane was surfaced with membranes, the M8 mat was placed directly upon these materials beginning at the offshore end of the lane (sta 2+00) and continuing to sta 0+35. Although the M8 mat had been used previously in the tests at La Turballe Beach and had been removed and transported to Susicinio for these latter tests, it was still in good condition with approximately 95 percent of the panels being completely undamaged. (Most of the

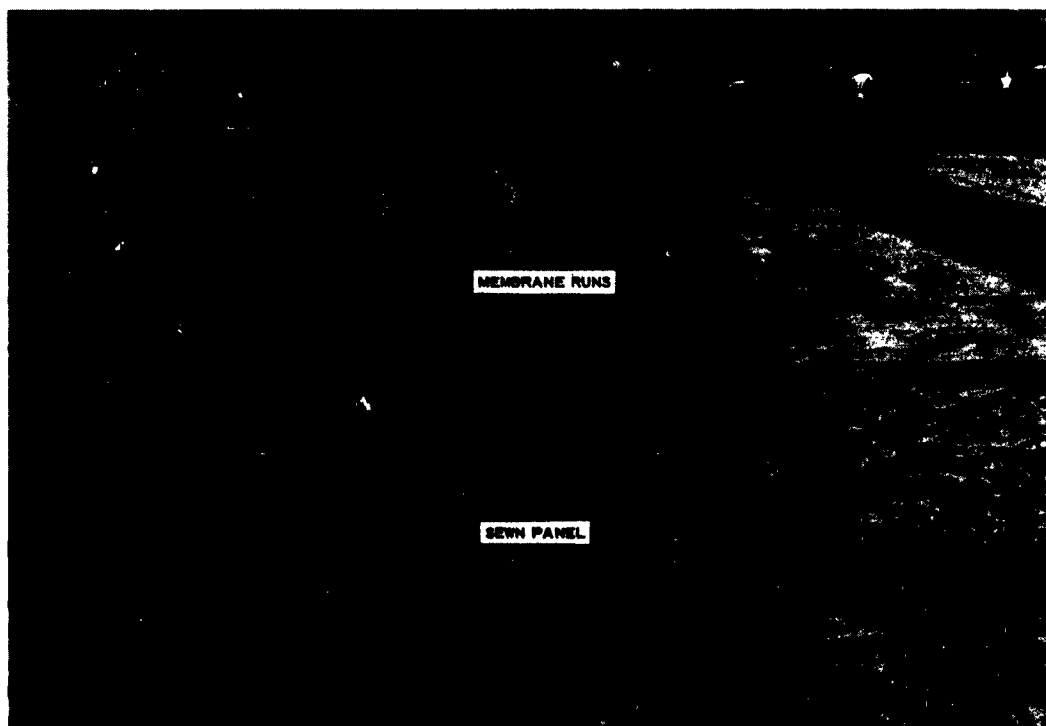


Fig. 17. Sewn membrane panel and membrane runs on lane 4, Susicinio Beach, prior to placement of M8 mat

minor damage to the M8 panels had been inflicted by inexperienced field troops during removal of the mat from the La Turballe Beach test lanes.) The full mat panels were staggered a distance of approximately 6 ft to prevent the panel ends from being in line. Eight men placed the mat at an average rate of 170.2 sq ft per man-hour. The entire operation of placing mat and membrane on the test lane was accomplished at an average rate of 154.0 sq ft per man-hour.

Towing tests

38. Prior to the beginning of traffic tests, towing tests were conducted on lanes 1, 2, and 4 (surfaced with T11, PSP, and M8 mats, respectively) and on the unsurfaced beach area between lanes 1 and 2 to determine the comparative rolling resistance offered by the various surfaces. The tests were performed by pulling the M51 dump truck (loaded to 32,900 lb, at tire inflation pressures of 70 psi) over the different surfaces at a slow, uniform speed. The M34, 2-1/2-ton, 6x6 truck was used to pull the M51 for all the tests performed on the mat-surfaced lanes; however, the M34 did not have enough power to tow the M51 on the unsurfaced beach and the winch of an M62, 5-ton, 6x6 wrecker was attached to the front end of the M51 to provide the necessary power. The force required to pull the M51 over the different surfaces was measured by a 20,000-lb-capacity dynamometer attached between the test vehicle and the towing vehicle. A Brush universal analyzer and a Brush direct-inking oscillograph were used to measure and record the data. Average values of the forces required to keep the test vehicle moving up the beach slope at a uniform speed on the various surfaces were considered representative for the specific purposes of these tests since the slopes of all the surfaces were so nearly equal.

39. The average towing force in pounds required to pull the test vehicle over each surface was as follows:

<u>Type Surface</u>	<u>Lane No.</u>	<u>Slope, %</u>	<u>Towing Force, lb</u>
T11 mat	1	8.3	3,840
PSP mat	2	8.1	4,200
M8 mat	4	5.6	3,158
Unsurfaced beach	-	8.2	19,435 (area of low tide) 10,900 (area of high tide)

It will be noted that the unsurfaced beach offered considerably more

rolling resistance under the conditions of these tests than any of the other surfaces, and the M8 mat offered the least rolling resistance. Two values are shown for the unsurfaced beach tests, because two distinct and different soil conditions were encountered in the tests. The material in the lower portion of the foreshore was relatively coarse and loose (fig. 18), and the maximum depth of rutting was 11 in.; the material farther inshore on the beach was finer (fig. 19), and the maximum depth of rutting was 8 in. Mat damage was not sustained in any of the towing tests.

Traffic tests and performance of test materials

40. Plates 15 and 16 show field CBR values in each lane before and after traffic. The data show that, in general, the bearing capacity of the subgrade in each lane decreased considerably under the accelerated traffic. No explanation is apparent for this reversal of the trend noted at La Turballe Beach (paragraph 18) other than the fact that, as explained subsequently, a storm struck the Suscinio Beach area after completion of most traffic and prior to measurement of final CBR values. The violent action of the waves and tides caused considerable changes in the average water content, density, CBR, etc., of the Suscinio Beach materials from the values obtained just prior to start of traffic. Plates 17 to 20, inclusive, show center-line profiles taken along each surfaced lane before and after traffic. These data indicate that the overall compaction effect of the traffic on the lanes was minor in most instances, with no appreciable change in slopes.

41. Lane 1. Preparation of lane 1 was completed on 1 June, and traffic was started on 3 June. A total of 1000 passes with the M51 dump truck and DUKW were completed on 8 June (see table 4). At the beginning of traffic the mat surface was generally smooth (photograph 24). The mat was bridging the beach intermittently throughout the lane since no attempt had been made to grade the beach or seat the mat, but the bridging was considerably less pronounced than at La Turballe because the surface of Suscinio Beach was smoother except for the sparse areas of gravel. In contrast to conditions experienced during the La Turballe tests, there was no erosion of consequence along the edges of this lane at the beginning of traffic. Although the mat on this lane had been used in the La Turballe



Fig. 18. Coarse material on foreshore, Susicinio Beach

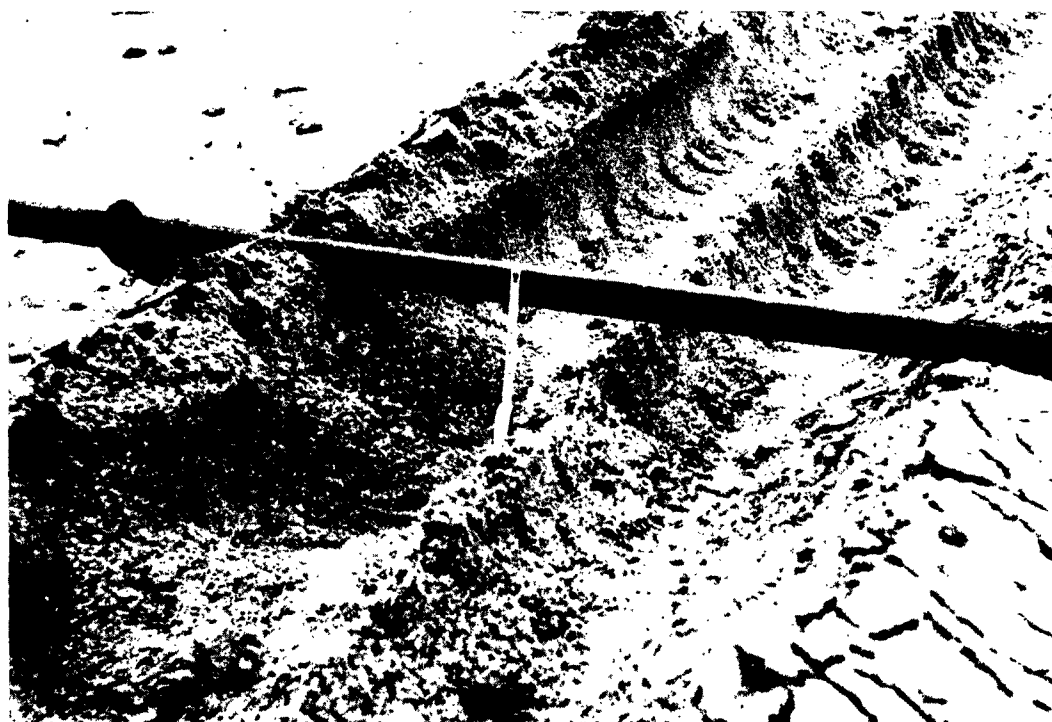


Fig. 19. Fine material on backshore, Susicinio Beach

tests, it was in good condition and there were no breaks or rivet failures (except for one panel as described in the next paragraph).

42. After 40 passes, some of the end joints started separating between sta 0+40 and 0+49 near the point of high tide. As mentioned in paragraph 34, drive rivets were not placed in runs from sta 0+00 to 0+45 during mat placement because of a shortage of rivets, but the runs from sta 0+45 to 0+80 had two rivets per end joint inserted before traffic. These rivets had sheared in the mat runs to sta 0+49 after the first 40 passes. The runs of panels where the end joints were separating were a few inches under water at this time, and the traffic vehicle was passing over this area while it was under water. With each pass of the truck, the joint separation increased. On the 200th pass a panel at sta 0+85 failed by shearing the splice-joint rivets along the entire length of the panel (photograph 25). This panel had been used in the La Turballe tests, and the splice-joint rivets had been sheared for a length of about 4 ft prior to use at Susicinio. The panel was replaced after 40 additional passes.

43. During the remainder of the trafficking period, the number of end-joint separations increased (including joints with two and four rivets per joint), as did the extent of joint separation. Sand was pumped through some of the separated joints near the offshore end of the lane and deposited on the mat; this caused rutting toward the end of the test. In addition, erosion occurred along the south edge of the lane. A storm during the night of 7 June prior to completion of traffic disengaged one panel but did not cause any other appreciable damage to the lane. Photograph 26 shows the general condition of the lane near the offshore end after 1000 passes; photograph 27 shows the maximum end-joint separation of about 30 in. Overall, the lane was in poor condition because of the separated end joints and the rutted areas at the offshore end of the lane. However, there were no mat breaks or failures of splice-joint rivets, and traffic could have continued for an appreciable period under the existing conditions by straddling the separated end joints. Examination of plate 17 shows that there was some settlement of the mat along the upper portion of the lane.

44. Lane 2. This lane was surfaced with the obsolete PSP mat used in previous NODEX operations and at La Turballe. Preparation of the lane

was completed on 1 June, and traffic was started on 3 June. A total of 1000 passes with the M51 truck and DUKW were completed on 6 June (table 4). At the beginning of traffic, the mat surface on this lane was generally smooth (photograph 28) and in good condition, although a considerable number of the panels were deformed from previous use. The mat bridged the beach intermittently throughout the lane since no attempt had been made to grade the beach or seat the mat. However, the bridging was less pronounced than that experienced on test lane 2 at La Turballe (paragraph 24).

45. The mat panels began to deform and buckle at the ends during the early stages of traffic, but no major damage occurred during the first 200 passes (see photograph 29). However, after 350 passes, minor rutting occurred in the tracking lane. Also, the buckling of the panel ends had increased, and some of the spring clips were loosened in the side connections. During the remainder of the test, the buckling of the end joints increased appreciably, as did the rutting of the panels under the load wheels.

46. At the conclusion of 1000 passes, the lane was in very poor condition (see photograph 30), but traffic could have continued. The surface of this lane was much rougher than that of lane 1 because of disengagement of panels at the side connections and general mat deformation. Some panel ends were curled upward about 12 to 15 in., and numerous spring clips were dislodged. Examination of plate 18 shows the extent of settlement of the mat.

47. The traffic tests were concluded on 6 June, but the mat on this lane was left intact and exposed to the action of waves and fluctuating tide until it was removed on 9 June. Violent rain squalls occurred throughout the afternoon and night of 7 June with the ocean becoming very rough; the next morning it was observed that additional material had been eroded or deposited at various locations throughout the lane. It was also noted that several PSP panels without spring clips had become disengaged.

48. Lane 3. This lane was surfaced with PSP mat underlain with T1 cotton duck and T14 nylon membranes. Preparation of the lane was completed on 2 June, and traffic was started on 4 June. A total of 1000 passes with the M51 truck and the DUKW were completed on 8 June. As shown in photograph 31, the surface of the mat was fairly smooth at the start of traffic,

although some panels were deformed from previous use. As traffic first was applied, some spring clips dislodged and a few panels deformed. However, after 200 passes the surface of the lane was still relatively smooth (photograph 32). As traffic continued, panel curl and deformation increased and the mat surface became wavy; however, no major failures had developed by the end of the test, and traffic could have continued. This lane was considered in better condition at the end of the test than lane 2.

49. During the storm of 7 June 1959 mentioned in paragraph 47, panels in lane 3 were flipped back and forth in areas where spring clips had been dislodged. Photograph 33 shows a section of PSP mat which was disengaged near the offshore end of the lane and rolled back by the wave action. Some of the membranes were also displaced as shown in photograph 34. However, the membranes were not damaged by the waves or punctured by the mat. Several panels farther inshore, with spring clips dislodged under vehicle traffic, were also disengaged by wave action and deposited on the lane as shown in photograph 35. Plate 19 shows the extent of settlement of the mat on lane 3. The sharp break in slope between sta 110+00 and 120+00 represents the displacement of the mat in this area during the storm just described.

50. Lane 4. This lane was surfaced with M8 mat placed over T1, T12, and T14 membranes. Preparation of the lane was completed on 2 June, and traffic was started on 4 June. A total of 1000 passes with the M51 truck and the DUKW were completed on 6 June. The surface of this mat was smooth, and the lane was in good condition. As traffic was applied, there was no visible deflection of panels under the vehicle wheel load. After 200 passes the riding surface was relatively unchanged, and there were no indications of permanent deformation of the mat, failure of the membranes, or erosion of the subgrade. The condition of the lane remained practically unchanged throughout the test with the exception that several runs of mat became buried at the offshore end of the lane (see photograph 36) under the action of the DUKW's which operated on the lane while this portion of the mat was submerged. Plate 20 indicates the extent of settlement of the mat during the test. The storm which developed during the night of 7 June after completion of traffic deposited additional sand upon the lane and overturned five or six runs of mat at the offshore end of the lane (photographs 37 and 38).

PART III: DISCUSSION OF RESULTS

51. The results of the tests at La Turballe and Suscinio Beaches on the four landing mat-membrane surfacing systems utilized in this investigation (T11 mat, PSP mat, PSP mat underlain with membrane, and M8 mat underlain with membrane) are discussed in the following paragraphs. In evaluating these results it should be kept in mind that these items were designed primarily for use as expedient surfacing materials on airfields rather than on unprepared beaches subject to tidal and wave action. From past experience it is known that these systems will sustain the test loads satisfactorily on dry areas or on areas not affected directly by tidal action.

T11 Aluminum Mat

52. The test results indicate that the T11 mat is unsatisfactory for use as a beach surfacing subject to the action of waves and fluctuating tides, although the lanes surfaced with this mat were operational throughout the entire period of testing and the trafficability potential of the beaches was improved at both sites. The T11 mat was difficult to place and interlock at both test sites, particularly on the inshore portion of the lane at La Turballe Beach. The difficulties experienced in this phase of the investigation alone normally would preclude further consideration of this item as a surfacing for unprepared beaches. However, the T11 mat is still in the development stage, and the connections used for interlocking the present panels are not the ultimate for this design.

53. The most severe problem encountered with the T11 mat during traffic was separation of the end joints. Numerous joints separated at both sites, even though the joints were tight and difficult to close during preparation of the lanes. This condition impeded traffic operations to some extent since it was necessary for the test vehicles to straddle the openings. Also, considerable erosion of the underlying beach occurred under the opened joints, particularly at La Turballe, resulting in failure of the splice-joint rivets near the separated ends. It is believed that most of the separation resulted from excessive deflection of the end

joints during traffic while the mat was under water and partially floating. The Tll panels are light solid surfaces, and these surfaces produce buoyancy which causes considerable fluctuation of the panels exposed to the action of waves and tides. End-joint separation was not experienced with the panels on the backshore of the lane at La Turballe Beach, nor on other portions of either lane from traffic while the panels were above water and substantially supported by the beach. Although the effects of the separated end joints were limited throughout the tests at both sites because of the outstanding structural strength of Tll panels and the effort made to have the test vehicles straddle openings, it is believed that conditions of this type would be detrimental during actual emergency offshore discharge operations.

54. In towing tests at Suscinio, the Tll mat offered considerably less rolling resistance than the unsurfaced beach, as the average towing capability over the beach was increased approximately four times by the use of the mat.

PSP Mat

Without membrane

55. The test results indicate that PSP mat is not satisfactory for use as a beach surfacing subject to the action of waves and fluctuating tides, even though the PSP lanes were operational throughout the entire period of the tests and improved the trafficability potential of the beaches. The lanes at both test sites were in poor condition at the conclusion of the tests because of deformation of the mat, erosion of the subgrade, and disengagement of the panels at the side connection. The PSP mat sustained considerably more deformation than the Tll mat under the vehicular traffic, since the structural strength of the PSP is considerably less than that of the Tll. However, the PSP mat probably would have sustained appreciably less damage than it did if it had been in good condition prior to its use in these tests.

56. Since the PSP is, as the name implies, a pierced-type surfacing, considerable erosion of the subgrade occurred beneath this mat under the action of the waves and fluctuating tide. However, the effect of the

erosion appeared to be more pronounced at the La Turballe Beach site where the erosion of material in the test lane created slack in the mat which caused it to roll up or buckle under the action of waves and fluctuating tide. The erosion of the subgrade under the lane at Suscinio Beach was more uniform and caused the mat to bridge the subgrade in numerous places and sustain increased deformation under the effects of the vehicular traffic. An appreciable amount of sand was deposited on the surface of the PSP mat by the tide at both test sites, either from erosion of soil at the upper limits of the lane or from adjacent unsurfaced areas; the soil remained on the surface of this mat, whereas no soil remained on the solid surface of the Tll mat at low tide. This deposition of sand on the surface of the PSP mat reduced the traction provided by the mat and caused the tires on the test vehicles to slip at various locations until ruts had been formed through the sand to the mat surface. This problem of deposition of soil on the surface of the PSP mat was considerably more pronounced on the La Turballe Beach lane, probably because of the steeper slope and the extremely loose soil surface. The action of the waves and fluctuating tide disengaged and overturned panels in each lane, especially where the spring clips had become disengaged from the side connections. The test results indicate that the PSP mat like the Tll mat is too light and buoyant for satisfactory use as a beach surfacing subject to the action of waves and fluctuating tides. The Tll mat is more buoyant than the PSP mat; and since the PSP mat is pierced, it is less affected by the action of the waves than the solid Tll mat. Therefore, except for erosion, the PSP will resist the direct action of the waves and fluctuating tide better than the Tll mat. The Tll mat prevents erosion of the subgrade better than the PSP mat because it is a solid surfacing.

57. The PSP mat offered considerably less rolling resistance than the unsurfaced beach in the towing tests as the average towing capability over the beach was increased approximately 3.5 times by the use of the mat.

With membrane underlay

58. The overall performance of the PSP mat was improved when it was placed over membrane. The latter prevented erosion of the subgrade underneath the PSP by waves and tides and thus reduced the extent of panel end curl and deformation. Otherwise, the performance of the mat was about the

same as without membrane placed underneath. The neoprene-coated nylon membrane (T14) placed beneath the PSP mat was not punctured or torn by the mat. However, the No. 8 cotton duck vinyl-coated membrane (T1) was punctured and torn by the bayonet side connectors. These perforations in the T1 membrane were not considered severe as erosion of the subgrade did not occur beneath the mat. Placing the ends of the membranes in backfilled ditches at the ends of the test lanes and the weight of the overlying mat panels provided adequate anchorage of the membranes. The storm at Suscinio just prior to completion of traffic caused considerable damage to the mat and displacement of membranes near the offshore end of the test lane.

M8 Steel Mat with Membrane Underlay

59. The M8 mat underlain with membrane was the most satisfactory surfacing tested, as the surface of the mat remained smooth and relatively unaffected throughout the test period. The panels were observed to deflect slightly under vehicle wheel loads, but the traffic did not produce any permanent deformation. Because of inexperience in placement of the M8 mat, field troops did not achieve a high placement rate per man-hour. Nevertheless, the M8 mat was placed faster than the PSP mat which the troops had placed previously on numerous occasions. Several mat panels were damaged when removed from the La Turballe test lane for transporting to the Suscinio test site. This damage was caused when panels were driven apart with sledge hammers before locking lugs were properly disengaged from adjacent mat panels. Because of the weight and configuration of the M8 mat, normal wave action which occurred during the test period at each test site had no apparent detrimental effect on the mat. However, the storm which occurred after completion of traffic did overturn several runs of mat at the offshore end of the lane. Towing force tests indicated that the M8 mat increased the average towing capability over the beach approximately five times.

60. Membranes placed beneath the M8 landing mat performed satisfactorily at both test sites. There was no evidence of scuffing, abrasion, puncture, or deterioration of the membranes placed beneath the M8 mat after the period of traffic tests, although slight indentations were visible on

the membrane surfaces. The 12-in. overlap of membrane runs provided adequate protection of the subgrade from waves and fluctuating tide. Although erosion occurred along the sides of the lanes, the membrane prevented it from extending appreciably under the test lane. Sewn joints of the T12 neoprene-coated nylon membrane test panel remained intact throughout testing at both test sites. The sewn membrane panel was a more rapid means of placing and removing membrane.

PART IV: SUMMARY OF RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

Results

61. Results of these tests indicate that the combination of M8 steel landing mat underlain with membrane was the most satisfactory surfacing expedient investigated. The other types of surfacing sustained 1000 passes of accelerated traffic but the effect of tides, waves, and traffic resulted in displacement and deformation of panels in some areas. The following specific results were obtained.

Membranes

62. a. All membranes performed satisfactorily beneath the PSP and M8 landing mats except that the No. 8 cotton duck, vinyl-coated membrane (T1) was punctured by the bayonet side connectors of the PSP.
- b. Membrane runs which overlapped 12 in. protected the sand subgrade beneath the landing mats from the erosive forces of waves and tide.
- c. Placing the ends of the membranes in backfilled ditches at each end of the test lanes plus the weight of the overlying mat panels provided adequate anchorage of the membranes.
- d. The sewn membrane test panel was placed and removed more rapidly than the rolls of membrane, and the joints remained intact throughout 1000 passes of vehicular traffic.
- e. The portable membrane rack facilitated unrolling the membrane rolls and accelerated the rate at which the runs of membrane were placed on the beaches.

Landing mats

63. a. The M8 was the most satisfactory mat tested as it was relatively unaffected by waves, tide, and accelerated vehicle traffic.
- b. The T11 aluminum landing mat was difficult to place and interlock at both test sites.
- c. Numerous end joints of the T11 aluminum mat became separated under the combined action of vehicle traffic, waves, and tide. After separation of the end joints, waves and tide caused erosion of the subgrade beneath the mat.
- d. Vehicle traffic caused considerable panel deformation and end curl on the PSP mat.
- e. Wave action caused several runs of the T11 and PSP mats to disengage at the side connections, whereas the M8 mat was not so affected.

- f. The PSP landing mat was placed easier and faster on membranes than on the unsurfaced sand beach.
- g. The towing capability over the beach was increased about three to five times by the use of landing mat.

Conclusions

64. Based on the results of this study, the following conclusions are believed warranted:

- a. All the types of portable surfacing tested improve vehicle trafficability across the beach test sites. Vehicle traffic alone causes very little damage to the surfacing materials.
- b. The M8 is the most satisfactory landing mat of those tested for increasing the trafficability potential of beaches.
- c. All landing mats tested increase the towing force capability of vehicles on sand beaches.
- d. All surfacing materials tested can be rapidly placed, removed, and reused on beach areas by field troops.
- e. Neoprene-coated nylon membranes perform best beneath the landing mats tested.
- f. Wave heights in the order of 5 ft will overturn and disengage T11 and PSP panels.

Recommendations

65. In view of the findings presented in this report, it is recommended that:

- a. The M8 steel landing mat (with or without membrane underneath) replace the PSP mat in future offshore discharge operations.
- b. A study, which would include laboratory and prototype tests, be conducted to determine the feasibility of developing a special beach surfacing expedient. Effects of waves, tides, beach slopes, materials, etc., should be investigated.

Table 1
Summary of Test Lane Construction Data, La Turballe Beach

Test Lane	Type Mat	Type Membrane	Materials Used		Avg Placing Crew		Placing Time		Placing Rate		Test Lane Const Rate sq ft/man-hour	Remarks
			sq ft	Mem-brane	No. of Men	Mem-brane	hr:min	Mem-brane	sq ft/man-hour	Mem-brane		
1	T11	None	4981.2	---	8	--	9:50	--	63.3	---	63.3	
2	PSP	None	5962.5	---	10	--	5:45	--	103.7	---	103.7	
3	PSP	1/2 T1 and 1/2 T14	4350.0	6552.0	10	8	2:45	0:30	158.2	1638.0	144.3	
4	10-gage M8	30 ft by 30 ft sewn T12, remainder 1/2 T1 and 1/2 T14	4865.0	6276.0	8	8	3:45	0:25	162.2	1913.4	149.0	T12 sewn panel placed at point of low tide

Table 2

Summary of Vehicle Traffic, La Turballe Beach

<u>Lane</u>	<u>Surfacing Materials</u>	<u>1959 Date</u>	<u>Type of Vehicle Traffic</u>	<u>Gross Load lb</u>	<u>Inflation Pressure* psi</u>	<u>Passes of Vehicle on Indicated Day</u>	<u>Total Passes</u>	<u>Remarks</u>
1	T11 aluminum mat	21 May	DUKW	20,000	25	8		Completed 21 May
			DUKW	20,000	40	6	14	
		22 May	M51	30,000	70	390	404	
		23 May	M51	30,000	70	86	490	
		25 May	M51	34,000	70	161	651	
		26 May	M51	34,000	70	349	1000	Exposed to tidal action for 8 days
2	PSP mat	19 May	M51	34,000	70	23		Completed 19 May
			DUKW	20,000	25	4	27	
		20 May	M51	34,000	70	260	287	
		21 May	M51	34,000	70	184		
			DUKW	20,000	25	20	491	
		22 May	M51	30,000	70	122		
				34,000	70	50	663	
3	PSP mat underlain with T1 and T14 membranes	23 May	M51	30,000	70	26		
			DUKW	20,000	25	20	709	
		25 May	M51	34,000	70	291	1000	Exposed to tidal action for 9 days
		20 May	M51	34,000	70	200		Completed 20 May
		22 May	M51	34,000	70	190	390	
		23 May	M51	34,000	70	12		
4	M8 mat underlain with T1, T12, and T14 membranes		DUKW	20,000	25	20	422	
		25 May	M51	34,000	70	274		
			DUKW	20,000	25	20	716	
		26 May	M51	30,000	70	284	1000	Exposed to tidal action for 8 days
		22 May	M51	34,000	70	405		Completed 21 May. Sewn panel (30 ft by 30 ft) of the T12 membrane placed between sta 2+00 and 1+70
		23 May	M51	34,000	70	177		
			DUKW	20,000	25	20	602	
		25 May	M51	30,000	70	200		
			DUKW	20,000	25	20	822	
		26 May	M51	34,000	70	178	1000	Exposed to tidal action for 8 days

* Front and rear wheels.

Table 3
Summary of Test Lane Construction Data, Suscinio Beach

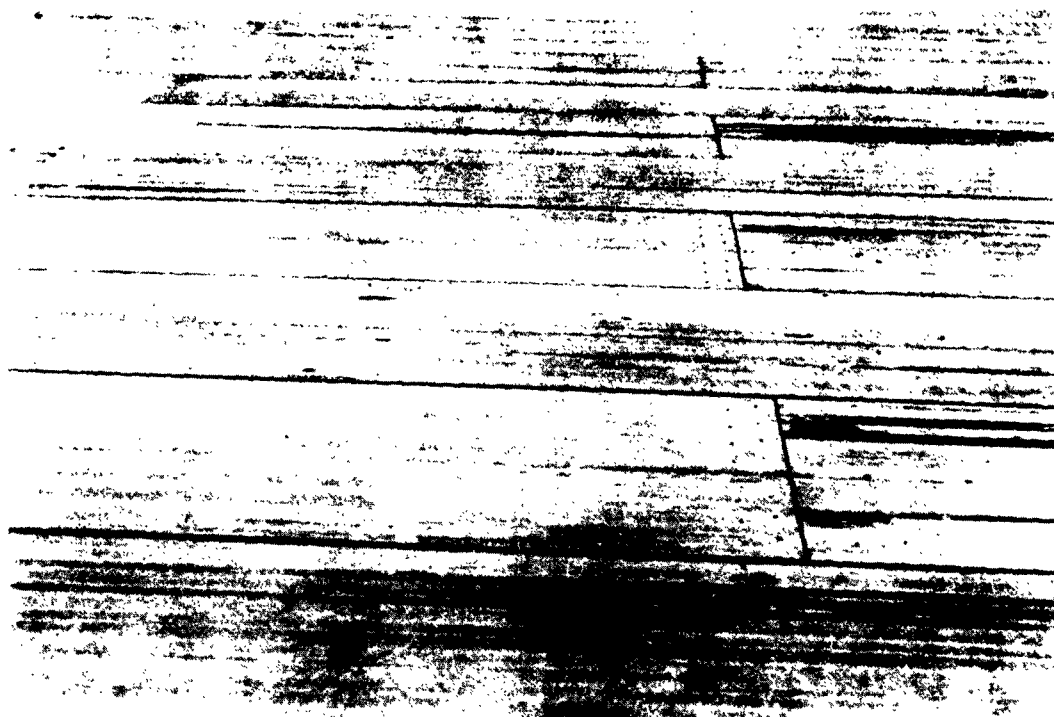
Test Lane	Type Mat	Type Membrane	Materials Used		Avg Placing Crew		Placing Time		Placing Rate		Test Lane Const Rate sq ft/man-hour	Remarks
			sq ft	Mem-brane	No. of Men	Mem-brane	hr:min	Mem-brane	sq ft/man-hour			
										Mat		
1	T11	None	4200	--	6	--	7:00	--	100.0	---	100.0	
2	PSP	None	4290	--	6	--	8:00	--	89.4	---	89.4	
3	PSP	1/2 T1 and 1/2 T14	4500	5250	6	6	4:30	0:30	166.7	1750.0	152.1	
4	M8	30 ft by 30 ft sewn panel T12, remainder 1/2 T1 and 1/2 T14	5445	6552	8	8	4:00	0:30	170.2	1638.0	154.0	T12 sewn panel placed near point of high tide

Table 4

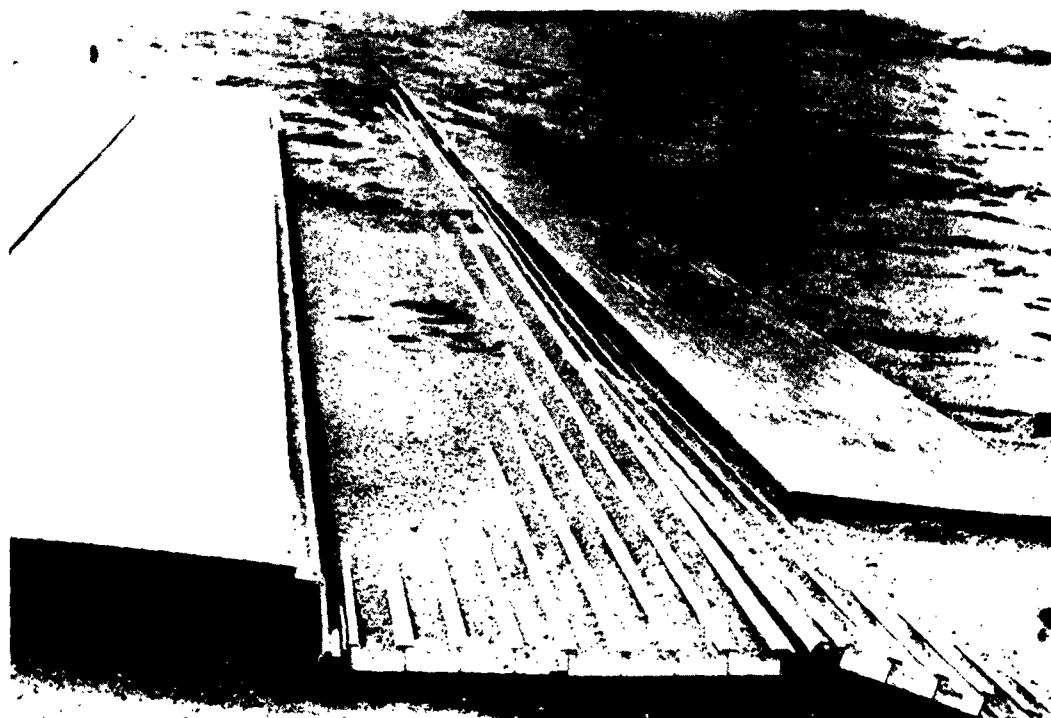
Summary of Vehicle Traffic, Suscinio Beach

<u>Lane</u>	<u>Surfacing Materials</u>	<u>1959 Date</u>	<u>Type of Vehicle Traffic</u>	<u>Gross Load lb</u>	<u>Inflation Pressure* psi</u>	<u>Passes of Vehicle on Indicated Day</u>	<u>Total Passes</u>	<u>Remarks</u>
1	T11 aluminum mat	3 June	M51	32,900	70	240		Completed 1 June
		5 June	M51	32,900	70	300	540	
		6 June	DUKW	20,000	25	110		
			DUKW	14,670	25	60		
			M51	32,900	70	50	760	
		8 June	M51	32,900	70	240	1000	Exposed to tidal action for 9 days
2	PSP mat	3 June	M51	31,240	70	200		Completed 1 June
		4 June	M51	31,240	70	150	350	
		5 June	M51	31,240	70	520	870	
		6 June	DUKW	20,000	25	70		
			DUKW	14,670	25	60	1000	Exposed to tidal action for 9 days
3	PSP mat underlain with T1 and T14 membranes	4 June	M51	32,900	70	500		Completed 2 June
		5 June	DUKW	20,000	40	160		
			DUKW	14,670	40	40	700	
		6 June	DUKW	20,000	25	105	805	
		8 June	M51	32,900	70	195	1000	Exposed to tidal action for 8 days
4	M8 mat underlain with T1, T12, and T14 membranes	4 June	M51	31,240	70	380		Completed 2 June
		5 June	DUKW	20,000	40	180		
			DUKW	14,670	40	40	600	
		6 June	M51	32,900	70	400	1000	Exposed to tidal action for 8 days

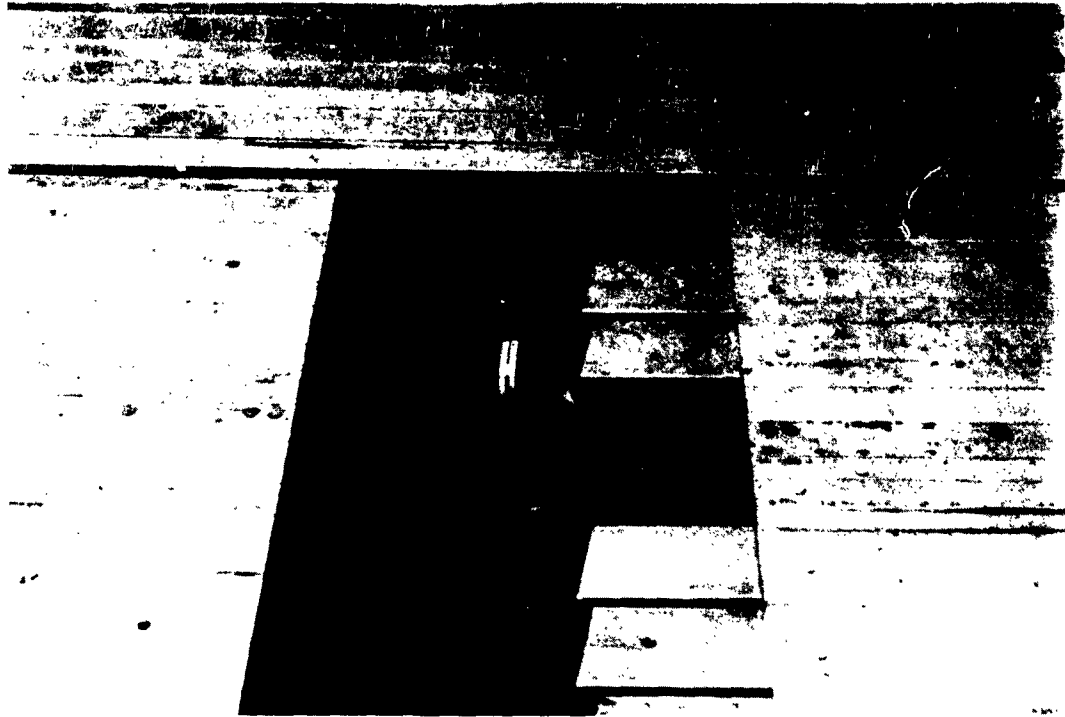
* Front and rear wheels.



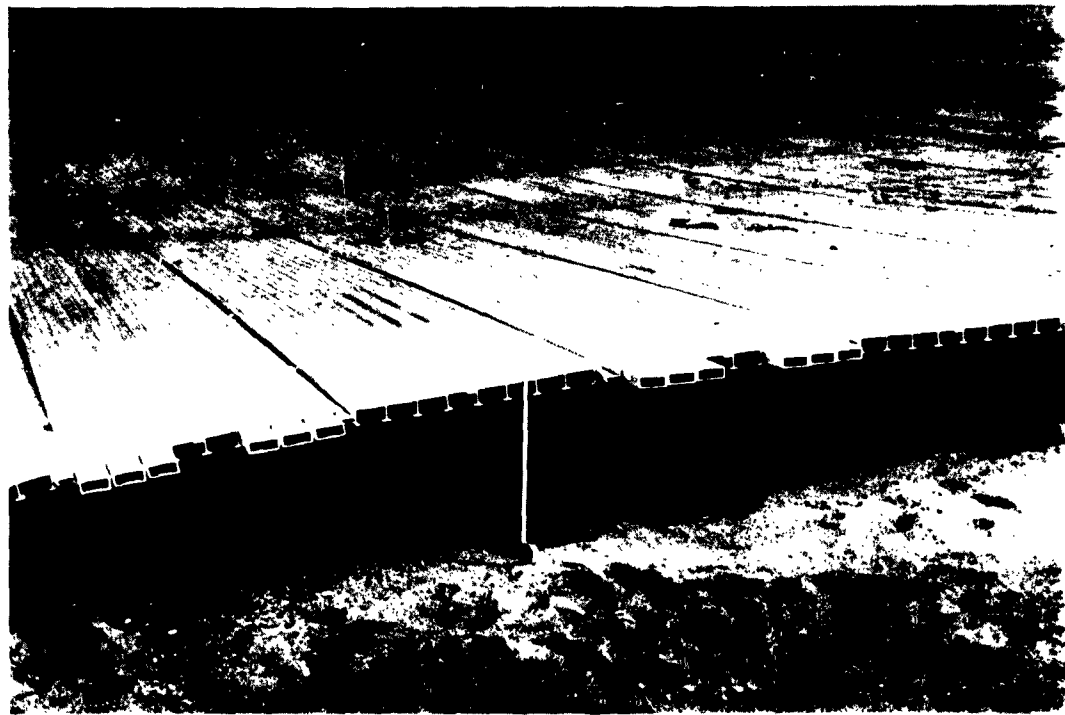
Photograph 1. T11 aluminum mat on lane 1, La Turballe, prior to traffic



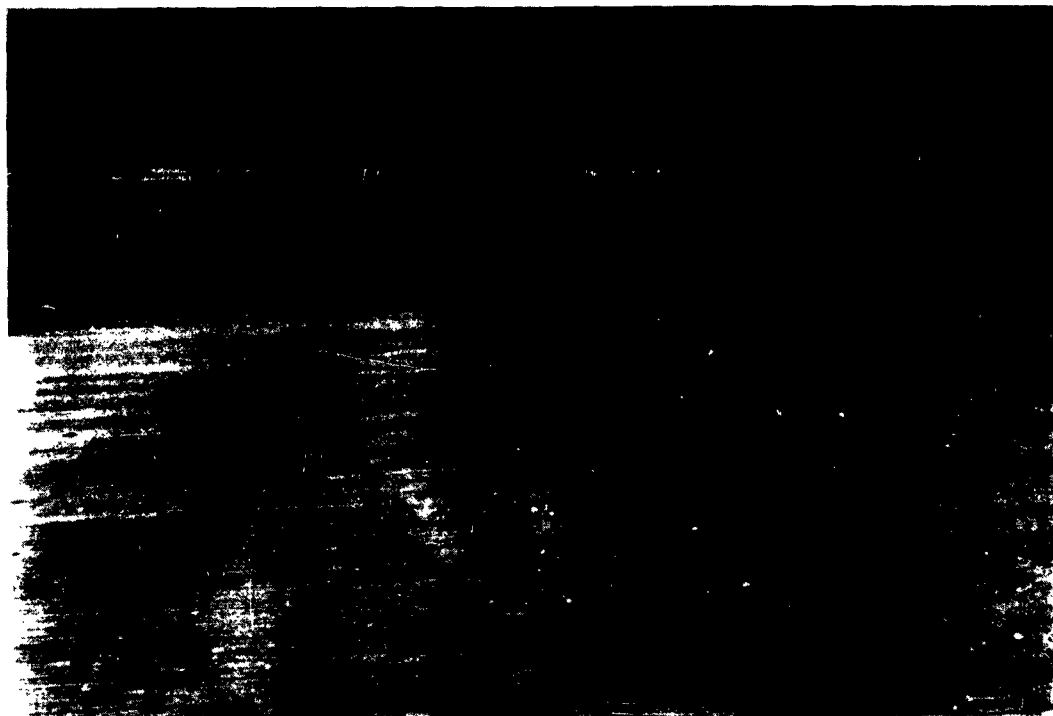
Photograph 2. Overturned panels at offshore end of lane 1, La Turballe,
404 passes



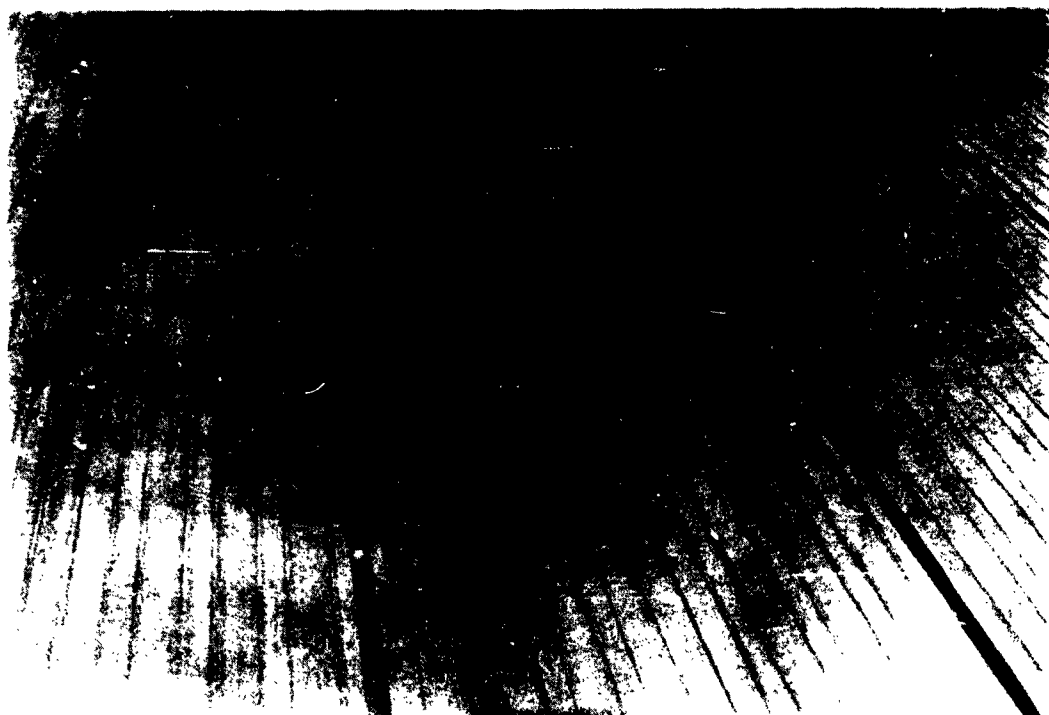
Photograph 3. Scour under separated end joint of lane 1, La Turballe,
404 passes



Photograph 4. Scour along south edge of lane 1, La Turballe, 404 passes



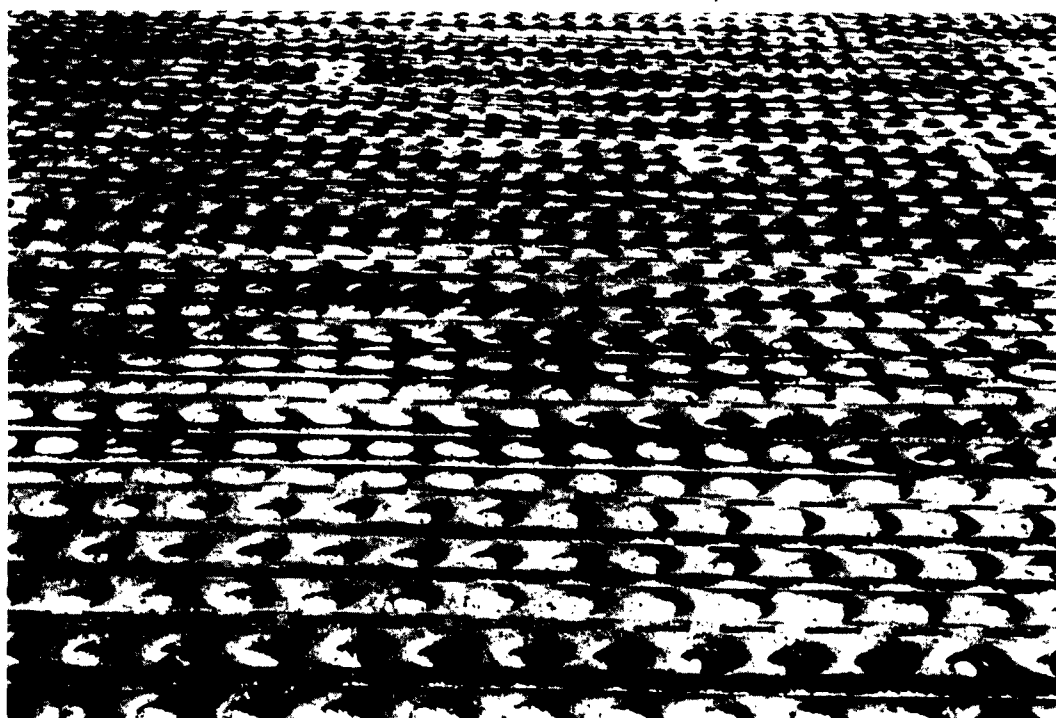
Photograph 5. General view of lane 1, La Turballe, 404 passes



Photograph 6. Splice-joint failure in Tll mat, lane 1, La Turballe,
452 passes



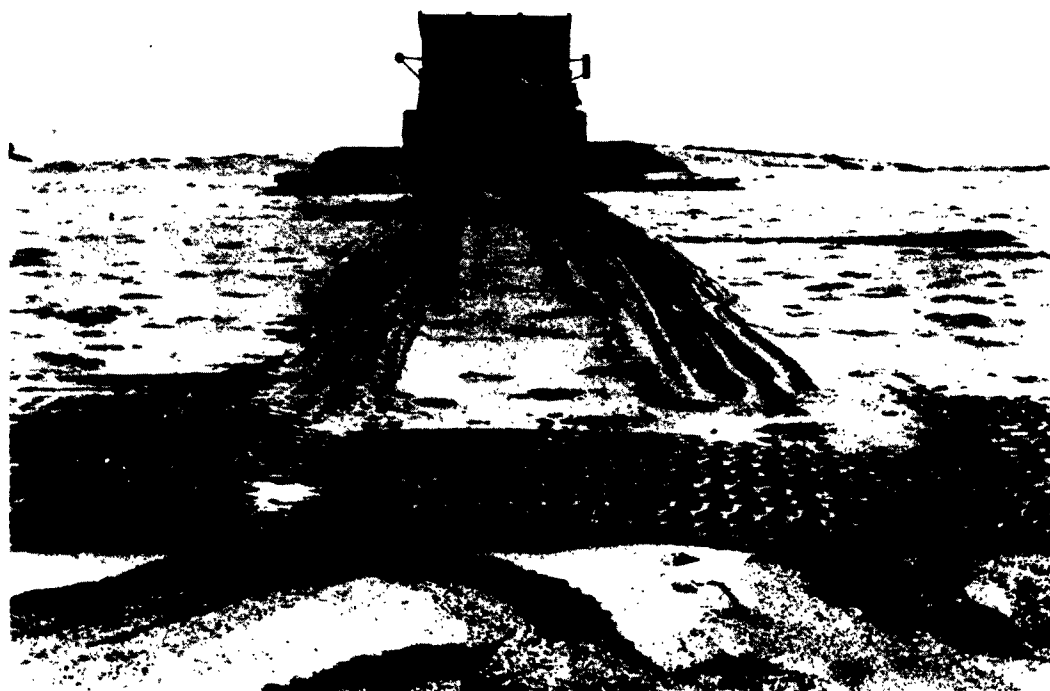
Photograph 7. General view of lane 1, La Turballe, 1000 passes



Photograph 8. PSP on lane 2, La Turballe, prior to traffic



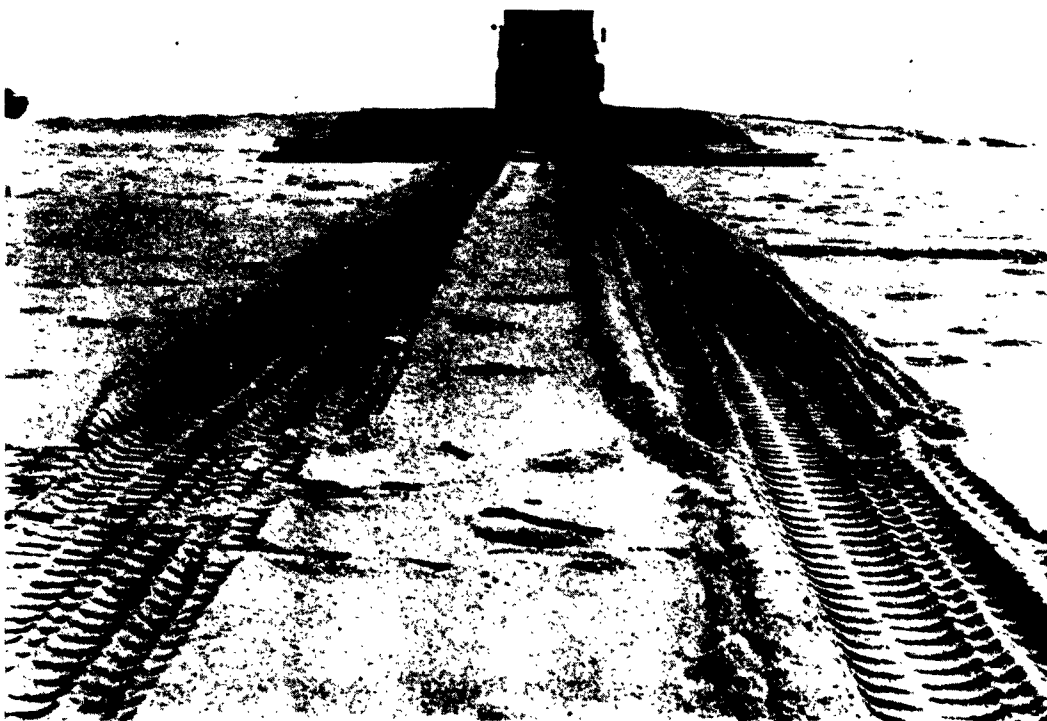
Photograph 9. Disengaged panels at offshore end of lane 2, La Turballe, 600 passes



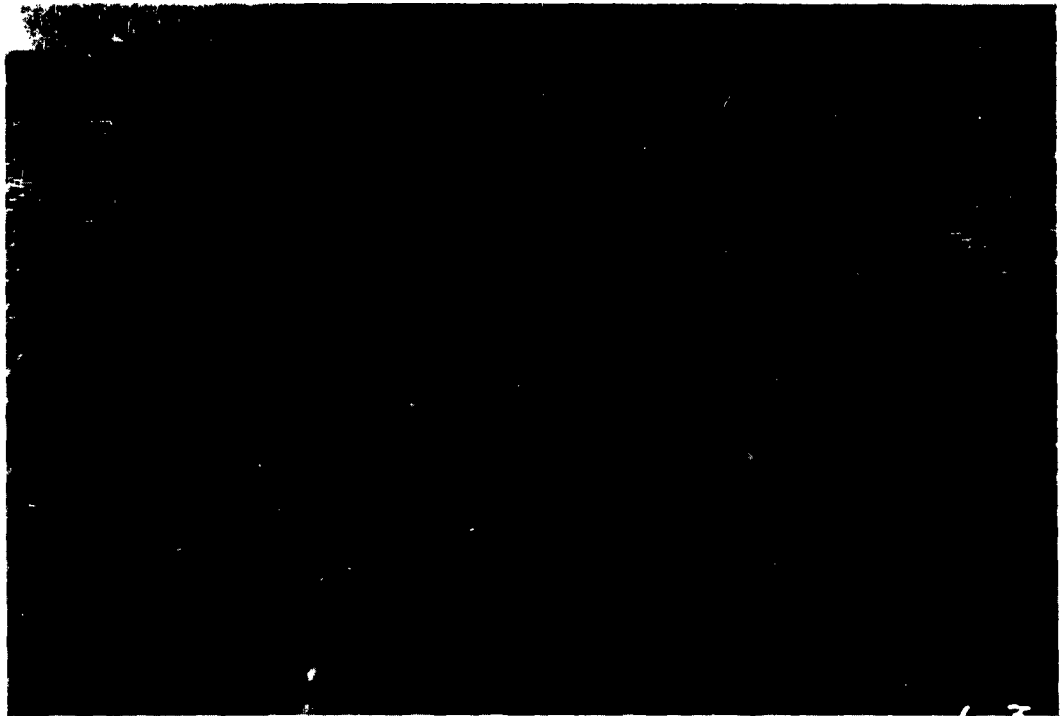
Photograph 10. Deposition of sand on lane 2, La Turballe, 600 passes



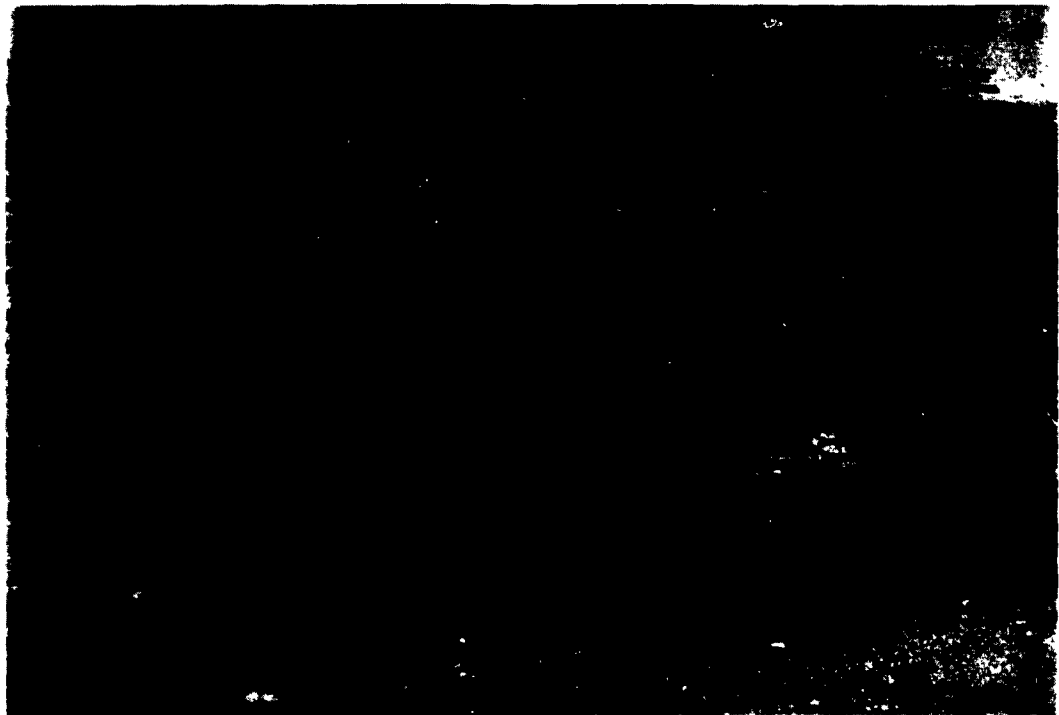
Photograph 11. Buckled-up mat on lane 2, La Turballe, 600 passes



Photograph 12. General view of lane 2, La Turballe, 1000 passes



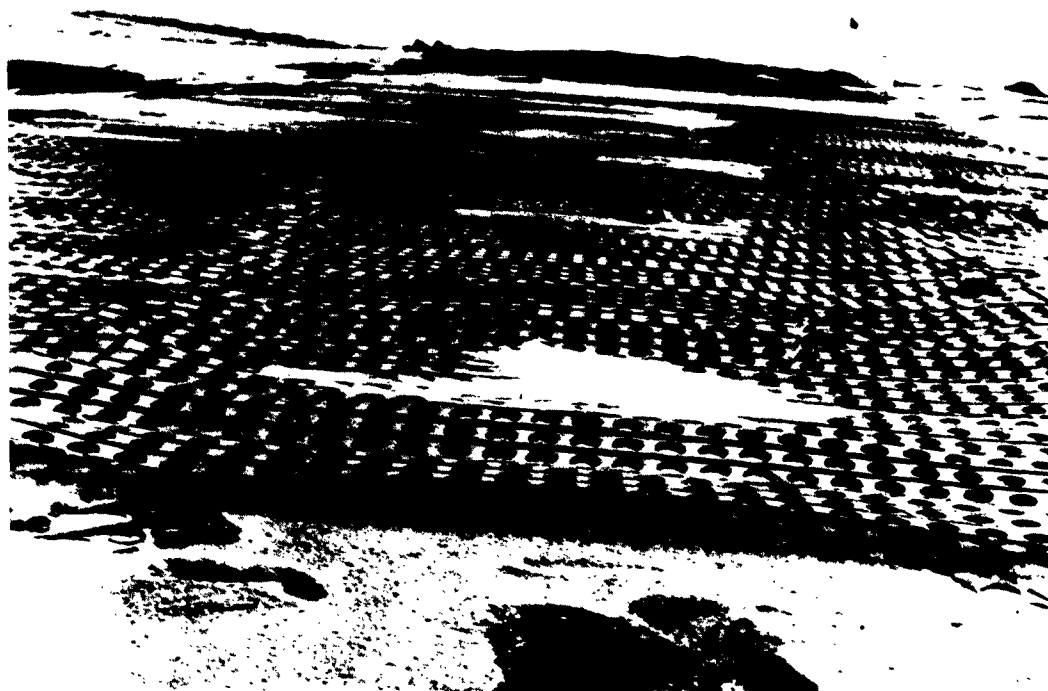
Photograph 13. PSP underlain with membrane on lane 3, La Turballe,
prior to traffic



Photograph 14. Disengaged panels at offshore end of lane 3, La Turballe,
390 passes



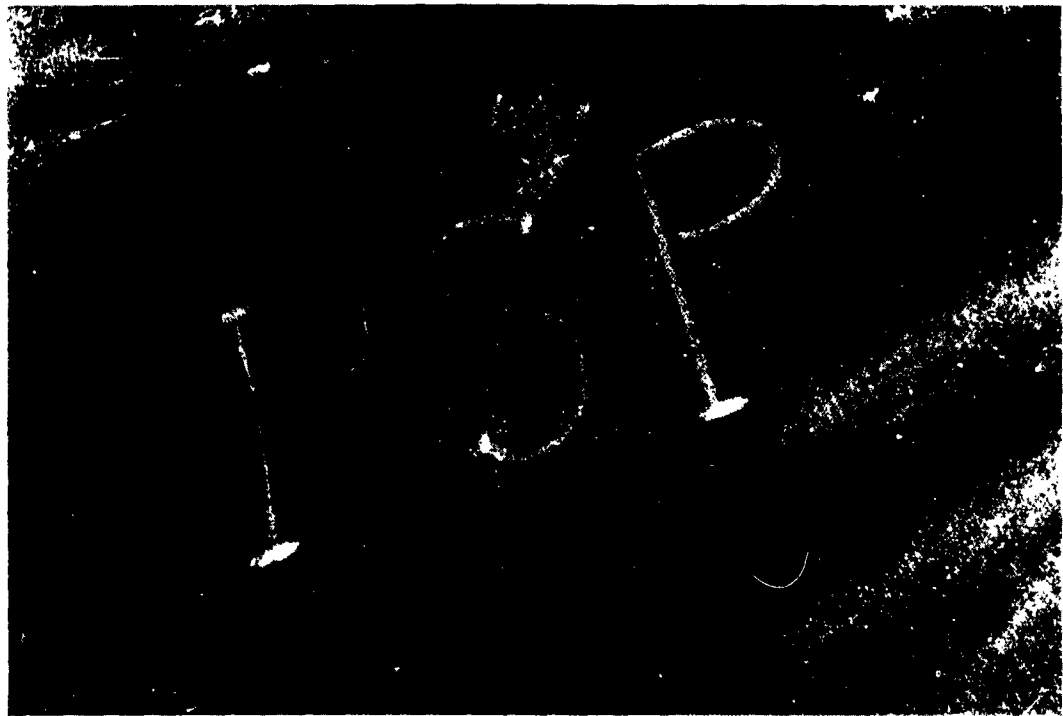
Photograph 15. Scour along southeast edge of lane 3, La Turballe,
390 passes



Photograph 16. General view of lane 3, La Turballe, 450 passes



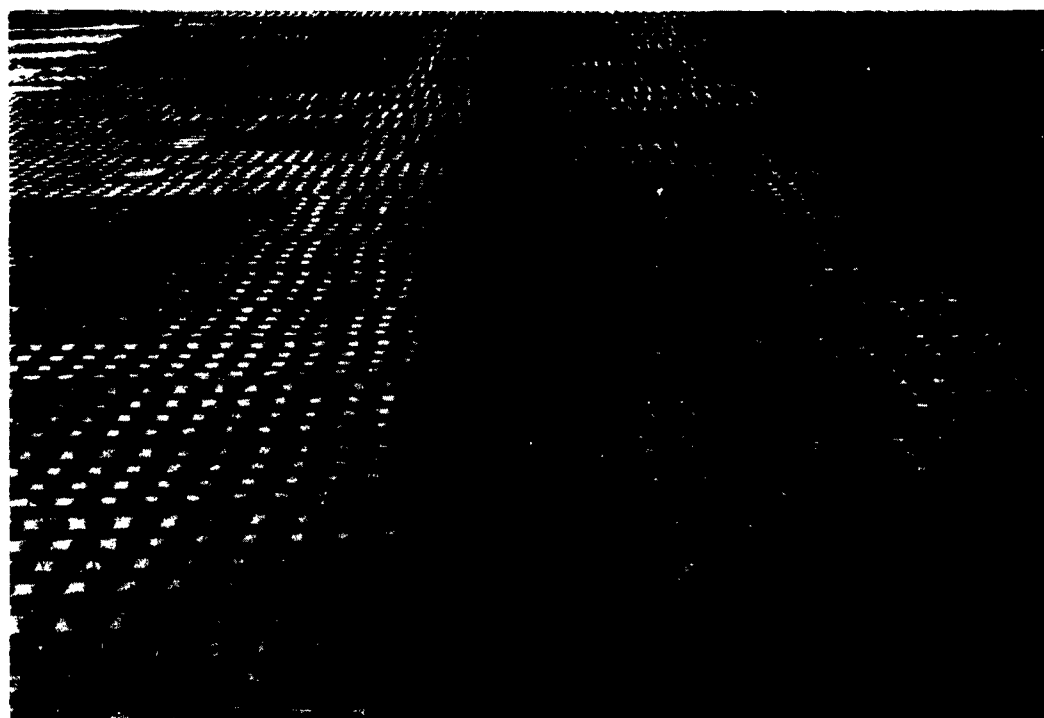
Photograph 17. General view of lane 3, La Turballe, 1000 passes



Photograph 18. T14 nylon membrane on lane 3, La Turballe, 1000 passes



Photograph 19. T1 cotton duck membrane on lane 3, La Turballe, 1000 passes



Photograph 20. M8 mat underlain with membrane on lane 4, La Turballe,
prior to traffic



Photograph 21. M8 mat on lane 4, La Turballe, 1000 passes



Photograph 22. T1 cotton duck membrane on lane 4, La Turballe, 1000 passes



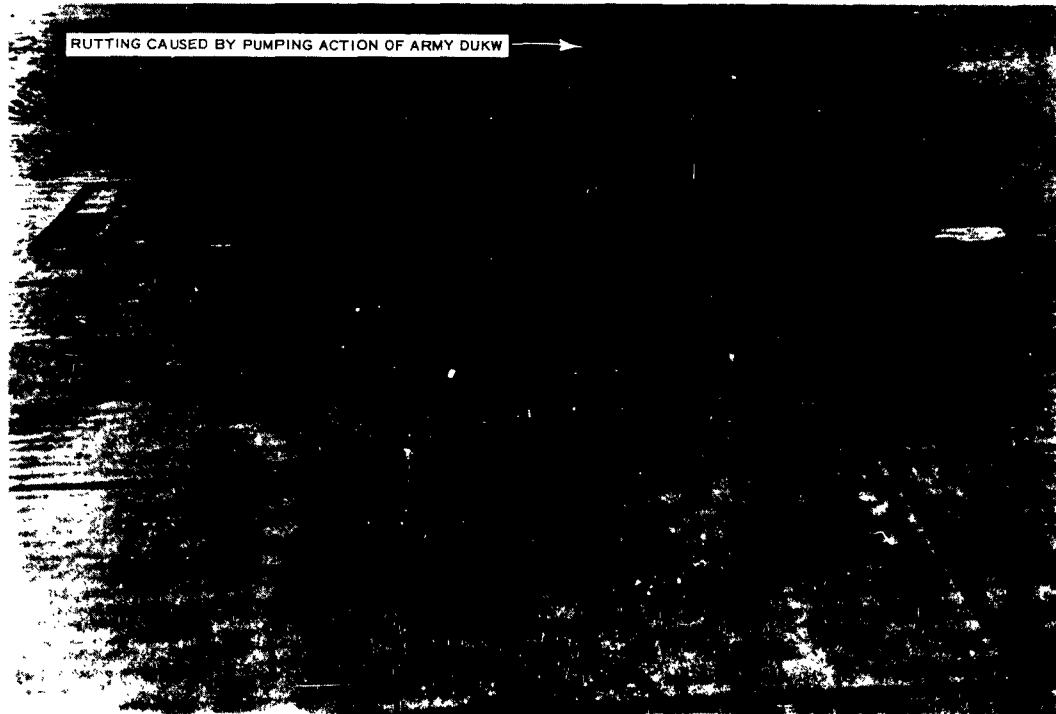
Photograph 23. T14 nylon membrane on lane 4, La Turballe, 1000 coverages



Photograph 24. T11 aluminum mat on lane 1, Suscinio, prior to traffic



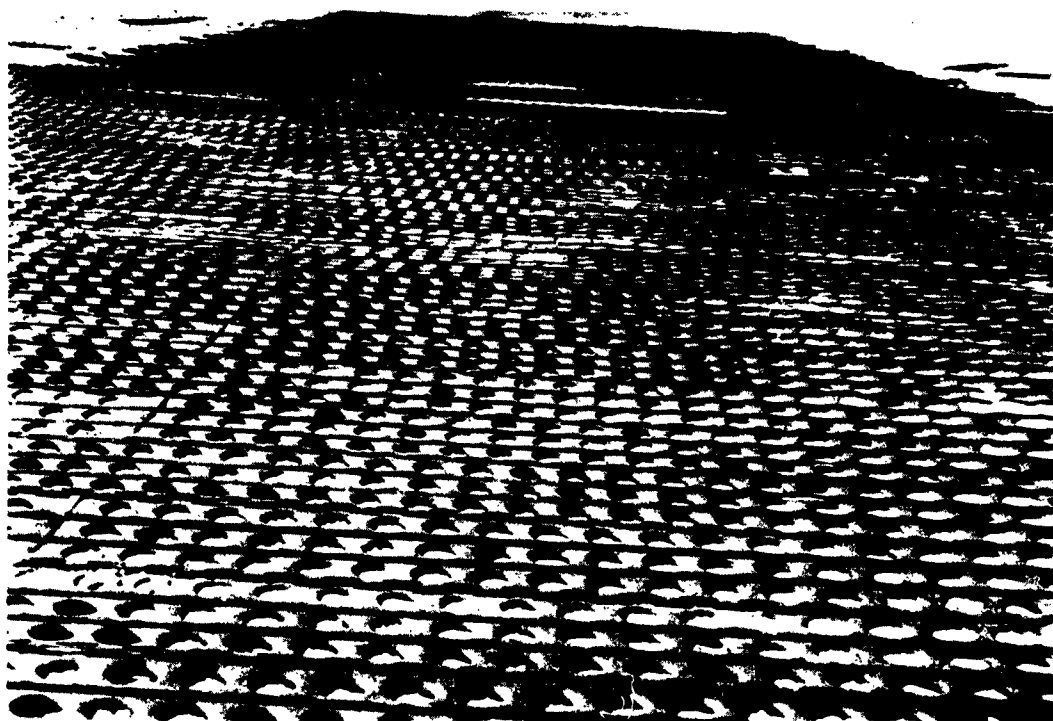
Photograph 25, Failure of splice-joint rivets in T11 mat, lane 1, Suscinio, 200 passes



Photograph 26. Offshore end of T11 mat, lane 1, Suscinio, 1000 passes



Photograph 27. End-joint separation in T11 mat, lane 1, Suscinio,
1000 passes



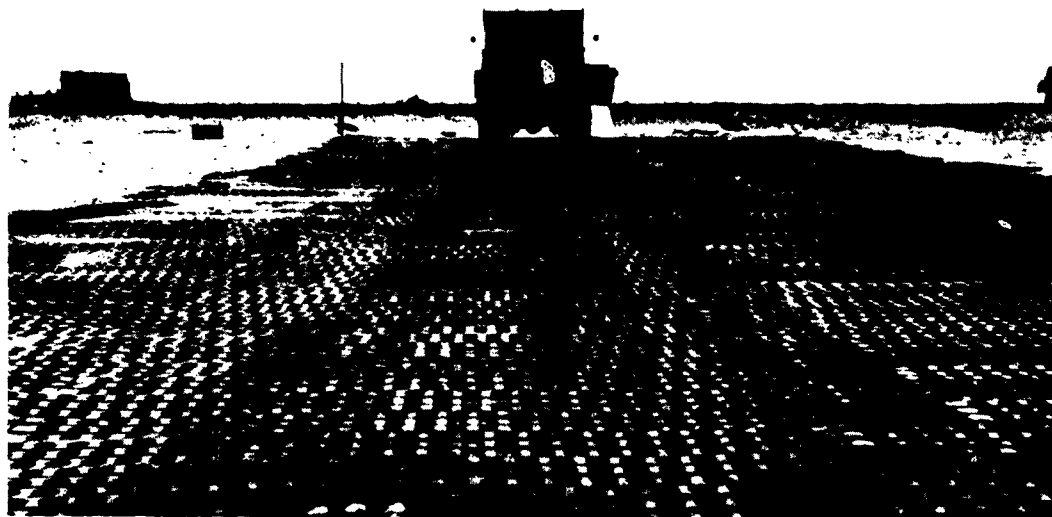
Photograph 28. PSP on lane 2, Suscinio, prior to traffic



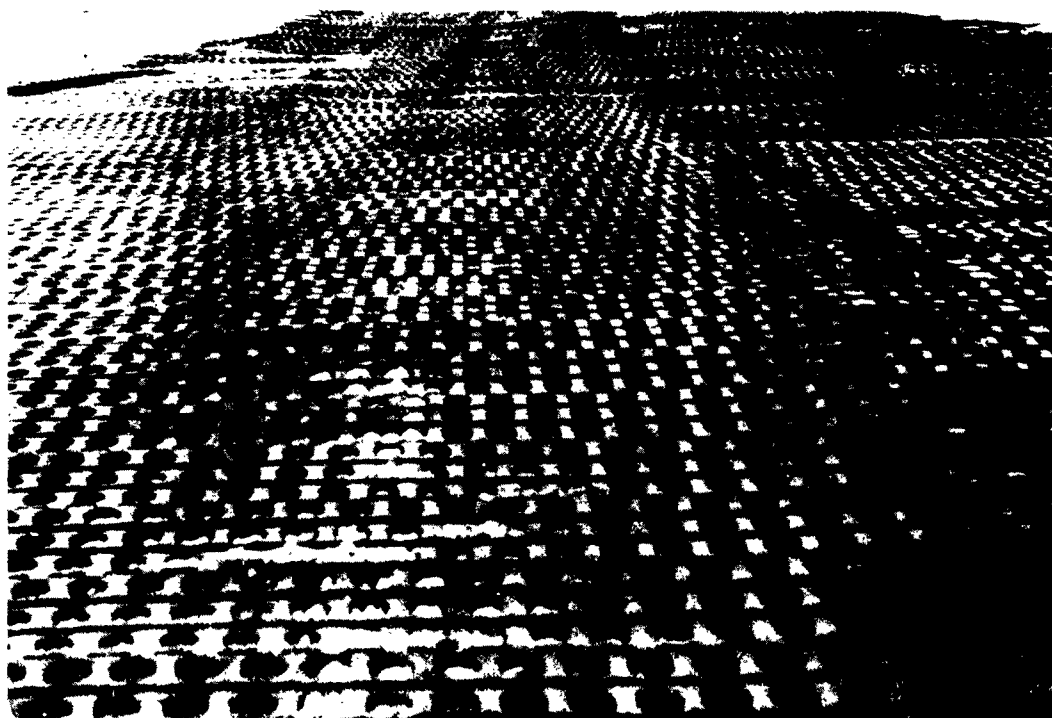
Photograph 29. PSP on lane 2, Suscinio, 200 passes



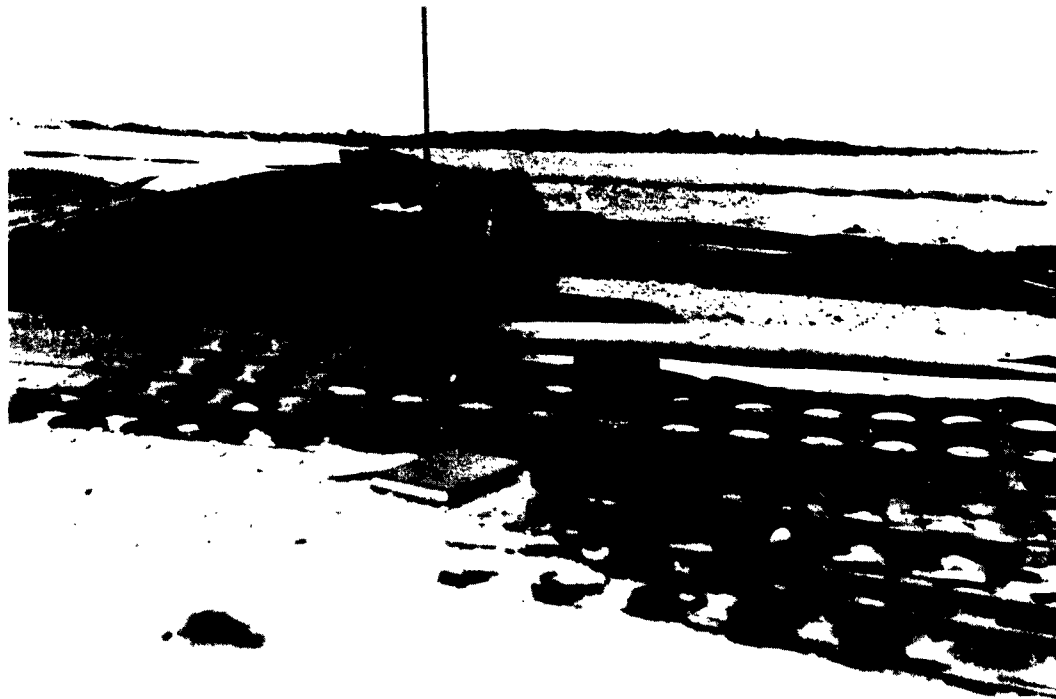
Photograph 30. General view of PSP on lane 2, Suscinio, 1000 passes



Photograph 31. PSP placed on membrane, lane 3, Suscinio, prior to traffic



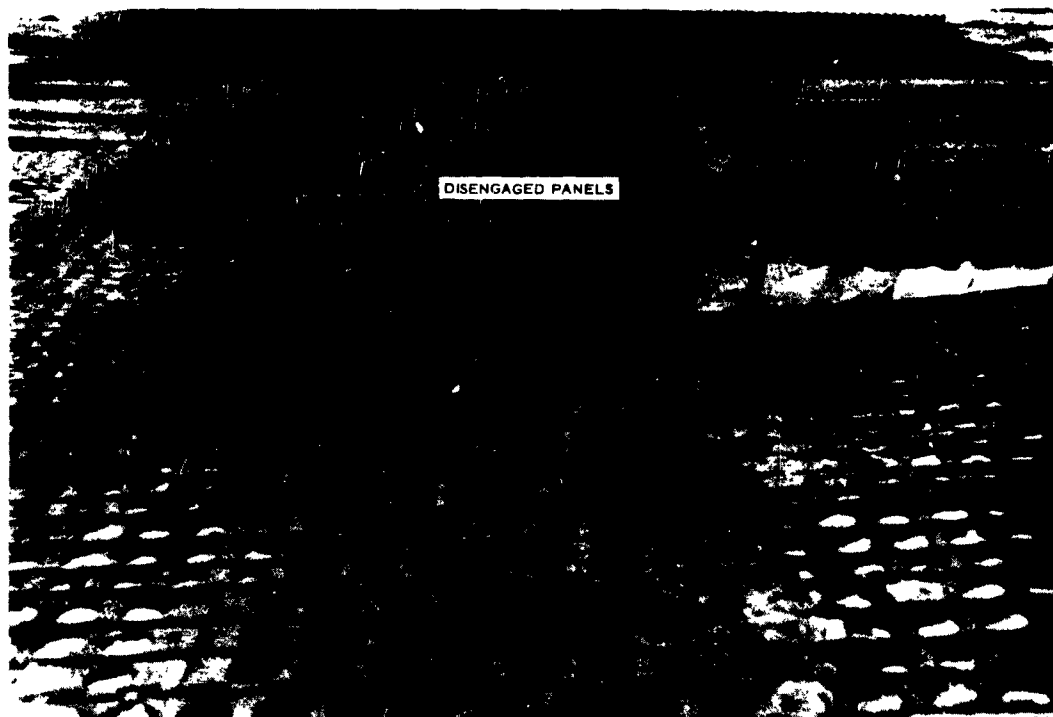
Photograph 32. PSP on membrane, lane 3, Suscinio, 200 passes



Photograph 33. Disengaged section of PSP mat near offshore end of lane 3, Susicinio, 1000 passes (after storm)



Photograph 34. Displaced membranes near offshore end of lane 3, Susicinio, 1000 passes (after storm)



Photograph 35. Disengaged panel of PSP mat on inshore portion of lane 3, Susicinio, 1000 passes (after storm)



Photograph 36. M8 mat placed over membrane, lane 4, Susicinio, 1000 passes



Photograph 37. General view of M8 mat placed over membrane, lane 4, Susicinio, after storm



Photograph 38. Close-up of M8 mat placed over membrane, lane 4, Susicinio, after storm

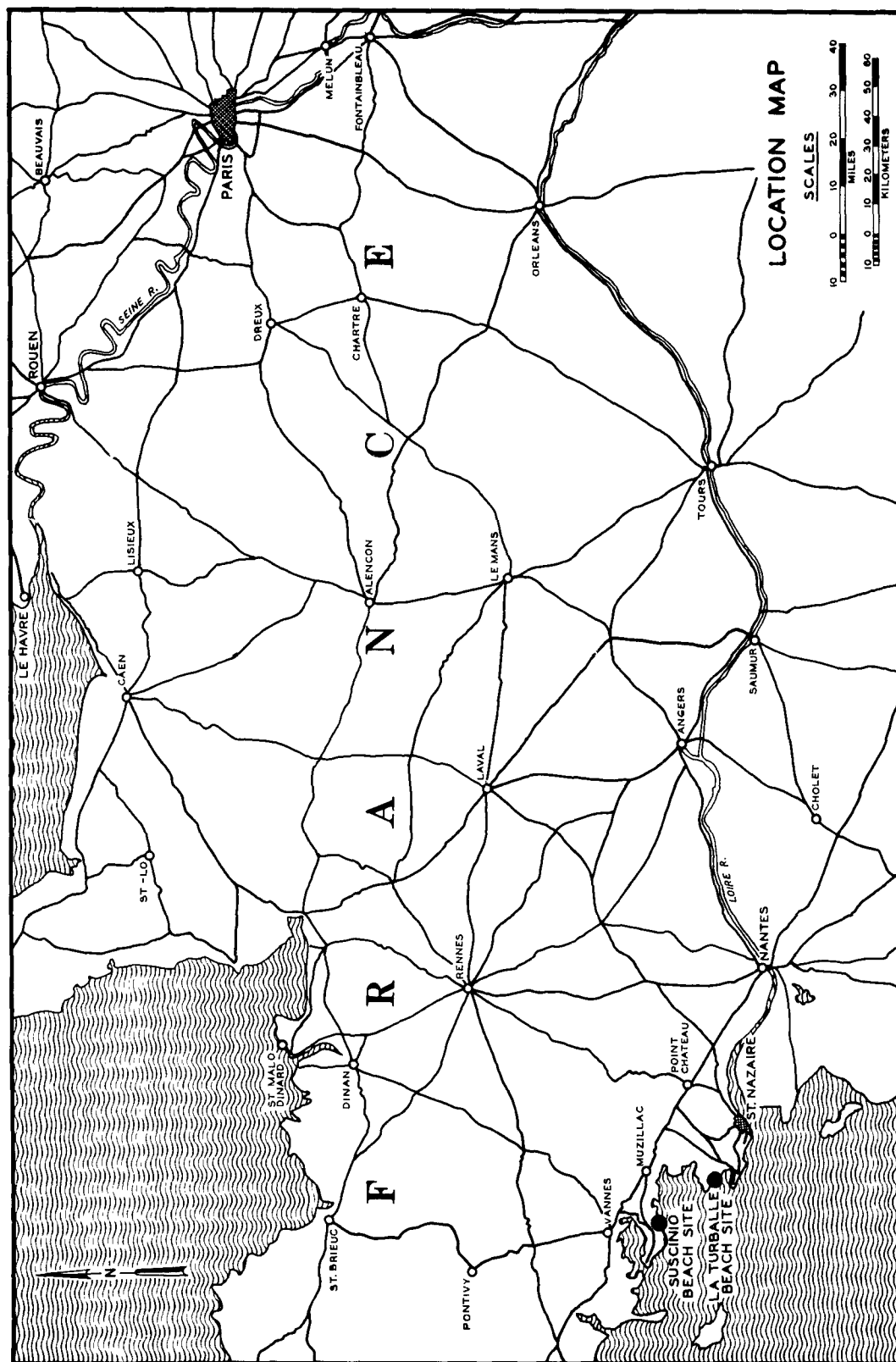
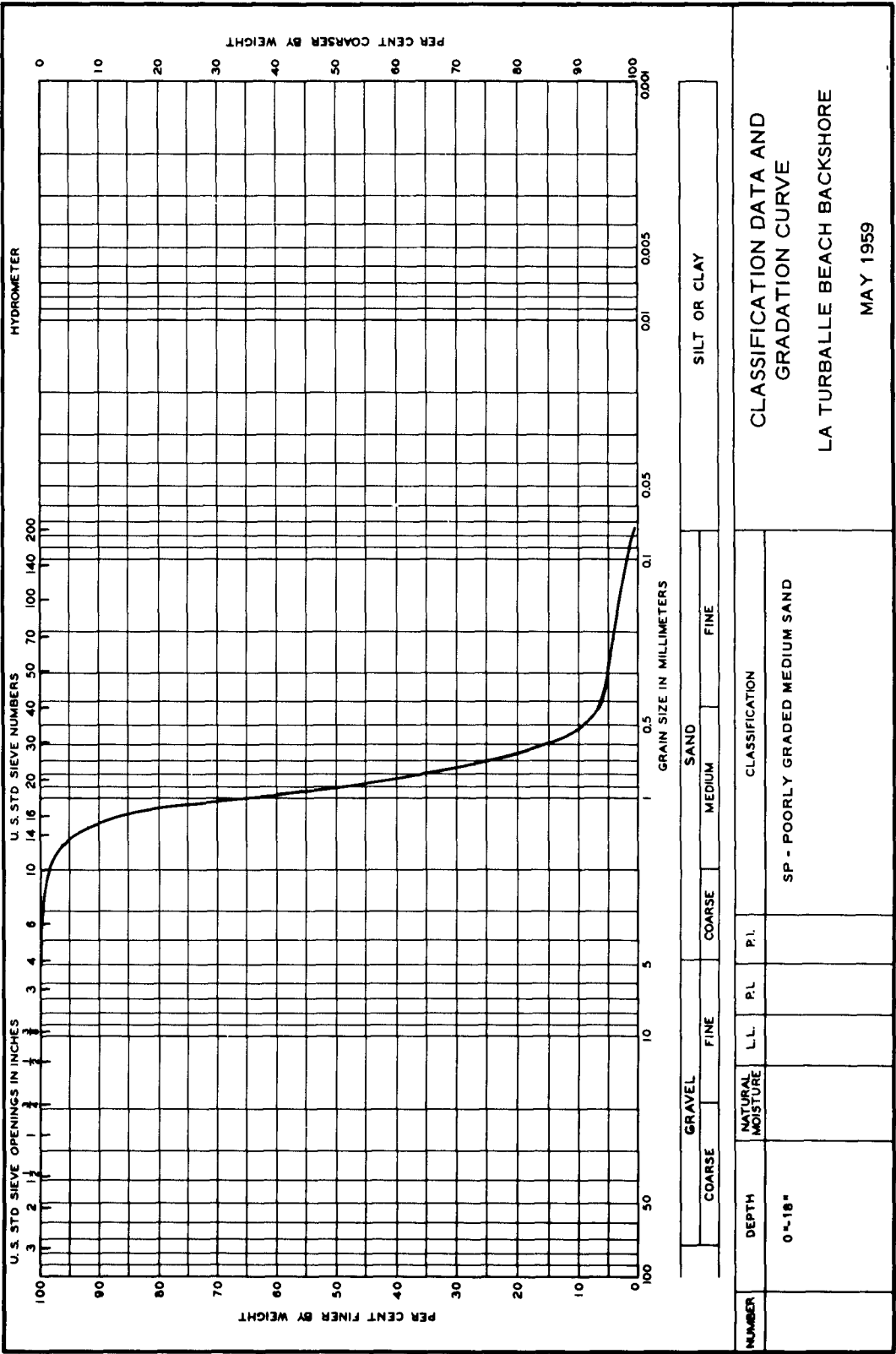


PLATE 2



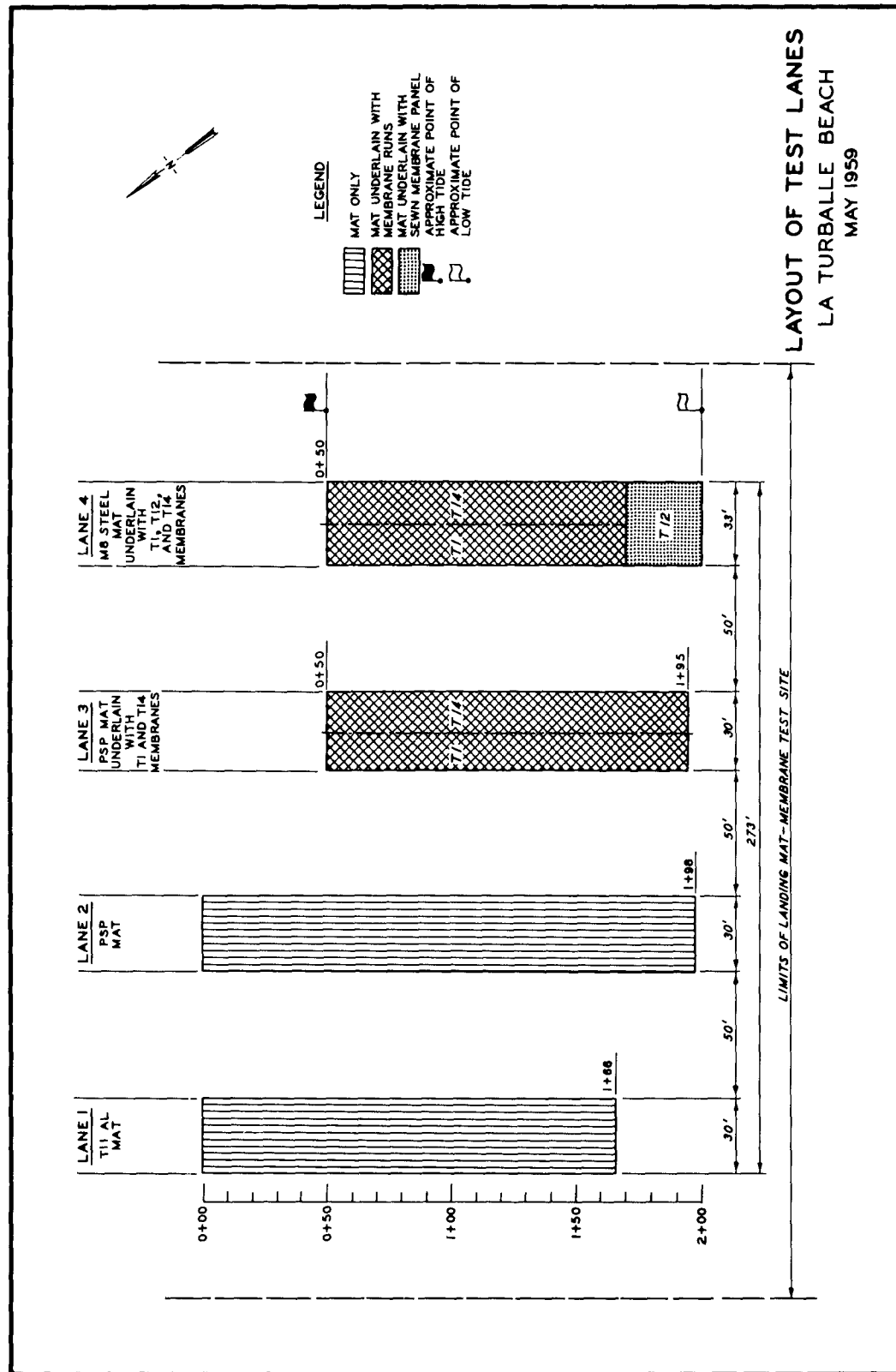
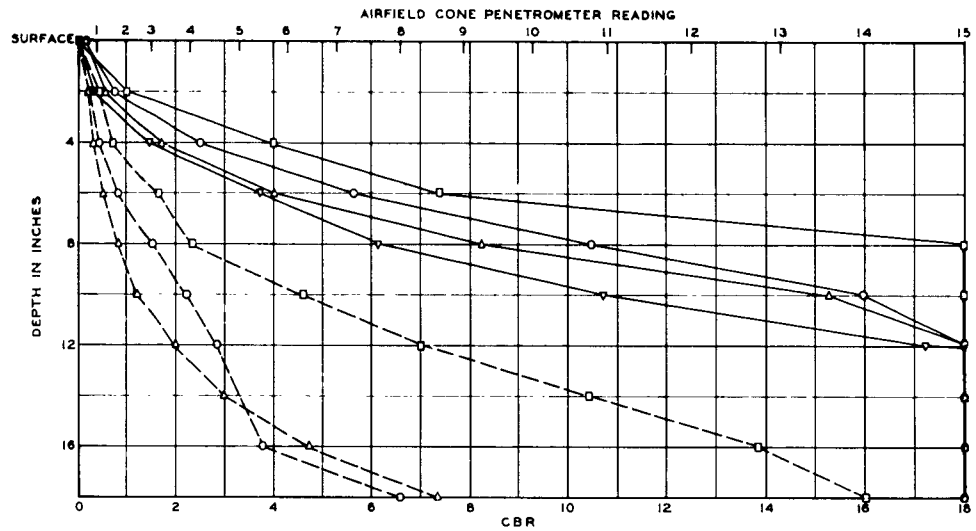
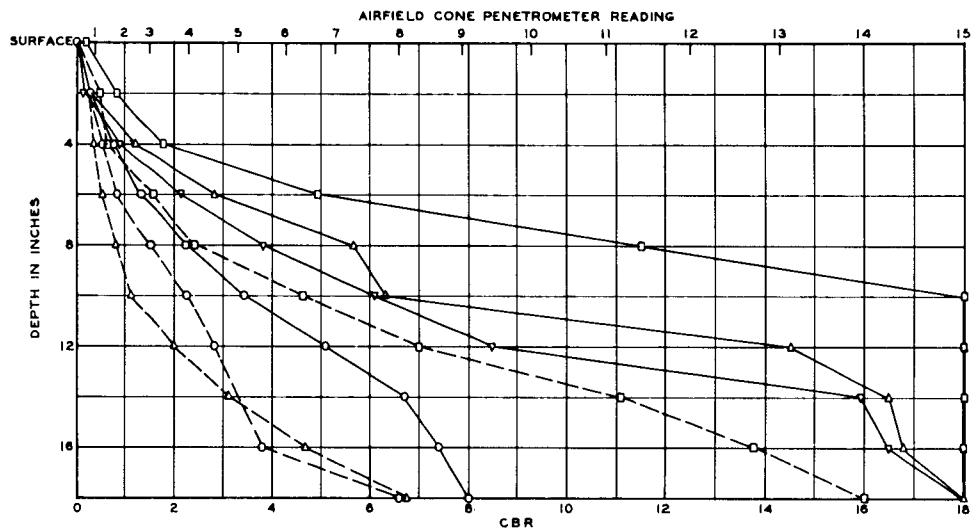


PLATE 4



LANE 1



LANE 2

LEGEND

----- BEFORE TRAFFIC

———— AFTER TRAFFIC

○ STA 0+00

△ STA 0+50

□ STA 1+00

◇ STA 1+50

CBR
BEFORE AND AFTER
TRAFFIC
LANES 1 AND 2
LA TURBALLE BEACH
MAY 1959

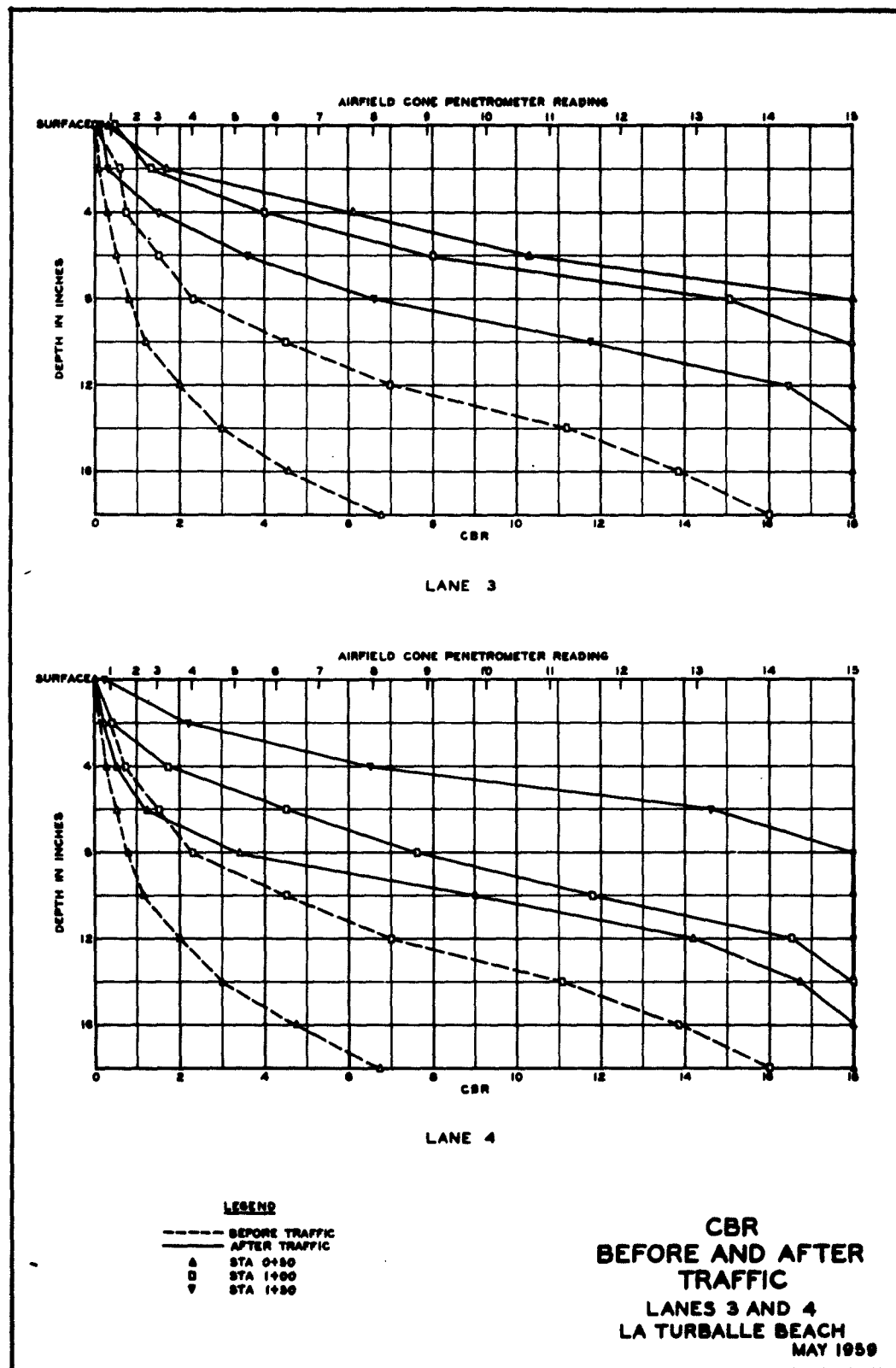


PLATE 6

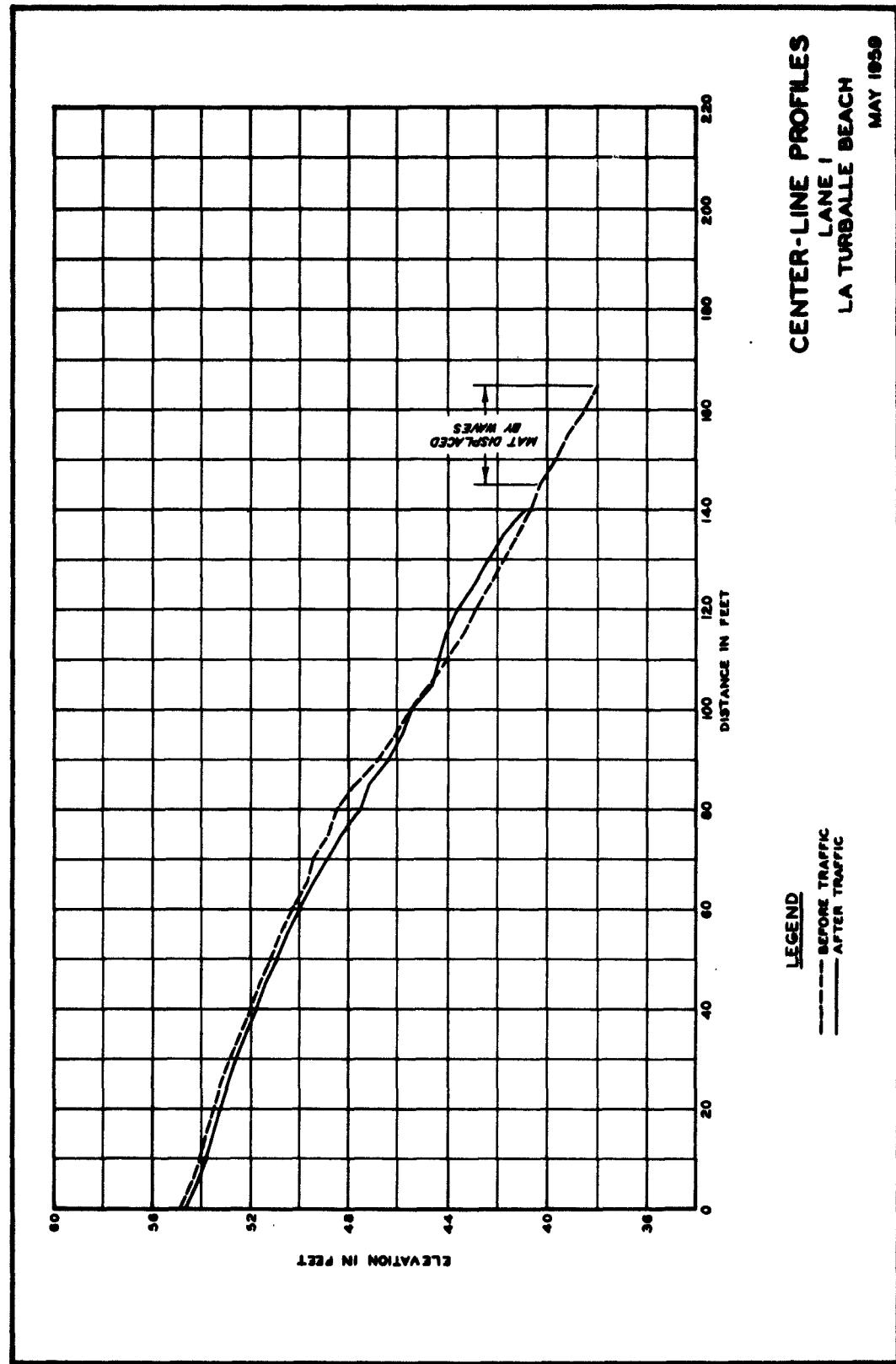
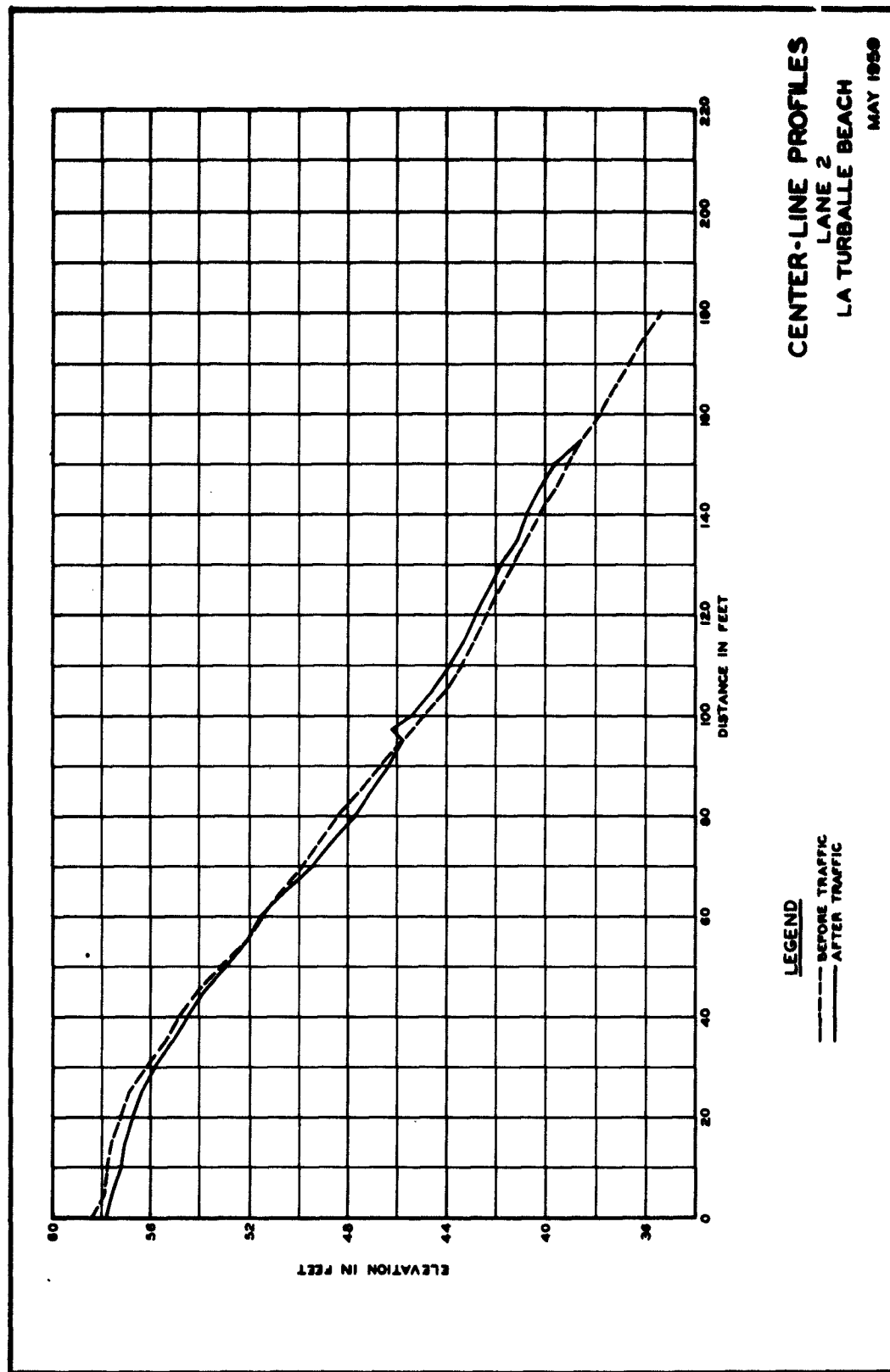
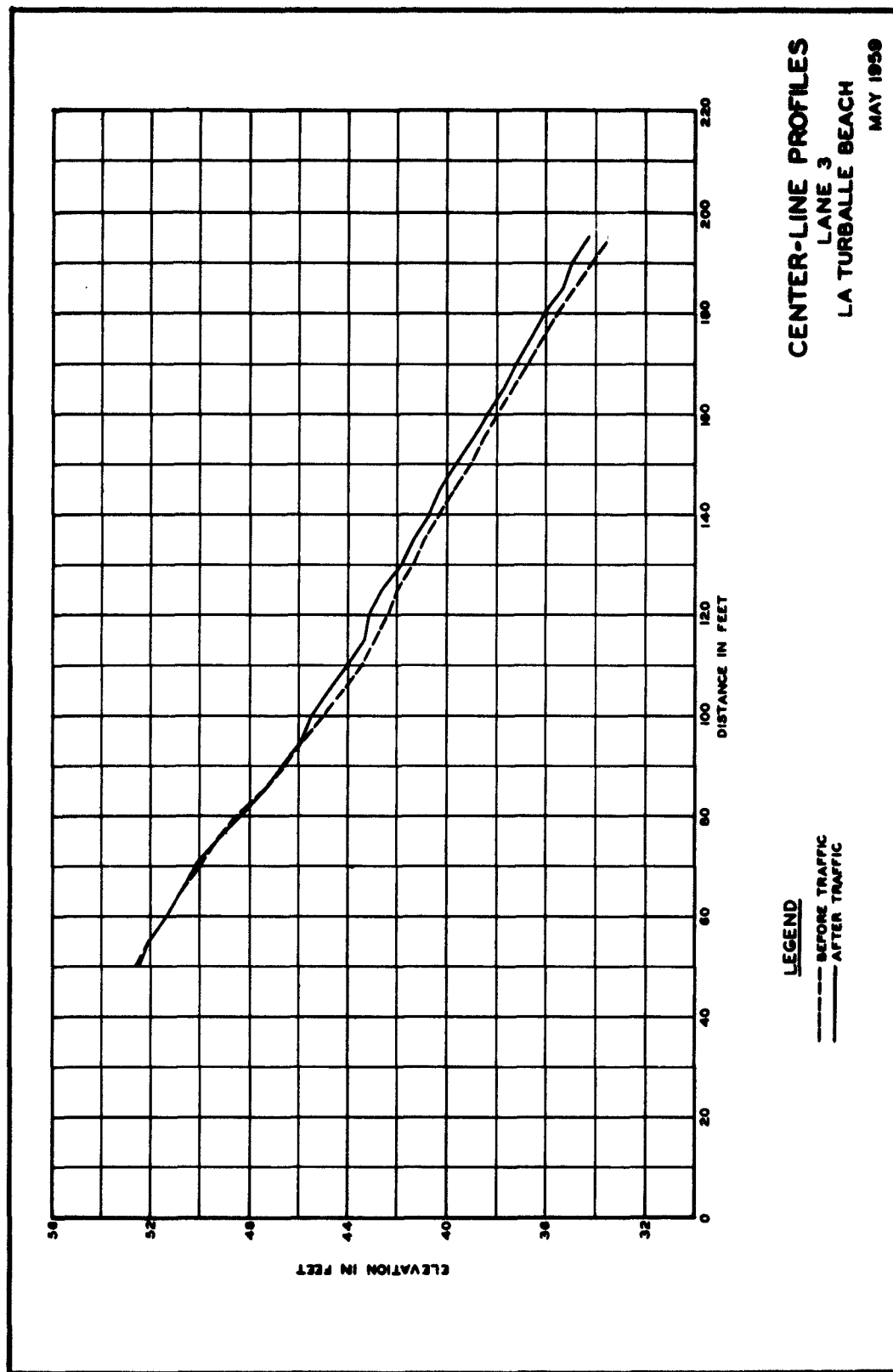


PLATE 8





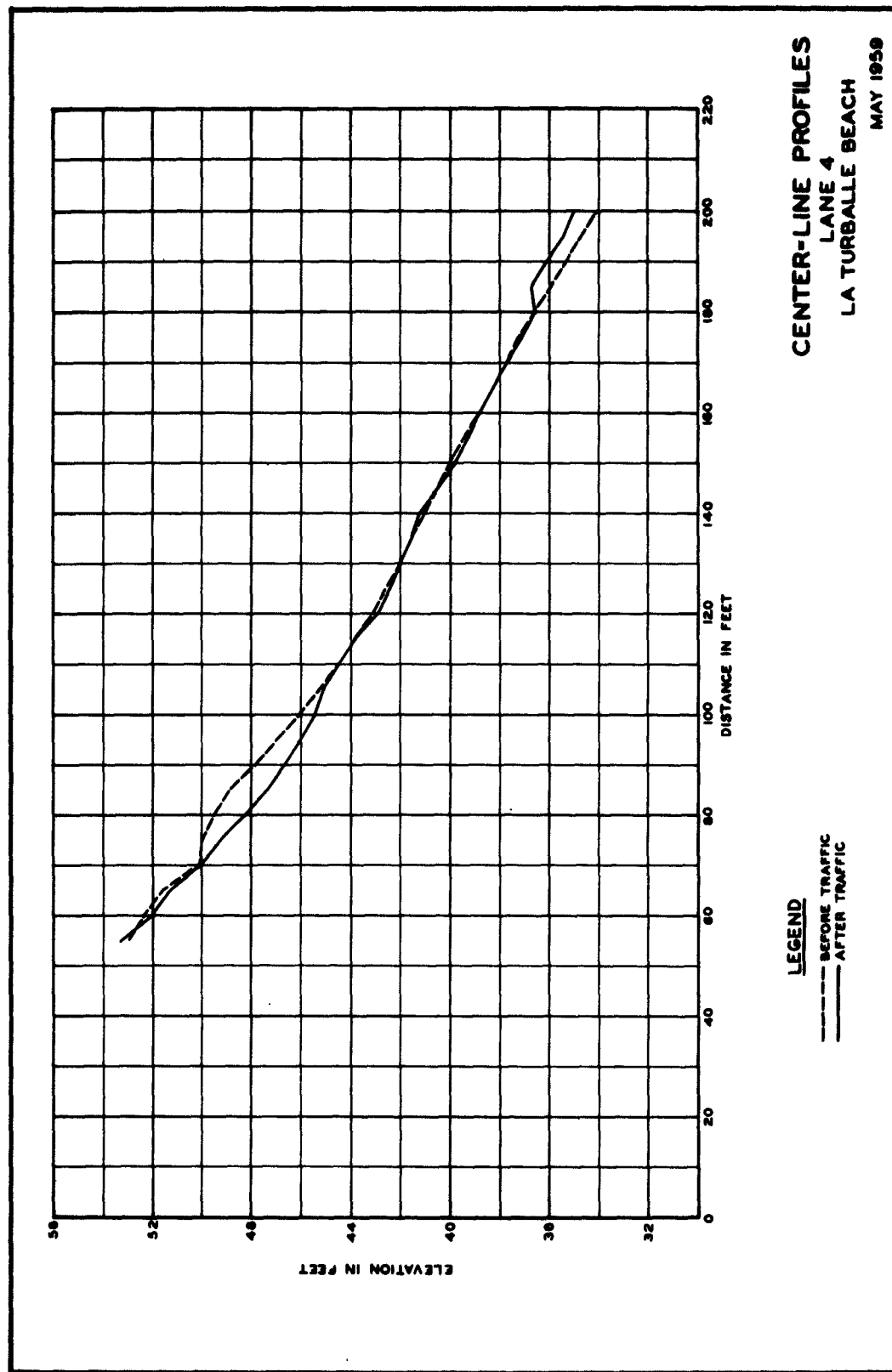
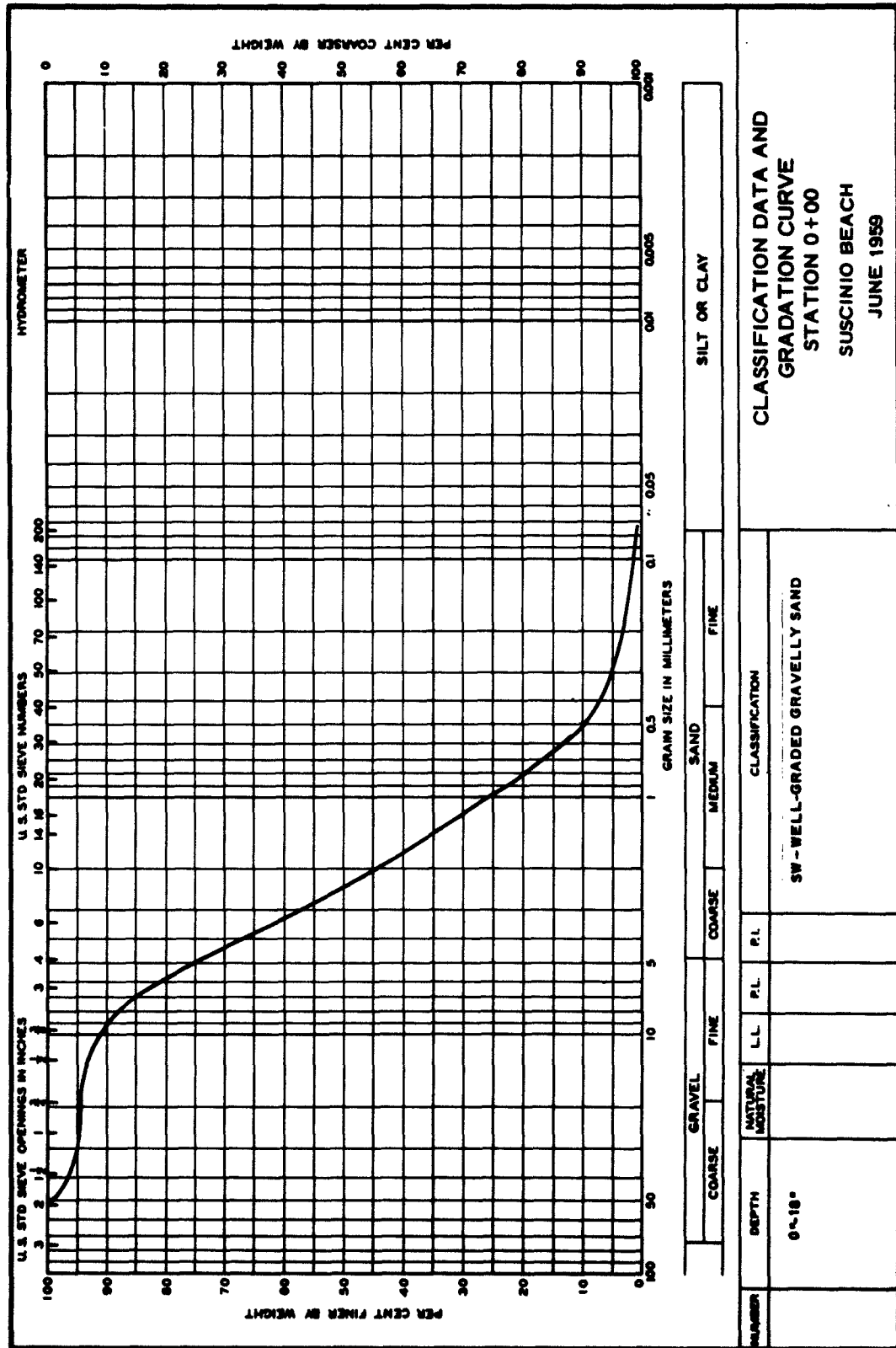


PLATE 10



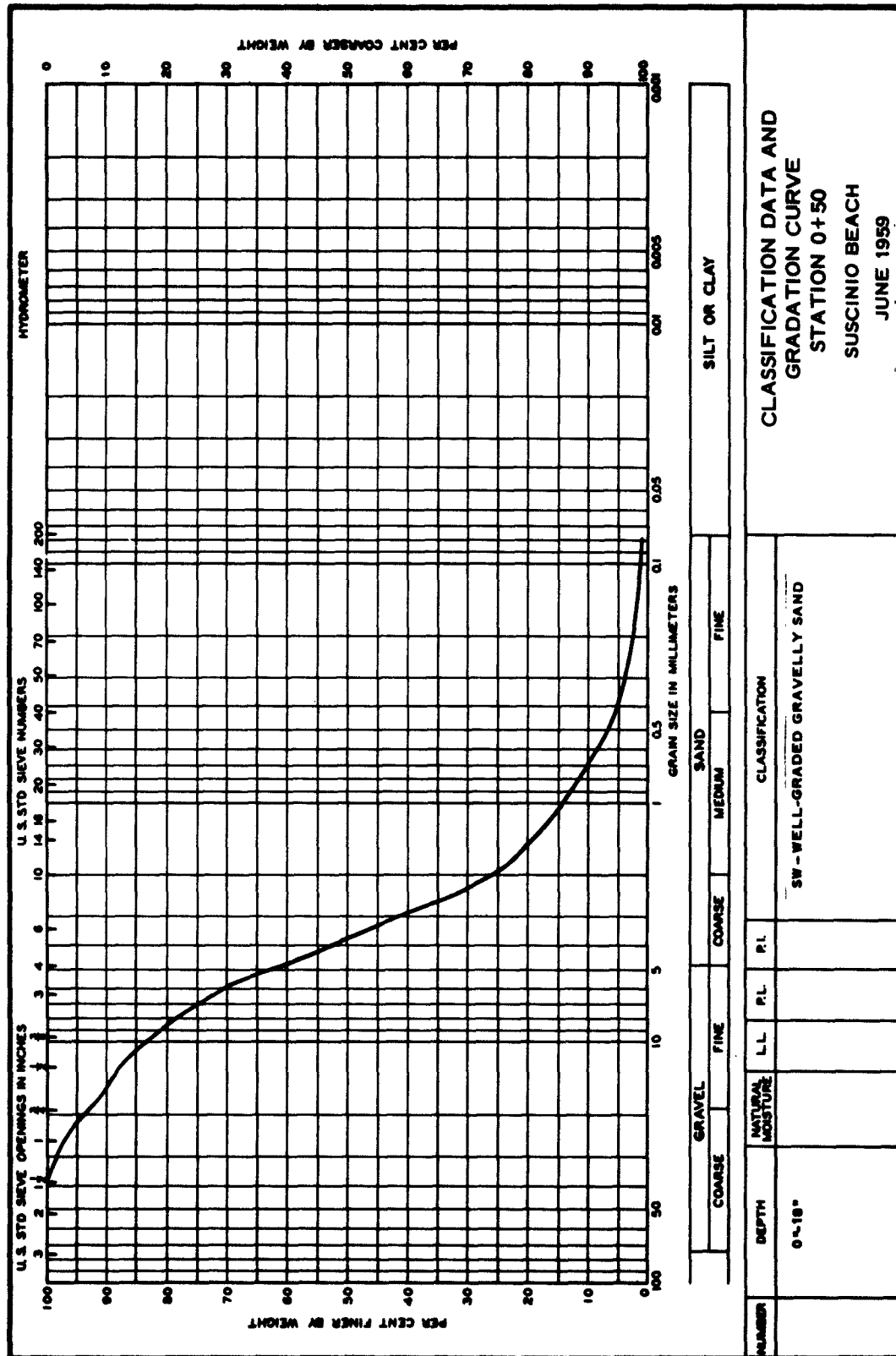
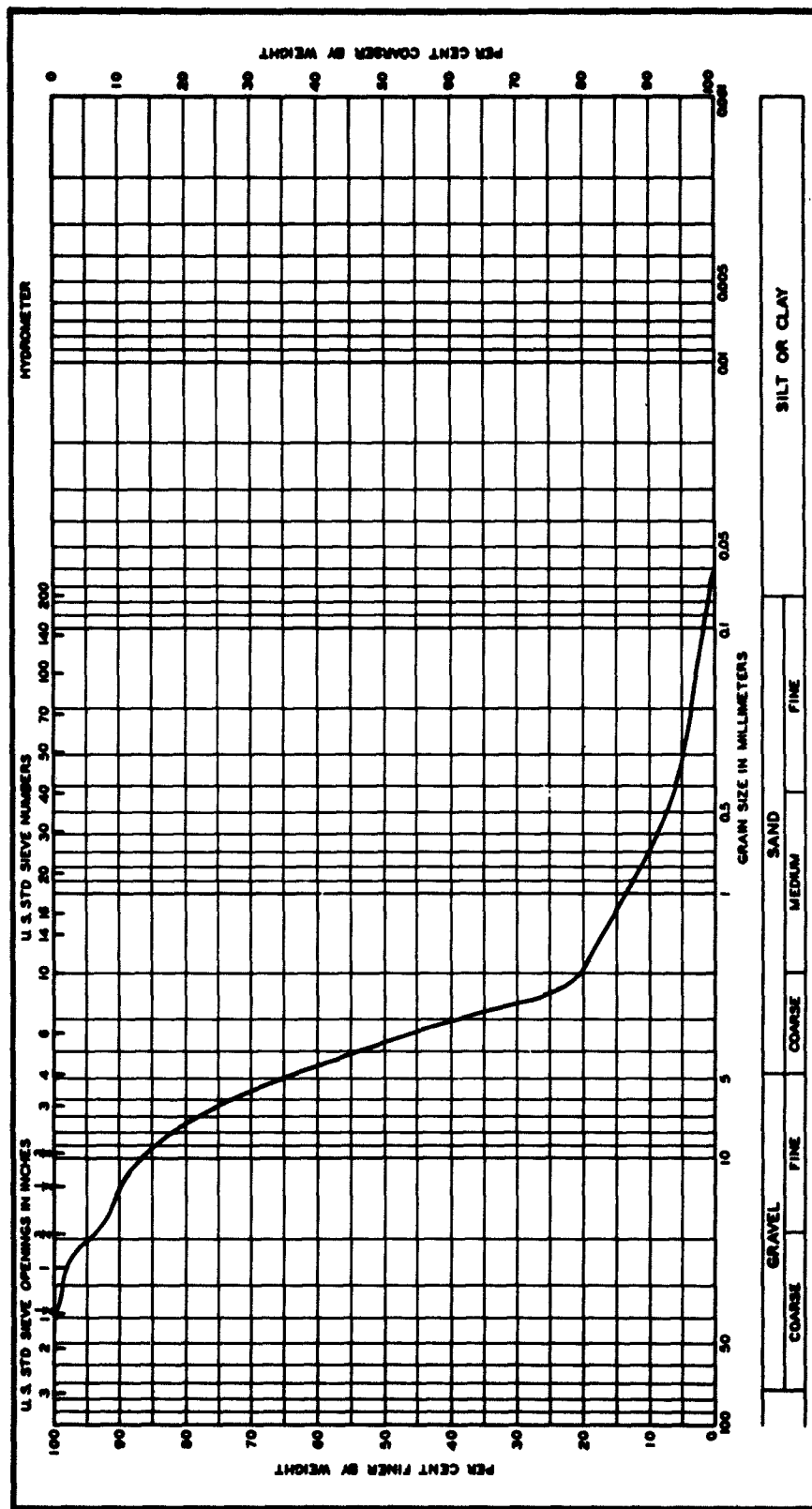


PLATE 12



CLASSIFICATION DATA AND
 GRADATION CURVE
 STATION 1+00
 SUSCINIO BEACH
 JUNE 1959

CLASSIFICATION		CLASSIFICATION	
SW - WELL-GRADED GRAVELLY SAND			
DEPTH	0'-10"	LL	P.L.
NATURAL MOISTURE		P.L.	P.L.

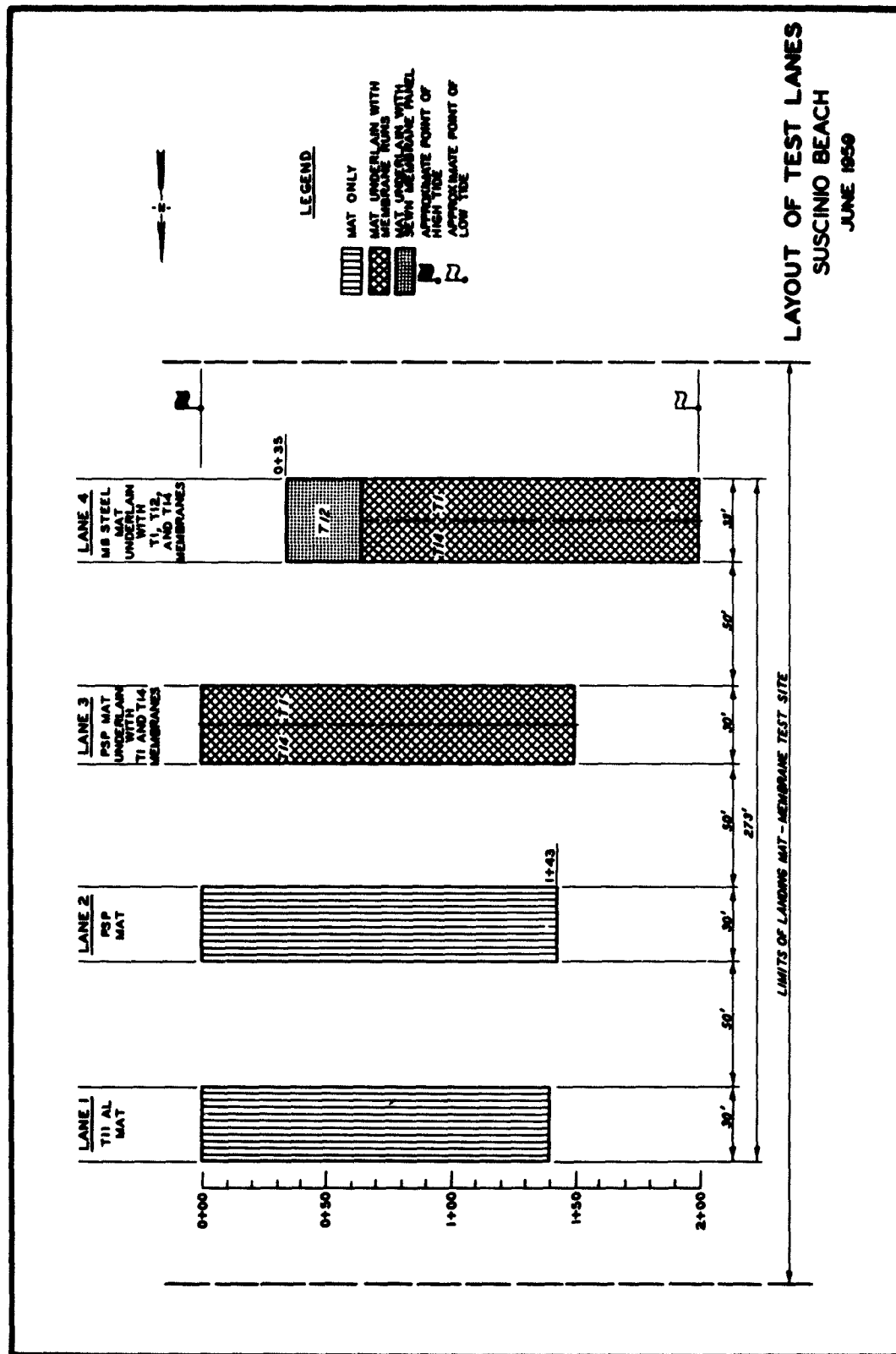
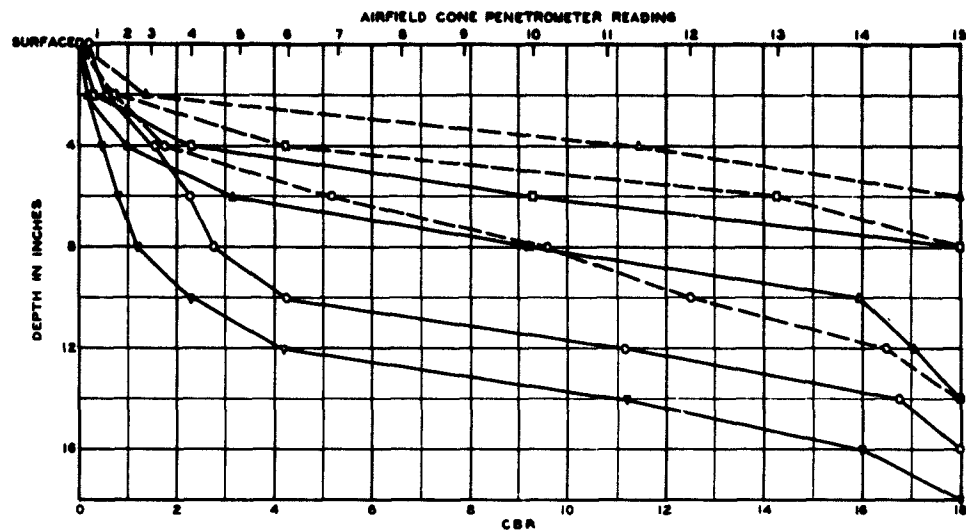
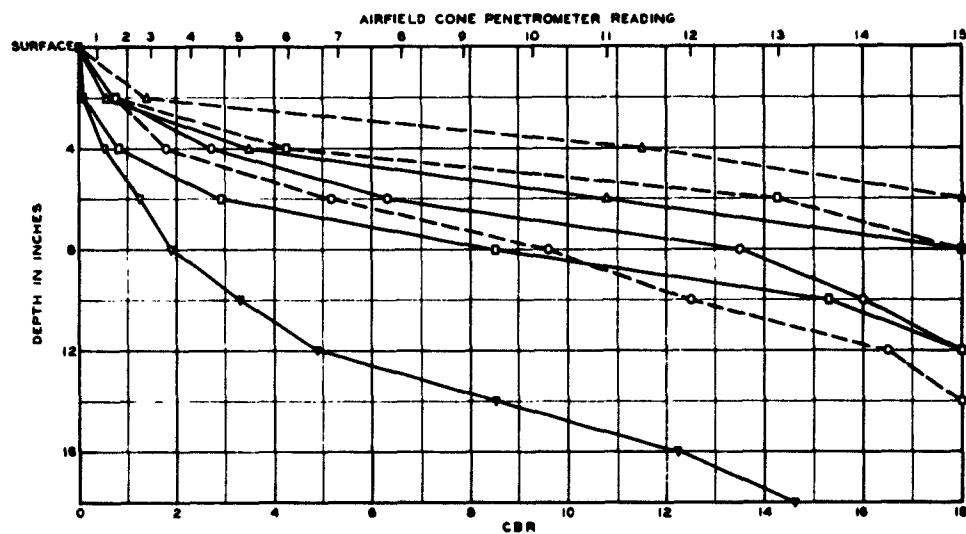


PLATE 14



LANE 1

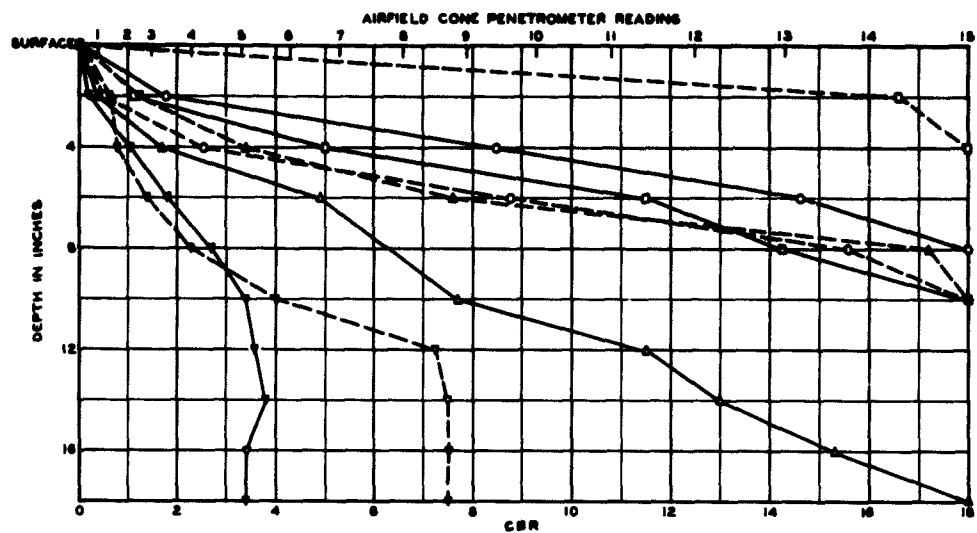


LANE 2

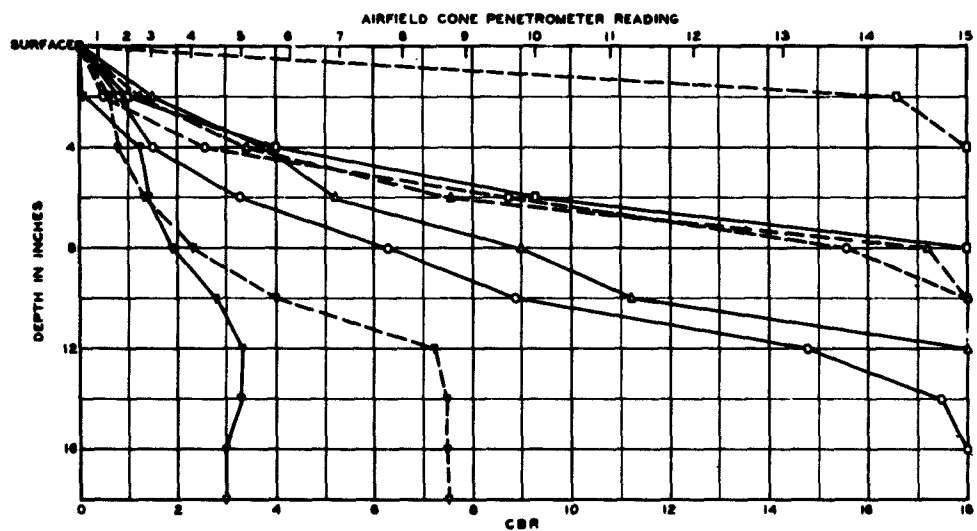
LEGEND

----- BEFORE TRAFFIC
 ——— AFTER TRAFFIC
 O STA 0+00
 ▲ STA 0+50
 □ STA 1+00
 ▼ STA 1+30

CBR
BEFORE AND AFTER
TRAFFIC
LANES 1 AND 2
SUSCINIO BEACH
JUNE 1959



LANE 3



LANE 4

LEGEND

- BEFORE TRAFFIC
- AFTER TRAFFIC
- STA 0+00
- △ STA 0+30
- STA 1+00
- ◇ STA 1+30

**CBR
BEFORE AND AFTER
TRAFFIC
LANES 3 AND 4
SUSCINIO BEACH
JUNE 1959**

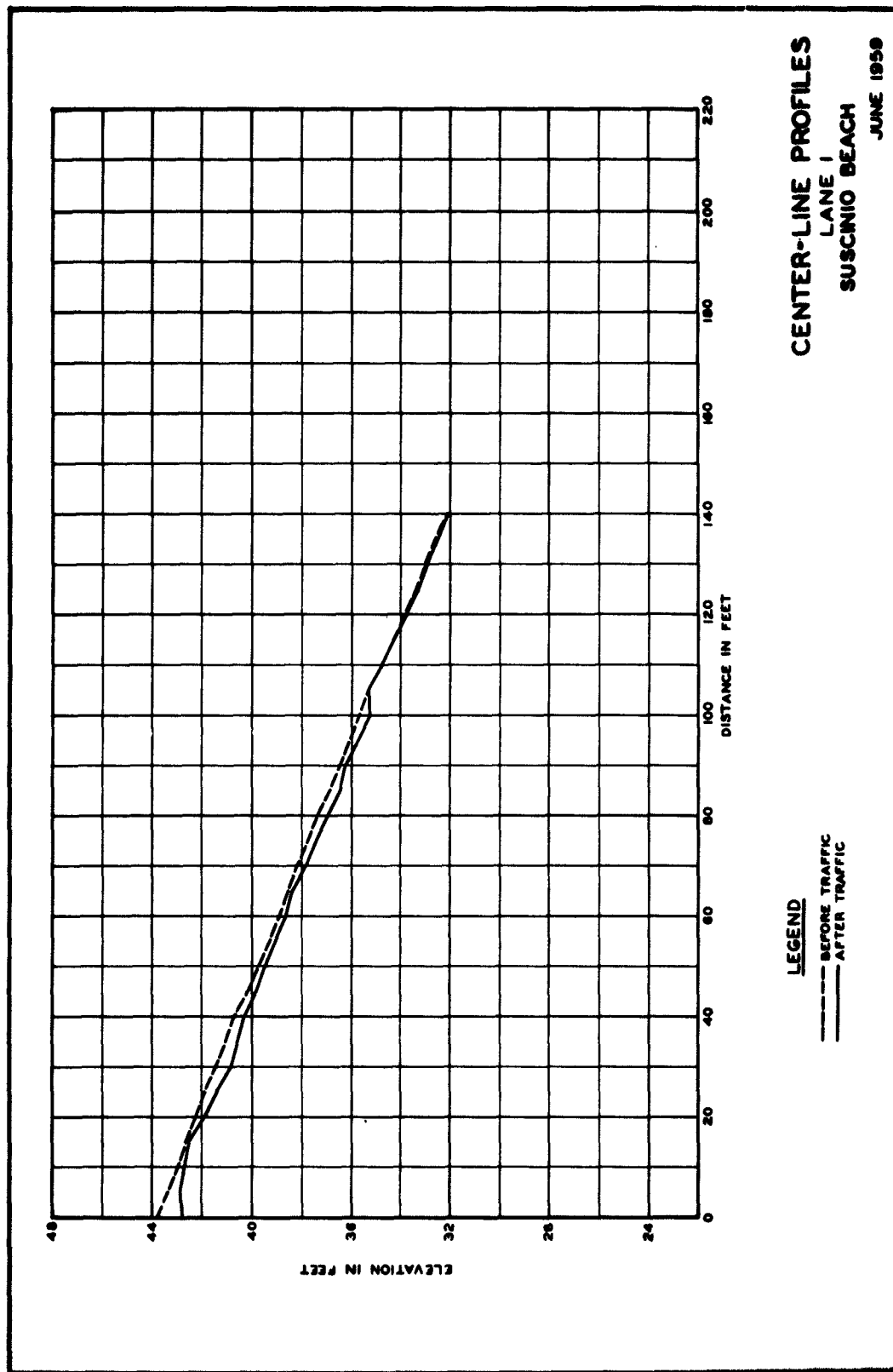
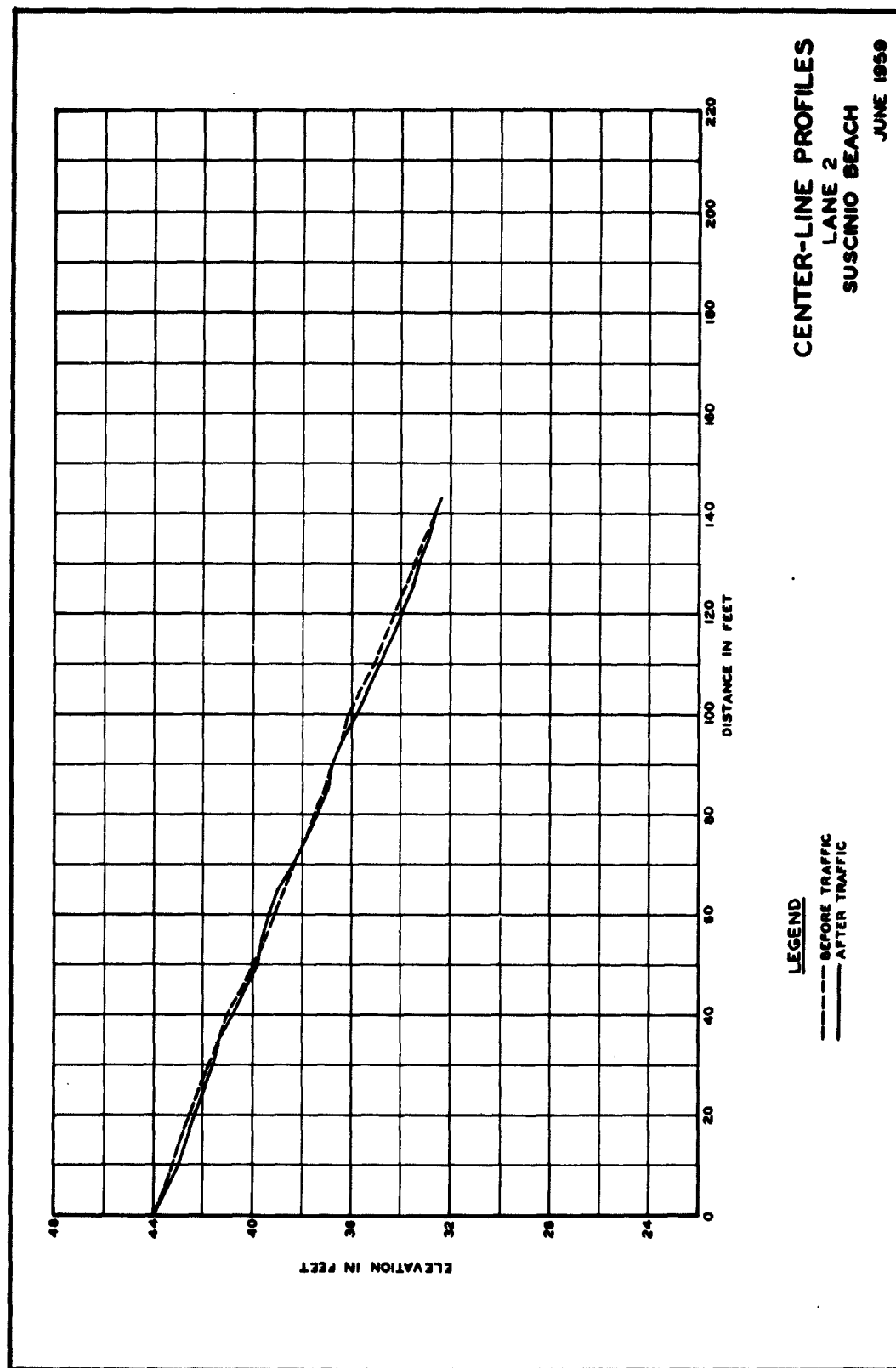
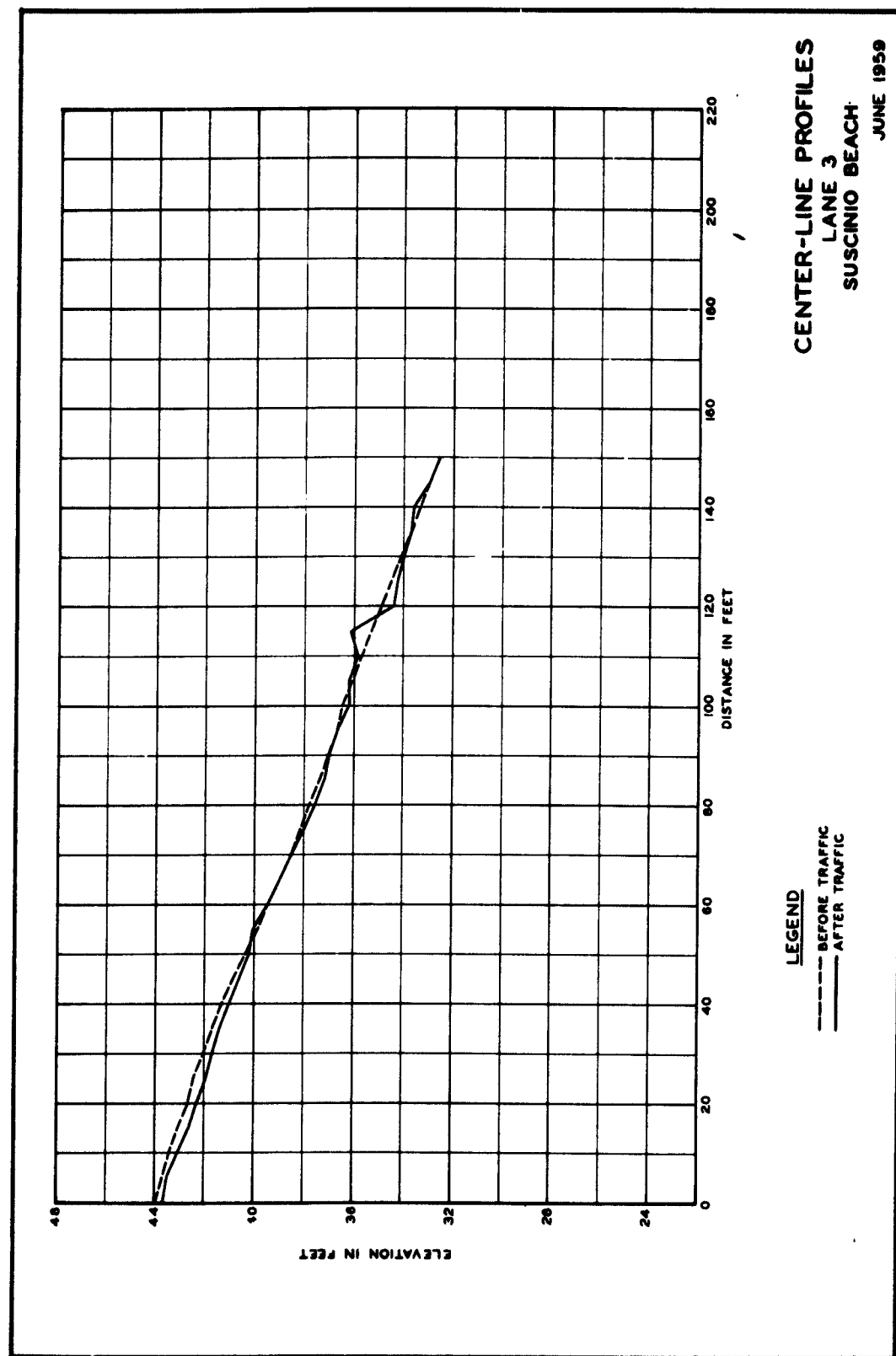


PLATE 18





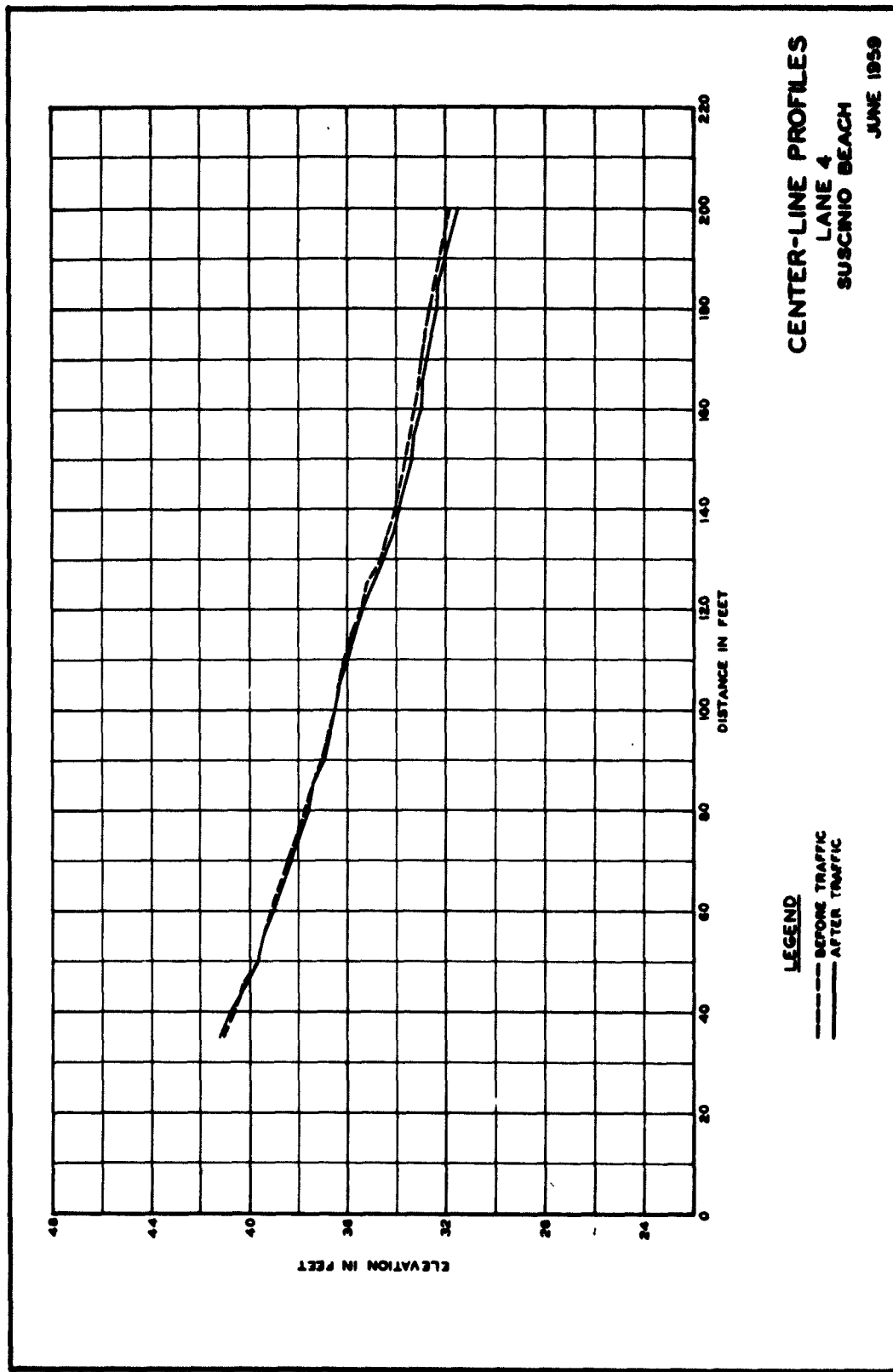


PLATE 20