AD/A-006 530

# EVALUATION OF M9M1 LANDING MAT

Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

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## PREFACE

The investigation reported herein was authorized by the Naval Air Material Center, Philadelphia, Pennsylvania, in Project Order No. 2-4014, dated 1 December 1961. Responsibility for prosecution of the investigation was assigned to the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. The tests reported were conducted by WES during the period 20 January through 1 March 1962.

Engineers of the WES Soils Division who were actively engaged in the planning, testing, analysis, and report phases of the investigation were Messrs. W. J. Turnbull, W. G. Shockley, A. A. Maxwell, O. B. Ray, W. L. McInnis, C. D. Burns, M. J. Mathews, and W. B. Fenwick. This report was prepared by Mr. Fenwick.

Director of WES during the conduct of this investigation and preparation of this report was Col. Alex G. Sutton, Jr., CE. Technical Director was Mr. J. B. Tiffany.

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## SUMMARY

This study was conducted to develop a CBR design curve for subgrades to be surfaced with M9M1 landing mat to withstand 1600 taxiing cycles of an aircraft with a 17,000-lb single-wheel load on a 30-7.7 tire inflated to 400 psi.

A test section consisting of several items with different subgrade strengths (CBR ranging from 9 to 65) and surfaced with the M9M1 landing mat was constructed and subjected to accelerated traffic of a 17,000-lb single-wheel load with a 26-6.6 tire inflated to 400 psi. (A 30-7.7 tire was not available at the time of the tests, and the 26-6.6 tire, which constitutes a more severe test condition, was used.)

Analysis of the data indicates that the M9M1 mat will not withstand traffic of the 17,000-lb load regardless of subgrade strength. Severe weld breakage and rivet shearing occurred during the first few coverages of the wheel load. The mat would probably perform satisfactorily under smaller loads (not exceeding 12,000 lb) and particularly with lower tire pressures.

It is recommended that use of continuous welds rather than spot welds, steel rather than aluminum rivets, and solid aluminum plates welded or riveted to the bottom of the mat be investigated as possible aids in improving mat performance.




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# EVALUATION OF M9M1 LANDING MAT

## PART I: INTRODUCTION

### Background

1. For several years the Marine Corps has been engaged in a study of problems involved in the construction and support of small airfields for tactical support (SATS) in amphibious operations. A SATS has been defined as a small, quickly constructed, tactical support airfield of temporary nature capable of handling modern jet aircraft of the Marine Corps and employing assisted takeoffs and arrested landings. The minimum operational installation must be ready for use in the objective area within the first three to five days of an amphibious assault. The runway must be capable of withstanding the airplane wheel loads, arresting-hook impacts of aircraft making arrested landings, and heat blasts from tailpipes of jet engines during takeoffs, and it must remain serviceable with minimum maintenance effort for 1600 aircraft taxiing cycles (or round trips) during a 30-day period. At the time of this study, the weight of the newest proposed Marine aircraft that will utilize SATS was 40,000 lb (17,000 lb per main wheel) with a 30-7.7, 18-ply tire inflated to 400 psi.

2. The Marine Corps has conducted numerous tests on various surfacing materials, including standard and experimental mats and membranes of the U. S. Army Corps of Engineers. A modification of the Corps of Engineers M9 aluminum mat, designated M9M1 airfield landing mat by the Marine Corps, has been adopted as an interim surfacing material for taxiways. The establishment and use of design criteria for a SATS taxiway surfaced with M9M1 mat would assure the most efficient use of the mat in amphibious operations or other tactical situations, thus contributing to the timely accomplishment of assigned missions.

### Objective and Scope of Investigation

3. The primary objective of this investigation was to develop a CBR curve which could be used to design areas surfaced with the M9M1 landing

mat that would support 1600 cycles of aircraft operations with a 17,000-lb single-wheel load and 400-psi tire inflation pressure. It was recognized early in the tests that this objective could not be realized because of mat failure after only a few coverages regardless of subgrade strength. However, the traffic tests were continued for the purpose of obtaining information on mat characteristics that would be useful in improving the design of the mat and thus its performance under traffic.

4. This report describes and gives results of field traffic tests conducted to obtain data on the performance of M9M1 landing mat. Conclusions concerning the capability of the mat to perform satisfactorily as a surfacing for taxiways are discussed with reference to the traffic test results and observations made during the tests.

# PART II: TEST SECTION, MAT, AND TEST LOAD CART

## Test Section

### Location

5. All traffic tests were conducted at the Waterways Experiment Station (WES), Vicksburg, Mississippi, on a special test section which was constructed and tested under shelter in order to control the subgrade water content and strength.

### Description

6. A layout of the test section is shown in plate 1. As can be seen, the section consisted of four test items, each of which was approximately 24 ft wide. Item 1 was 40 ft long, and items 2, 3, and 4 were 30 ft long. Items 1 and 2 were constructed of a heavy clay soil, item 3 was constructed of uncompacted rock (limestone), and item 4 was constructed of a loose sand. The entire test section was surfaced with M9M1 mat so that whenever the load cart (described subsequently) traversed the length of the test section, data were obtained for the several different types of subgrades.

### Subgrade materials

7. Gradation and classification data for the subgrade materials used in the test section are shown in plate 2. The sand was obtained from a local river bar and had characteristics resembling those of a beach sand. It classified as SP according to the Unified Soil Classification System. The rock classified as GP and was a hard, durable, crushed limestone obtained from a nearby source. It was graded from a maximum size of 2 in. down to that passing a No. 4 screen, and was used to simulate an existing paved taxiway or an area constructed of broken concrete. The heavy clay soil (locally termed "buckshot") had a liquid limit of 56, a plasticity index of 33, and classified as CH. Laboratory compaction and CBR data for the heavy clay are shown in plate 3.

### Construction of subgrade

8. Items 1 and 2. The existing material in the area to be used for items 1 and 2 was excavated to a depth of 24 in. below finished grade. It was desired to construct items 1 and 2 with the heavy clay soil at water

contents that would result in CBR's of 7 and 12, respectively, after compaction. The soil for each item was processed to the desired water content, hauled to the test-section site by truck, spread, and compacted in four 6-in.-thick lifts. Compaction was accomplished by applying eight coverages on each lift of a four-wheel roller (fig. 1) loaded to 40,000 lb with tires inflated to 90 psi. The surface of each compacted lift was

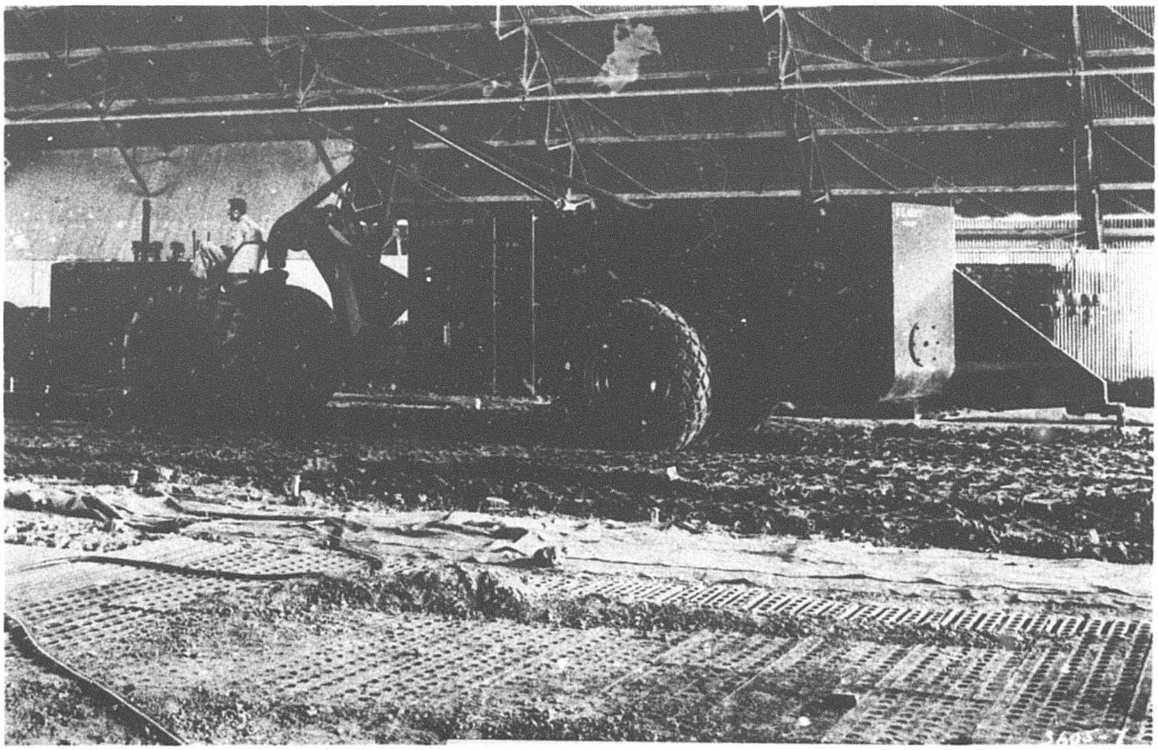

Fig. 1. Roller used in compaction of items 1 and 2

scarified prior to placement of the next lift. After placement and compaction of the fourth and final lift, the surface of the subgrade was fine-bladed to grade with a motor patrol. Construction-strength control data were obtained for each lift immediately after placement. Strengths were measured by means of in-place CBR tests. Construction-control data representing the average of the measurements made on the four lifts are shown below:

| Test Item | Water Content, % | Dry Density lb/cu ft | CBR |
|---|---|---|---|
| 1 | 27.1 | 96.2 | 6 |
| 2 | 23.0 | 100.0 | 12 |

9. Items 3 and 4. Item 3 consisted of 12 in. of uncompacted, loose rock that was end-dumped (fig. 2) and spread by hand. Due to the coarseness of the material and the loose state in which it was placed, no attempt


Fig. 2. End-dumping rock in item 3

was made to measure its initial strength. However, it was anticipated that the material would consolidate and develop a relatively high strength when surfaced with landing mat and subjected to traffic.

10. Item 4 consisted of 24 in. of sand that was end-dumped (fig. 3)

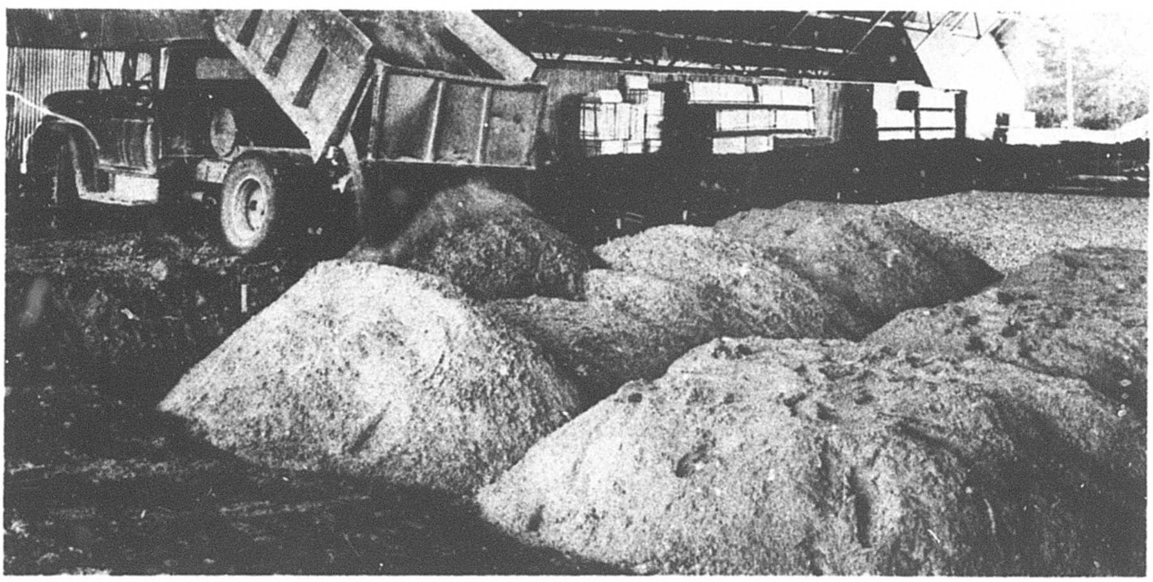

Fig. 3. End-dumping sand in item 4

and spread with a D4 tractor. A CBR of about 2 was measured in this item prior to placement of the mat. The sand was left in a loose state, but it was anticipated that it would consolidate and develop reasonable strength under traffic.

Mat surfacing

11. As mentioned earlier, the entire subgrade was surfaced with the M9M1 mat for a width of 24 ft, as shown in plate . A view of the test section after placement of the mat is shown in fig. 4 where it can be seen that the mat was laid with the end joints connected in a straight line along the center of the test section. In previous tests of the M9M2 mat,*

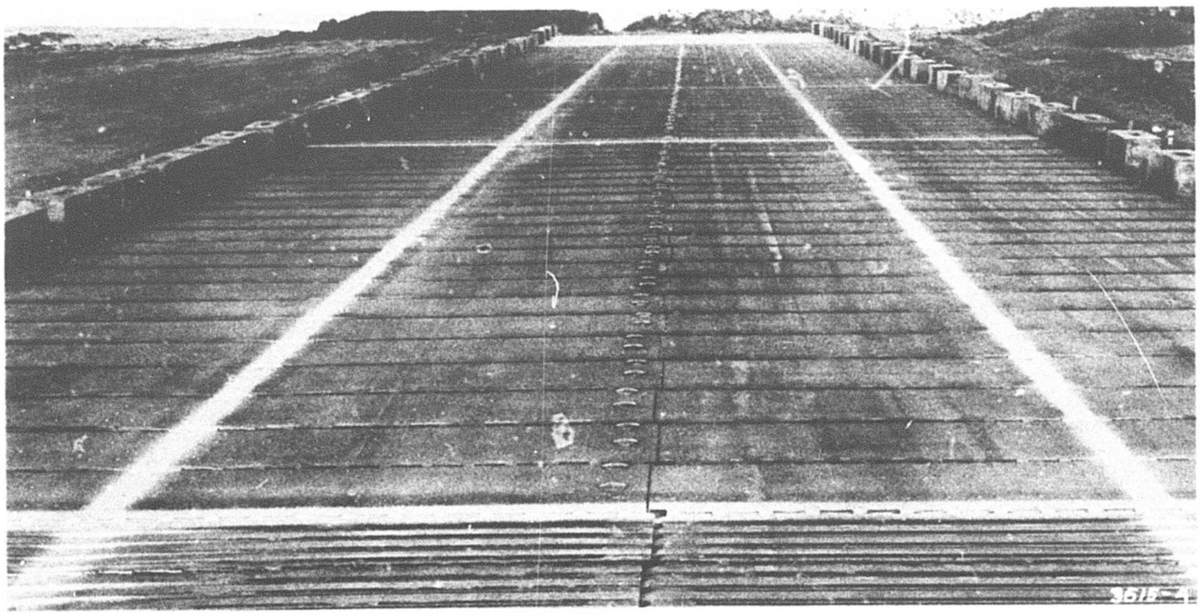

Fig. 4. Test section after placement of mat with end-joints in a straight line. (Mat in approach section in foreground is T10 aluminum)

the mat was laid in this manner at the request of the Naval Air Engineering Laboratory (NAEL), Philadelphia, Pennsylvania, and it performed satisfactorily. However, the M9M1 mat did not perform satisfactorily when laid with the joints in a straight line, and consequently a staggered joint system (discussed subsequently) was devised later in the test program.

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* These tests were reported in U. S. Army Engineer Waterways Experiment Station, CE, Development of CBR Design Curve for M9M2 Landing Mat, Miscellaneous Paper No. 4-501 (Vicksburg, Miss., June 1962).

## Mat

### Description

12. The M9M1 landing mat, shown on NAEL drawing No. 608942 and in fig. 5, is Corps of Engineers M9 aluminum mat modified by riveting and welding of a solid aluminum plate (5/32 in. thick) to the top of the mat. Aluminum alloy used in the M9 mat is 6061-T6, and that used in the top plate is 5456-H321. Two cap screw-pilot nut combinations are used to form

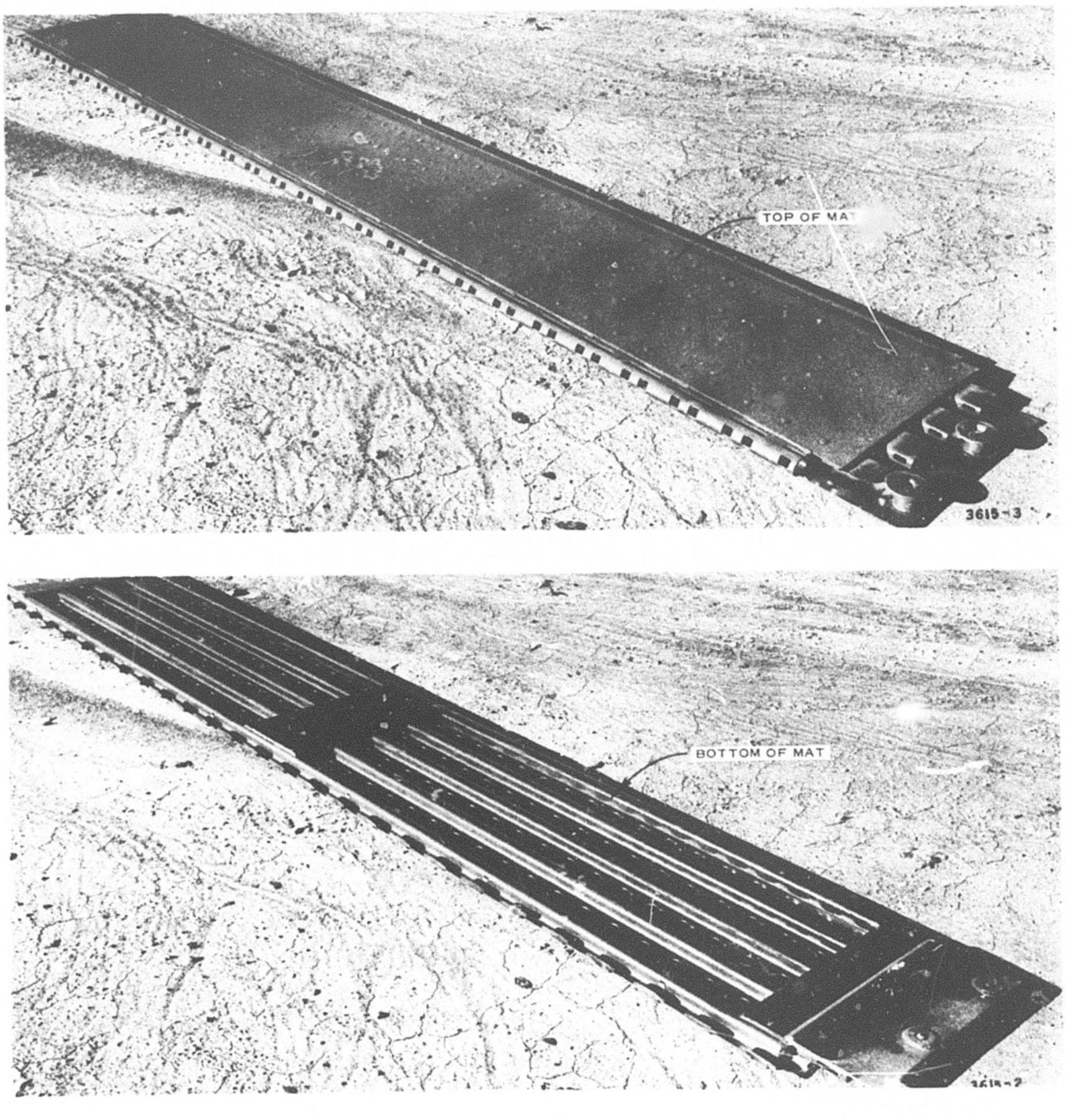


Fig. 5. M9M1 landing mat

end connections for the M9M1 mat instead of the integral M9 connectors, while the standard bayonet and connector slots are used for side connections.

13. A total of 17 bundles, each consisting of 11 full planks, 2 half planks, and 24 cap screws, were received at WES for surfacing the test section. The average plank length was 12 ft 3-5/8 in., and the average width, 1 ft 11-3/4 in. Average plank weight was 121 lb.

Placement procedures

14. The M9M1 mat was placed on the test section by a crew of six experienced laborers working under the supervision of a foreman. The mat bundles were placed alongside the test section by crane, and the laborers carried the individual mats about 30 ft into place. One laborer placed the end connecting cap screws and tightened them with an electric impact wrench. Since the mat was shipped with the cap screws in place to avoid the necessity of a separate package, some time was consumed in removing the caps, joining the planks, and replacing the cap screws. No exact laying speed was determined, but it was estimated at approximately 400 sq ft per man-hour.

## Test Load Cart

15. A specially designed single-wheel test cart, loaded to 17,000 lb, was used in the traffic tests (fig. 6). It was fitted with an

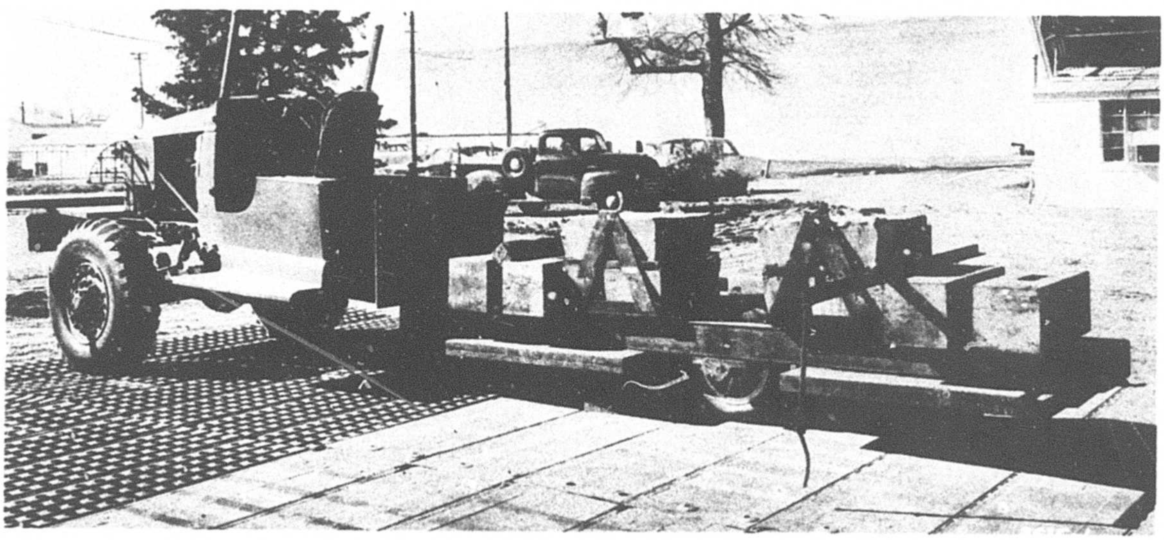

Fig. 6. Single-wheel test load cart

outrigger wheel (not visible in fig. 6) to prevent overturning and was powered by the front half of a 4-wheel-drive truck. The aircraft which the load cart simulated is equipped with 30-7.7, 18-ply tires inflated to 400 psi. However, such tires were not available for test purposes, and F8U aircraft wheels and tires furnished by the NAEL were used in the test. These tires were 26-6.6, 16-ply and were inflated to 400 psi which, when the cart was loaded to 17,000 lb, resulted in a tire contact area of about 48 sq in. or an average contact pressure of 355 psi, a more severe test condition than would have been provided by the 30-7.7 tires.

# PART III: TESTS AND RESULTS

## Traffic Tests

16. A statistical study of aircraft landings on a 78-ft-wide runway by the Marine Corps Equipment Board,* Quantico, Virginia, indicated that for about 90 percent of the landings the main gear load was fairly evenly distributed over a 10-ft width. For the simulated taxiway traffic tests reported herein, it was assumed that 100 percent of the main gear load operations of the design aircraft would be evenly distributed over about a 10-ft width of taxiway. This assumption was considered reasonable for test purposes. Therefore, a traffic lane 10 ft wide was laid out down the center of the test section (see fig. 4, page 6). Traffic was applied by driving the load cart forward and then backward the length of the traffic lane, shifting the path of the cart laterally 5 in. or each successive forward trip. This resulted in two complete coverages each time the load cart maneuvered from one side of the traffic lane to the other, and 25 round trips, or 50 passes, were required to apply two coverages of traffic over the entire traffic lane. One round trip on a taxiway comprises one aircraft cycle. Therefore, 1600 cycles of aircraft operations are equivalent to 3200 passes. Since 25 passes of the load cart were required for one complete coverage, 128 coverages by the load cart are equivalent to 1600 cycles of aircraft operations, and this number of coverages was set up as a test criterion.

## Soil Tests and Miscellaneous Observations

17. Water content, density, and in-place CBR were determined in each test item prior to and at various stages of traffic. Data obtained are summarized in table 1. In general, these tests were made at depths of 0, 6, 12, and 18 in. in the sand and clay items, and on the surface of the rock item. At least three tests were made at each depth, and the values

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* Marine Corps Equipment Board, Small Airfield for Tactical Support (SATS) Concept, Second Interim Report, Project No. 51-58-01 (Quantico, Va., 5 March 1960).

listed in table 1 are the averages of the values measured at each particular depth.

18. Visual observations of the behavior of the test items and other pertinent factors were recorded throughout the traffic testing period. These observations were supplemented by photographs. Level readings were taken prior to and at intervals during traffic to show the development of roughness, settlement, and mat deformation and deflection under the wheel load. The term "permanent deformation" as used herein refers to the change in surface elevation of the mat at any given interval of traffic from the original elevation prior to traffic. The term "deflection" denotes the elastic vertical movement or rebound of the mat surface following the passing of the wheel load.

## Behavior Under Traffic of Mat Laid with End Joints in Straight Line

19. As mentioned earlier, the mat was originally placed with all end joints in a straight line down the center line of the test section (see fig. 4, page 6). As traffic was applied, the M9M1 mat deformed severely. After two coverages, the end joints down the center of the traffic lane had curled up and arched, forming a ridge 2 to 3 in. high for the full length of the traffic lane. Photograph 1 shows a close-up of this condition in item 1. After six coverages, the ridge down the center line was more pronounced (see plate 4). The planks had arched about 3 in. above the subgrade and were not deflecting down to the subgrade under the wheel load. A general view of the test section after six coverages is shown in photograph 2. A large number of rivets near the end joint and welds on the bayonet edge had broken by this time. Therefore, traffic was discontinued and the NAEL was informed of the mat's performance. Representatives of NAEL and the Marine Corps Equipment Board then visited the WES to observe the condition of the landing mat. It was agreed that the mat was unsuitable for the design aircraft traffic when laid with the end joints in a straight line, and that the mat should be tested with the joints staggered.

## Laying and Behavior of Mats with End Joints Staggered

### Laying procedure

20. In order to lay the mat with the joints staggered, two half planks were needed for every three whole planks. Since only two half planks had been shipped with each bundle of mat, a number of available, unused whole planks were cut to make the necessary half planks. It was also determined that the used planks that had deformed under traffic could be straightened easily, and that by reversing the ends, they could be relaid so that the portion inside the traffic lane would be that not previously damaged. Fig. 7 shows the relaid test section.

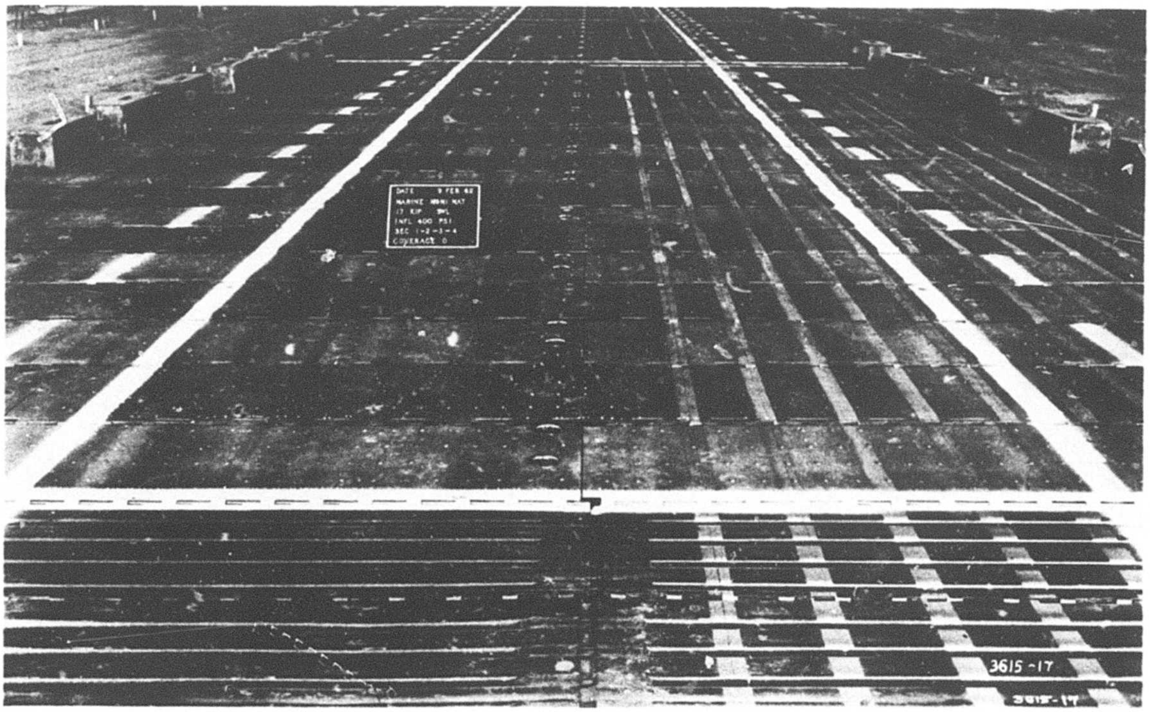



Fig. 7. Test section after mat had been relaid with staggered joints

21. When the mat with the straight-line end joints was removed from the test section, it was found that most of the solid end plates had completely sheared loose, as shown in fig. 8. It was believed that the plates on the bottom of the mat (see fig. 5b, page 7) hindered embedding of the planks and might have contributed to their deformation and curling. To determine whether there would be any difference in the performance of the

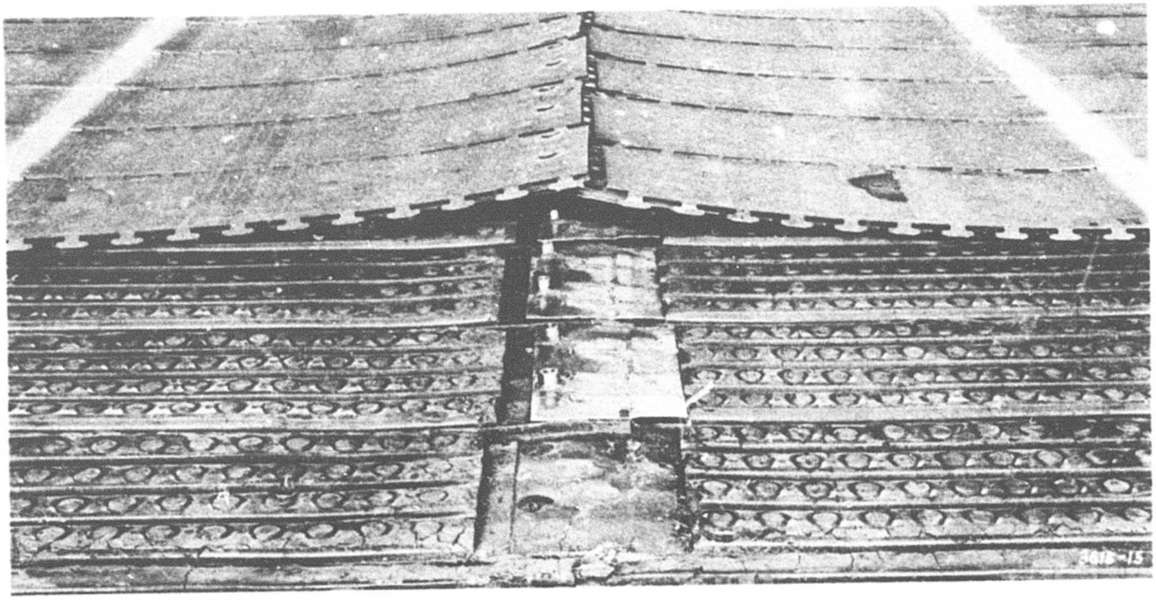


Fig. 8. Sheared end plates after six coverages

mat without the plates, the middle plates were removed from two planks and these planks were incorporated in item 2 of the staggered end joint test section.

Behavior of mat under traffic

22. The behavior under traffic of the mat with staggered end joints was somewhat better than that of the mat with the joints laid in a straight line but was still less than satisfactory for aircraft traffic with a 17,000-lb single-wheel load and tire pressure of 400 psi, as discussed subsequently.

23. A total of 50 traffic coverages was applied to all four test items. During this traffic the mat behavior over the four different subgrades was similar in that the planks deformed by embedding between the bottom plates and curling upward at the ends. The general uniformity of mat behavior in all test items is illustrated in photographs 3 and 4, which show the test section after 6 and 20 coverages, respectively. General views of items 1, 2, 3, and 4 after 50 coverages are shown in photographs 5 through 8, respectively. The deformation of the planks resulted in an elevation differential between adjacent planks down the center line of the traffic lane. After 50 coverages, the elevation differential between adjacent planks was approximately 1 in. in all four test items, as can be

seen in the center-line profiles taken on the surface of the mat (see plates 5 and 6). These rather large elevation differentials resulted in a very rough riding surface.

24. Mat deflections were measured in each test item at various intervals of traffic. These measurements were made at three locations on the mat surface: the center line of a plank, quarter point of a plank, and on the joint at the center of the traffic lane (see plate 7). At the start of traffic (0 coverages) the largest deflections were measured at the quarter point of the mat. The measured values ranged from 1.8 in. in item 1 (lowest strength subgrade) to 0.8 in. in item 3 (highest strength subgrade). These values were all considered excessive; however, as traffic progressed the mat became partially embedded in the subgrades and the mat deflections were not as pronounced.

25. The large deflections under load contributed to the large number of weld breaks and rivet failures which occurred in the mat during the initial 50 coverages of traffic. Most of the weld failures occurred on the bayonet edge of the mat planks, and most of the rivet failures were near the end connection joints. The weld breaks on the bayonet edge of the planks and rivet failures which occurred during the first 50 coverages are shown in plate 8 and summarized below:

| Test Item | Total No. of Welds | Weld Failures | | No. of Rivets Sheared |
|---|---|---|---|---|
| | | No. | Percent of Total Welds | |
| 1 (clay) | 287 | 275 | 96 | 68 |
| 2 (clay) | 192 | 169 | 88 | 14 |
| 3 (rock) | 205 | 186 | 91 | 5 |
| 4 (sand) | 192 | 189 | 98 | 27 |

As can be noted above, more than 90 percent of the welds on the bayonet edge of the planks had failed in all test items by 50 coverages of traffic. Some rivet failures had also occurred in all items with the largest number of failures in item 1.

26. The weld failures alone did not appear to affect greatly the performance of the mat as long as the rivets held, because the rivets held the top plates in position and the surface remained relatively smooth. However, in item 1 a combination of weld and rivet failures near the end

joints permitted the sharp corners of the top plate to protrude upward creating a severe tire hazard. At this stage of traffic it was obvious that the M9M1 mat was not adequate to support an aircraft with a 17,000-lb single-wheel load with 400-psi tire pressure on any of the test subgrades for the desired 1600 cycles of operations. However, it was felt that some worthwhile information on improvements that might be made to the mat could be obtained by continuing traffic to 128 coverages on items 2, 3, and 4. Traffic was discontinued on item 1 at the end of 50 coverages due to the tire hazard.

27. The greatest defects of the mat from an operational viewpoint were considered to be surface roughness and rivet failures. The roughness was partially due to the nonuniform embedment of the mat. The mat embedded in the subgrade at the quarter points, but not at the midpoint and ends of the planks where the solid plates were welded on the bottom of the planks (see fig. 5b, page 7). It was believed that this nonuniform embedment contributed to the deformity and curling at the ends of the planks, which resulted in the rough riding surface. The rivet failures were considered serious because loose rivets on the surface of the mat would be hazardous to jet aircraft operating on the mat.

28. Before traffic was resumed on the test section for the purpose of obtaining additional information to aid in improvement of the mat design, four runs of mat in item 1 adjacent to item 2 were removed, straightened, and replaced with the ends reversed. Prior to replacement, the subgrade under three of the runs was shaped to allow the bottom plates at the ends and center of the planks to embed about the same amount as the remainder of the plank. For the fourth run of replaced mat, the aluminum rivets near the end joints were removed and replaced with steel and steel-core rivets. These four runs of mat were subjected to 78 coverages of traffic as traffic was continued to a total of 128 coverages on items 2, 3, and 4.

29. Embedding the bottom plates of the mat as described above did not appear to improve the performance of the mat, as the planks still deformed and the ends curled up as in the initial traffic. However, the steel and steel-core rivets did perform much better than the aluminum rivets, as no failures occurred during the 78 coverages of traffic.

Fig. 9 shows the steel and steel-core rivets at end of traffic. Even though the steel rivets held at the end joints, the plank ends curled up

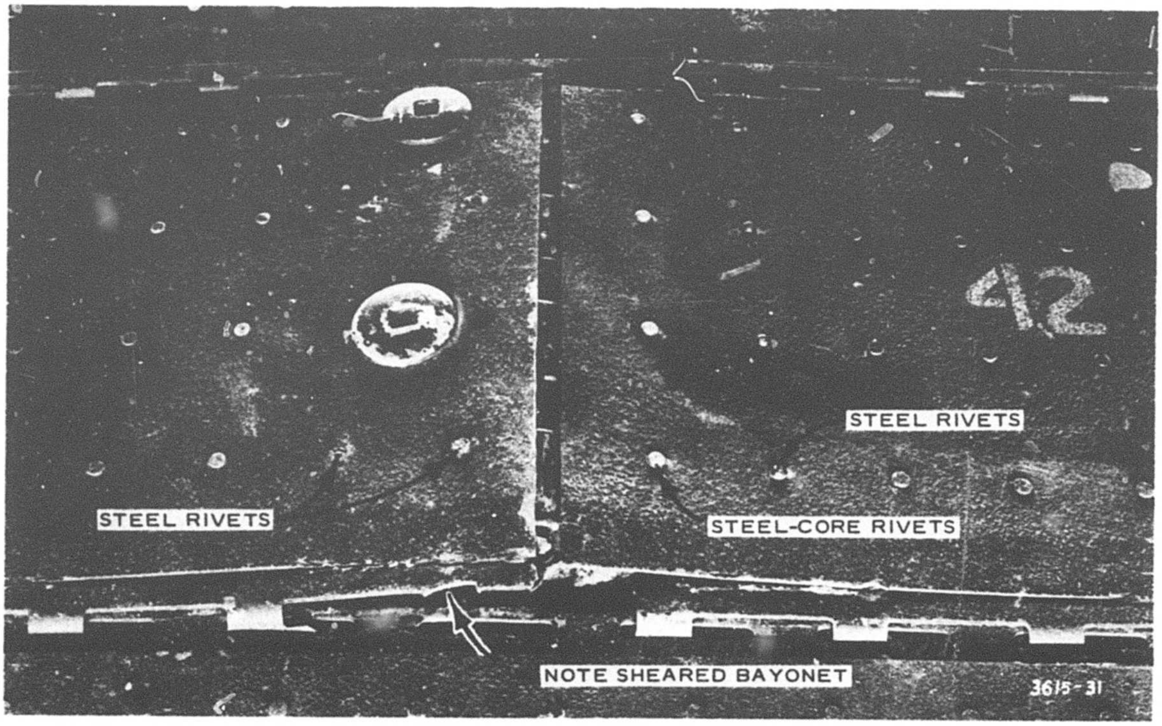



Fig. 9. Condition of steel rivets in plank after 78 coverages. Note sheared bayonet and end curl

and exerted sufficient stress to shear one of the bayonets near the end of the plank (see fig. 9).

30. As traffic was continued from 50 to 128 coverages in items 2, 3, and 4, additional weld breaks and rivet failures occurred, but very little change in the overall appearance of the mat was noted during the final 78 coverages. Views of items 2, 3, and 4 after 128 coverages are shown in photographs 9 through 14. It is pointed out that although traffic was continued to 128 coverages in items 2, 3, and 4, these items were probably too rough for safe aircraft operations after a very few coverages of the load wheel.

31. As mentioned in paragraph 21, the middle plates were removed from two planks in item 2 prior to applying traffic. It can be seen from the mat deflection data (plate 7) that as the number of coverages increased the deflection decreased more on the planks with the center plates removed than on the other planks in item 2. This was due to the greater tendency

of the planks with the center plates removed to embed in the subgrade.

## Summary of Results

### Mat performance

32. A summary of the effects of the traffic tests on the M9M1 mat is shown in table 2. This table identifies the test items, shows the rated subgrade CBR of each item, indicates the total number of mat planks in each, and presents data on mat breakage and deflection at various stages of traffic. The rated subgrade CBR was based on the results of actual in-place tests along with judgment as discussed below.

### Subgrade strength

33. Item 1. Table 1 shows that the actual in-place CBR values at 0 and 50 coverages of item 1 (and of traffic on this item) were quite uniform with depth. From previous experience in developing subgrade design criteria for flexible pavements and landing mats, it has been established that higher soil strengths are required near the surface than at lower depths, and that the performance of landing mats is influenced more by the strength of the upper 6 in. of subgrade than by the strength of the material below the 6-in. depth. Therefore, for subgrade soils in which the strength does not radically decrease with depth, the CBR at the surface and at the 6-in. depth can be used for rating the load-carrying capacity of the subgrade. For item 1 of this test the average strength of the top 6 in. of subgrade at 0 coverages was 8, and at 50 coverages about 9.5. Therefore, item 1 was assigned a rated CBR value of 9.

34. Item 2. This item was assigned a rated CBR value of 15 following the same procedure used for item 1.

35. Item 3. The rock in this item was placed loose, and no initial CBR determination was made. However, at the end of traffic (128 coverages) a CBR of 65 was measured. The rock was a clean, well-graded, crushed stone, and most of the densification occurred during the first few coverages of traffic. Therefore, the CBR value of 65 is considered fairly representative of the subgrade strength throughout the major portion of the traffic, and the item was rated as having a CBR of 65.

36. Item 4. The sand in this item was placed loose in a 24-in. lift

and spread and leveled with a D4 tractor. An initial in-place CBR of 2 was measured. However, the material densified under traffic and developed a CBR of about 25 by the end of 128 coverages. Considerable damage occurred to the mat during the early stages of traffic as the sand was densifying. Therefore, it is somewhat difficult to evaluate the effective strength of the subgrade from the standpoint of mat performance. However, the behavior of the mat in this item was somewhat better than that in item 1 (9 CBR), although not quite as good as that in item 2 (15 CBR). Therefore a CBR of 12 was considered to be the effective subgrade strength for the sand.

## Analysis and Discussion of Test Results

### Effect of subgrade strength

37. As can be noted from table 2, the rated subgrade CBR for test items 1 through 4 varied from 9 to 65. Weld breaks and rivet failures were somewhat more severe and occurred at a faster rate in item 1, which had the lowest subgrade strength, than in test items 2, 3, and 4. The mat deflection at the end joints of the planks was also greater in item 1 than in the other test items, as indicated in table 2. This greater deflection at the mat joints probably contributed to more severe breakage and rivet failures. The overall performance of items 2, 3, and 4 was about the same. As can be noted from table 2, essentially all bayonet-edge welds in these items had failed by the end of 128 coverages. Also, the mat deflection was about the same.

38. As previously stated, the mat deformed in all items after a very few coverages of the load wheel. This deformation was mostly due to embedding of the mat in the subgrade between the bottom plates and the curling upward of the ends of the planks at the end joints. This condition resulted in an elevation differential between adjacent planks which created an extremely rough riding surface over the entire traffic lane. This behavior indicates that the M9M1 mat does not have sufficient stiffness to support adequately the test load used in this study regardless of subgrade strength.

### Evaluation of mat

39. The primary objective of the traffic test was to develop a CBR

design curve for the M9M1 mat for 1600 cycles (128 coverages) of aircraft operations with a 17,000-lb single-wheel load and 400-psi tire-inflation pressure. This objective was not attained because the mat failed under the test load in all the test items regardless of subgrade strength. The M9M1 mat is not considered satisfactory for any aircraft operations with a 17,000-lb single-wheel load and 400-psi tire pressure for the following reasons:

a. The mat deformed severely within the first few coverages in all test items; this resulted in an excessively rough riding surface.

b. Excessive failures occurred in spot welds along the bayonet edge of all mat planks.

c. Excessive failure of aluminum rivets occurred near the end connection joints. (Loose, sheared rivet heads on the mat surface would be hazardous to jet aircraft operating on the mat.)

40. Although the M9M1 mat in its present form is not considered satisfactory for aircraft operations with a 17,000-lb single-wheel load at 400-psi tire pressure, it would probably perform satisfactorily under a less severe load when placed on a subgrade with a CBR of 12 or greater. The maximum capability of the mat cannot be determined without further tests, but it is believed that its use should not be considered for wheel loads exceeding 12,000 lb at tire pressures in excess of 300 psi.

# PART IV: CONCLUSIONS AND RECOMMENDATIONS

## Conclusions

41. On the basis of the test results presented herein, it is concluded that the M9M1 landing mat is not suitable for use as a subgrade surfacing to be subjected to a 17,000-lb single-wheel load with tire-inflation pressure of 400 psi, regardless of subgrade strength. Similar test results were obtained in items 1 through 4 in which subgrade CBR ranged from 9 to 65. Excessive weld breakage, rivet shearing, and surface roughness were noted in all test items.

## Recommendations

42. It is recommended that the use of continuous welds in place of spot welds and steel rivets in place of aluminum rivets (particularly at the end joints) be investigated as possible aids to the successful performance of the M9M1 mat. It is believed that the load-carrying capacity of the mat can be improved significantly by welding and/or riveting a solid aluminum plate similar to the top plate to the bottom of the mat.

Table 1

Summary of CBR, Density, and Water Content Data

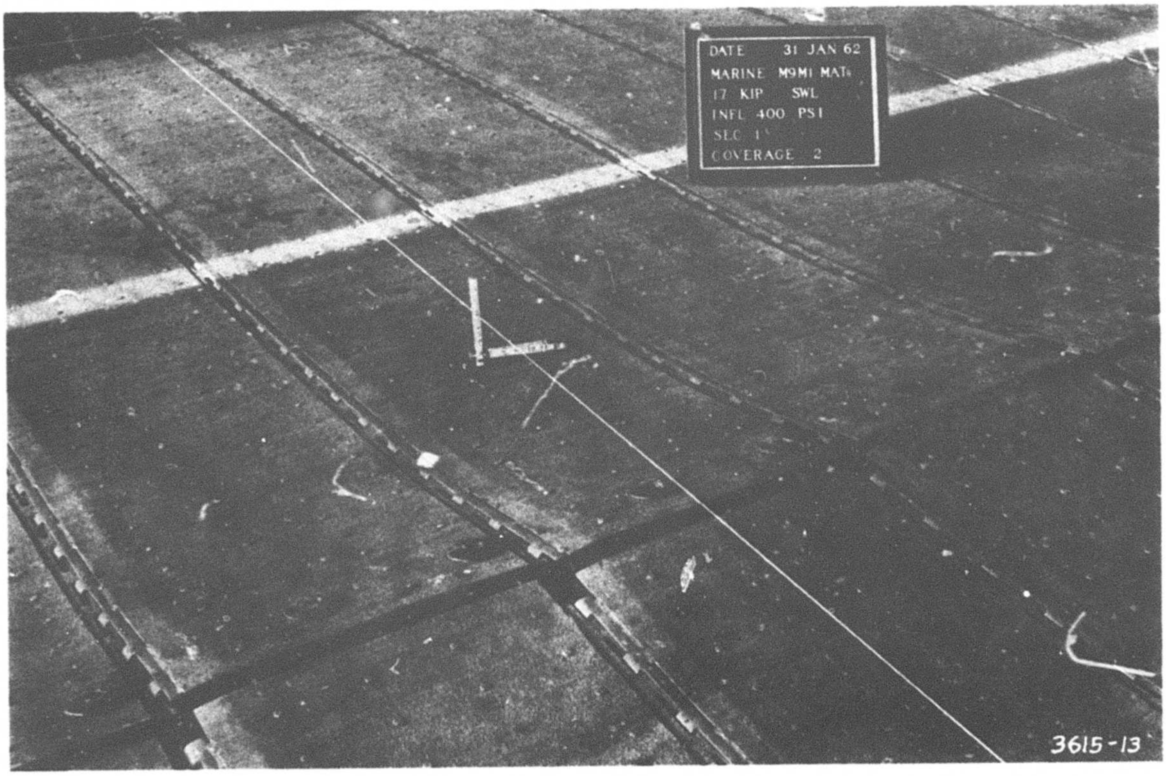
| Test Item | Subgrade Material | Depth in. | 0 Coverages | | | 50 Coverages | | | 128 Coverages | | | Total Traffic Coverages Applied |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CBR | Water Content % | Dry Density lb/cu ft | CBR | Water Content % | Dry Density lb/cu ft | CBR | Water Content % | Dry Density lb/cu ft | |
| 1 | Clay | 0 | 8 | 26.8 | 96.0 | 10 | 25.2 | 100.0 | -- | -- | -- | 50 |
| | | 6 | 8 | 26.1 | 95.9 | 9 | 25.2 | 99.5 | -- | -- | -- | |
| | | 12 | 6 | 28.8 | 92.8 | 9 | 25.7 | 93.1 | -- | -- | -- | |
| | | 18 | 7 | 27.2 | 95.9 | 10 | 27.3 | 96.2 | -- | -- | -- | |
| 2 | Clay | 0 | 17 | 21.1 | 100.6 | -- | -- | -- | 13 | 23.8 | 101.9 | 128 |
| | | 6 | 14 | 22.1 | 99.1 | -- | -- | -- | 17 | 22.0 | 102.2 | |
| | | 12 | 10 | 26.4 | 98.1 | -- | -- | -- | 10 | 27.0 | 96.8 | |
| | | 18 | 11 | 27.3 | 96.3 | -- | -- | -- | 9 | 29.1 | 93.6 | |
| 3 | Rock | 0 | -- | -- | -- | -- | -- | -- | 65 | -- | -- | 128 |
| 4 | Sand | 0 | 2 | 4.2 | 91.3 | -- | -- | -- | 18 | 3.1 | 101.0 | 128 |
| | | 6 | -- | -- | -- | -- | -- | -- | 29 | 4.2 | 105.5 | |
| | | 12 | -- | -- | -- | -- | -- | -- | 32 | 5.3 | 104.7 | |
| | | 18 | -- | -- | -- | -- | -- | -- | 21 | 6.4 | 105.5 | |

Table 2

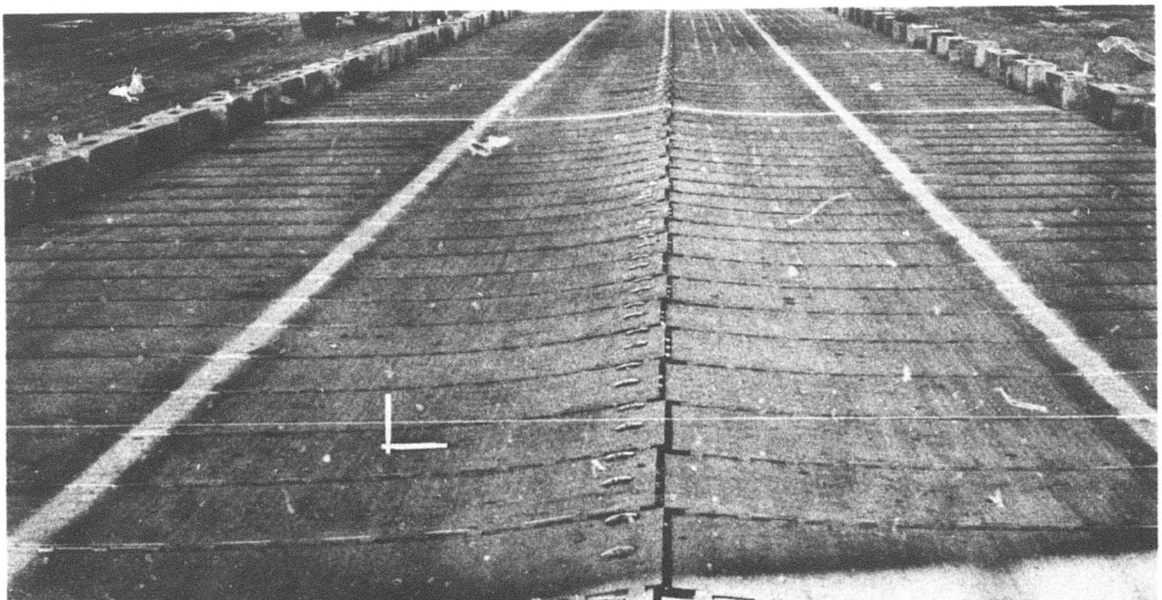
Summary of Traffic Test Results

| Test Item | Subgrade Material | Rated Subgrade CBR | No. of Planks in Item | No. of Traffic Coverages | Mat Welds: Bayonet Edge: Total No. Welds | Bayonet Edge: Welds Broken: Completely | Bayonet Edge: Welds Broken: Partially | Rolled Edge: Total No. Welds | Rolled Edge: Welds Broken: Completely | Rolled Edge: Welds Broken: Partially | No. of Rivets Sheared | Mat Deflection, in.: ℄ Traffic Lane: Midpoint of Plank | ℄ Traffic Lane: On Joint | Quarter Point of Plank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mat Laid with End Joints in Straight Line*** | | | | | | | | | | | | | | |
| 1 | Clay | 9 | 46 | 0 | 287 | 0 | 0 | 287 | 0 | 0 | 0 | --- | 0.7 | --- |
| | | | | 6 | 287 | 213 | 57 | 287 | 14 | 0 | 40 | --- | --- | --- |
| 2 | Clay | 15 | 32 | 0 | 192 | 0 | 0 | 192 | 0 | 0 | 0 | --- | 0.5 | --- |
| | | | | 6 | 192 | 100 | 53 | 192 | 0 | 0 | 16 | --- | --- | --- |
| 3 | Rock | 65 | 34 | 0 | 205 | 0 | 0 | 205 | 0 | 0 | 0 | --- | 0.4 | --- |
| | | | | 6 | 205 | 77 | 61 | 205 | 1 | 0 | 0 | --- | --- | --- |
| 4 | Sand | 12 | 32 | 0 | 192 | 0 | 0 | 192 | 0 | 0 | 0 | --- | 0.6 | --- |
| | | | | 6 | 192 | 110 | 63 | 192 | 0 | 0 | 0 | --- | --- | --- |
| **Mat Relaid with Staggered Joints** | | | | | | | | | | | | | | |
| 1 | Clay | 9 | 46 | 0 | 287 | 0 | 0 | 287 | 0 | 0 | 0 | 0.9 | 1.0 | 1.8 |
| | | | | 6 | 287 | 119 | 109 | 287 | 0 | 0 | 6 | --- | --- | --- |
| | | | | 20 | 287 | 221 | 51 | 287 | 0 | 0 | 18 | 0.5 | 1.0 | 0.5 |
| | | | | 50** | 287 | 261 | 14 | 287 | 49 | 72 | 68 | 0.5 | 1.0 | 0.4 |
| 2 | Clay | 15 | 32 | 0 | 192 | 0 | 0 | 192 | 0 | 0 | 0 | 0.8 | 0.8 | 1.7 |
| | | | | 6 | 192 | 36 | 101 | 192 | 0 | 0 | 0 | --- | --- | --- |
| | | | | 20 | 192 | 101 | 67 | 192 | 0 | 0 | 3 | 0.5 | 0.6 | 0.3 |
| | | | | 50 | 192 | 144 | 25 | 192 | 0 | 13 | 14 | 0.5 | 0.5 | 0.3 |
| | | | | 128 | 192 | 166 | 20 | 192 | 13 | 48 | 24 | 0.3 | 0.5 | 0.3 |
| 3 | Rock | 65 | 34 | 0 | 205 | 0 | 0 | 205 | 0 | 0 | 0 | 0.8 | 0.3 | 0.8 |
| | | | | 6 | 205 | 32 | 125 | 205 | 0 | 0 | 0 | --- | --- | --- |
| | | | | 20 | 205 | 88 | 94 | 205 | 0 | 0 | 0 | 0.5 | 0.3 | 0.4 |
| | | | | 50 | 205 | 141 | 45 | 205 | 0 | 16 | 5 | 0.5 | 0.3 | 0.5 |
| | | | | 128 | 205 | 178 | 25 | 205 | 16 | 28 | 8 | 0.5 | 0.6 | 0.6 |
| 4 | Sand | 12 | 32 | 0 | 192 | 0 | 0 | 192 | 0 | 0 | 0 | 0.8 | 0.5 | 1.2 |
| | | | | 6 | 192 | 93 | 78 | 192 | 0 | 0 | 1 | --- | --- | --- |
| | | | | 20 | 192 | 156 | 26 | 192 | 0 | 0 | 4 | 0.4 | 0.6 | 0.4 |
| | | | | 50 | 192 | 177 | 12 | 192 | 0 | 17 | 27 | 0.4 | 0.4 | 0.4 |
| | | | | 128 | 192 | 180 | 10 | 192 | 0 | 25 | 62 | 0.4 | 0.4 | 0.5 |

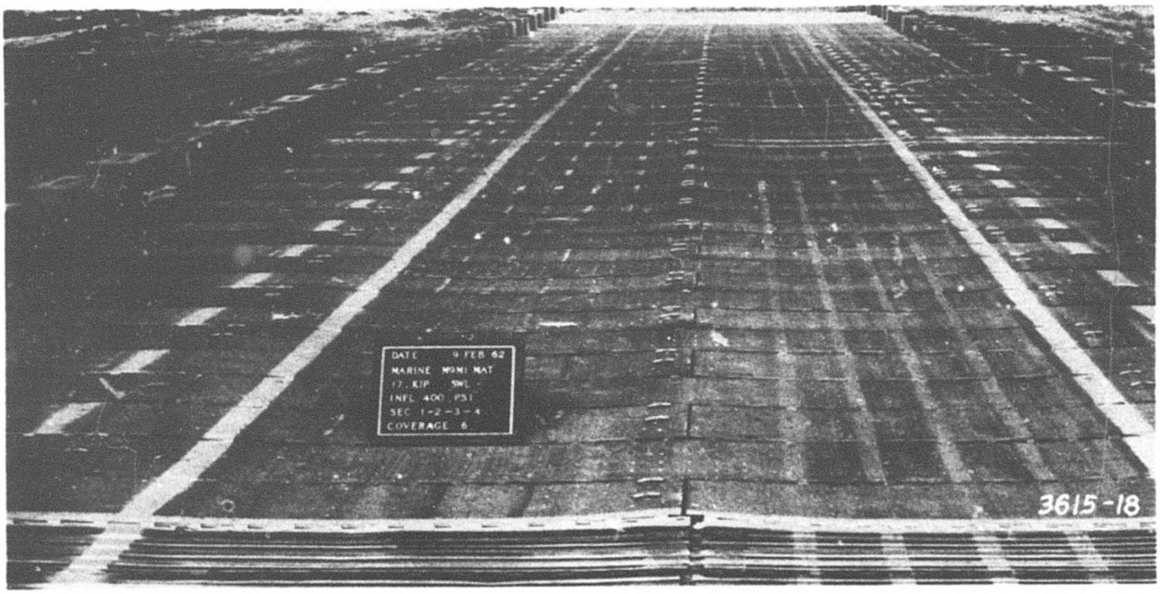
* Mat laid with end joints in straight line down center of test lane proved unsatisfactory due to buckling and bridging at joints.
** Traffic discontinued due to excessive mat breakage.



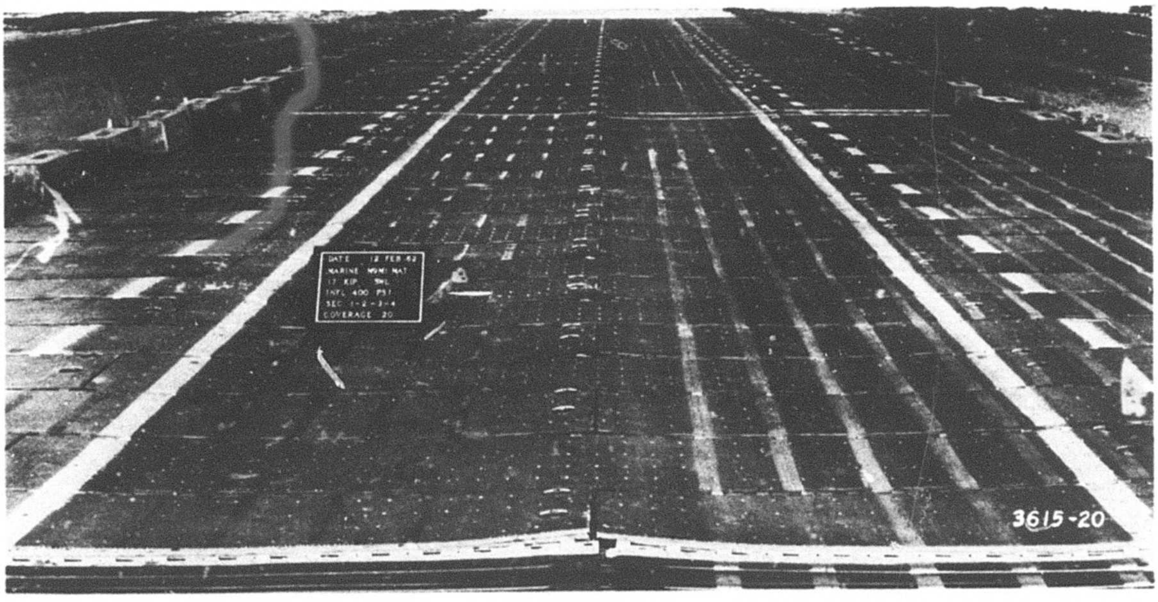

Photograph 1. Item 1 after 2 coverages had caused end joints to arch up



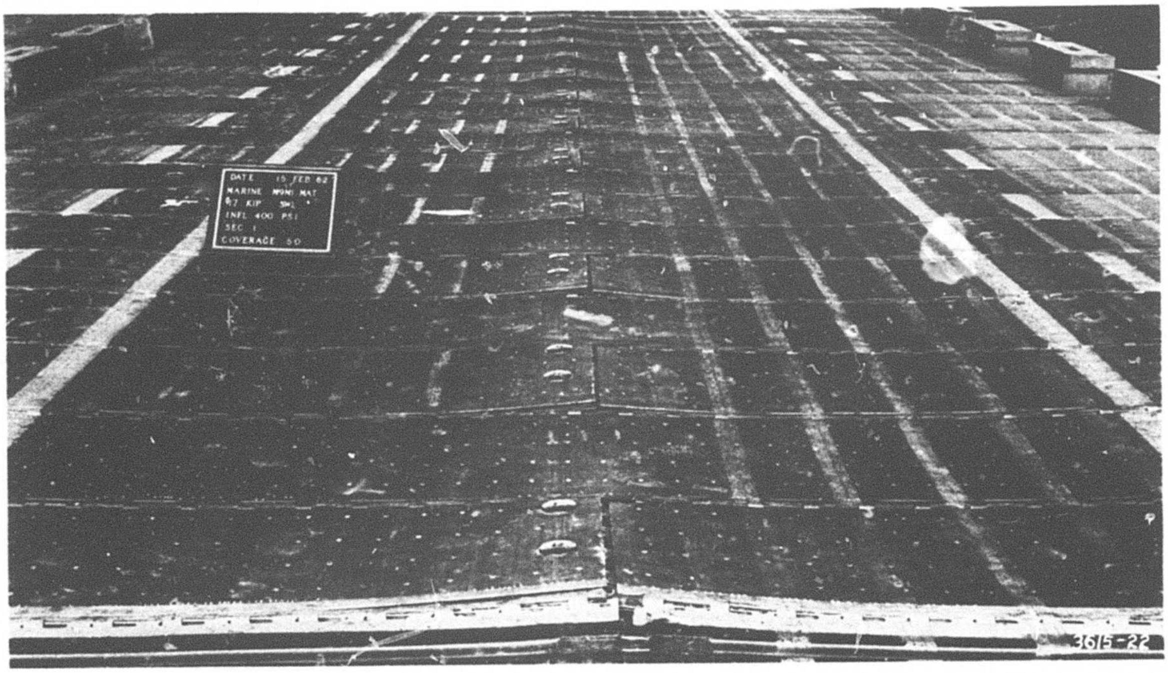
Photograph 2. Test section with end joints in straight line after 6 coverages. Note deformation of planks



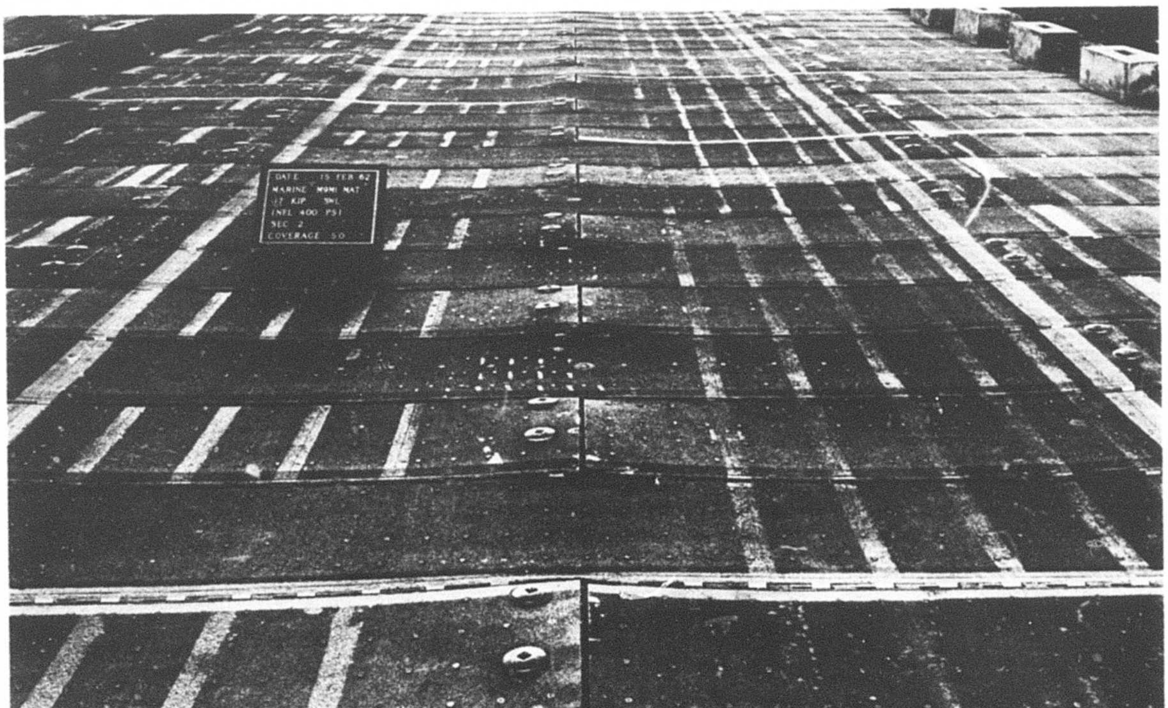

Photograph 3. Test section with staggered end joints after 6 coverages



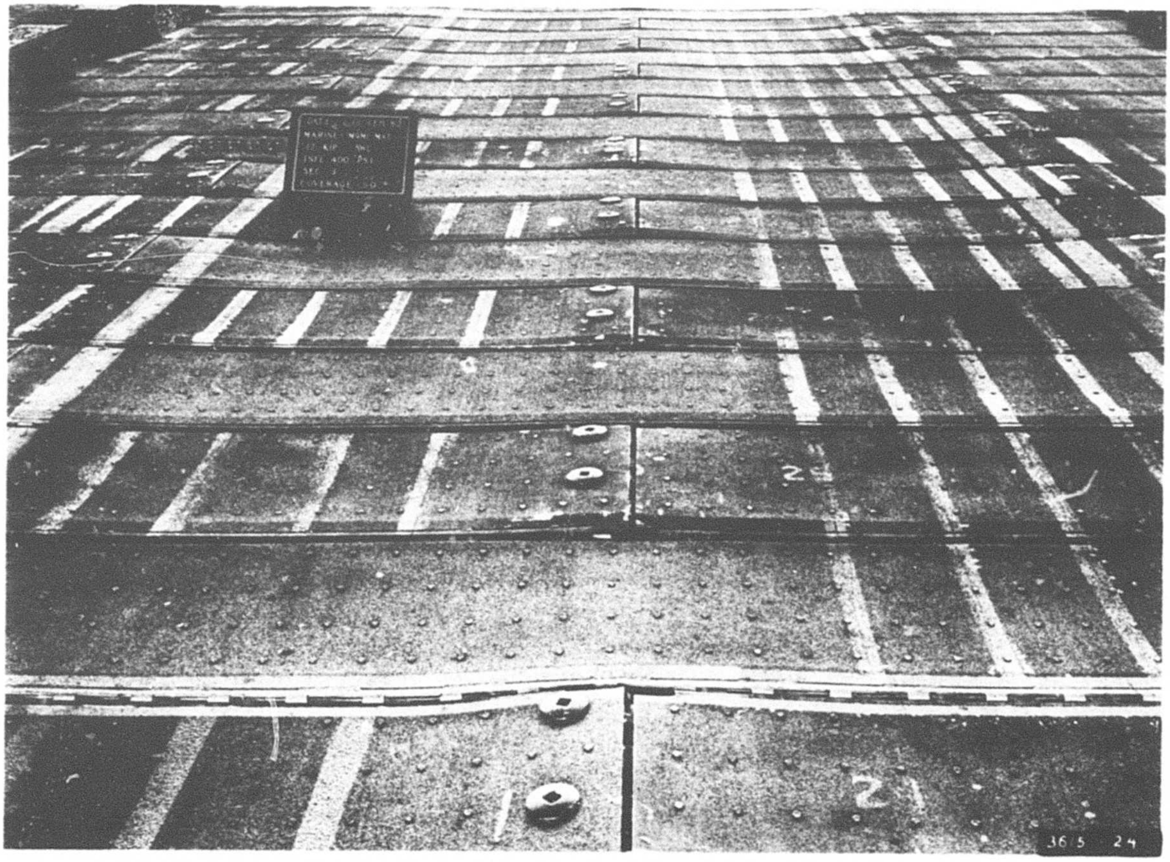

Photograph 4. Test section with staggered end joints after 20 coverages



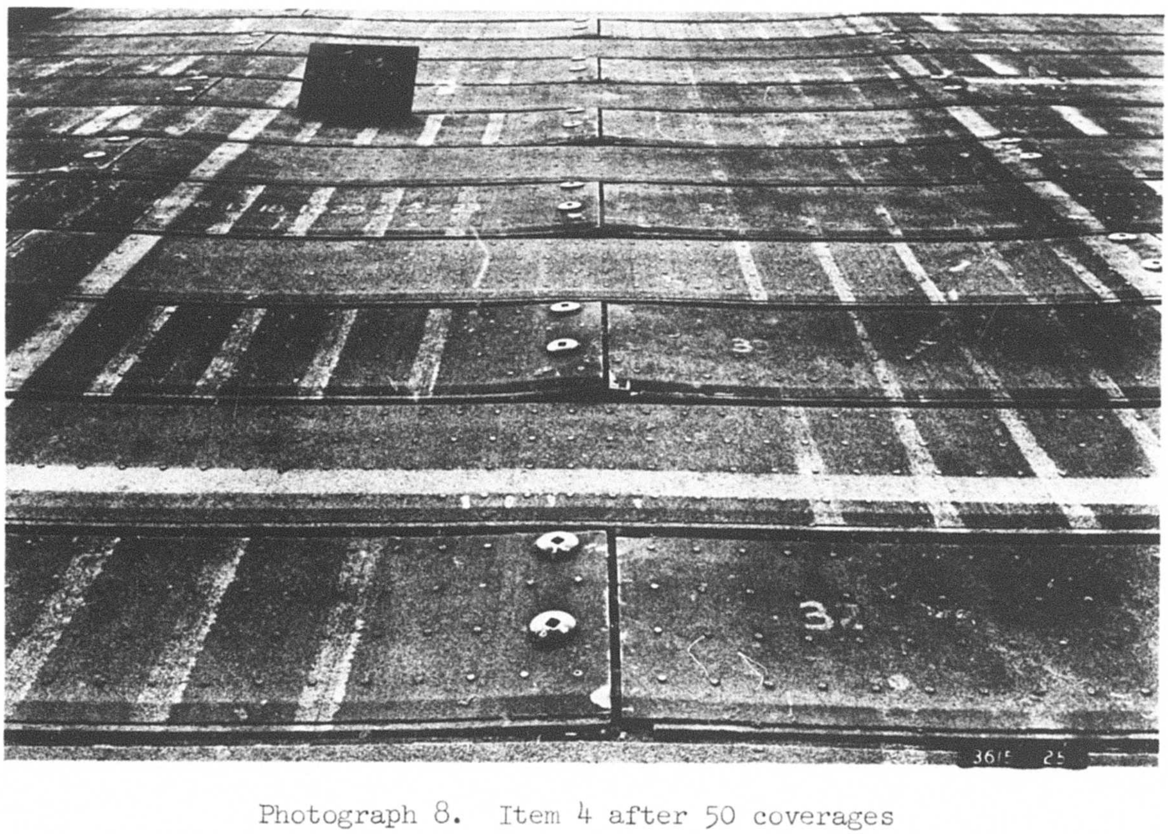

Photograph 5. Item 1 after 50 coverages



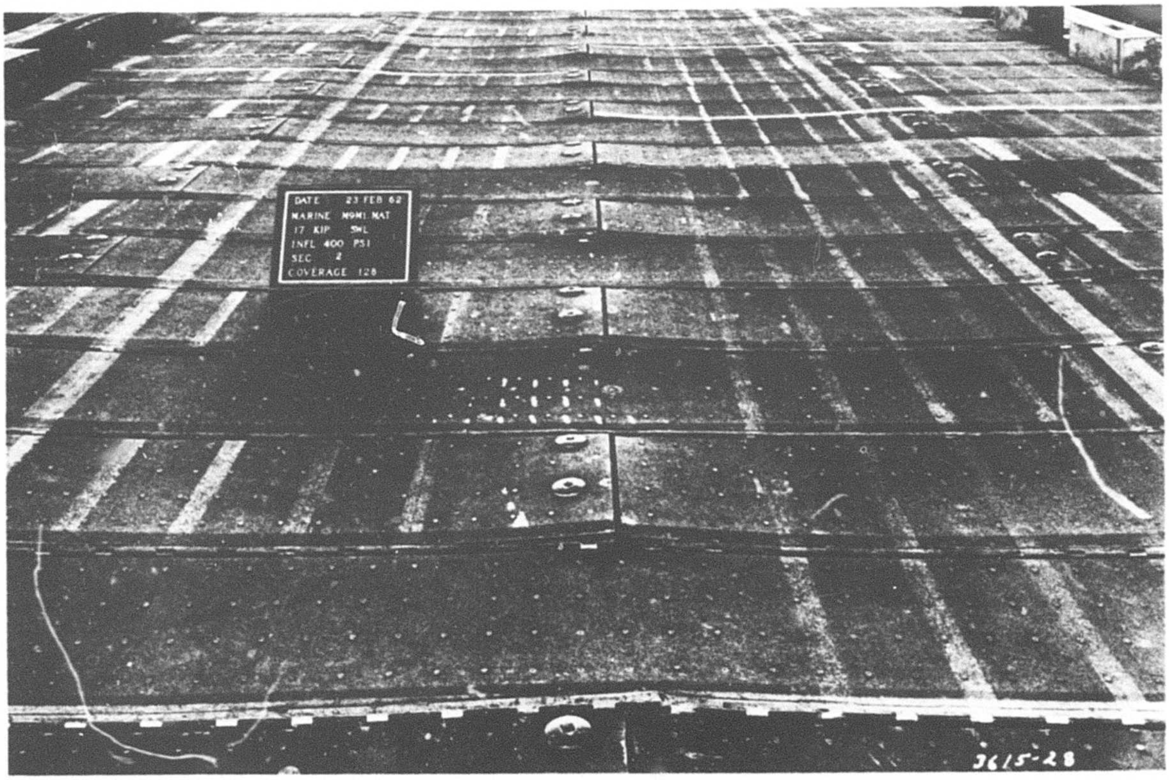

Photograph 6. Item 2 after 50 coverages



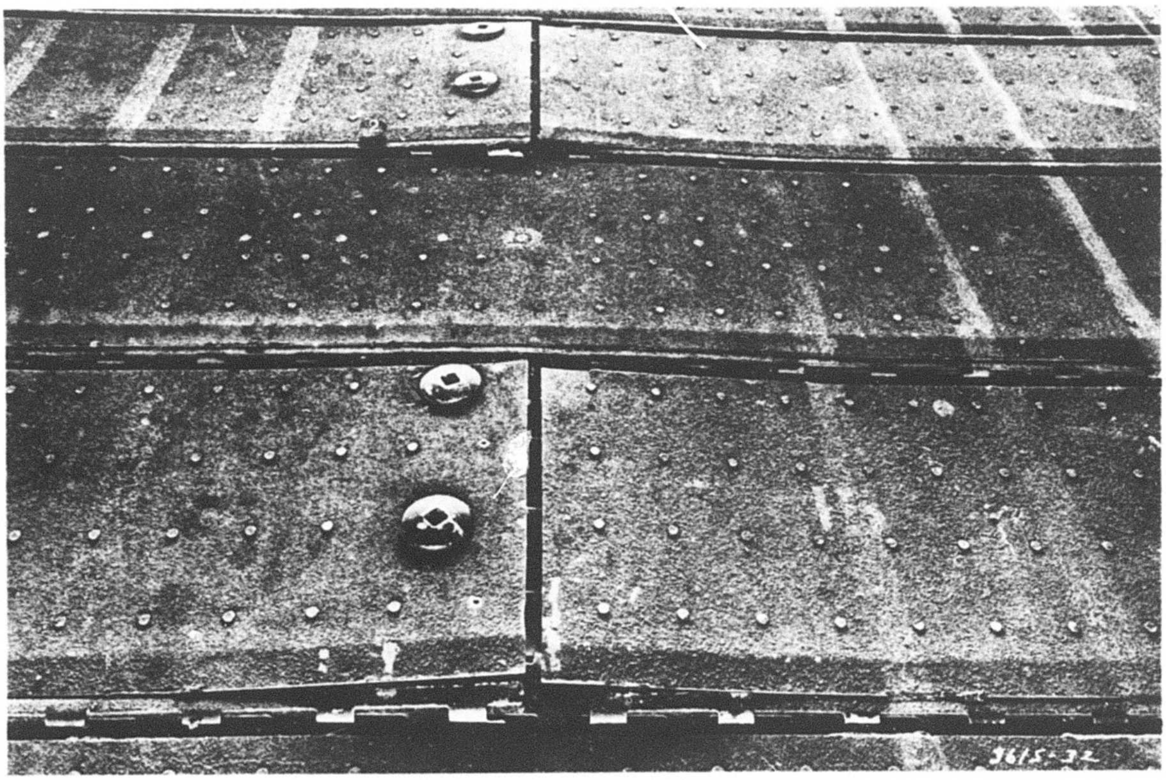
Photograph 7. Item 3 after 50 coverages



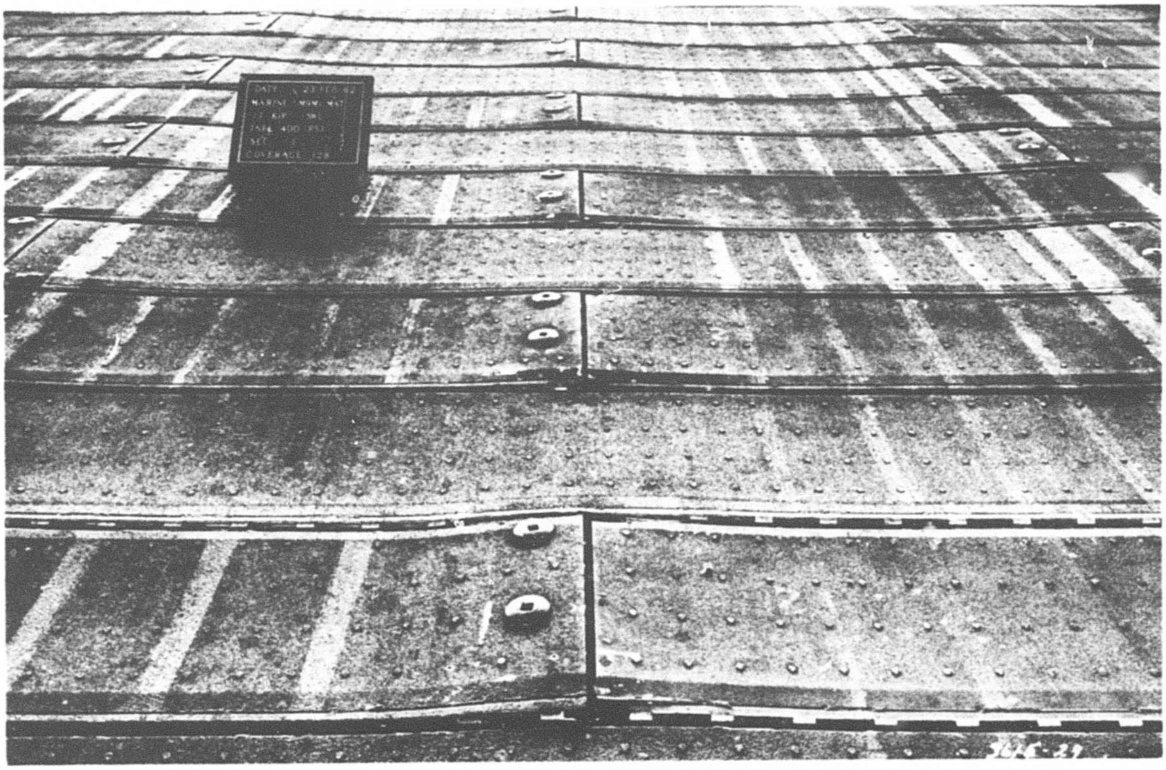
Photograph 8. Item 4 after 50 coverages




Photograph 9. Item 2 after 128 coverages

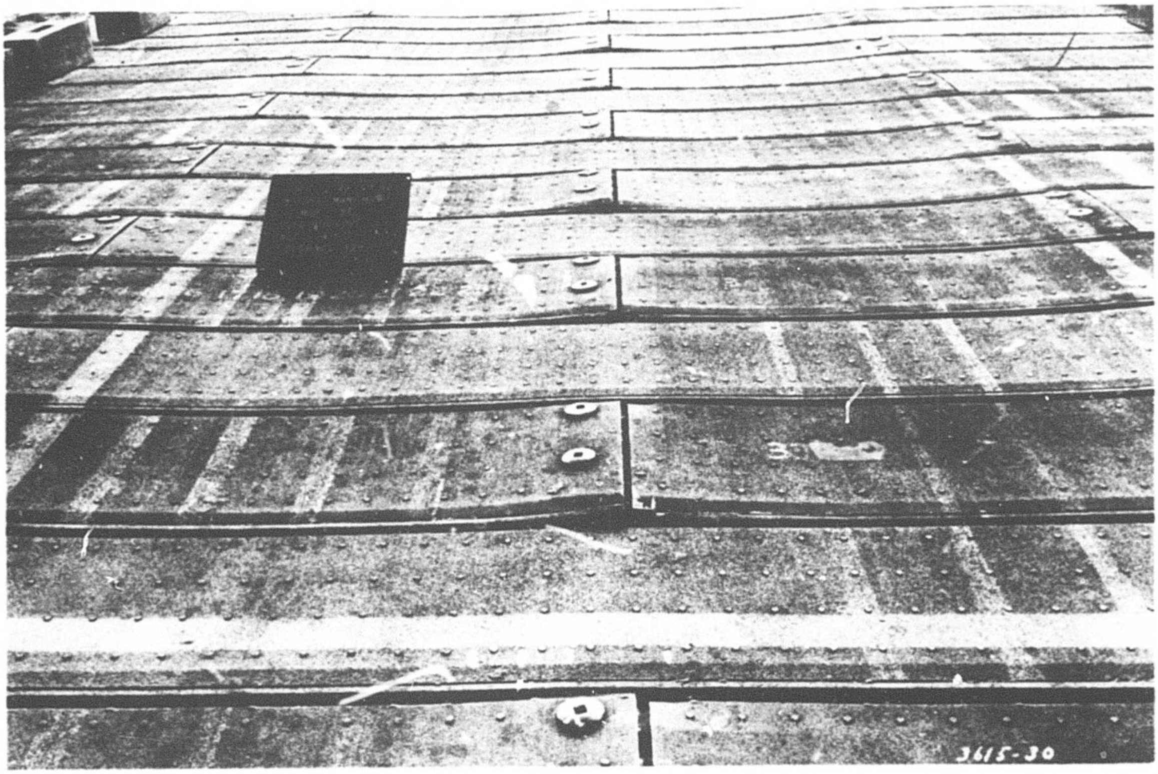



Photograph 10. Close-up of item 2 after 128 coverages

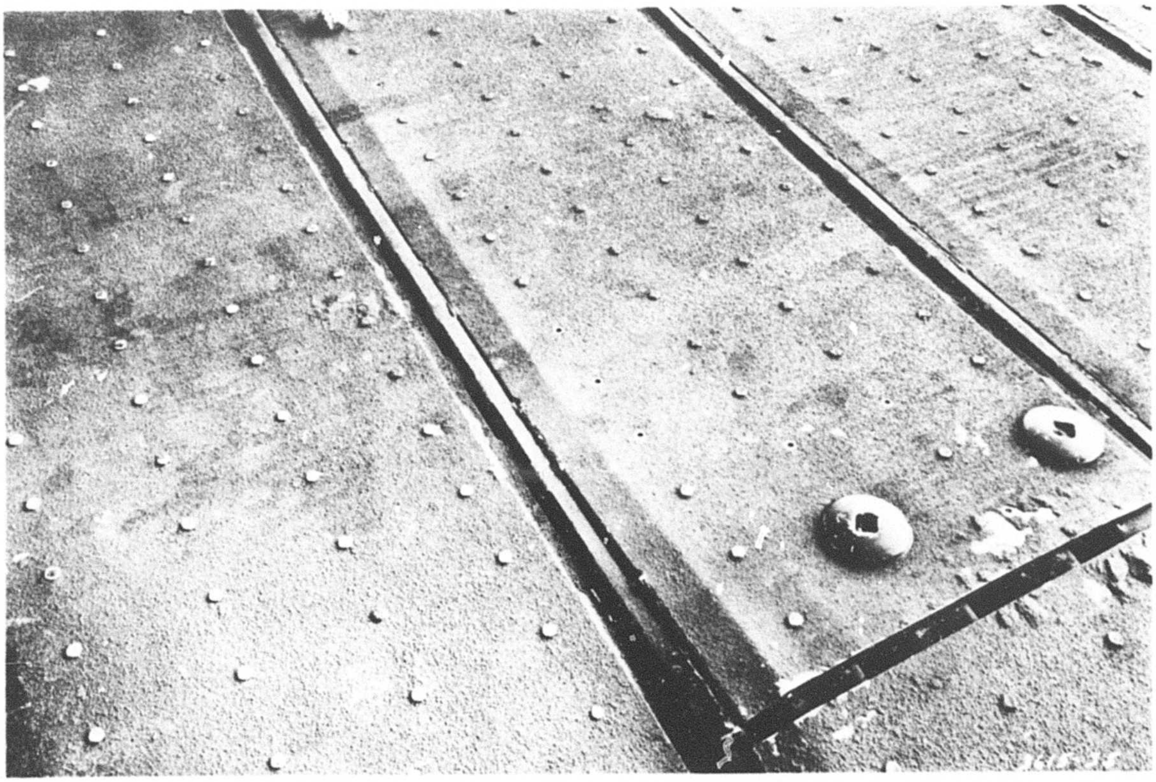


Photograph 11. Item 3 after 128 coverages

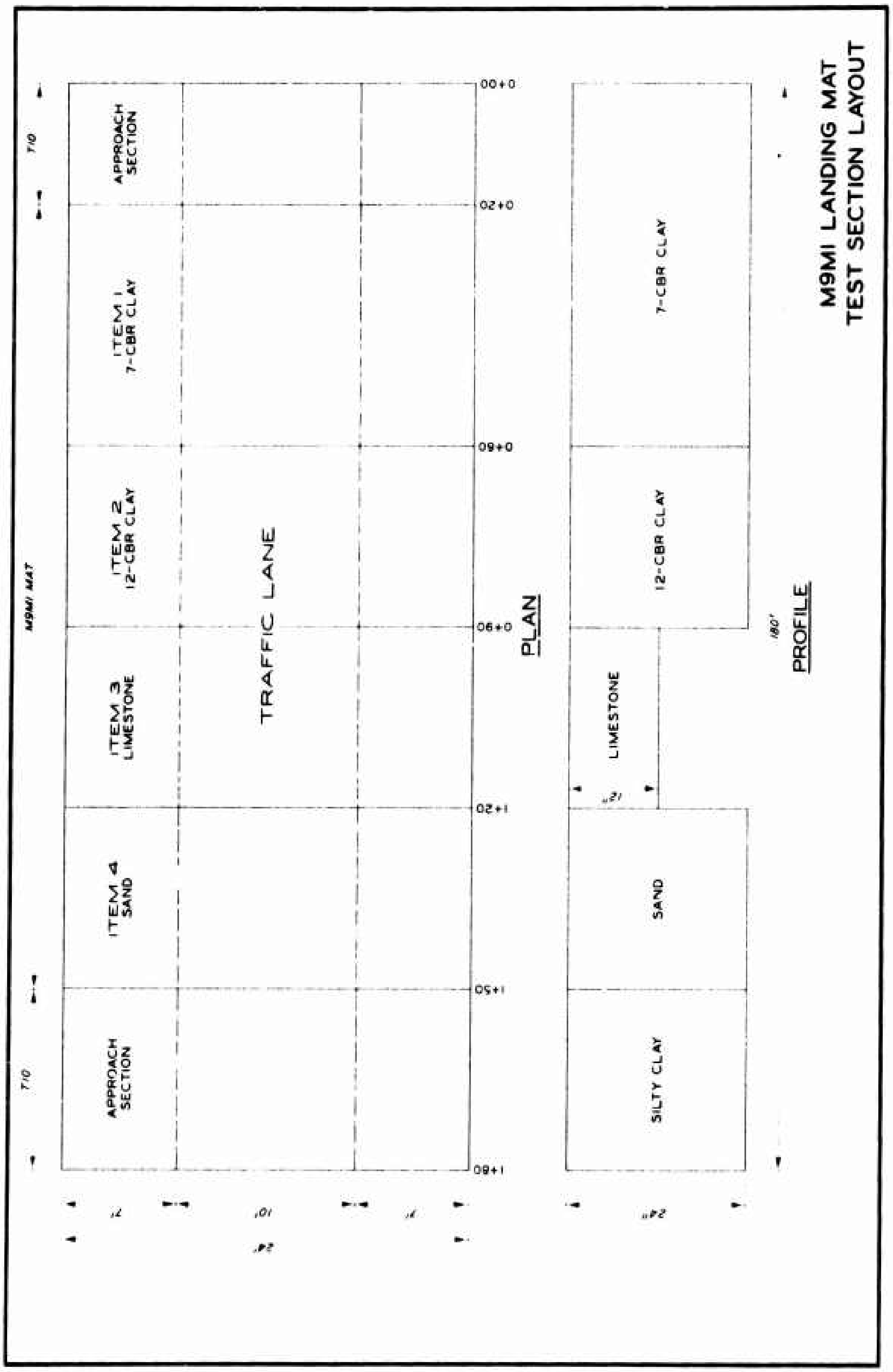
Photograph 12. Close-up of item 3 after 128 coverages

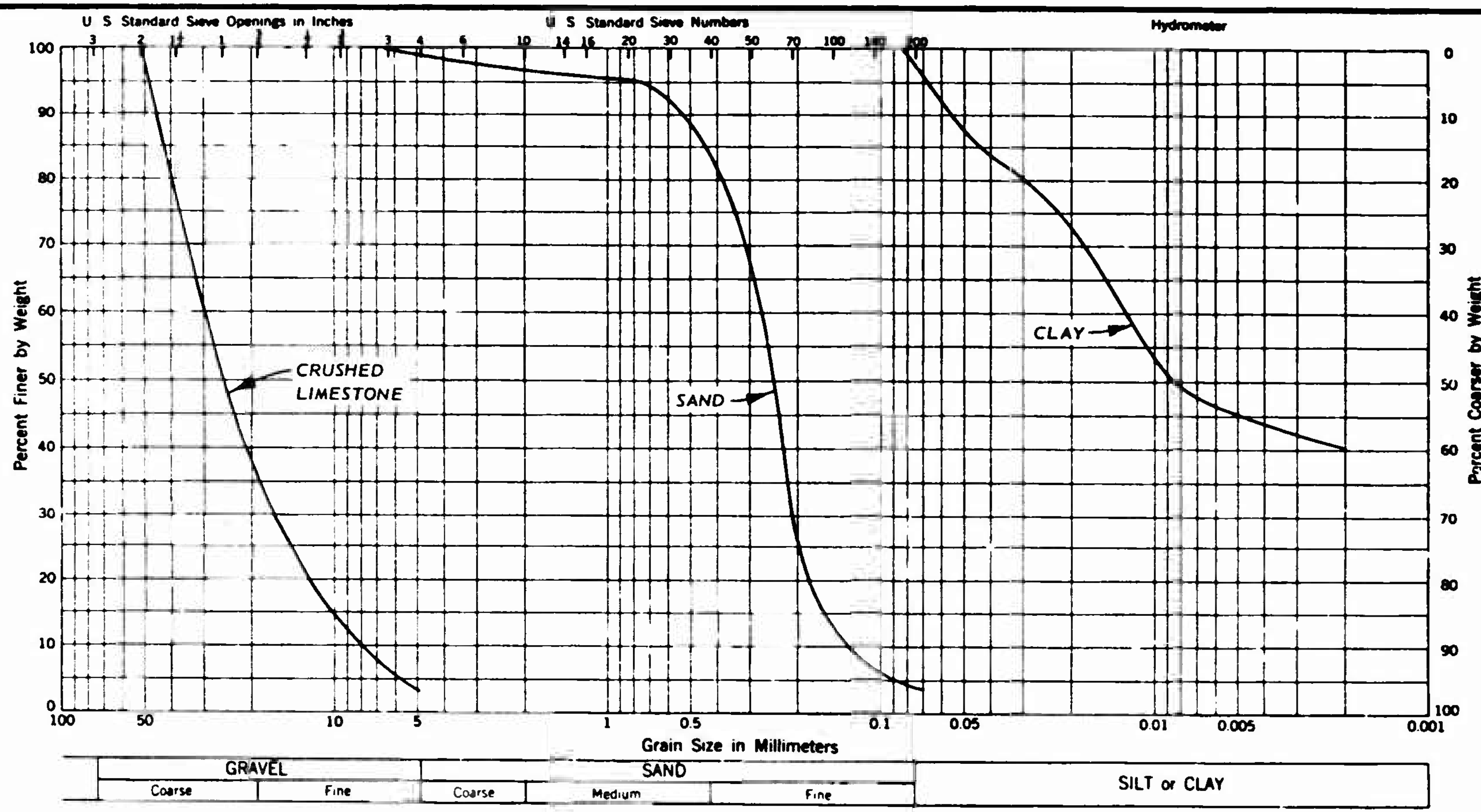



Photograph 13. Item 4 after 128 coverages



Photograph 14. Close-up of item 4 after 128 coverages

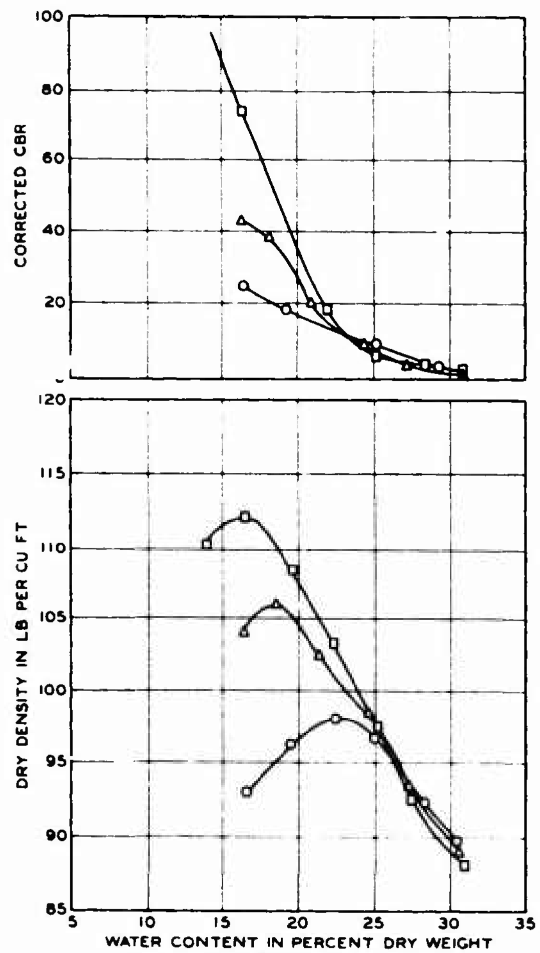

M9M1 LANDING MAT
TEST SECTION LAYOUT
PLAN
PROFILE
M9M1 MAT
TRAFFIC LANE
APPROACH SECTION
ITEM 1 7-CBR CLAY
ITEM 2 12-CBR CLAY
ITEM 3 LIMESTONE
ITEM 4 SAND
APPROACH SECTION
0+00
0+20
0+60
0+90
1+20
1+50
1+80
7-CBR CLAY
12-CBR CLAY
LIMESTONE
SAND
SILTY CLAY
180'
24'



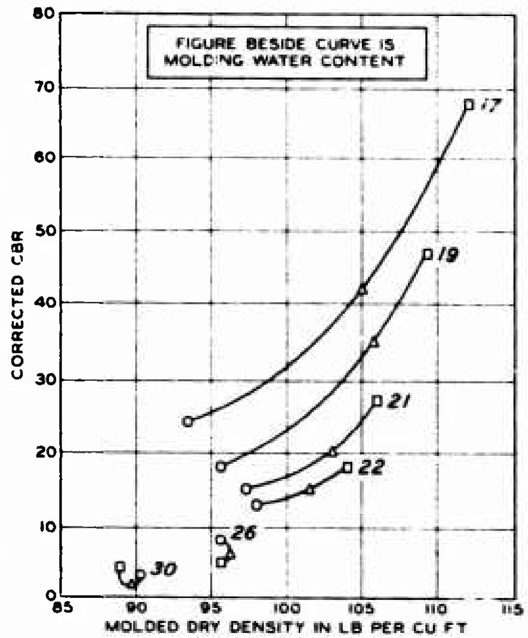

| Number | Depth | Natural Moisture | L. L. | P. L. | P. I. | Classification |
|---|---|---|---|---|---|---|
| | | | 56 | 23 | 33 | HEAVY CLAY (BUCKSHOT), CH |
| | | | | | | |
| | | | | | | |

CLASSIFICATION DATA

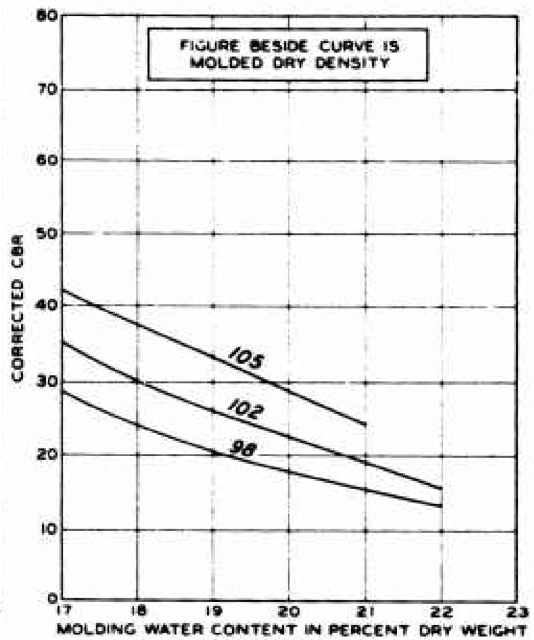
PLATE 2




MOLDING WATER CONTENT VS DENSITY AND CBR




DENSITY VS CBR




WATER CONTENT VS CBR

LEGEND

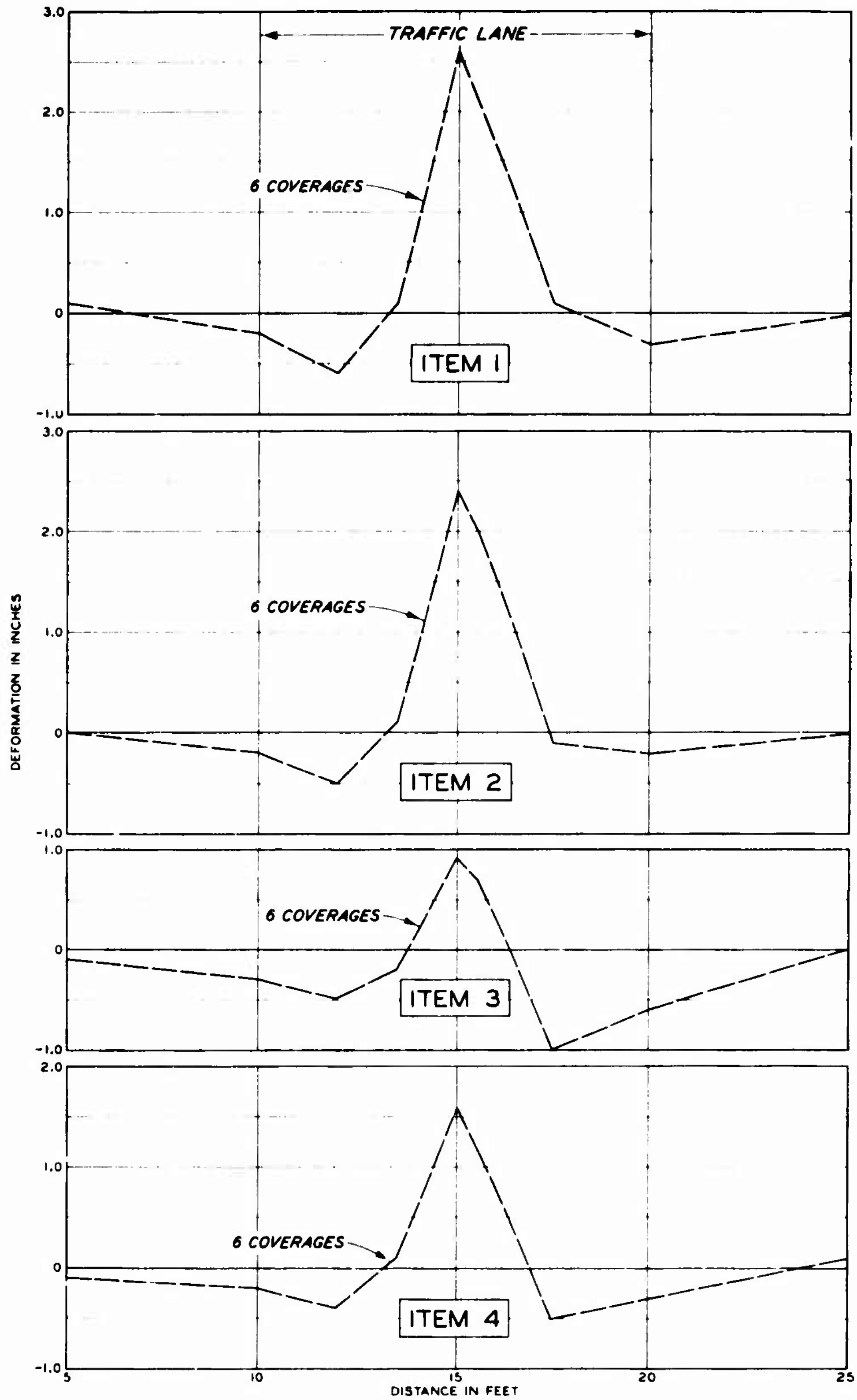
| SYMBOL | LAYERS | BLOWS PER LAYER | WT HAMMER IN LB | DROP IN INCHES | |
|---|---|---|---|---|---|
| O | 5 | 12 | 10 | 18 | |
| Δ | 5 | 26 | 10 | 18 | |
| □ | 5 | 55 | 10 | 18 | (MOD AASHO) |

## CBR, DENSITY, AND WATER CONTENT DATA

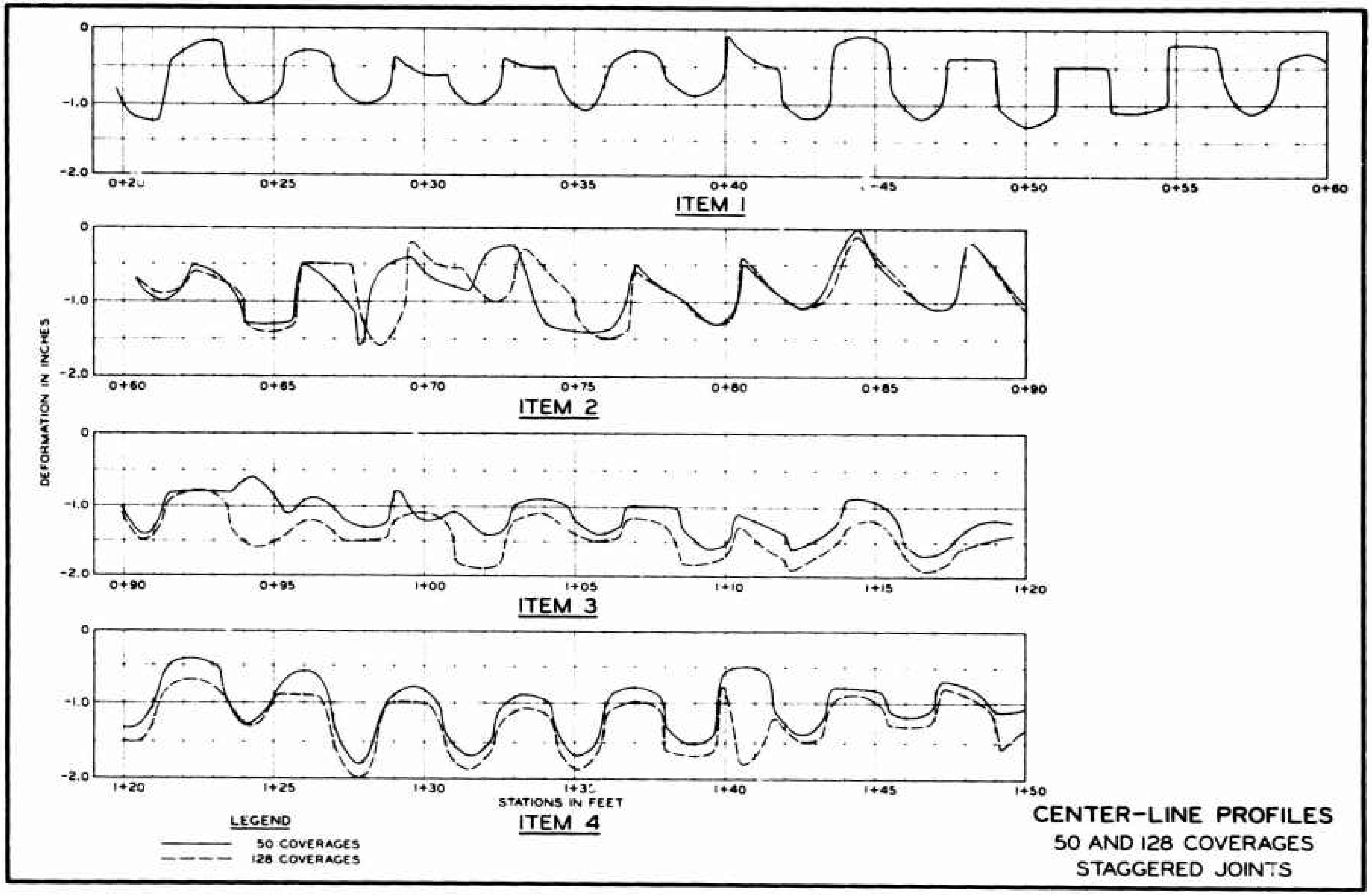
HEAVY CLAY (CH)

(UNSOAKED)

32.




PERMANENT DEFORMATION
MAT JOINT AT CENTER LINE




CENTER-LINE PROFILES
50 AND 128 COVERAGES
STAGGERED JOINTS

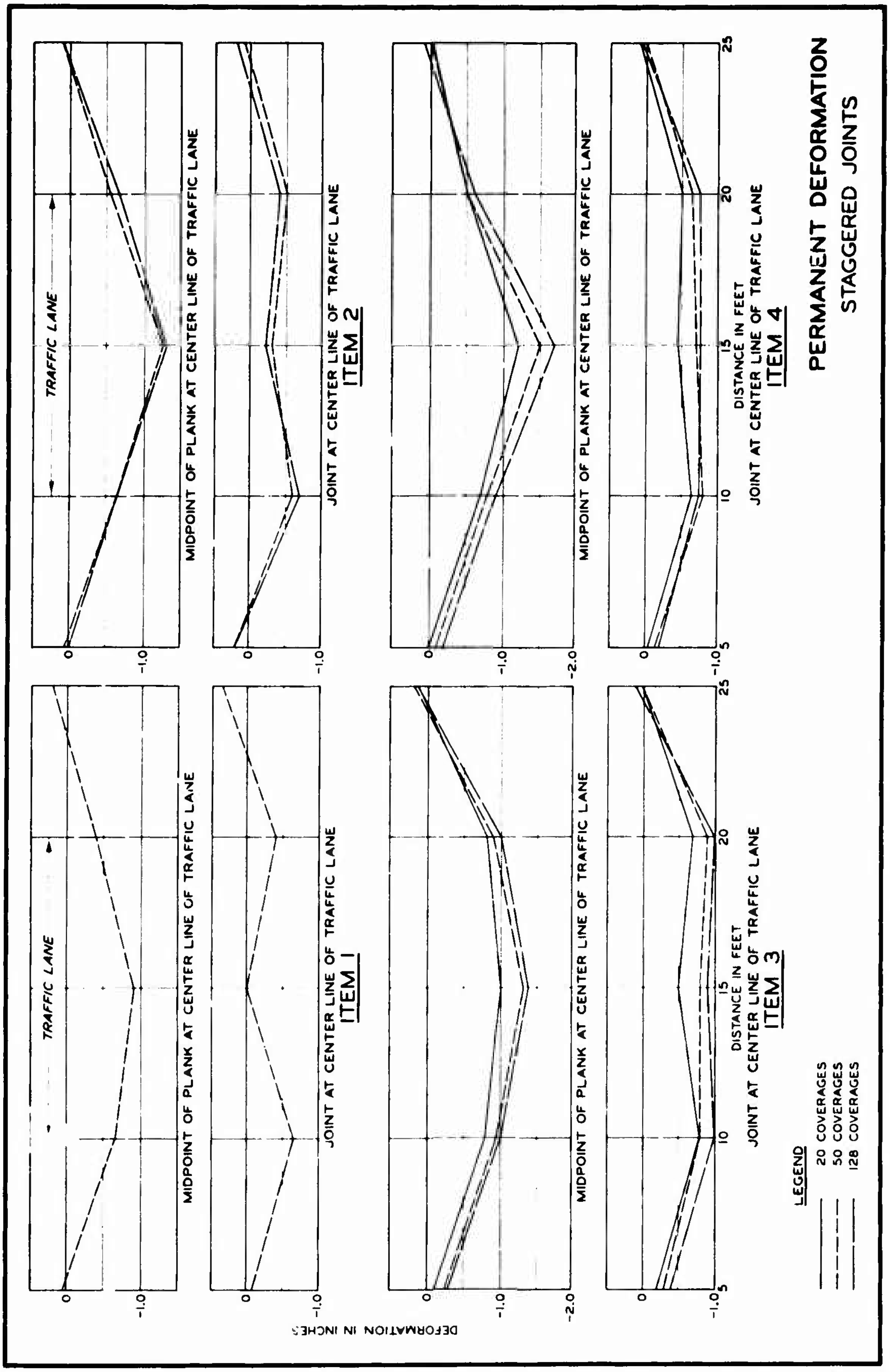
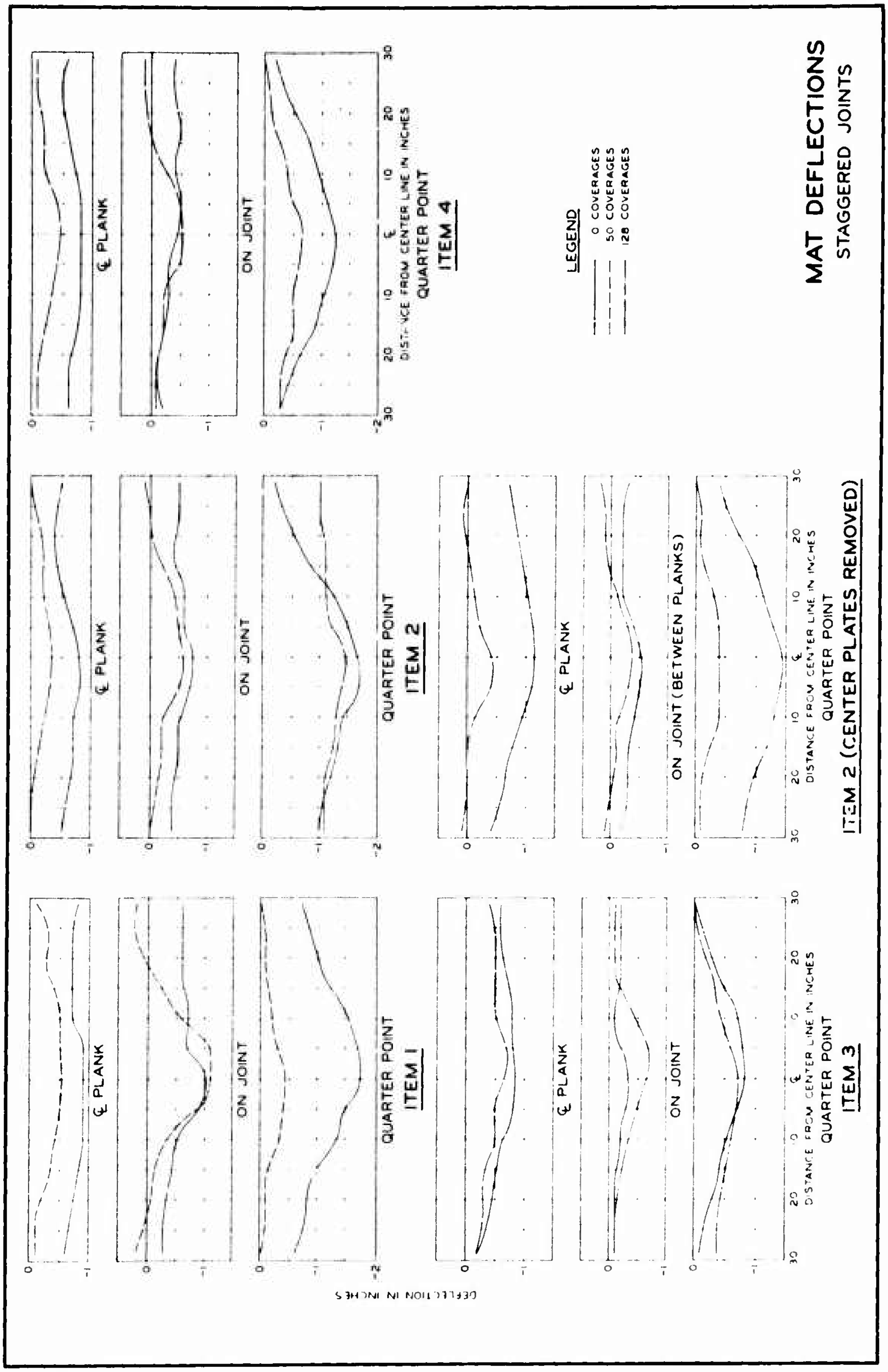
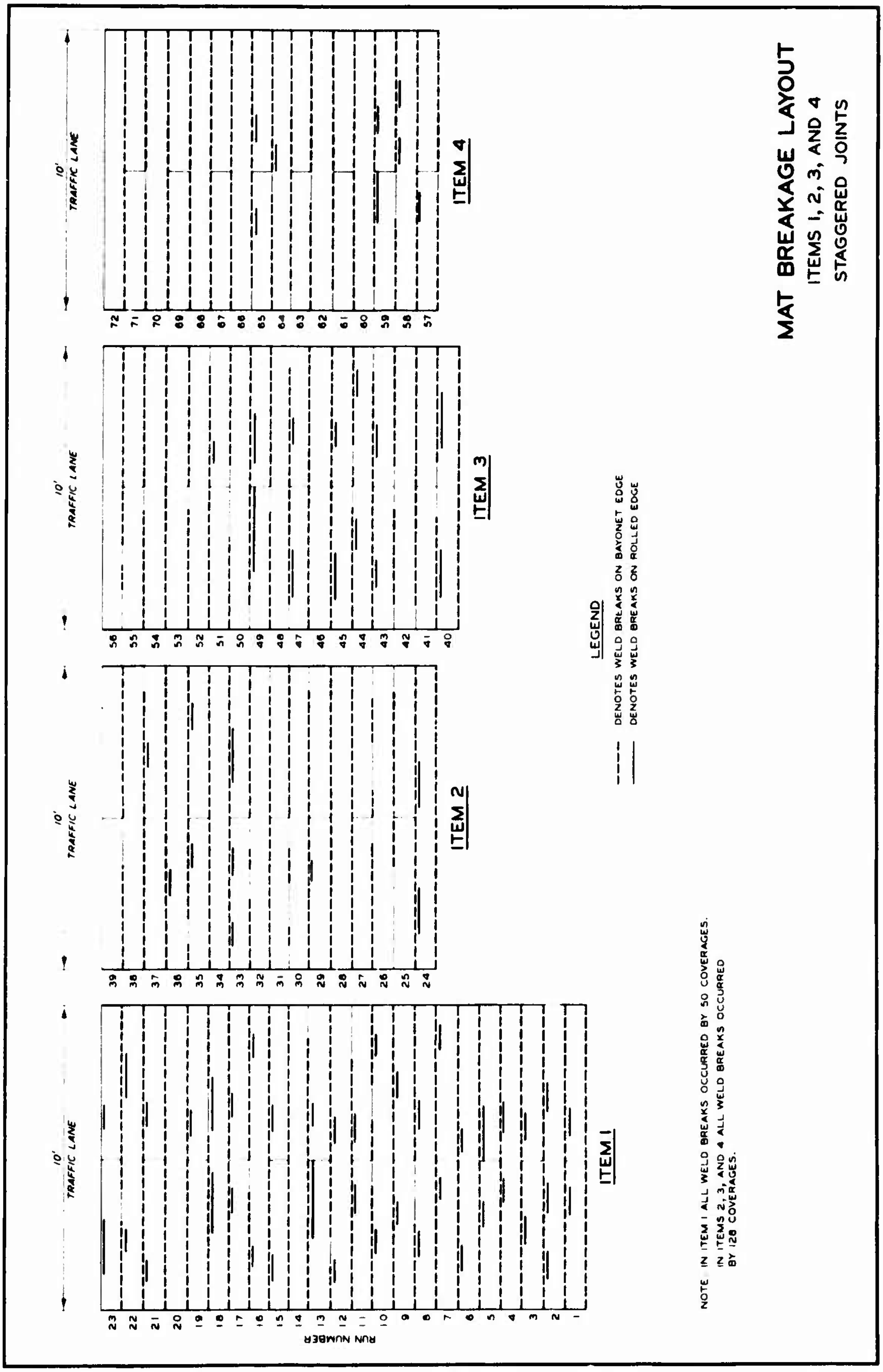

PERMANENT DEFORMATION
STAGGERED JOINTS
ITEM 1
ITEM 2
ITEM 3
ITEM 4
MIDPOINT OF PLANK AT CENTER LINE OF TRAFFIC LANE
JOINT AT CENTER LINE OF TRAFFIC LANE
TRAFFIC LANE
DISTANCE IN FEET
DEFORMATION IN INCHES
LEGEND
20 COVERAGES
50 COVERAGES
128 COVERAGES

PLATE 6


MAT DEFLECTIONS
STAGGERED JOINTS
LEGEND
0 COVERAGES
50 COVERAGES
128 COVERAGES
℄ PLANK
ON JOINT
QUARTER POINT
ITEM 1
ITEM 2
ITEM 4
ITEM 3
ON JOINT (BETWEEN PLANKS)
ITEM 2 (CENTER PLATES REMOVED)
DISTANCE FROM CENTER LINE IN INCHES
DEFLECTION IN INCHES

26.



MAT BREAKAGE LAYOUT
ITEMS 1, 2, 3, AND 4
STAGGERED JOINTS
10' TRAFFIC LANE
ITEM 1
ITEM 2
ITEM 3
ITEM 4
RUN NUMBER
LEGEND
DENOTES WELD BREAKS ON BAYONET EDGE
DENOTES WELD BREAKS ON ROLLED EDGE
NOTE: IN ITEM 1 ALL WELD BREAKS OCCURRED BY 50 COVERAGES.
IN ITEMS 2, 3, AND 4 ALL WELD BREAKS OCCURRED BY 128 COVERAGES.


PLATE 8