DEVELOPMENT OF CBR DESIGN CURVES FOR AM1 LANDING MAT

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PREFACE

The investigations reported herein were authorized by the Naval Air Material Center, Philadelphia, Pennsylvania, in Project Orders No. 2-4036 and 3-4007, dated 15 February 1962 and 19 July 1962, respectively. Responsibility for prosecution of these investigations was assigned to the U. S. Army Engineer Waterways Experiment Station (WES), and they were performed by WES during the period March through November 1962.

The investigations were under the general supervision of Messrs. W. J. Turnbull, Chief, and W. G. Shockley, Assistant Chief, of the WES Soils Division. Engineers of the Flexible Pavement Branch, Soils Division, who were actively concerned with the planning, testing, analysis, and report phases of the study were Messrs. A. A. Maxwell, Branch Chief, O. B. Ray, W. L. McInnis, C. D. Burns, M. J. Mathews, and W. B. Fenwick. This report was prepared by Messrs. Burns and Fenwick.

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

CONTENTS

SUMMARY

The initial phase of this study was conducted to evaluate four experimental, aluminum landing mats, and to develop CBR design curves for the one selected as most satisfactory, which was standardized and designated by the Navy as Airfield Matting No. 1 (AM1). The design curves were to represent 1600 operational cycles of an aircraft having a 60,000-lb gross weight with a single-wheel, main-gear assembly weight of 27,000 lb and a 30-7.7 tire inflated to 400 psi. CBR design curves were also desired for 1600 passes of a 39,000-lb single-wheel load applied in a single track to represent the loading calculated to be imposed on the landing mat during the launching of a 60,000-lb aircraft by catapult.

A test section consisting of items with different subgrade strengths, surfaced with the four mat types, was constructed and subjected to accelerated traffic of 27,000- and 39,000-lb single-wheel loads with a 30-7.7 tire inflated to 400 psi. Analysis of the data obtained indicates that mat 1-d, later designated AM1, will satisfactorily sustain 1600 cycles of aircraft operations with a 27,000-lb single-wheel load and 400-psi tire pressure when placed over a subgrade having a CBR of 7 or greater throughout the traffic period. The minimum subgrade strength required for 1600 passes of the 39,000-lb load was not determined; however, it was determined that mat 1-d would support this traffic when placed on a subgrade with a CBR of 13 or more.

For the second phase of the study, a production quantity of the AM1 mat was manufactured and subjected to the same types of field tests used for the experimental mats on subgrades with CBR's ranging from about 5 to 16. Because the end joints of the mats in test item 1 with the weakest subgrade began to fail early in the tests whereas the mats in the other items showed no distress, the mats in item 1 were strengthened with end-connecting rods. Analysis of the test results indicates that the mat with end-connecting rods will sustain 1600 cycles of the 27,000-lb single-wheel load, or 1600 passes of the 39,000-lb single-wheel load on a subgrade with a CBR of 8 or more throughout the traffic period. Without the end-connecting rods, the AM1 mat must be placed on a subgrade having a CBR of about 10.7 to carry the design traffic.

DEVELOPMENT OF CBR DESIGN CURVES FOR AM1 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 sustaining operations of modern jet aircraft of the Marine Corps 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 heavy wheel loads and arresting-hook landing impacts of the using aircraft, and heat blasts from tailpipes of jet engines during takeoffs; it must also remain serviceable with minimum maintenance for 1600 aircraft 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 60,000 lb (27,000 lb per main wheel) with a 30-7.7, 18-ply tire inflated to 400 psi (formerly, the weight of this aircraft was 40,000 lb, or 17,000 lb per main wheel, with the same tire size). Computations show that a single-wheel load of 39,000 lb will be imposed on the landing mat during the launching of the 60,000-lb aircraft by catapult.

2. At the beginning of fiscal year 1962, the responsibility for development of SATS landing mat was assigned to the Naval Air Material Center. This agency requested several manufacturers to develop small quantities of experimental landing mats for use in tests to establish their suitability for surfacing SATS. The first of these experimental mats to be tested consisted of a group of four mats manufactured by Fenestra, Inc., Philadelphia, Pennsylvania. These mats were initially identified as Fenestra Mark III. Based on the results of these tests, one of these mats was standardized and designated as Airfield Matting No. 1 (AM1) by the Navy. A contract was subsequently let by the Navy to Butler Manufacturing

Company, Kansas City, Missouri, for a production quantity of AM1 mat. A portion of this mat was furnished WES for further testing.

Objectives of the Investigations

3. The preliminary objective of the investigations reported herein was to evaluate the performance of the four experimental Fenestra Mark III mats under accelerated traffic tests with single-wheel loads of 17,000, 27,000, and 39,000 lb with 400-psi tire pressures. Tests with the 17,000-lb single-wheel load were included to provide a comparison of performance of the Fenestra mats with previous mats tested with the 17,000-lb single-wheel load. The primary objective of the investigations was to develop CBR design curves for the most satisfactory Fenestra Mark III mat, later designated AM1, and the Butler AM1 mat. The CBR design curves were to indicate the minimum strength required for subgrades surfaced with the AM1 mat to support 1600 cycles of aircraft operations with 27,000- and 39,000-lb single-wheel loads with 400-psi tire pressures.

Scope of Report

4. Part II of this report describes and gives the results of the field traffic tests which were conducted to evaluate the four experimental landing mats. Part III describes tests on production quantities of the most satisfactory of these mats (designated AM1), and includes an analysis of the data obtained and the CBR design curves which were developed for use in designing airfields to be surfaced with AM1 mat. Part IV summarizes the conclusions derived from the investigations.

PART II: TESTING AND DEVELOPMENT OF DESIGN CURVES FOR THE FENESTRA MARK III MAT

Mat

5. The landing mats used in this investigation were fabricated from nine aluminum extrusions which were mechanically interlocked and usually welded to form a mat plank approximately 2 by 12 ft. Aluminum end connectors were welded across the ends of the 2-ft planks. The variation in the experimental mats was primarily in the degree of welding along the longitudinal joints of the individual extrusions. A top view of the four experimental mat types studied is shown in fig. 1. A brief description of the mats is given below:

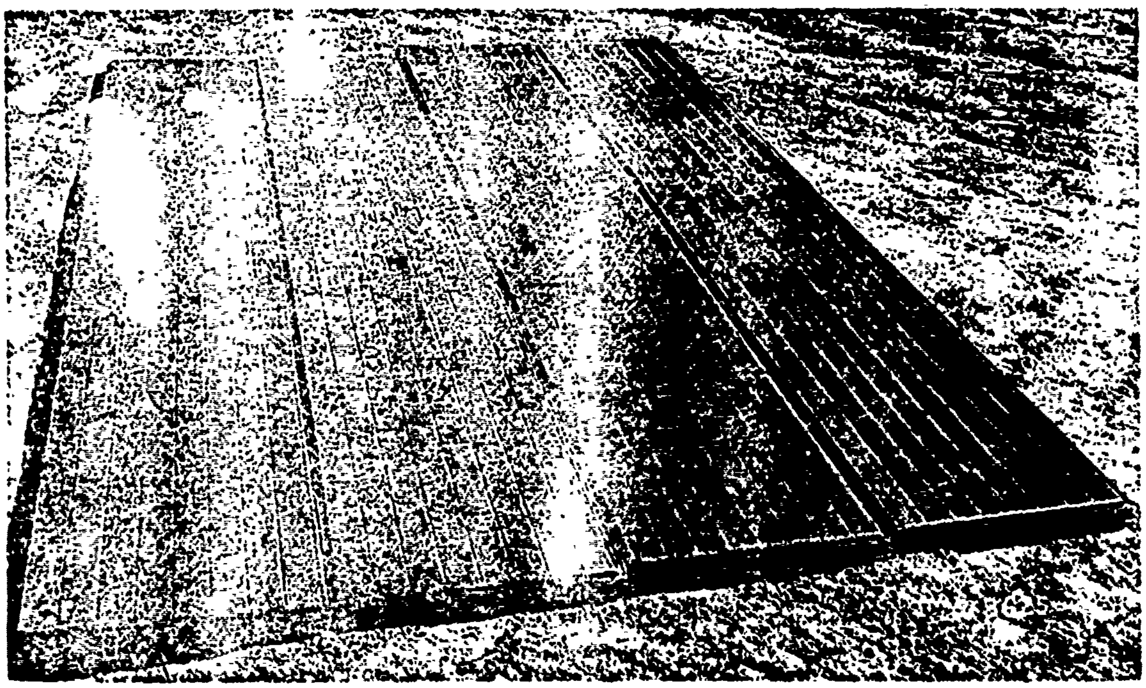


Fig. 1. The four types of Fenestra mat

Designation in fig. 1	Official Designation	Description	Full Plank Laying Dimensions: Length	Full Plank Laying Dimensions: Width	Weight of Full Plank, lb
R	1-a	Longitudinal weld; with leg	11 ft 11-3/4 in.	2 ft 1/4 in.	176.5
Y	1-b	Tack weld; with leg	12 ft	2 ft 1/8 in.	172.0

(Continued)

Designation in fig. 1	Official Designation	Description	Full Plank Laying Dimensions Length	Full Plank Laying Dimensions Width	Weight of Full Plank, lb
W	1-c	No weld; with leg	11 ft 11-7/8 in.	2 ft 1/4 in.	169.0
B	1-d	Longitudinal weld; without leg	11 ft 11-3/4 in.	2 ft 1/8 in.	173.0

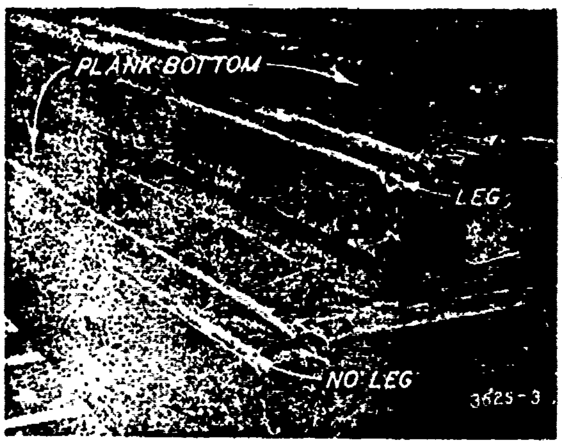


Fig. 2. Bottom view of type 1-a mat with leg and 1-d mat without leg

The leg is a small extension of the underlapping plank edge (fig. 2) on the bottom of the mat. When the mat is in place, the leg rests on the bottom extension of the overlapping plank, thus furnishing vertical support to the underlapping plank. A total of 15 bundles of mat, each consisting of 9 full planks and 6 half planks, were received for surfacing the test section.

Test Section

Location

6. All traffic tests were conducted at the WES on a test section which was constructed and tested under shelter to control the water content and strength of the subgrade.

Description

7. A layout of the test section is shown in plate 1. The test section consisted of four items, each approximately 24 ft wide and 40 ft long. Items 1 and 2 were constructed of a heavy clay soil, item 3 of an uncompacted rock, and item 4 of a loose sand.

Subgrade materials

8. Gradation and classification data for the subgrade materials used in the test section are shown in plate 2. The sand used in this investigation 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. The rock was used to simulate an existing paved runway or an area surfaced with broken concrete. The heavy clay soil (buckshot) had a liquid limit of 5[illegible], a plasticity index of 33, and classified as CH. Laboratory compaction and CBR data for the heavy clay soil are shown in plate 3.

Construction of subgrade

9. Items 1 and 2. These items were to be constructed to a total thickness of 24 in.; therefore, the existing material at the test site was excavated to a depth of 24 in. below finished grade. The soil at the bottom of the excavation was a lean clay having a CBR value of about 10. It was desired to construct items 1 and 2 with the heavy clay soil at water contents that would result in CBR values of 5 and 10, respectively, when compacted. The soil for each item was processed to the desired water content, hauled to the test section site by truck, spread, and compacted in 6-in. lifts. Compaction of items 1 and 2 was accomplished by applying eight coverages of a four-wheel rubber-tired roller loaded to 40,000 lb with tires inflated to 90 psi. The surface of each compacted lift was 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 control data were obtained for each lift immediately after placement. Strengths were measured by in-place CBR tests. Construction data representing the average of the four lifts are shown below.

Test Item	Water Content, %	Dry Density lb/cu ft	CBR
1	27.6	95.0	5
2	24.3	97.3	11

10. Items 3 and 4. Item 3 of the test section consisted of 12 in. of uncompacted, loose rock that had been end-dumped (fig. 3) and spread by hand. Item 4 consisted of 24 in. of uncompacted sand that had been end-dumped (fig. 4) and spread with a D4 tractor. A CBR of about 3 was measured in the sand item prior to placement of the mat. A CBR of 3 for a

Fig. 3. End-dumping of rock in item 3

Fig. 4. End-dumping of sand in item 4

loose, unconfined sand has little meaning with respect to its strength when confined, as sand consolidates and develops a higher strength under traffic.

Due to the coarseness and loose state of the rock, no attempt was made to obtain an initial CBR value in item 3.

Placement of mat

11. The Fenestra 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 individual planks were carried about 30 ft into place (fig. 5). Approximately 250 sq

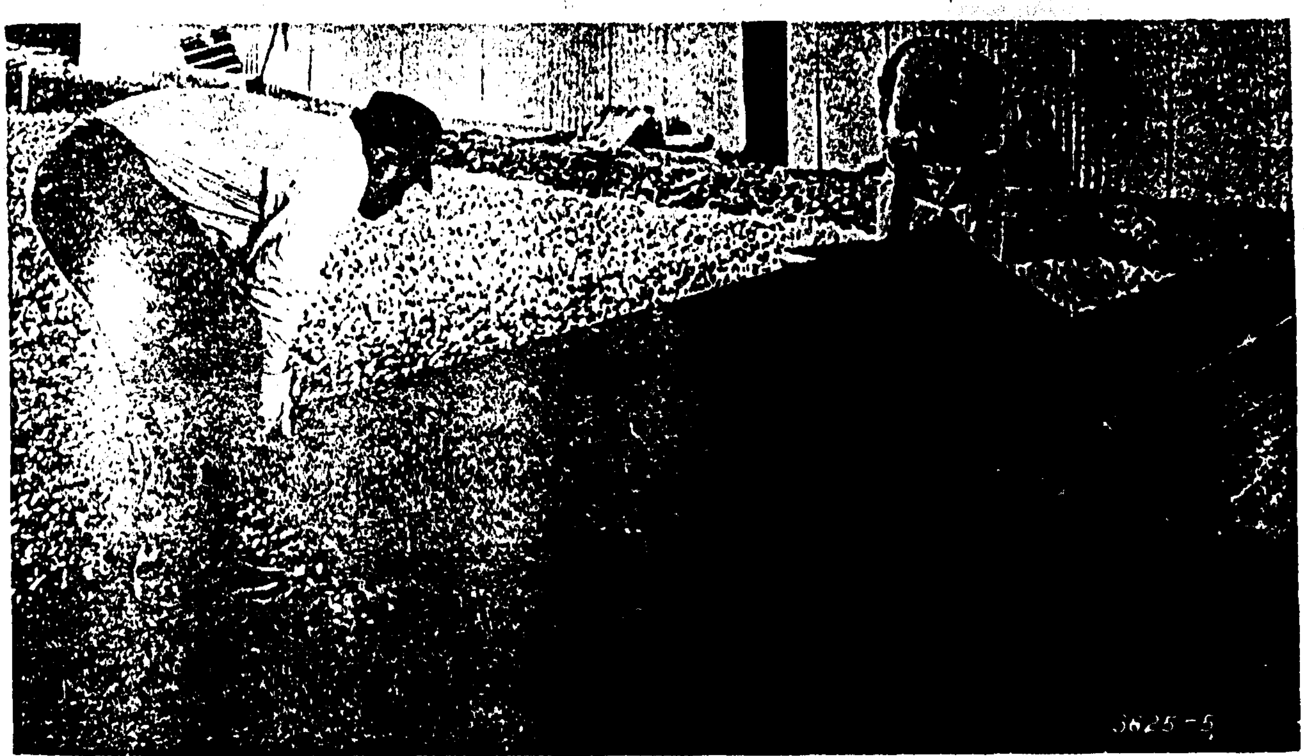


Fig. 5. Placement of Fenestra mat on test section

ft per man-hour was laid by the seven-man crew. This laying speed included opening the bundles and carrying the mats into place. Minor difficulties were encountered occasionally in aligning the slots on adjacent planks. This would be considered a serious handicap only if the mat were being placed on an irregular subgrade surface.

12. The entire test section was surfaced with Fenestra mat for a total width of 24 ft, as shown in plate 1. Five runs of each type of mat were placed in each of the four test items to evaluate all four mat types on each subgrade strength. The laying order in all items was 1-d, 1-a, 1-b, and 1-c. Photograph 1 shows a general view of the test section prior to trafficking. With this arrangement, each time the load cart (described on following page) traversed the entire length of the section,

the four types of mat were tested on each type of subgrade.

Test Load Cart

13. A specially designed single-wheel test cart (fig. 6) was used for traffic tests with 17,000- and 27,000-lb single-wheel loads. This test cart was fitted with an outrigger wheel (not visible in fig. 6) to prevent

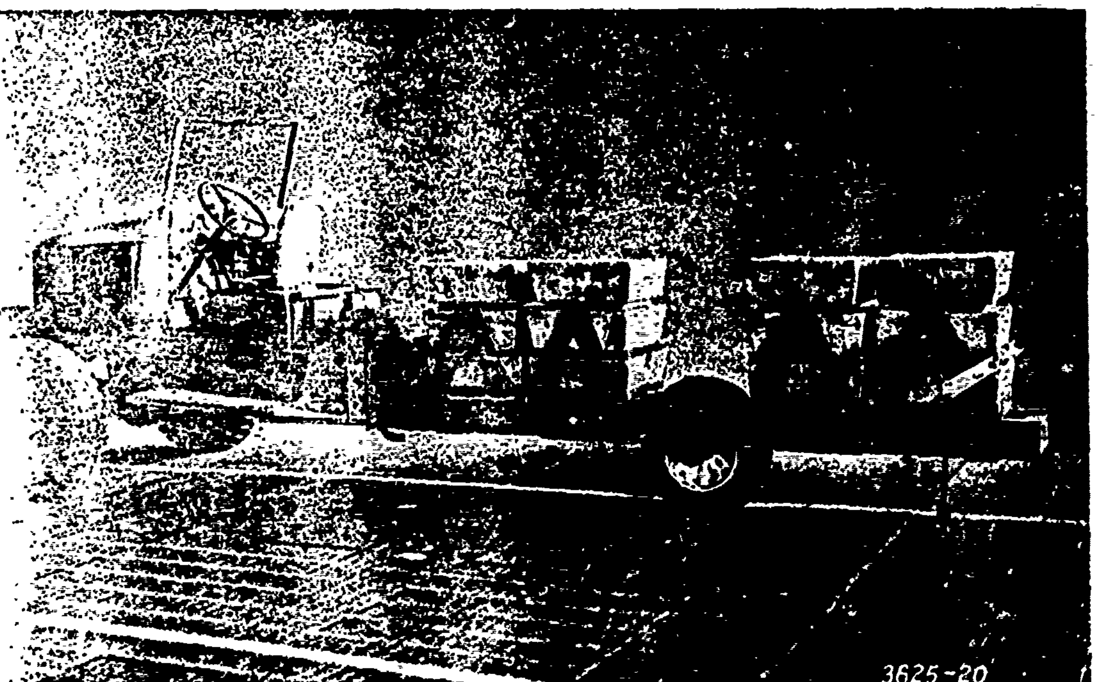


Fig. 6. Test load cart with 27,000-lb single-wheel load with tire inflated to 400 psi

overturning, and was powered by the front half of a four-wheel-drive truck. The aircraft which the test load was to simulate is equipped with 30-7.7, 18-ply tires inflated to 400 psi. However, at the time the tests were initiated, these tires were not available for test purposes, and F8U aircraft wheels and tires, furnished by the Naval Air Engineering Laboratory (NAEL), were used for the 17,000-lb single-wheel-load tests. The F8U, 26-6.6, 16-ply tires were inflated to 400 psi, which resulted in a tire-contact area of about 48 sq in. with a tire-print width of about 5 in. when loaded to 17,000 lb. The average contact pressure was about 355 psi. The 30-7.7 tires were obtained after 50 coverages of traffic had been applied with the 17,000-lb load on the 26-6.6 tires. At this stage of traffic, NAEL requested that the 30-7.7 tires be used and the test load be increased to 27,000 lb. The 27,000-lb load on the 30-7.7 tire resulted in a tire-

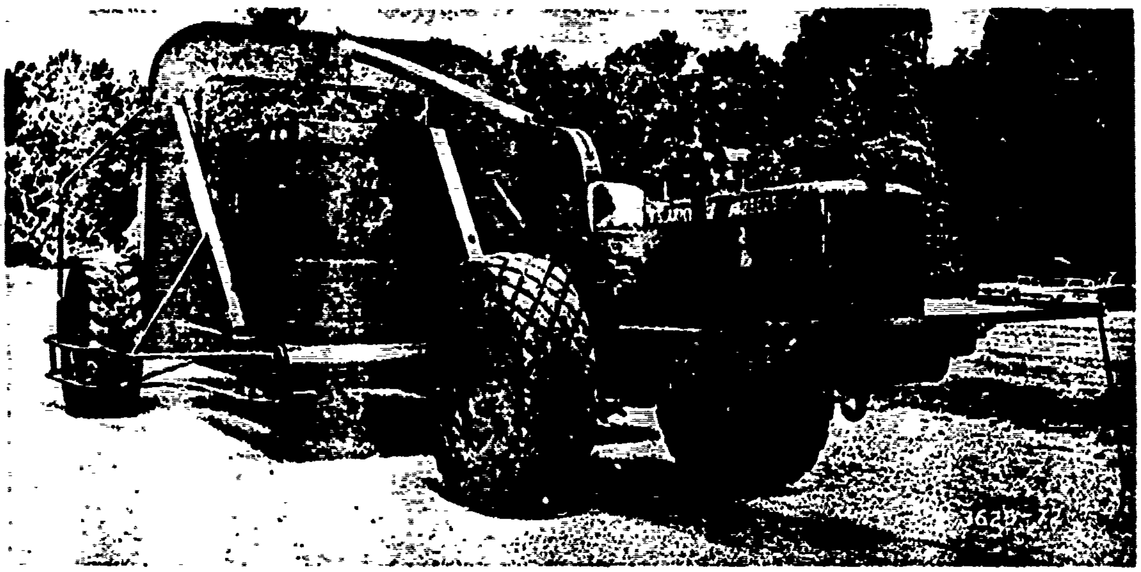


Fig. 7. Test load cart with 39,000-lb single-wheel load with tire inflated to 400 psi

contact area of 82 sq in. with a tire-print width of 7.3 in. The average contact pressure was about 330 psi. A large runway test cart (fig. 7) was used with the 30-7.7 tire for the 39,000-lb, single-wheel-load traffic. A close-up of the load wheel mounted under the load box is shown in fig. 8. The 39,000-lb load on this tire resulted in a contact area of 103 sq in. and an average contact pressure of 378 psi.

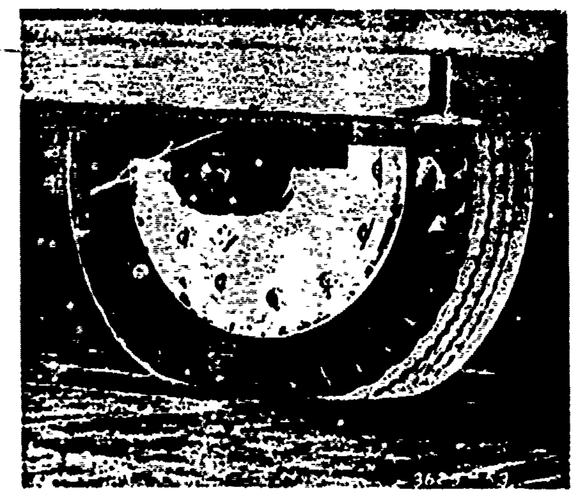


Fig. 8. Close-up of 39,000-lb single-wheel assembly

Traffic Tests

Uniform-coverage traffic

14. A statistical study of aircraft landings on a 78-ft-wide runway

by the Marine Corps Equipment Board* indicated that with a probability of 100 percent, a main landing-gear wheel path would not vary more than 25 ft laterally from the runway center line. For about 90 percent of the landings, the main gear load was fairly evenly distributed over a 10-ft width of runway. For the 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 runway, which may be slightly conservative based on the statistical results of the study referenced at the beginning of this paragraph. However, for test purposes, this assumption was considered reasonable. Therefore, a 10-ft-wide traffic lane was laid out down the center of the test section.

15. The test objective was to develop a CBR design curve for 1600 cycles of aircraft operations. One takeoff and one landing comprise one aircraft cycle. Therefore, 1600 cycles is equivalent to 3200 passes of the load wheel. For the 17,000- and 27,000-lb single-wheel loads, the traffic passes were evenly distributed over the 10-ft-wide traffic lane. Since the tire-print width of the 26-6.6 tire was 5 in., 24 passes of the load wheel were required to obtain one coverage over the 10-ft-wide lane. This 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. on 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. For the 27,000-lb wheel load, the tire-print width was 7.3 in.; therefore, about 17 passes of the wheel load would be required to obtain one complete coverage over the 10-ft-wide traffic lane, or a total of 188 coverages to equal 3200 passes. However, since guidelines had previously been laid out for shifting laterally 5 in. on each successive forward trip, the same guidelines were used for the 27,000-lb load traffic; this resulted in an overlap of 46 percent on each forward pass. Thus, each 24 passes of the load cart with a 27,000-lb load and 5-in. spacing resulted in 1.46 coverages.

Single-track traffic

16. If a catapult system is used for launching the aircraft from the

* Small Airfield for Tactical Support (SATS) Concept, Second Interim Report, Project No. 51-58-01, dated 5 March 1960.

mat-surfaced runway, then the main-gear wheels of a given type aircraft will run in the same path during each takeoff operation. In this type of operation there will also be an added vertical load imposed on the mat besides the static load of the aircraft. NAEL has calculated that the main-gear single-wheel load which will be imposed on the landing mat during the launching of a 60,000-lb aircraft by catapult may be as much as 39,000 lb. For 1600 cycles of aircraft operations, 1600 launchings would be required. Therefore, to simulate these operations, traffic was applied in a single path with the single-wheel test cart loaded to 39,000 lb with a tire pressure of 400 psi. The load cart was driven forward and backward in the same track. The center line of the traffic path was located 2 ft outside the uniform-coverage traffic lane and 5 ft from the outside edge of the section, as shown in plate 1.

Soil Tests and Miscellaneous Observations

17. For the 17,000- and 27,000-lb load tests, water content, density, and in-place CBR were determined in test items 1 and 2 prior to traffic and at various stages during traffic, and in item 4 before and after traffic. CBR measurements were made in item 3, the rock item, at the end of the traffic period. These data are summarized in table 1. These tests were made at depths of 0, 6, and 12 in. in the clay and sand subgrades, and on the surface of the rock item. A minimum of three tests were made at each depth, and the values listed in table 1 are the averages of the values measured at each depth. No CBR tests were made in the subgrades along the wheel path used for the 39,000-lb single-wheel-load traffic. However, the CBR values shown in table 1 are considered to be representative of the subgrade strength along the 39,000-lb single-wheel-load traffic path.

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 various intervals during traffic to show the development of permanent deformation and deflection of the mat under the wheel loads.

Behavior of Mat Under Traffic

17,000-lb single-wheel load

19. Observations. A total of 50 coverages of traffic with the 17,000-lb single-wheel load were applied to the test lane. The mat performance was considered satisfactory in all test items. However, some weaknesses did appear in the mat types designated 1-b and 1-c. The tack welds in the type 1-b mat (fig. 9) were completely ineffective, as more than 50 percent of these welds failed in all test items during the 50 coverages of traffic. Therefore, the performance of types 1-b and 1-c mats, which had no longitudinal welds between the individual extrusions, was quite similar. There was a tendency for the individual extrusions of both types 1-b and 1-c mats to work or move with respect to each other under the rolling wheel loads; this caused a number of minor cracks to develop at the end-connector joints, as shown in fig. 10. A number of overlapping corner breaks along the side connector also developed, as shown in fig. 10. These breaks were more prevalent in test item 1, the low-strength clay subgrade, than in the other test items. The traffic with the 17,000-lb

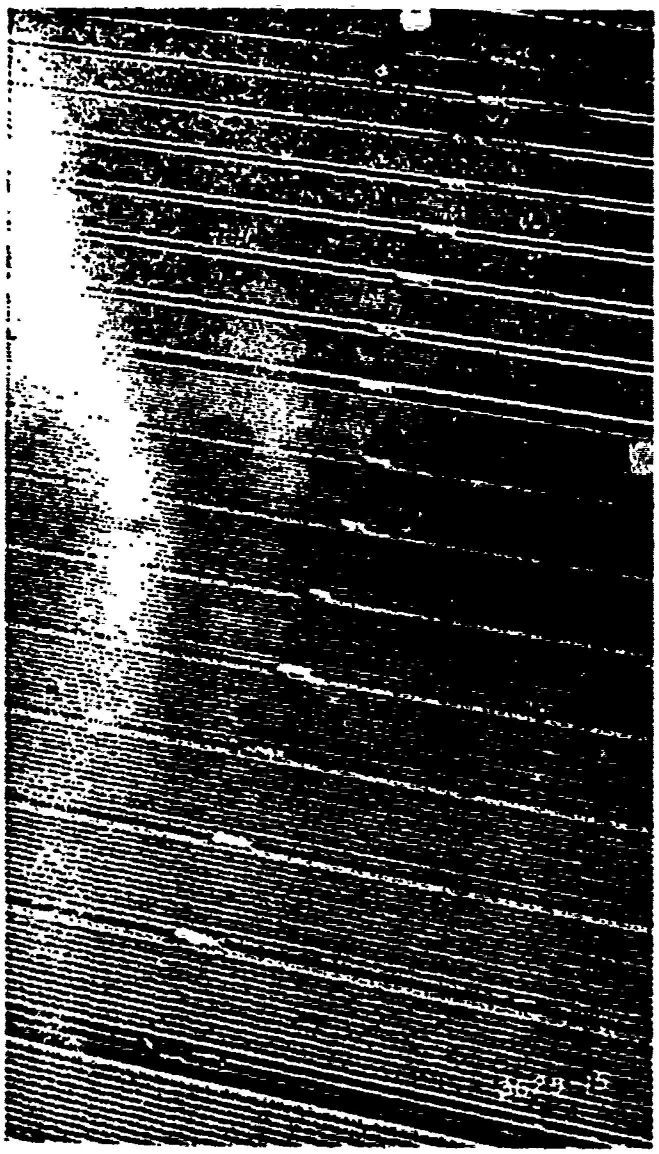


Fig. 9. Tack weld breaks in mat 1-b in item 2 after 20 coverages of 17,000-lb single-wheel load

Fig. 10. Cracks at end joint and overlapping corner break in item 1 after 20 coverages of traffic

single-wheel load had no detrimental effects on types 1-a and 1-d mats, except for a minor crack at an end joint of a plank of type 1-d mat.

20. Permanent deformation. Level readings taken to show permanent deformation of the mat during traffic are shown in plate 4. As the mat was laid in a staggered pattern, every other run of mat consisted of two whole planks with an end joint located at the center of the traffic lane. The adjacent runs consisted of two half planks and a whole plank; one half plank was located on each side of the lane with the whole plank in the center so that the center of the whole plank was located at the center of the traffic lane. The data in plate 4 show average cross sections for both conditions for each item of the test lane. These data indicate that the deformation across the traffic lane is about the same regardless of where the end joint is located. The data also show that the permanent deformation in items 1 and 2 was very small with a maximum of about 1/4 in.,

whereas in items 3 and 4 the permanent deformation exceeded 1/2 in. This was due to the fact that the rock and sand were placed loose with no compaction, and were densified by the traffic load.

21. Center-line profiles showing deformation of the mat in each test item down the center line of the test lane are shown in plate 5. These profiles show slight deviations in deformation within the various test items, but no consistent difference due to mat type. In general, the surface grade remained smooth throughout the 50 coverages of traffic, as can be noted in photograph 2.

22. Mat deflection. Level readings taken to show the mat deflection under load are shown in plate 6. These data indicate the elastic deflection, or rebound, of the mat as the wheel load moved over the surface. Data are shown for three locations on a mat panel in each test item: at an end joint, at a quarter point, and at a center point of a plank. The maximum deflection indicated is for item 4 where the value approached 1 in. at the end of 50 coverages of traffic. The severe deflection in item 4 was due to the densification of the sand under the mat and the bridging of the subgrade by the mat. A few observations made at the end of 50 coverages of traffic indicated that the subgrade was 1/2 to 3/4 in. below the mat along the center line of the section in test item 4.

27,000-lb single-wheel load

23. Traffic tests with the 27,000-lb single-wheel load were conducted in the same traffic lane used for the 17,000-lb single-wheel-load traffic. This load was considerably more detrimental to the mat than the 17,000-lb load. The behavior of the mat in the various test items is discussed in the following paragraphs.

24. Item 1. Types 1-b and 1-c mats in item 1 deteriorated rapidly under the 27,000-lb wheel load. After 18 coverages, two end joints in each type of mat sheared completely off, as shown in fig. 11. A close-up of one of the end-joint failures is shown in fig. 12. This condition created a tire hazard, and traffic was discontinued on types 1-b and 1-c mats. Types 1-a and 1-d mats were still in good condition. At this stage types 1-b and 1-c mats were removed from item 1, and types 1-a and 1-d mats were shifted and placed adjacent to item 2. As traffic continued, a number of mat breaks developed in both types 1-a and 1-d mats. By 29 coverages, a

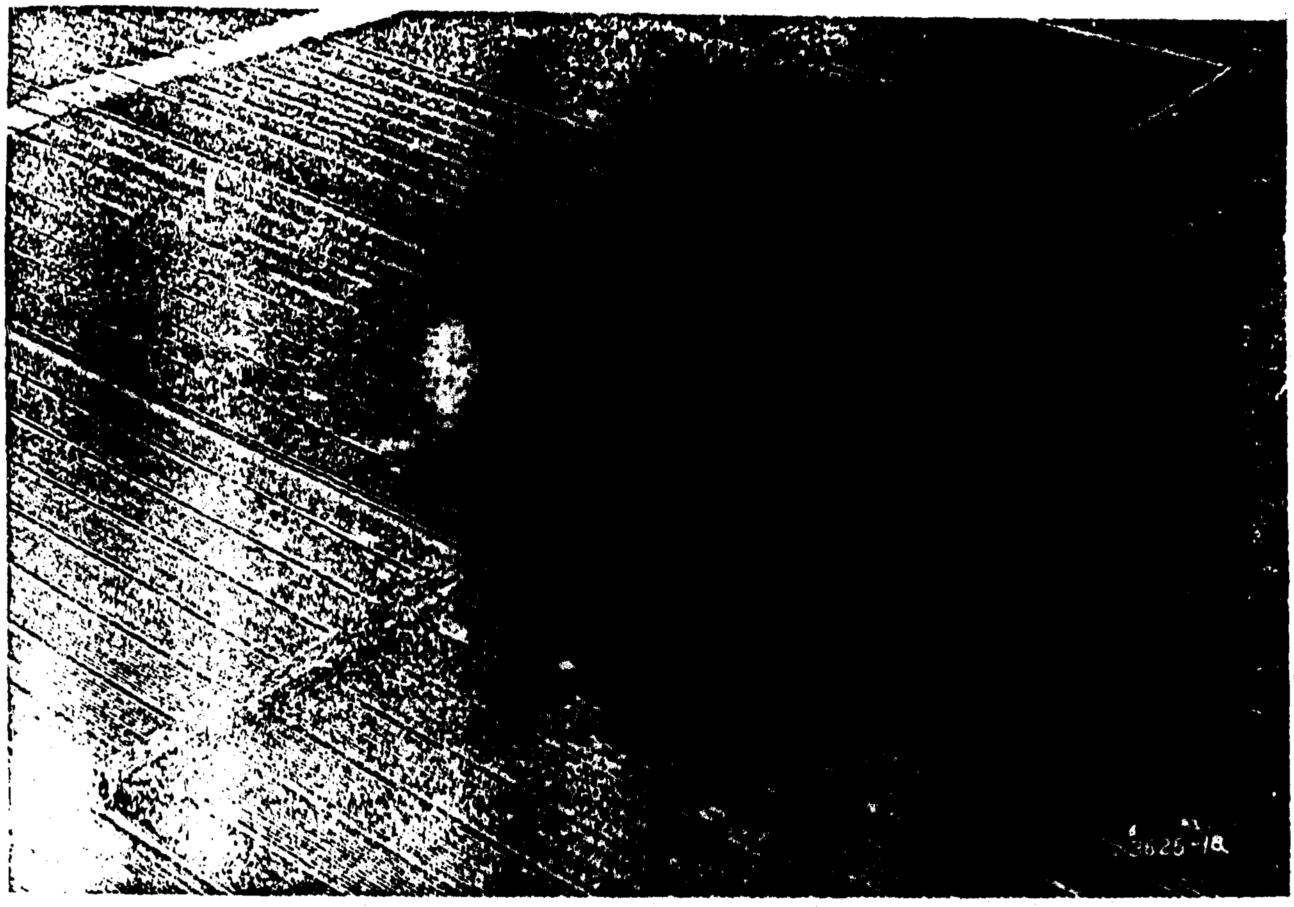


Fig. 11. Failures in types 1-b and 1-c mats in item 1 after 18 coverages of traffic with 27,000-lb single-wheel load

Fig. 12. Close-up of end-joint failure

number of overlapping corner breaks had developed, as shown in fig. 13. The loose projecting ends from these breaks were cut off to prevent tire damage, as shown in fig. 14. The breaks continued to progress as traffic

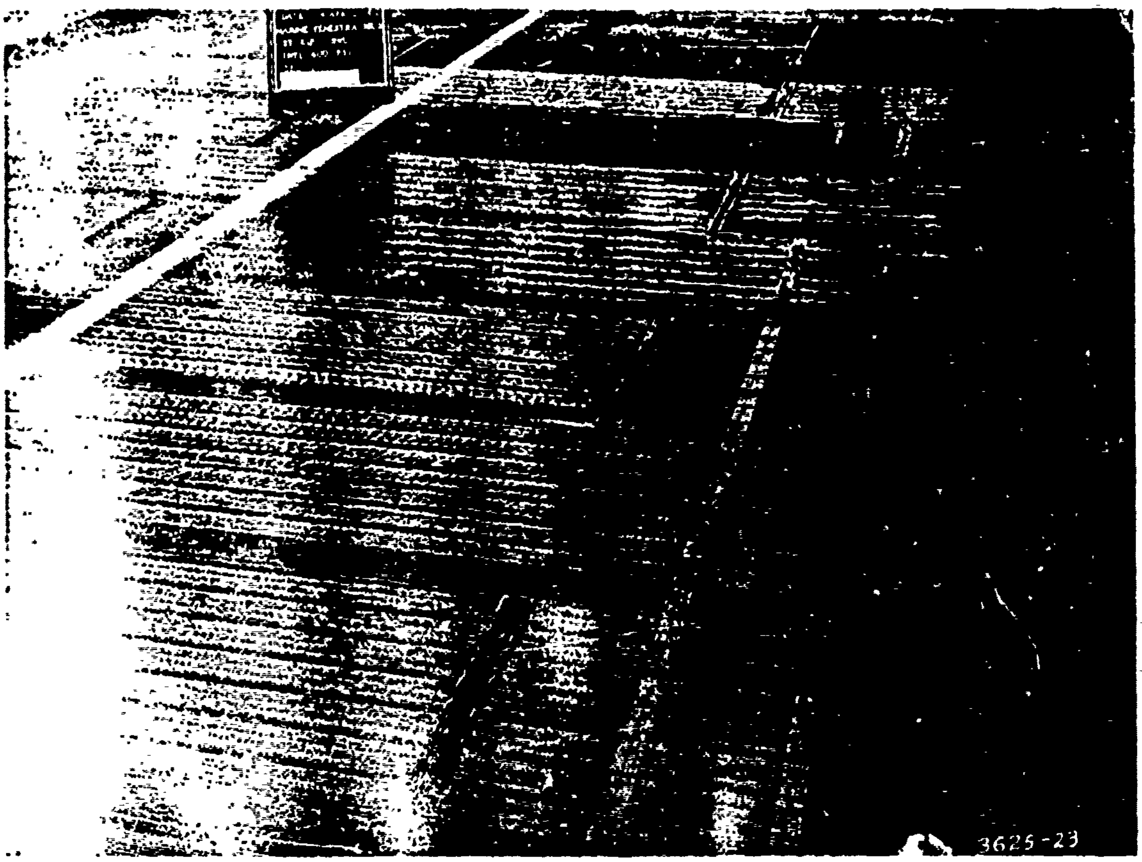


Fig. 13. Overlapping corner breaks in item 1 after 29 coverages of traffic with 27,000-lb single-wheel load

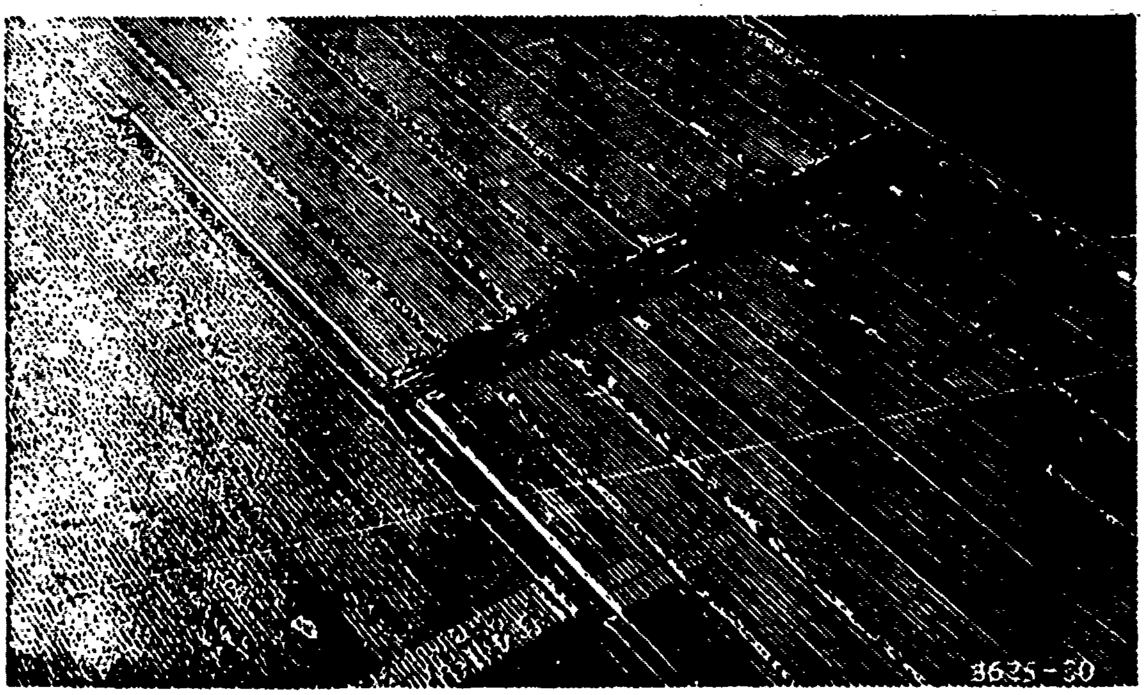


Fig. 14. Area where loose projecting ends of overlapping edge of mat were cut off

was continued, and by 128 coverages three end-joint failures developed; at this point, traffic was discontinued. A general view of item 1 at the end of 128 coverages of traffic is shown in photograph 3.

25. Item 2. All mat in this item withstood the full 188 coverages of traffic with the 27,000-lb single-wheel load. However, there was considerable breakage in types 1-b and 1-c mats of the same type that occurred in item 1, but the breaks were not as severe. Only one serious break developed in the entire item--an end-joint failure in one plank of type 1-b mat, which occurred at about 73 coverages. No breaks developed in type 1-d mat, and only two minor overlapping corner breaks developed in type 1-a mat.

26. Item 3. All four mat types performed satisfactorily in this item. Although practically all the tack welds on type 1-b mat failed early during the traffic period, this did not affect the performance of the mat. A few other minor breaks developed in types 1-b and 1-c mats, but no breaks were noted in type 1-a or 1-d mat.

27. Item 4. Considerable breakage occurred in types 1-b and 1-c mats. These breaks were similar to those discussed for item 1, and started during the early stages of traffic. By 73 coverages, three end joints had completely failed, as shown in fig. 15, and types 1-b and 1-c mats were removed from the item. Types 1-a and 1-d mats performed satisfactorily for the full period of traffic (188 coverages).

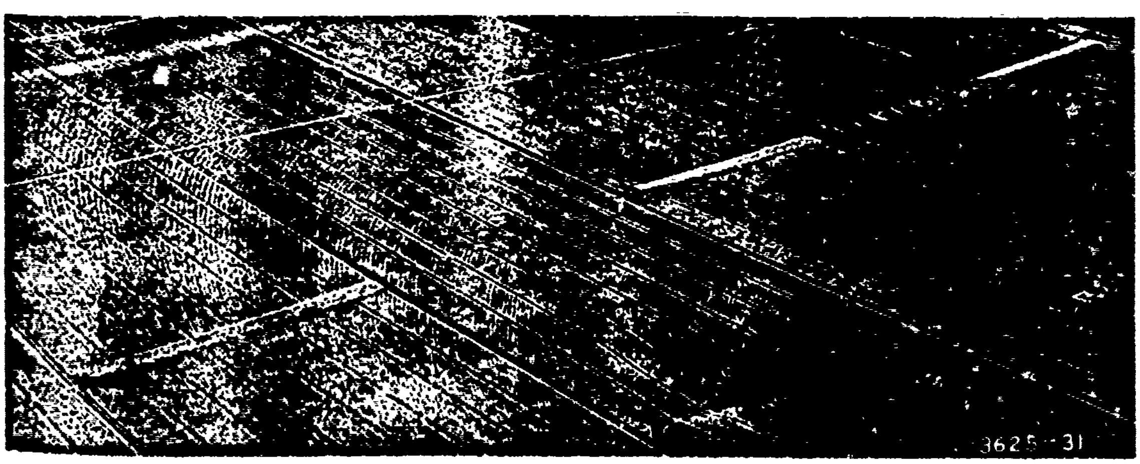


Fig. 15. Failed end joints in item 4 after 73 coverages with 27,000-lb single-wheel load

28. Permanent deformation. Level readings taken to show permanent deformation across the traffic lane during the 27,000-lb single-wheel-load

traffic tests are shown in plate 7. These data show about the same pattern as that discussed in paragraph 20 for the 17,000-lb single-wheel load, except that the degree of deformation had increased. Center-line profiles showing the deformation down the center of each test item are shown in plate 8. These data show that by the end of traffic (188 coverages) the permanent deformation down the center of the traffic lane exceeded 1 in. in test items 3 and 4.

29. Mat deflection. Plots presenting elastic deflection of the 1-a and 1-d mats under load for the various intervals of traffic are shown in plate 9. The mat deflection in item 4 was severe, exceeding 1.5 in. As discussed in paragraph 22, this severe deflection was due to the mat bridging the subgrade, as the mat did not conform to the subgrade after densification of the sand occurred under traffic. As can be noted in table 1, the density of the sand increased from about 91 lb per cu ft prior to traffic to about 106 to 111 lb per cu ft after traffic.

Single-track traffic,
39,000-lb single-wheel load

30. Based on the performance of the various types of mats under the 27,000-lb single-wheel load, it was concluded that only types 1-a and 1-d, which had continuous longitudinal welds, should be considered for traffic with the 39,000-lb single-wheel load. There was only a sufficient quantity of this mat for two complete test items; therefore, only items 2 and 3, the high-strength clay and the rock items, were utilized for the 39,000-lb single-wheel-load test. For this test, it was necessary to reuse types 1-a and 1-d mats that had previously been subjected to traffic with the 17,000- and 27,000-lb single-wheel loads. However, the mat was taken up and relaid on items 2 and 3 with the ends reversed so that none of the mat along the single-track traffic path had previously been trafficked. Although all planks used were in good condition, some difficulty was encountered in relaying the mat, mostly in aligning the connector slots on adjacent planks. Sixteen runs of mat were placed on each of the two test items.

31. The mat in both test items performed satisfactorily under the 39,000-lb single-wheel load. Fig. 16 shows a failure of the interior of one plank; this failure occurred in item 2 after 400 passes of the load wheel. The reason that the mat collapsed was not apparent, and this

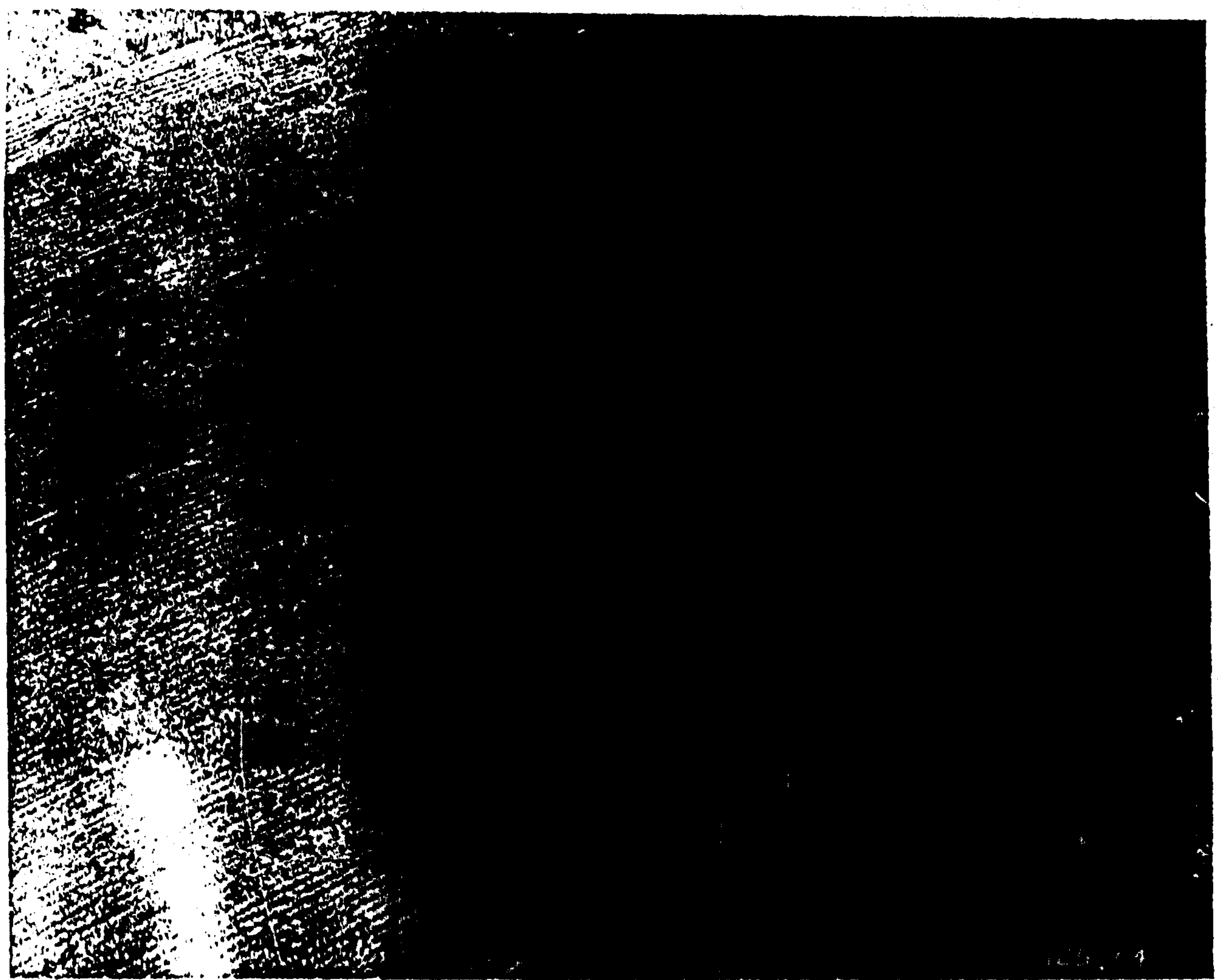


Fig. 16. Interior failure of mat plank in item 2 after 400 passes of 39,000-lb single-wheel load

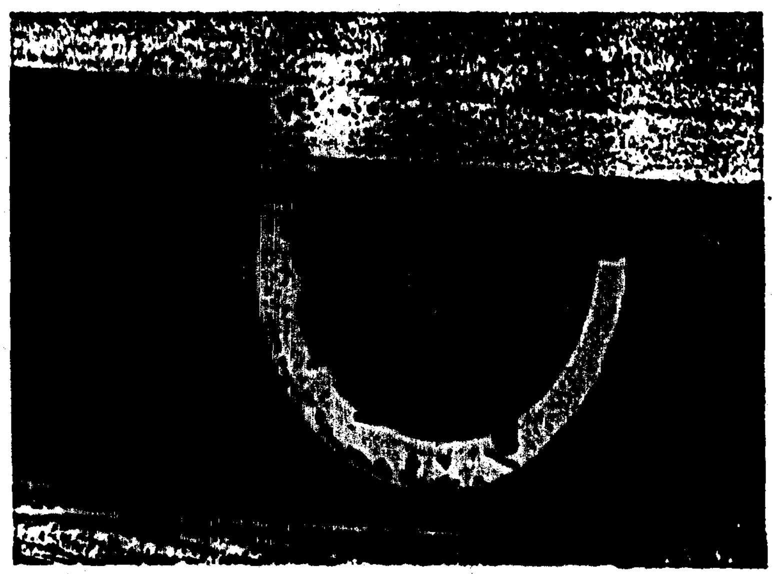


Fig. 17. Blowout of 30-7.7 tire (39,000-lb single-wheel load with tire inflated to 400 psi)

condition was not representative of the section.

32. The load tire blew out after 260, 435, and 638 passes, and in each instance, the impact of the wheel rim caused rather severe damage to the mat. A view of a blown-out tire is shown in fig. 17. Fig. 18 shows a close-up of damage to the mat caused by a tire blowout. Immediately after these

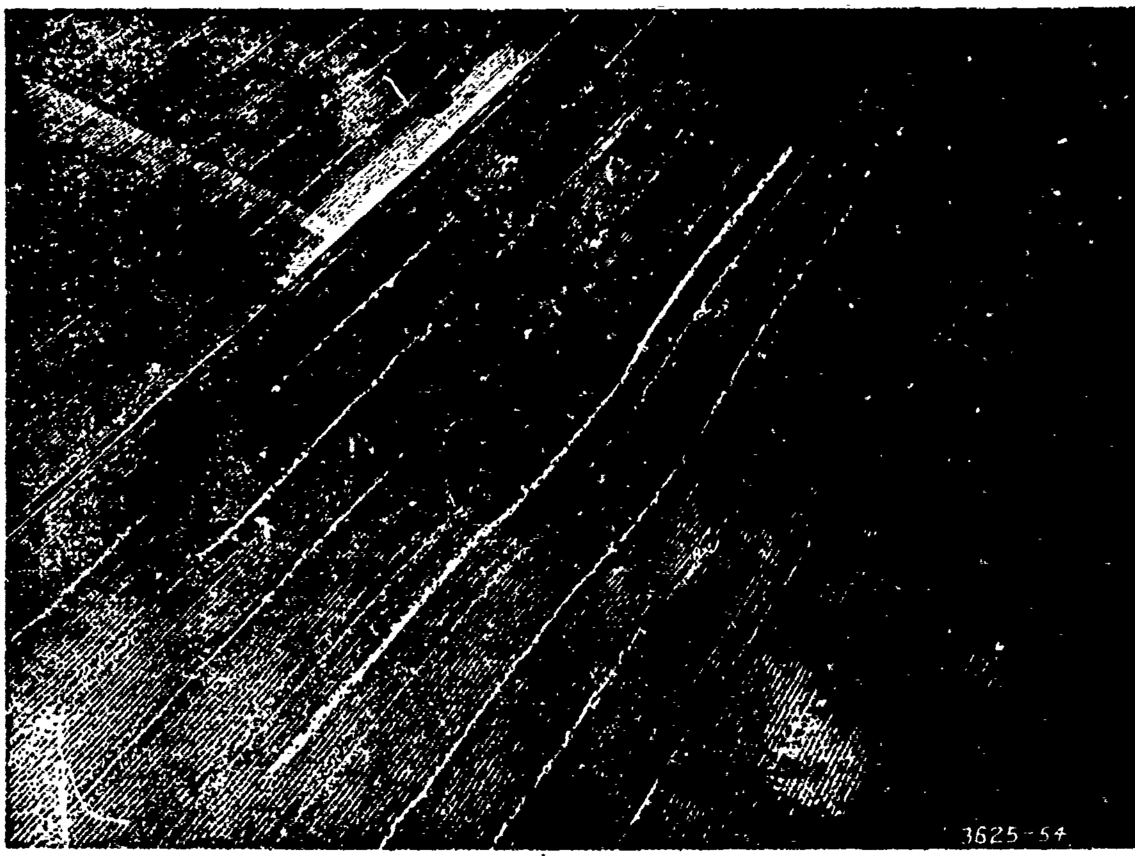


Fig. 18. Mat damage from blowout at 638 passes

blowouts, the damaged mat run was offset by 2 ft to avoid interference with continued trafficking operations. A total of 946 passes had been applied when the carcass of the last available tire separated and became unsafe for further use. It was apparent at this stage of trafficking that the mat would satisfactorily withstand the full 1600 passes of the load wheel, and the test was considered complete.

Failure Criteria and Analysis of Test Results

Failure criteria

33. The criteria for failure of the Fenestra Mark III mat were essentially the same as that used for the M9M2 mat, as reported in WES Miscellaneous Paper No. 4-501, Development of CBR Design Curve for M9M2 Landing Mat, dated June 1962. However, some slight modifications had to be made due to the differences in the design and performance of the

Fenestra mat. The failure criteria used for the Fenestra mat were as follows:

a. Excessive mat breakage

End-joint failures
Core (interior) failures

b. Deflection

Maximum permissible, about 1 in.

34. It was assumed that a certain amount of maintenance would be performed in the field during actual usage, and that short weld breaks, overlapping corner breaks, etc., could be repaired rather easily. However, when an end-connector joint sheared off or a mat core failed, the mat plank would be considered failed, and should be replaced. It was also considered feasible to replace up to 10 percent of the mat with new planks during the design life of the runway. For replacement of more than 10 percent of the planks, the maintenance effort would be excessive. Therefore, for the test section, it was assumed that up to 10 percent of the mat planks in each item could be replaced, and when an additional 10 percent failed, or a total of 20 percent, the entire item was considered failed.

35. The deflection criterion of 1-in. maximum is based on previous experience in mat testing in which it has been observed that a deflection in excess of 1 in. causes the mat to break up at a rapid rate, and also to create a high rolling resistance.

36. The degree of roughness is also normally used in judging failures. However, for this mat, it was not used, as the surface remained smooth throughout the period of traffic except when an end joint of a plank failed.

Summary of test results

37. A summary of the traffic test results for the 17,000- and 27,000-lb single-wheel-load uniform-coverage traffic is shown in table 2. This table identifies the test items, shows the rated subgrade CBR, indicates the number of planks of the different type mats in each item, and presents data on mat breakage and deflection at various stages of traffic. The last column in table 2 indicates a rating for each type of mat in each item, based on the failure criteria described previously.

38. The rated subgrade CBR for the clay subgrade (items 1 and 2) is

based on the numerical averages of the CBR values measured at 0-, 6-, and 12-in. depths prior to traffic and at various traffic intervals where tests were made (see table 1). The only value measured for the rock subgrade was a CBR of 81 at the end of traffic. However, this strength was developed as a result of densification and confinement of the rock under the mat during traffic. As previously stated, the material was placed loose with no compaction, and would have had a very low CBR value at the start of the test. Therefore, the item is not assigned a CBR value, as the mat behavior was probably influenced more by the initial strength than by the strength which developed during the traffic tests. The sand in item 4 had an initial CBR of 3.5, but the value increased considerably to about 15 to 20 during the traffic period, as shown in table 1. The bridging and severe mat deflection, as discussed previously for this item, were due to densification of the sand during traffic. The initial CBR value is a relative measure of the degree of density in a sand, and the lower the initial CBR value, the more settlement can be anticipated. Therefore, the initial CBR strength of 4 is used for evaluating this item, as it is believed that the initial strength, or density, of the sand more nearly indicates how the mat will behave.

39. Since the 27,000-lb single-wheel-load traffic was applied on the same traffic lane as that previously subjected to 50 coverages of a 17,000-lb single-wheel load, the effects of the initial traffic are considered in the evaluation. This was accomplished by taking the actual coverages applied with the 17,000-lb single-wheel load and converting them to equivalent coverages of a 27,000-lb single-wheel load. The conversion was based on equivalent-wheel-load relations which have been developed at the WES for flexible-pavement design.* From these relations it was computed that 50 coverages of the 17,000-lb single-wheel load were equivalent to 6 coverages of the 27,000-lb single-wheel load. Therefore, the 6 coverages were added to the number of coverages of the 27,000-lb load (see "Equivalent Accumulative Coverages of 27,000-lb Load" in table 2).

40. The borderline ratings of types 1-a and 1-d mats in items 3 and

* U. S. Army Engineer Waterways Experiment Station, CE, Revised Method of Thickness Design for Flexible Highway Pavements at Military Installations, Technical Report No. 3-582 (Vicksburg, Miss., August 1961).

..r. based on the deflections exceeding 1 in. However, the mat planks did not fail, and were in good condition at the end of the test. These severe deflections were due to densification of the subgrade and to the mat bridging the subgrade as previously discussed. This condition is not desirable, and could be eliminated in practice by some compaction of the rock or sand prior to laying the mat.

41. As previously stated, the single-track traffic with 39,000-lb wheel load was applied on test items 2 and 3 only. No CBR tests were made in the subgrade along the wheel path, and it was assumed that the subgrade strength was the same as was measured in these items within the uniform-coverage traffic lane. The mat performed satisfactorily through 946 passes of the 39,000-lb wheel load. The maximum mat deflection under load was about 0.6 to 0.7 in. in item 2 and about 0.7 to 0.8 in. in item 3. Based on the mat performance through 946 passes, it was evident that the mat could sustain the desired 1600 passes of the 39,000-lb single-wheel load when placed on a subgrade with a CBR of 13 or greater.

Development of Design Curves

Approach

42. In arriving at a CBR design curve for the Fenestra Mark III mat, the mat was considered to behave similar to a base course in distributing load over the subgrade, and thus, in a sense, to replace a certain thickness of base course. Therefore, a standard flexible-pavement CBR design curve for 188 coverages of a 27,000-lb single-wheel load with a tire pressure of 400 psi was used as a basis, and the reduction in the thickness of base course that could be applied to the flexible-pavement design curve was determined from the landing-mat test data.

CBR design curves

43. A plot of CBR versus coverages for the 27,000-lb single-wheel-load traffic is shown in plate 10. The points plotted are the rated CBR values listed in table 2, which correspond to the number of coverages at failure or end of traffic. Failures developed in types 1-b and 1-c mats on the subgrade with a rated CBR of 6 at about 24 coverages; types 1-a and 1-d mats failed on the same strength subgrade at about 134 coverages. Therefore, to determine the minimum CBR required to support the load for

1?? coverages, the failure points at 24 and 134 coverages were translated to 1?? coverages by use of the CBR equation, which is written in the following general form:*

$$\frac{t}{0.23 \log_{10} C + 0.15} = \sqrt{P\left(\frac{1}{8.1\ \text{CBR}} - \frac{1}{p\pi}\right)}$$

where

t = thickness, in.

C = number of coverages

P = single-wheel load, lb

CBR = measure of subgrade strength

p = tire pressure, psi

For flexible-pavement design, the value of t obtained from this equation indicates the total thickness of base course and pavement construction which would be required to support the load for a given number of coverages on a subgrade of given strength. In the case of landing mat, the t value indicates the thickness of base course and pavement which the mat can replace. For the data shown in plate 10, the t value was computed for the failure points on the clay subgrade at 24 and 134 coverages. Then, on the assumption that the thickness of the base course and pavement which was replaced by the mat was constant throughout the range of coverages from failure to 188 coverages, the minimum CBR which would support 188 coverages was computed. The computed values were a CBR of 13 for types 1-b and 1-c mats and a CBR of 7 for types 1-a and 1-d mats. An example of these computations is given in WES Miscellaneous Paper No. 4-501, pages 17 and 18. It is interesting to note that the computed failure point for types 1-b and 1-c mats is 188 coverages on a CBR of 13. The subgrade strength for test item 2 was rated at a CBR of 13, and although the mat performance was considered satisfactory at the end of 194 coverages, one plank of type 1-b mat had failed, and numerous mat breaks were noted in other planks of types 1-b and 1-c mats. Thus, complete failure of these mats was imminent at the

* This is a combination of equation 2, page 2, WES Instruction Report No. 4, Developing a Set of CBR Design Curves, dated November 1959, and the equation for slope of curve, plate 6, of the same report.

of the tests. This indicates that the method used for translating coverages is reasonably accurate.

44. Plate 11 shows CBR design curves for 188 coverages of a 27,000-lb single-wheel load with a tire pressure of 400 psi. The lower curve is a standard flexible-pavement CBR design curve. The curves for the Mark III landing mat were developed as follows: In plate 10, it was shown that a subgrade with a CBR of 13 would satisfactorily support a 27,000-lb single-wheel load for 188 coverages when surfaced with type 1-b or 1-c mat. It can be seen from plate 11 that a flexible-pavement design based on a subgrade CBR of 13 would require about 10 in. of base course. Thus, types 1-b and 1-c mats are equivalent to about 10 in. of base course. Similarly for the types 1-a and 1-d mats, it was shown in plate 10 that a subgrade with a CBR of 7 would satisfactorily support the 27,000-lb single-wheel load for 188 coverages; and as shown in plate 11, the indicated thickness for a flexible-pavement design for a subgrade with a CBR of 7 would be about 14 in. Thus, types 1-a and 1-d mats are equivalent to 14 in. of base course. The CBR design curves for types 1-b and 1-c mats, and 1-a and 1-d mats were obtained by taking 10 and 14 in., respectively, from the thickness indicated by the flexible-pavement design curve.

45. The data obtained from the loose rock and sand test items were not used in developing the design curves shown in plate 11. However, the data indicated that a loose sand or rock subgrade with an initial CBR of 4 or better, surfaced with type 1-a or 1-d mat, would perform satisfactorily for 188 coverages of the 27,000-lb wheel load provided that the severe mat deflections caused by the mat bridging the subgrade were not detrimental to aircraft performance. A slightly higher initial subgrade strength would be required for type 1-b or 1-c mat.

46. The minimum subgrade strength required for type 1-a or 1-d mat to sustain 1600 passes of the 39,000-lb single-wheel load in a single path was not determined. However, from the performance of the mat through 946 passes on a subgrade with a CBR of 13, it was evident that the mat could carry the desired 1600 passes of traffic when placed on a subgrade with a CBR of 13 or greater.

Conclusions and Action Taken

47. From the results of the tests discussed in the preceding para- graphs, it was concluded that the continuous welds used in the types 1- and 1-d mats provided a stronger mat and were needed to meet the test re- quirements. It was further concluded that types 1-b and 1-c mats did n meet the test requirements of the Navy. Therefore, type 1-d mat was standardized and designated AM1 by the Navy.

PART III: TESTING AND DEVELOPMENT OF DESIGN CURVES FOR BUTLER AM1 MAT

Mat

48. The AM1 mat was essentially the same design as the Fenestra type 1-d mat except that a groove along the overlapping edge of the panels was omitted in the AM1 mat. Fig. 19 shows the AM1 plank. The planks were about 2 ft wide, 12 ft long, and weighed approximately 171 lb. A total of 16 bundles, each consisting of 10 full planks and 4 half planks, were received for surfacing the test section.

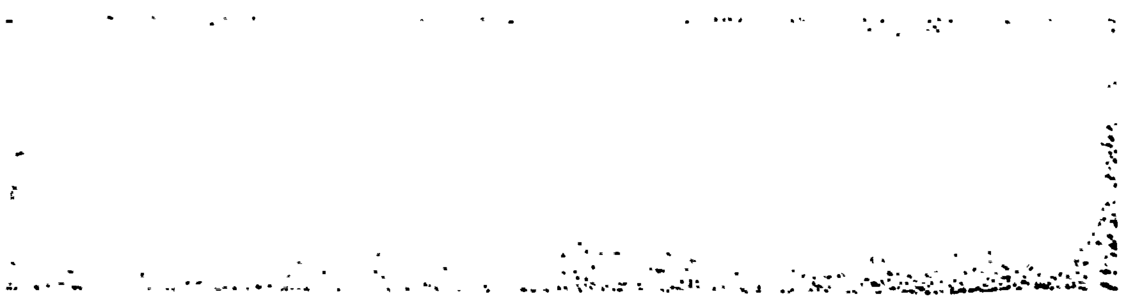


Fig. 19. Butler AM1 mat plank

Test Section

Location

49. All traffic tests were conducted at WES on a test section which was constructed and tested under shelter to control the water content and strength of the subgrade.

Description

50. A layout of the test section is shown in plate 12. As can be seen, the test section consisted of five test items, each of which was approximately 24 ft wide and 30 ft long. Items 1, 2, and 3 were constructed of a heavy clay soil, item 4 of an uncompacted rock, and item 5 of a loose sand.

Subgrade materials

51. These materials were similar to those used in the Fenestra mat tests and have been described in paragraph 8 of this report. Gradation and classification data are shown in plate 2.

Construction of subgrade

52. Items 1, 2, and 3. It was desired to construct items 1, 2, and 3 of the heavy clay soil at water contents that would result in CBR's of 5, 10, and 15, respectively, when compacted. Construction procedures were the same as those described in paragraph 9. Construction data representing the average of four lifts are shown below.

Test Item	Water Content, %	Dry Density lb/cu ft	CBR
1	27.5	93.5	5
2	23.7	96.3	10
3	19.7	97.1	14

53. Items 4 and 5. Items 4 and 5 were constructed using the same procedures as those described in paragraph 10 of this report.

Mat placement

54. The AM1 mat was placed in the same manner as the Fenestra mat (see paragraph 11). Approximately 290 sq ft per man-hour were laid by the six-man crew. No difficulties were encountered during the placement operation. The entire subgrade was surfaced with AM1 mat, resulting in a total mat width of 24 ft, as shown in plate 12. Fifteen runs of mat were placed in each of the five test items.

Test Load Cart

55. The test load cart described in paragraph 13 and shown in fig. [illegible] was used in the 27,000-lb single-wheel traffic tests. This same cart was strengthened and used for the 39,000-lb single-wheel-load tests. A 30-7.7 tire inflated to 400 psi was used for both wheel loads.

Traffic Tests

Uniform-coverage traffic

56. The test section was subjected to traffic with the 27,000-lb single-wheel load at a tire pressure of 400 psi. Each time the load cart traversed the length of the test section, data were obtained for each type of subgrade. The traffic was distributed uniformly over a traffic lane

10 ft wide laid out down the center of the test section, as indicated in plate 12. Traffic was applied on each test item until failure or to a maximum of 188 coverages. The coverage criterion was established as described in paragraph 15.

Single-track traffic

57. Traffic with the 39,000-lb single-wheel load was applied to a single-wheel path to simulate catapult launching operations. The traffic path was located 5 ft from one edge of the mat section and 2 ft from the edge of the 27,000-lb single-wheel-load, uniform-coverage lane, as indicated in plate 12. The traffic path was also 1 ft from an end joint on every other run of mat.

Soils Tests and Miscellaneous Observations

58. Water content, density, and in-place CBR data were obtained in each test item prior to traffic and at the end of the traffic period. These data are shown in table 3. A minimum of three tests was made at each depth, and the values listed in table 3 are averages of the values measured at the indicated depths. The test values shown in table 3 were obtained from within the area subjected to the 27,000-lb single-wheel-load traffic. No tests were made along the 39,000-lb wheel path; however, the rated CBR values derived from the 27,000-lb test lane were considered applicable for analysis of tests with the 39,000-lb single-wheel load.

59. 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 the traffic period to show the development of permanent deformation and mat deflection under the wheel load.

Behavior of Mat Under Traffic

Uniform-coverage traffic,
27,000-lb single-wheel load

60. Observations. It was apparent at the beginning of trafficking operations that considerably more flexing of the mat was occurring in item 1 than in the other items. Small breaks in the overlapping ends

Fig. 20. Overlapping-edge breaks in item 1 after 10 coverages of traffic with 27,000-lb single-wheel load

and in the overlapping edges began to occur at an early stage of traffic in item 1. Fig. 20 shows two overlapping-edge breaks in item 1 after 10 coverages of traffic. This same type of break occurred in item 2 after 10 coverages, although it was much less severe than in item 1. No breaks had occurred in items 3, 4, and 5 by the end of 10 coverages of traffic, and the riding surface remained in excellent condition over the entire test section.

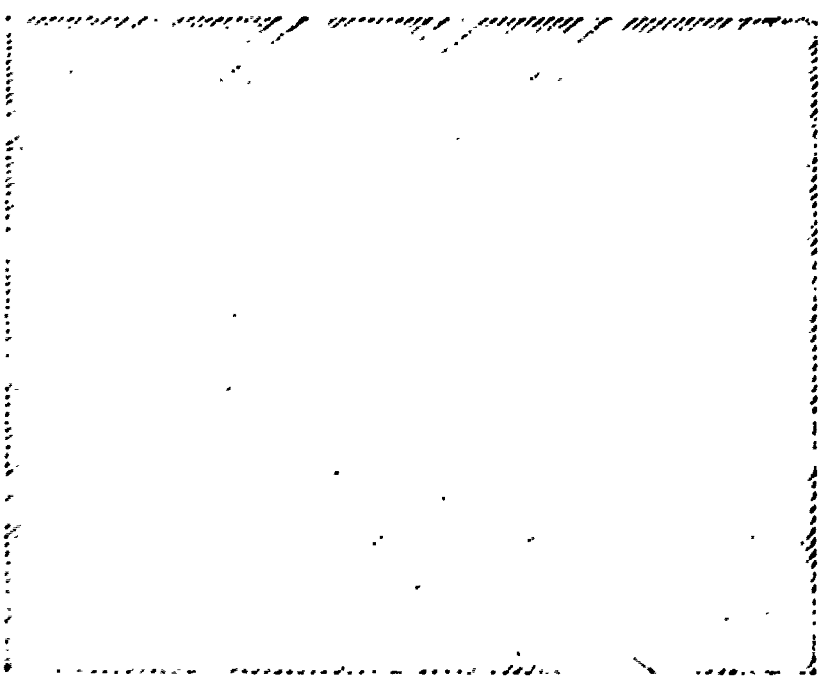


Fig. 21. Overlapping-edge and end-joint breaks in item 1 after 20 coverages of traffic with 27,000-lb single-wheel load

61. The number and severity of breaks in item 1 increased rather rapidly as traffic continued. Fig. 21 shows an overlapping-edge break and an

end-joint break in item 1 after 20 coverages of traffic. The broken overlapping edges were cut off after 22 coverages, and the sharp edges beaten

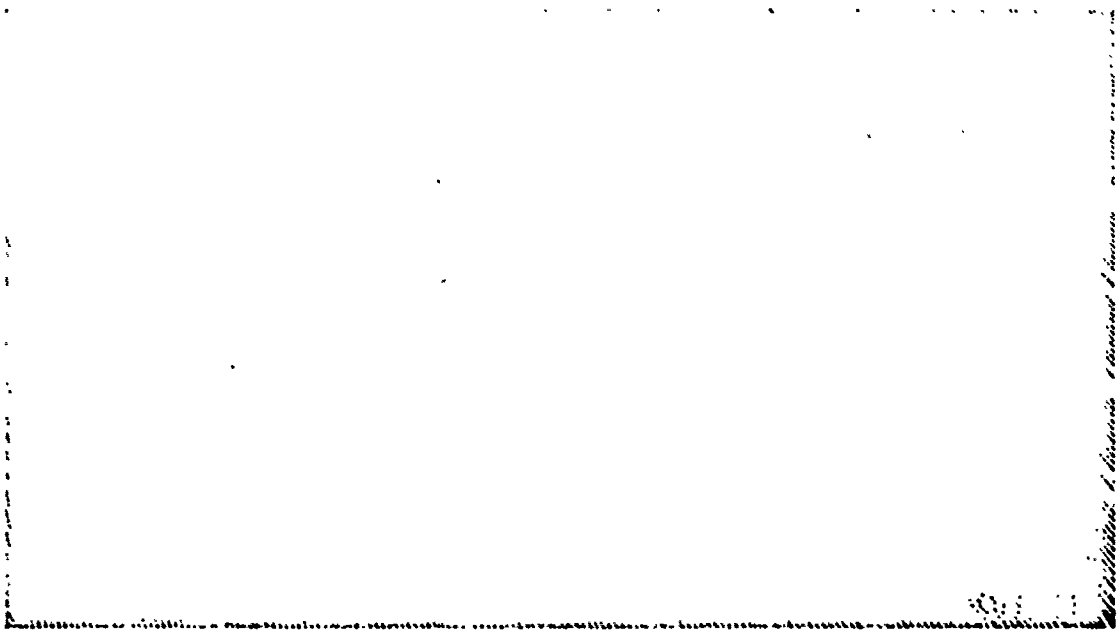


Fig. 22. End-joint failure in item 1 after 30 coverages of traffic with 27,000-lb single-wheel load

down to eliminate a tire hazard. After 30 coverages, an end joint in item 1 sheared completely (see fig. 22). Fig. 23 shows the load wheel stopped on this end joint. It can be seen that the mat deformed severely which resulted in a considerable amount of roughness in item 1. This item was considered failed after 36 coverages, although traffic was continued to 42 coverages. A close-up of an overlapping-edge failure in item 1 after 42 coverages of traffic is shown in fig. 24.

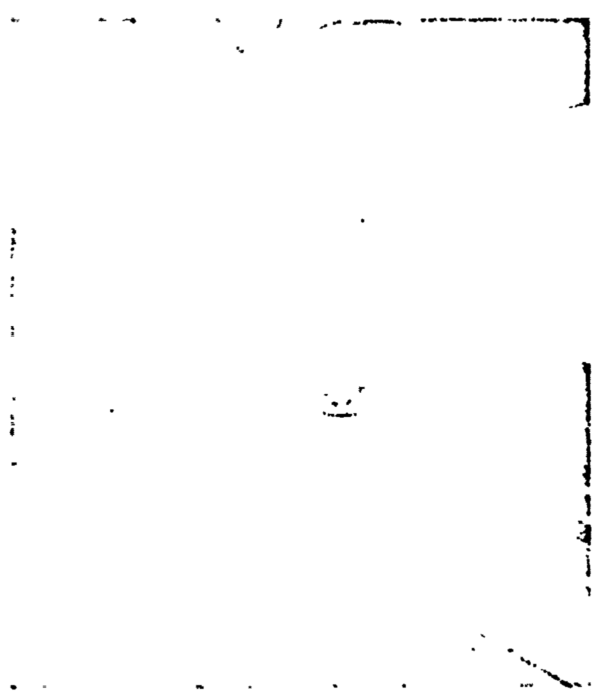


Fig. 23. Load over end joint in item 1 after 30 coverages of traffic with 27,000-lb single-wheel load

62. The AM1 mat was designed so that a 5/8-in.-diameter

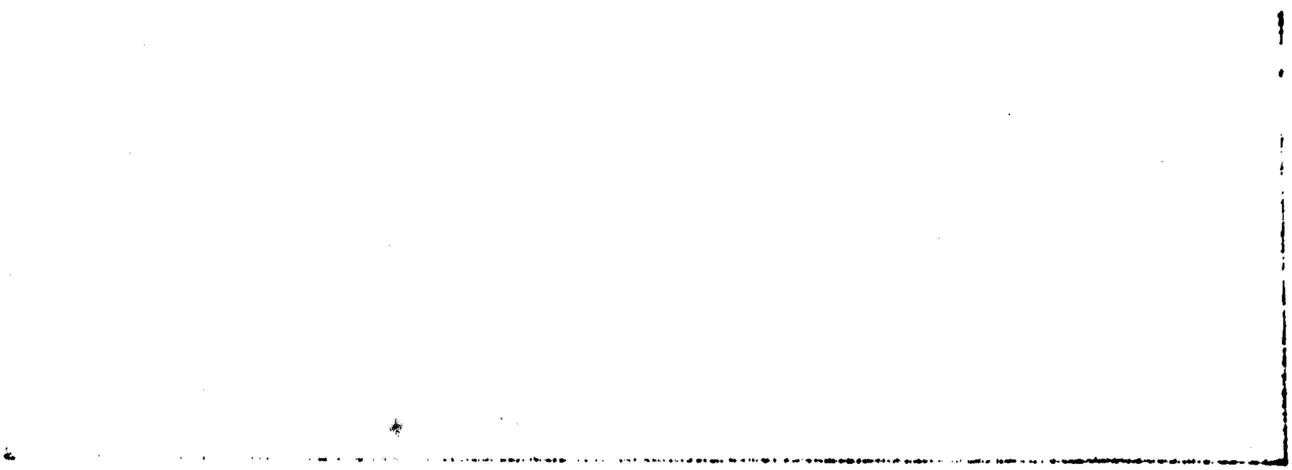


Fig. 24. Failure of mat in center of plank. Item 1 after 42 coverages of traffic with 27,000-lb single-wheel load

rod could be used at the end joints, which would provide some load transfer across the end joints. The end rods were not used initially in laying the mat as the NAMC preferred to use the mat without the rods. However, because of the early mat failure in item 1, it was decided to take up the mat in this item and relay it using the end-connecting rods in order to evaluate the benefits in load-carrying capacity that might result from use of these rods. Therefore, as traffic continued from 42 to 50 coverages in items 2, 3, 4, and 5, the mat in item 1 was removed, the ends of the mats were reversed, and the mat was relaid using 5/8-in.-diameter steel rods in the end joints as shown in fig. 25. Traffic was then resumed on the test lane with 0 coverages on item 1, and 50 coverages on the other items. It was found that the rods added significantly to the load-carrying capabilities of the mat. After 30 coverages on item 1 with the end-connecting rods installed, the section was in good condition with only

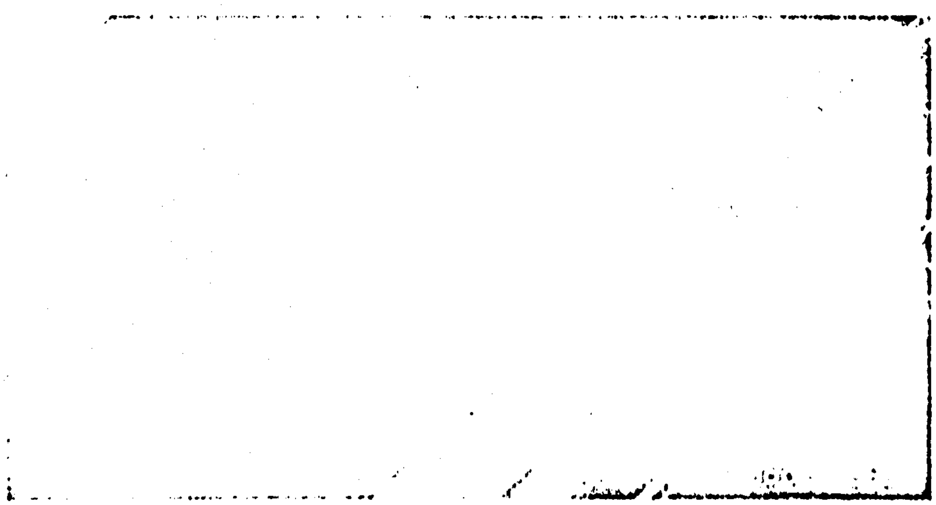


Fig. 25. End-connecting rod in joint of Butler AM1 mat

minor deformities. However, after 32 coverages, one end joint sheared (see fig. 26), and the entire mat run was replaced.

63. An end-joint break developed in item 2 after 90 coverages and became more severe with increasing traffic (fig. 27). It was noted after 100 coverages that small amounts of clay were being squeezed up between the joints in items 1 and 2, and some side slipping was occurring in item 4 (rock section).

64. After 110 coverages of traffic (60 coverages on item 1), 1/4-in.-diameter holes were drilled near the ends of progressing edge breaks in items 1 and 2 in an effort to stop the breaks. A second end joint sheared in item 1 at 66 coverages, and the entire run was replaced. As traffic progressed, some of the breaks extended beyond the drilled holes. After 90 coverages on item 1, 20 percent of the mat planks

Fig. 26. Broken end joint, weld, and overlapping edge. Item 1 mat with end-connecting rod after 32 coverages of traffic with 27,000-lb single-wheel load

Fig. 27. End-joint break in item 2 after 188 coverages with 27,000-lb single-wheel load

had failed; however, traffic was continued through 138 coverages with frequent maintenance of the test item. Test items 2 through 5 withstood the full 188 coverages of traffic with only one plank failure in item [illegible] a few minor breaks in the other items. A general view of the test lane at the end of traffic is shown in photograph 4.

65. Permanent deformation. Level readings taken to show permanent deformation of the mat during traffic are shown in plate 13 for all test items. From these data it can be noted that little settlement occurred in any of the clay subgrades, items 1 through 3. However, considerable deformation occurred in items 4 and 5, rock and sand subgrade items, respectively. This deformation was due to densification of the rock and sand under traffic, as was the case for the Fenestra mat discussed previously.

66. Profiles showing the deformation of the mat along the center line of the test lane are shown in plate 14. These data show considerable deviation in the deformation of adjacent mat planks in item 1 at the end of 36 and 138 coverages, respectively. This is due primarily to breaks in the end joints. This condition would result in a rough riding surface. The mat surface remained fairly smooth in items 2, 3, 4, and 5 throughout the period of traffic, even though considerable deformation occurred in items 4 and 5.

67. Mat deflection. Plots showing elastic deflection of the mat under load at various intervals of traffic for all test items are shown in plate 15. The rather high deflections indicated for the mat in items 4 and 5 were due to the mat bridging the subgrade, as was discussed for the Fenestra mat.

Single-track traffic,
39,000-lb single-wheel load

68. No mat breakage was noted in any of the test items during the initial stages of traffic using the 39,000-lb single-wheel load. Two mat runs in test item 4 were damaged by a tire blowout at 146 passes (see fig. 28). The damaged mat was replaced with new mat planks. As traffic continued, some breaks did develop in all test items. A core failure started developing in a mat plank in item 1 at about 150 passes and progressed to complete failure at about 400 passes. At this point, the end joint also sheared, as shown in fig. 29. By 500 passes, three end-[illegible]

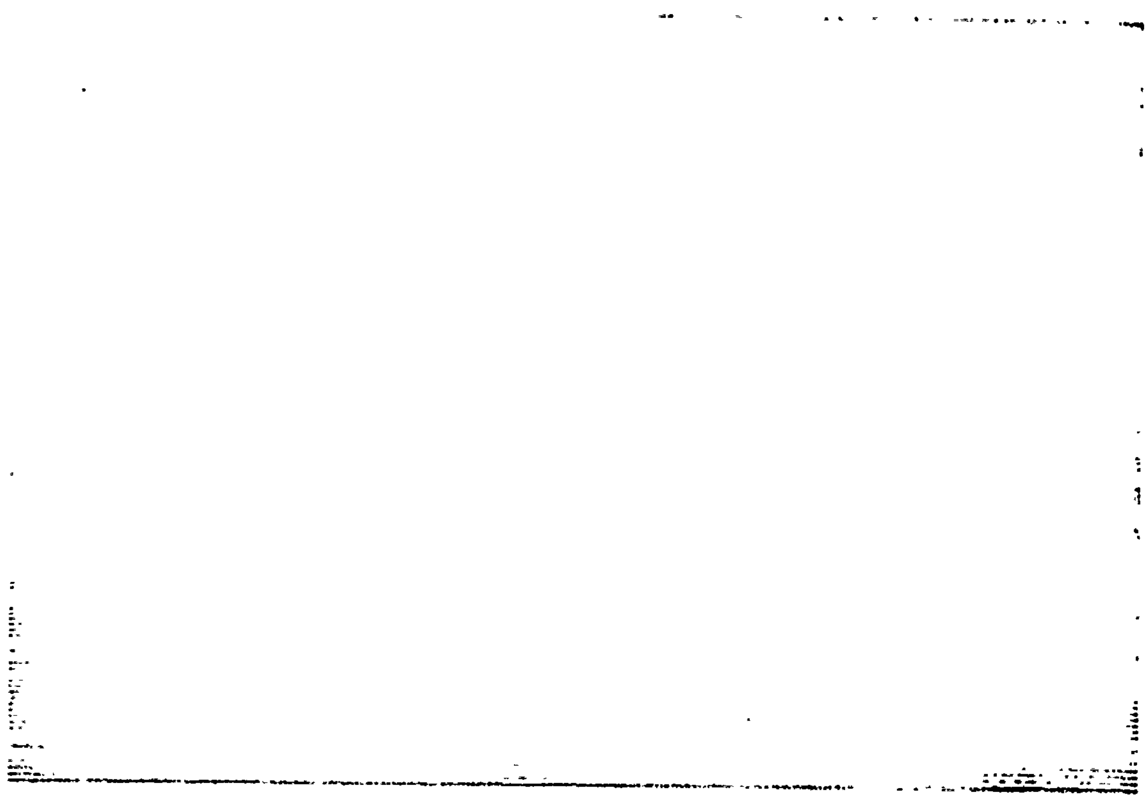


Fig. 28. Damaged AM1 mat in item 4 caused by tire blowout after 146 passes of 39,000-lb single-wheel load

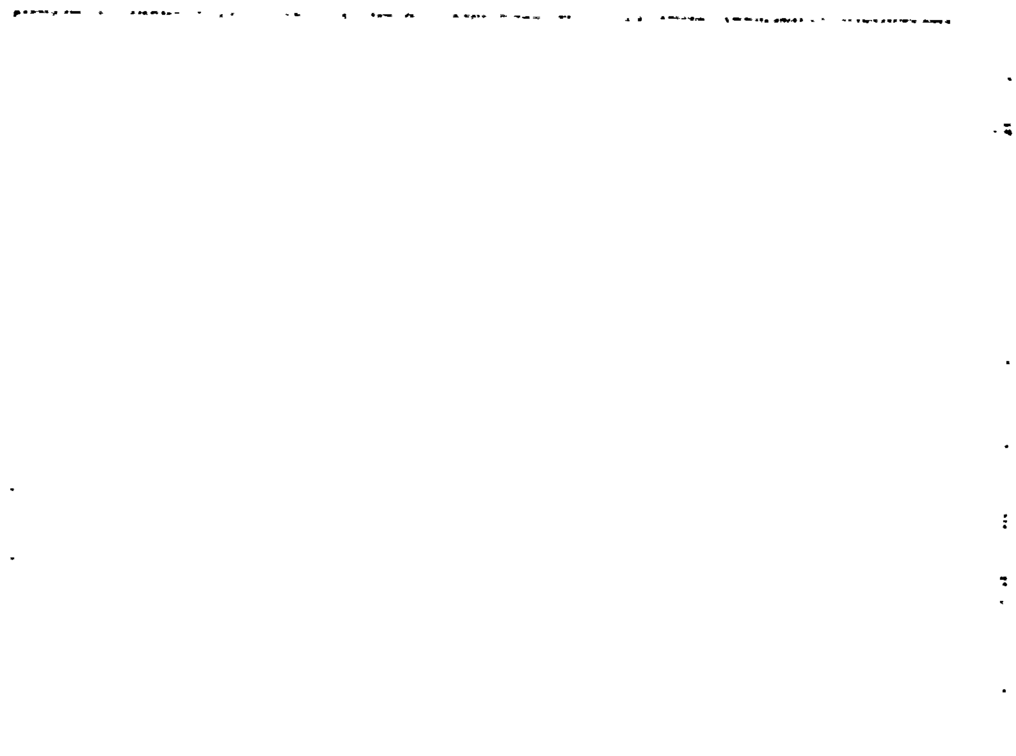


Fig. 29. Sheared end joint after core failure of AM1 mat in item 1 after 400 passes of 39,000-lb single-wheel load

failures and one core failure had developed in item 5, and one core failure and several longitudinal-weld failures were noted in item 4. Typical longitudinal-weld failures are shown in fig. 30. General views of items 1

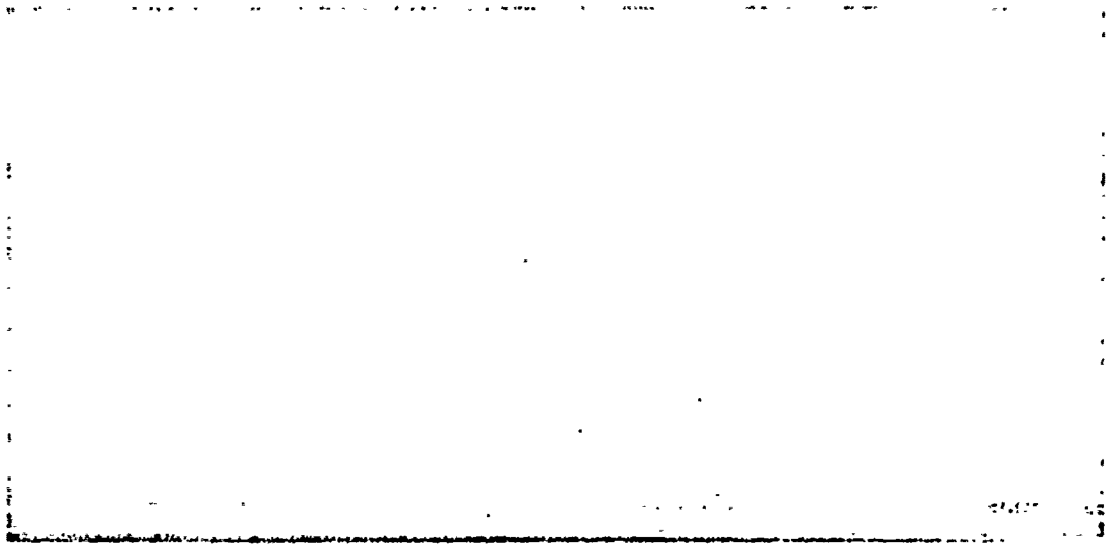


Fig. 30. Typical longitudinal-weld failures in AM1 mat

through 5 at the end of 500 passes are shown in photographs 5 through 9, respectively. A close-up of a mat depression indicating a core failure in item 5 is shown in fig. 31.

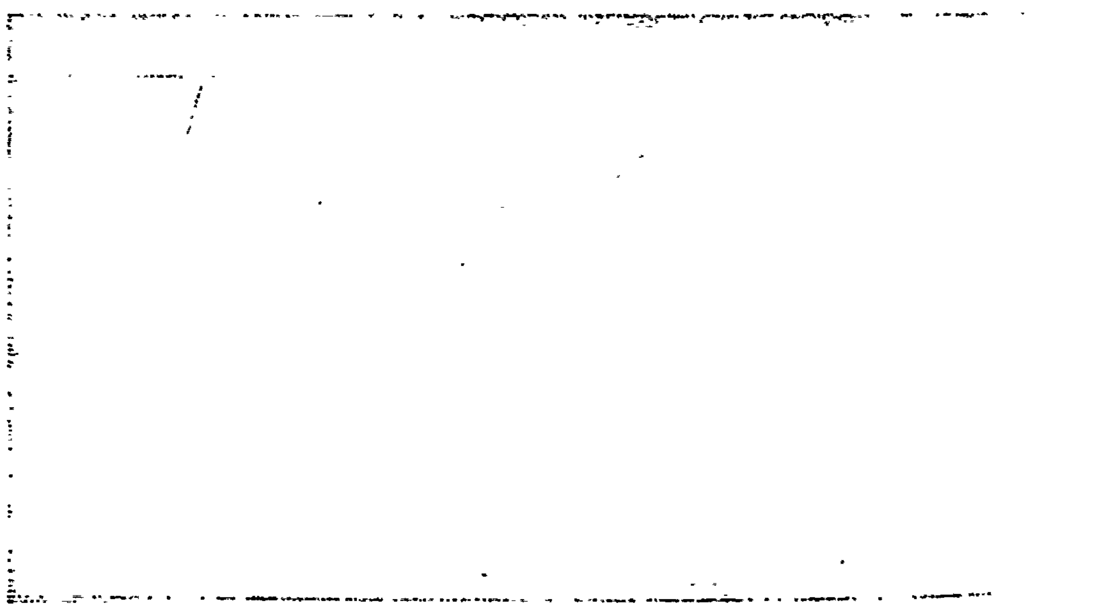


Fig. 31. Depression in AM1 mat in item 5 indicating core failure after 500 passes of 39,000-lb single-wheel load

69. As traffic continued, test items 1 and 5 deteriorated quite rapidly, and were considered failed at about 616 passes. However, traffic was continued to 750 passes on item 5 and to 954 passes on item 1. The mat in items 2, 3, and 4 performed satisfactorily through 1200 passes, although some minor breaks developed in all test items. Traffic was discontinued at the end of 1200 passes as it was evident that items 2, 3, and 4 would sustain 1600 passes of the wheel load with a reasonable maintenance effort. General views of test items 1 through 5 at the end of traffic are shown in photographs 10 through 14, respectively.

Summary and Analysis of Test Results

70. The results of traffic tests with the 27,000-lb single-wheel load are summarized in table 4. The rated subgrade CBR shown therein was determined from the test values shown in table 3, using the method of analysis described in paragraph 38. The failure criteria were the same as those discussed in paragraph 33. From table 4 it can be noted that mat failure occurred in only item 1. Item 5 is rated borderline due to the mat deflection under load exceeding 1 in. at the end of 188 coverages of traffic. However, there was no mat breakage in item 5, and the item would be considered satisfactory provided the severe deflection is not detrimental to aircraft performance. This deflection was due to the densification of the sand and to the mat bridging the subgrade, as previously discussed.

71. A summary of test results of the 39,000-lb single-wheel load is shown in table 5. As previously stated, traffic was applied in a single path 2 ft outside the uniform-coverage traffic lane used for the 27,000-lb single-wheel load. No CBR tests were made along this traffic path, and it was assumed that the subgrade strength was the same as that for the 27,000-lb single-wheel-load traffic. Therefore, the same rated CBR values are used for analysis.

CBR Design Curves

72. The approach used for establishing CBR design curves for the Butler AM1 mat was the same as that used for the Fenestra mat and described in paragraph 42.

27,000-lb single-wheel load

73. A plot of CBR versus coverages is shown in plate 16. The points plotted are the rated CBR values listed in table 4 for test items 1 through 4 corresponding to the number of coverages at failure or at end of traffic. As can be seen in plate 16, all test items with a subgrade CBR of 12 or greater were satisfactory at the end of 188 coverages of traffic. Failure occurred in item 1 (rated CBR of 6.4) at 36 coverages of traffic for the mat without end-connecting rods and at 90 coverages of traffic for the mat with end-connecting rods. These failure points were translated to 188 coverages by use of the CBR equation given in paragraph 43. From these data the indicated CBR required for 188 coverages of the 27,000-lb single-wheel load is 10.7 for the AM1 mat without end-connecting rods and 7.9 for the AM1 mat with end-connecting rods.

74. CBR design curves for 188 coverages of the 27,000-lb single-wheel load with a tire pressure of 400 psi are shown in plate 17. The lower curve is a standard flexible-pavement CBR design curve. The curves for the Butler AM1 mat were developed in the same manner as those for the Fenestra mat, as discussed in paragraph 44.

75. The data obtained from the sand test item were not used in developing the design curves shown in plate 17. However, the data indicate that a loose-sand subgrade with an initial CBR of 5.6 or better surfaced with Butler AM1 mat would perform satisfactorily for 188 coverages of the 27,000-lb single-wheel load with 400-psi tire pressure, provided the severe mat deflection caused by the bridging of the subgrade by the mat was not detrimental to aircraft performance.

39,000-lb single-wheel load

76. A plot of CBR versus passes for the 39,000-lb single-wheel-load traffic is shown in plate 18. The points plotted are the rated CBR values listed in table 5 for test items 1 through 4 corresponding to the number of passes at failure or end of traffic. From these data it can be noted that all test items with a subgrade CBR of 12 or better performed satisfactorily. However, mat failure occurred on the subgrade with a rated CBR of 6.4 at about 616 passes of the load wheel. In order to determine the minimum CBR required to support the 39,000-lb single-wheel load for 1600 passes, this failure point at 616 passes was translated to 1600 passes by

use of the CBR equation in paragraph 45. The indicated minimum CBR required to sustain 1600 passes of the 39,000-lb single-wheel load is 8. This minimum CBR of 8 is based on the performance of the mat in test item 1, which was placed with the end-connecting rods at joints. By comparing the performance of the AM1 mats with and without the end-connecting rods under the 27,000-lb single-wheel-load traffic (see plates 16 and 17), the minimum subgrade CBR required to support the 39,000-lb single-wheel load for 1600 passes on the AM1 mat without the end-connecting rods would be about 10.8. The satisfactory points shown in plate 18 are for the AM1 mat without end-connecting rods.

77. A CBR design curve for 1600 passes of the 39,000-lb single-wheel load with a 400-psi tire pressure for the Butler AM1 mat with end-connecting rods is shown in plate 19. This curve was developed in the same manner as that previously described.

78. The Butler AM1 mat placed on a sand subgrade with an initial CBR of 5.6 withstood 616 passes of the 39,000-lb single-wheel load. During the application of traffic, the sand densified under the mat, resulting in depression of the subgrade under the mat. The strength of the sand increased considerably due to densification. However, the mat did not conform to the subgrade settlement and tended to bridge the subgrade. This resulted in rather severe mat deflections and caused the mat to break up. Therefore, for the AM1 mat to sustain 1600 passes of the 39,000-lb single-wheel load, the sand should receive some initial compaction to avoid detrimental settlement. By translating the failure point for the sand subgrade (CBR 5.6 at 616 passes) to 1600 passes, the indicated initial CBR required for the sand subgrade to sustain 1600 passes of the 39,000-lb single-wheel load is about 7. This is just slightly less than the strength required for a clay subgrade.

PART IV: CONCLUSIONS

79. The following conclusions are drawn from the data presented in this report.

- a. The Fenestra type 1-d mat, designated AM1 by the Navy, will sustain 1600 cycles of aircraft operations with a 27,000-lb single-wheel load and a 400-psi tire pressure when placed on a subgrade having a CBR of 7 or better throughout the period of traffic.
- b. The minimum subgrade strength required for the Fenestra type 1-d (AM1) mat to sustain 1600 passes in a single path of the 39,000-lb single-wheel load with a 400-psi tire pressure was not determined. However, it was determined that the mat would support the desired 1600 passes of the 39,000-lb single-wheel load with a 400-psi tire pressure when placed on a subgrade with a CBR of 13 or greater.
- c. The Butler AM1 mat with end-connecting rods will sustain 1600 cycles of aircraft operations with a 27,000-lb single-wheel load and a 400-psi tire pressure when placed on a subgrade having a CBR of 8 or better throughout the period of traffic. For the Butler AM1 mat without the end-connecting rods, the subgrade CBR required for 1600 cycles of the same loading is about 10.7.
- d. The Butler AM1 mat with end-connecting rods will sustain 1600 passes of a 39,000-lb single-wheel load with a tire pressure of 400 psi applied in a single path when placed on a subgrade having a CBR of 8 or better throughout the period of traffic. For the same mat without the end-connecting rods, the subgrade strength required for 1600 passes of the same loading is about 10.8.

Table 1

Summary of CBR, Water Content, and Density Data

Fenestra Mark III Mat

Test Item	Subgrade Material	Single-Wheel Load lb	Traffic Coverages*	Depth in.	CBR	Water Content %	Dry Density lb/cu ft	Remarks
1	Clay	17,000	0	0	4.8	28.1	94.4	A total of 50 coverages of traffic applied with 17,000-lb, single-wheel load; mat performance satisfactory
				6	6.7	25.6	97.0	
				12	4.6	28.9	93.0	
		27,000	18	0	5.7	27.3	94.1	Types 1-b and 1-c mats failed after 50 coverages of 17,000-lb, single-wheel load plus 18 coverages of 27,000-lb, single-wheel load; types 1-a and 1-d mat performance satisfactory
				6	7.3	26.6	97.3	
				12	5.6	27.4	95.3	
		27,000	128	0	8.5	26.1	98.1	Types 1-a and 1-d mats failed after 50 coverages of 17,000-lb, single-wheel load plus 128 coverages of 27,000-lb, single-wheel load
				6	7.8	27.0	96.6	
				12	6.4	27.3	95.9	
2	Clay	17,000	0	0	11.1	25.3	97.2	A total of 50 coverages of traffic applied with 17,000-lb, single-wheel load; mat performance satisfactory
				6	12.0	23.4	98.0	
				12	12.2	24.1	95.5	
		27,000	18	0	15.5	19.9	103.3	Mat performance satisfactory
				6	15.0	23.3	98.8	
				12	15.9	23.7	97.0	
		27,000	188	0	14.0	24.2	99.7	Mat performance satisfactory
				6	12.2	24.1	100.2	
				12	14.8	23.5	98.4	
3	Rock	17,000	0	--	--	--	---	50 coverages of traffic applied with 17,000-lb, single-wheel load
		27,000	188	0	81.0	--	---	Mat performance satisfactory
4	Sand	17,000	0	0	3.5	4.0	91.3	50 coverages of traffic applied with 17,000-lb, single-wheel load; mat performance satisfactory
		27,000	188	0	11.9	5.4	106.1	Traffic discontinued on types 1-b and 1-c mat after 73 coverages. Types 1-a and 1-d mat performed satisfactorily for a total of 50 coverages of 17,000-lb, single-wheel load plus 188 coverages of 27,000-lb, single-wheel load
				6	23.8	7.9	111.0	
				12	15.7	4.0	---	

Note: All test values tabulated are averages of three determinations. 400-psi tire pressure used in each test.
* Coverages at which soil data were obtained.

Table [illegible]

[illegible] of Traffic Test Results

[illegible] 17,000- and 27,000-lb [illegible] Loads, [illegible]

Test Item	Subgrade Material	Rated Subgrade CBR	Single-Wheel Load lb	Traffic Coverages	Equivalent Accumulative Coverages of 27,000-lb Load	Mat Type	No. of Mat Rows	Row of Panels in Traffic Lane	Panel Cracks in End Connector	End-Joint Failures	Overlapping Corner Breaks	Spot-Weld Failures	[illegible] Panels Failed	[illegible]	Percent	[illegible]	Remarks
1	Clay	[illegible]	17,000	0	0	1-a	5	7	--	---	--	---	---	[illegible]	0.[illegible]	0.[illegible]	
			17,000	50	6	1-a	5	7	0	0	0	---	---	0.4	[illegible]	0.3	[illegible]
						1-b	5	8	2[illegible]	0	[illegible]	8[illegible]	0	---	---	---	[illegible]
						1-c	5	7	11	0	2	---	0	---	---	---	[illegible]
						1-d	5	8	1	0	0	---	---	---	---	---	[illegible]
			27,000	19	24	1-a	5	7	0	0	0	---	0	---	---	--	[illegible]
						1-b	5	8	23	2	2	[illegible]	2	0.8	0.7	0.[illegible]	[illegible]
						1-c	5	7	12	2	2	---	2	---	---	---	[illegible]
						1-d	5	8	0	0	0	---	0	---	---	---	[illegible]
			27,000	73	79	1-a	5	7	1	0	4	---	0	0.4	0.7	0.[illegible]	[illegible]
						1-d	5	8	1	0	4	---	0	---	---	--	[illegible]
			27,000	129	134	1-a	5	7	2	1	6	---	1	0.6	0.9	[illegible].8	[illegible]
						1-d	5	8	3	[illegible]	6	---	2	---	---	---	[illegible]
2	Clay	13	17,000	0	0	1-a	5	7	--	---	--	---	---	[illegible]	0.2	0.4	
			17,000	50	6	1-a	5	7	0	0	1	---	[illegible]	0.[illegible]	0.4	[illegible]	
						1-b	5	8	12	0	0	64	0	---	---	---	[illegible]
						1-c	5	7	7	0	0	---	0	---	---	---	[illegible]
						1-d	5	8	0	0	0	---	0	---	---	---	[illegible]
			27,000	73	79	1-a	5	7	0	0	2	---	0	0.3	0.[illegible]	0.4	[illegible]
						1-b	5	8	14	1	6	90	1	---	---	---	[illegible]
						1-c	5	7	8	0	2	---	0	---	---	---	[illegible]
						1-d	5	8	0	0	0	---	0	---	---	---	[illegible]
			27,000	184	194	1-a	5	7	0	0	2	---	0	0.3	0.[illegible]	0.[illegible]	[illegible]
						1-b	5	8	15	1	7	94	1	0.5	0.4	0.[illegible]	[illegible]
						1-c	5	7	10	0	3	---	0	---	---	---	[illegible]
						1-d	5	8	0	0	0	---	0	---	---	---	[illegible]
3	Rock	--	17,000	0	0	1-a	5	7	--	---	--	---	---	0.4	0.3	0.4	
			17,000	50	6	1-a	5	7	0	0	0	---	0	0.8	0.7	0.7	Satisfactory
						1-b	5	8	0	0	0	90	0	---	---	---	Satisfactory
						1-c	5	7	0	0	0	---	0	---	---	---	Satisfactory
						1-d	5	8	0	0	0	---	0	---	---	---	Satisfactory
			27,000	73	79	1-a	5	7	0	0	0	---	0	1.2	1.[illegible]	0.9	[illegible]; severe deflections
						1-b	5	8	10	0	2	102	0	---	---	---	[illegible]
						1-c	5	7	9	0	1	---	0	---	---	---	Satisfactory
						1-d	5	8	0	0	0	---	0	---	---	---	Satisfactory
			27,000	188	194	1-a	5	7	0	0	0	---	0	1.2	1.3	1.0	Borderline; severe deflections
						1-b	5	8	12	0	2	102	0	1.2	1.2	1.0	Borderline; severe deflections
						1-c	5	7	10	0	2	---	0	---	---	---	Borderline; severe deflections
						1-d	5	8	0	0	0	---	0	---	---	---	Borderline; severe deflections
4	Sand	4	17,000	0	0	1-a	5	7	--	---	--	---	---	0.4	0.3	0.1	
			17,000	50	6	1-a	5	7	0	0	0	---	0	1.1	1.3	0.9	Satisfactory
						1-b	5	8	6	0	0	87	0	---	---	---	Satisfactory
						1-c	5	7	8	0	0	---	0	---	---	---	Satisfactory
						1-d	5	8	0	0	0	---	0	---	---	---	Satisfactory
			27,000	73	79	1-a	5	7	0	0	0	---	0	1.5	1.7	1.2	[illegible]; severe deflections
						1-b	5	8	14	2	10	100	2	1.0	0.7	0.9	Failed at about 79 coverages
						1-c	5	7	16	1	4	---	1	---	---	---	Failed at [illegible] 79 coverages
						1-d	5	8	0	0	0	---	0	---	---	---	[illegible] deflections
			[illegible]	[illegible]	[illegible]	[illegible]	5	7	0	0	4	---	0	1.7	1.9	1.4	[illegible]
						[illegible]	5	8	0	[illegible]	4	---	0	---	---	---	[illegible] deflections

Table 3

Summary of CBR, Density, and Water Content Data

Butler AM1 Mat, 27,000-lb Single-Wheel Load, 400-psi Tire Pressure

Test Item	Subgrade Material	0 Coverages Depth in.	0 Coverages CBR	0 Coverages Water Content %	0 Coverages Dry Density lb/cu ft	36 Coverages Depth in.	36 Coverages CBR	36 Coverages Water Content %	36 Coverages Dry Density lb/cu ft	188 Coverages* Depth in.	188 Coverages* CBR	188 Coverages* Water Content %	188 Coverages* Dry Density lb/cu ft	Mat Performance
1	Clay	0	4.7	27.4	91.4	0	7.4	25.6	94.9	0	8.2	25.1	94.0	More than 20% of planks failed by 36 coverages. Mat relaid with end-connecting rods. Item failed at 90 coverages
		6	4.7	27.6	90.2	6	4.0	28.6	92.1	6	6.7	24.5	95.0	
		12	5.0	26.8	94.6	12	7.3	25.7	95.6	12	9.3	24.7	95.6	
		18	5.0	26.8	91.3	18	4.3	28.9	90.5	18	8.3	25.0	95.1	
2	Clay	0	9.3	24.7	97.6					0	16.0	21.9	101.3	Several breaks occurred but only one plank failed. Overall performance was satisfactory
		6	10.0	22.1	94.2					6	15.0	23.1	98.2	
		12	10.7	22.3	97.4					12	12.0	22.5	97.7	
		18	9.3	24.1	95.5					18	14.0	23.4	98.0	
3	Clay	0	15.3	20.3	93.5					0	19.0	19.3	95.6	Several minor breaks occurred
		6	13.0	18.5	95.9					6	22.0	20.2	99.8	
		12	14.7	19.7	94.0					12	10.0	22.5	95.9	Overall performance satisfactory
		18	14.7	21.0	94.4					18	12.0	22.1	97.2	
4	Rock	0	8.0	--	--					0	25.0	--	---	Satisfactory
5	Sand	0	3.0	5.1	--					0	30.0	3.2	109.4	Satisfactory
		6	8.7	4.7	--					6	48.0	3.8	106.6	
		12	5.0	4.3	--					12	45.0	4.2	106.1	
		18	--	--	--					18	27.0	3.8	105.6	

* 133 coverages in item 1.

Table 4

Summary of Traffic Test Results

Butler AM1 Mat, 27,000-lb Single-Wheel Load, 400-psi Tire Pressure

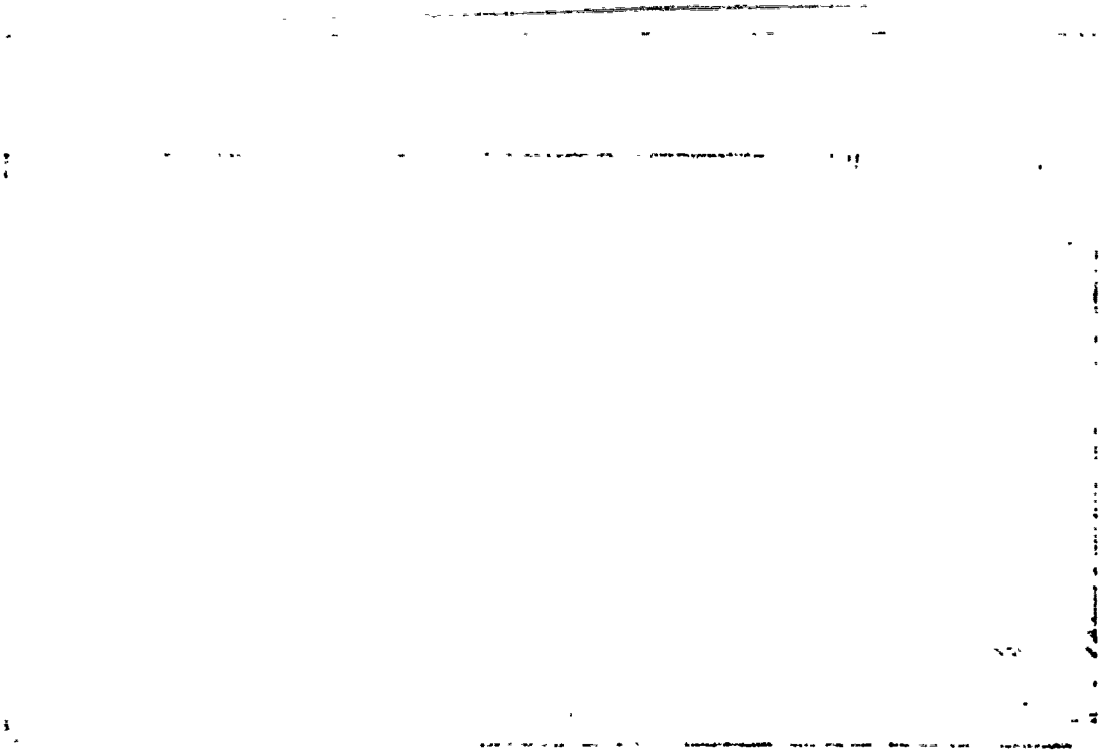
Test Item	Subgrade Material	Rated Subgrade CBR	No. Mat Runs in Item	Traffic Coverages	Mat Breakage: End-Joint Failures	Mat Breakage: Planks with Core Failures	Mat Breakage: Longitudinal Breaks	Mat Breakage: Failed Planks	Max Mat Defl, in.: Quarter Point	Max Mat Defl, in.: Mid-Point	Max Mat Defl, in.: On Joint	Rating of Item
1	Clay	6.4	15	0	0	0	0	0	0.5	0.5	0.6	
				20	0	0	6	0	0.4	0.5	0.6	
				36	0	0	9	0	0.4	0.4	0.8	Failed (excessive breakage)
				0	0	0	0	0	0.6	0.5	0.7	Mat relaid with end-connecting rods, and traffic resumed
				20	0	0	0	0	0.5	0.4	0.5	
				50	1	0	2	1	0.4	0.4	0.5	
				66	1	0	3	1	---	---	---	
				90	2	1	3	4	0.4	0.6	0.5	Failed (excessive breakage)
2	Clay	12.2	15	0	0	0	0	0	0.2	0.1	0.4	
				20	0	0	1	0	0.2	0.1	0.4	
				50	0	0	1	0	0.2	0.2	0.4	
				100	0	0	2	0	0.2	0.2	0.4	Minor breakage but overall condition satisfactory
				188	0	0	6	1	0.3	0.3	0.4	
3	Clay	15.7	15	0	0	0	0	0	0.6	0.4	0.3	
				20	0	0	0	0	0.4	0.2	0.2	
				50	0	0	0	0	0.4	0.2	0.3	
				100	0	0	0	0	0.5	0.2	0.3	
				188	0	0	2	0	0.6	0.2	0.3	Satisfactory
4	Rock	16.5	15	0	0	0	0	0	0.6	0.3	0.2	
				20	0	0	0	0	0.4	0.3	0.1	
				50	0	0	0	0	0.5	0.5	0.3	
				100	0	0	0	0	0.7	0.7	0.5	
				188	0	0	1	0	0.8	0.9	0.6	Satisfactory
5	Sand	5.6	15	0	0	0	0	0	0.2	0.3	0.3	
				20	0	0	0	0	0.5	0.6	0.7	
				50	0	0	0	0	0.7	0.8	0.9	
				100	0	0	0	0	0.9	1.1	1.1	
				188	0	0	0	0	1.0	1.1	1.3	Borderline due to severe deflection

Table 5

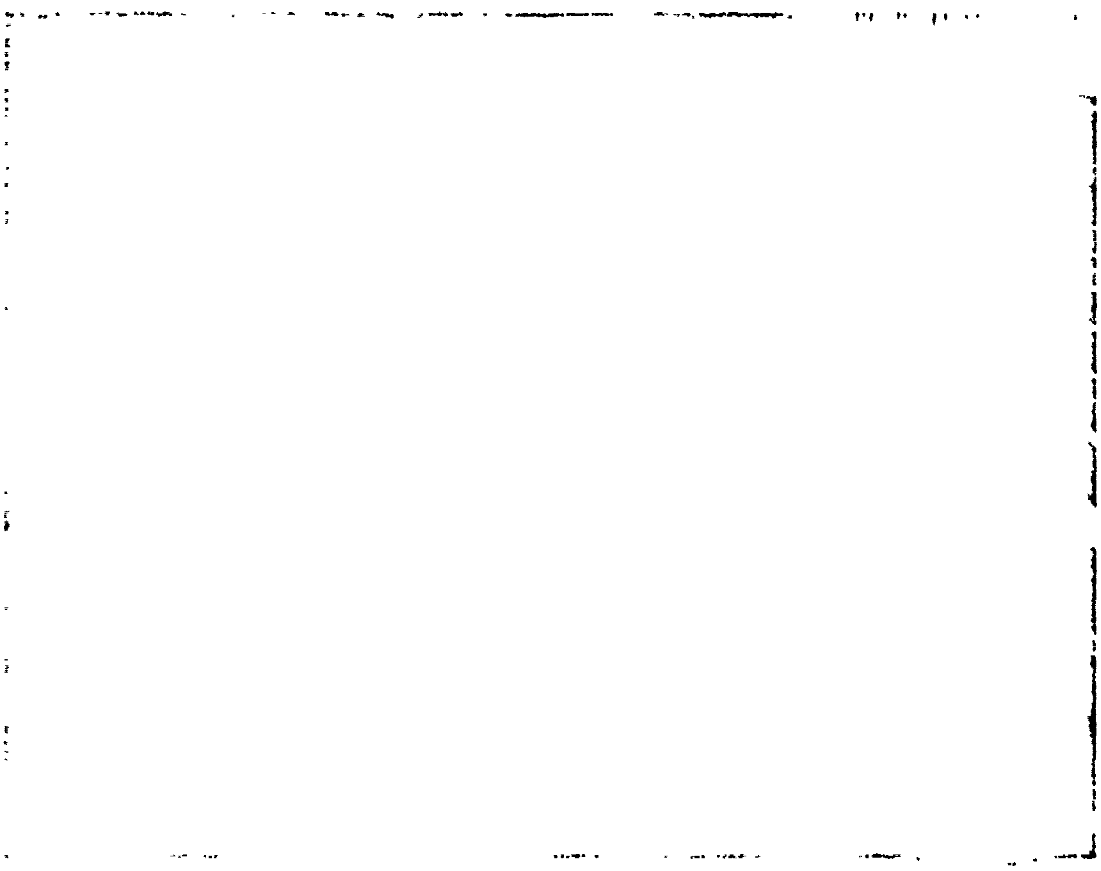
Summary of Traffic Test Results

Butler AM1 Mat, 39,000-lb Single-Wheel Load, 400-psi Tire Pressure

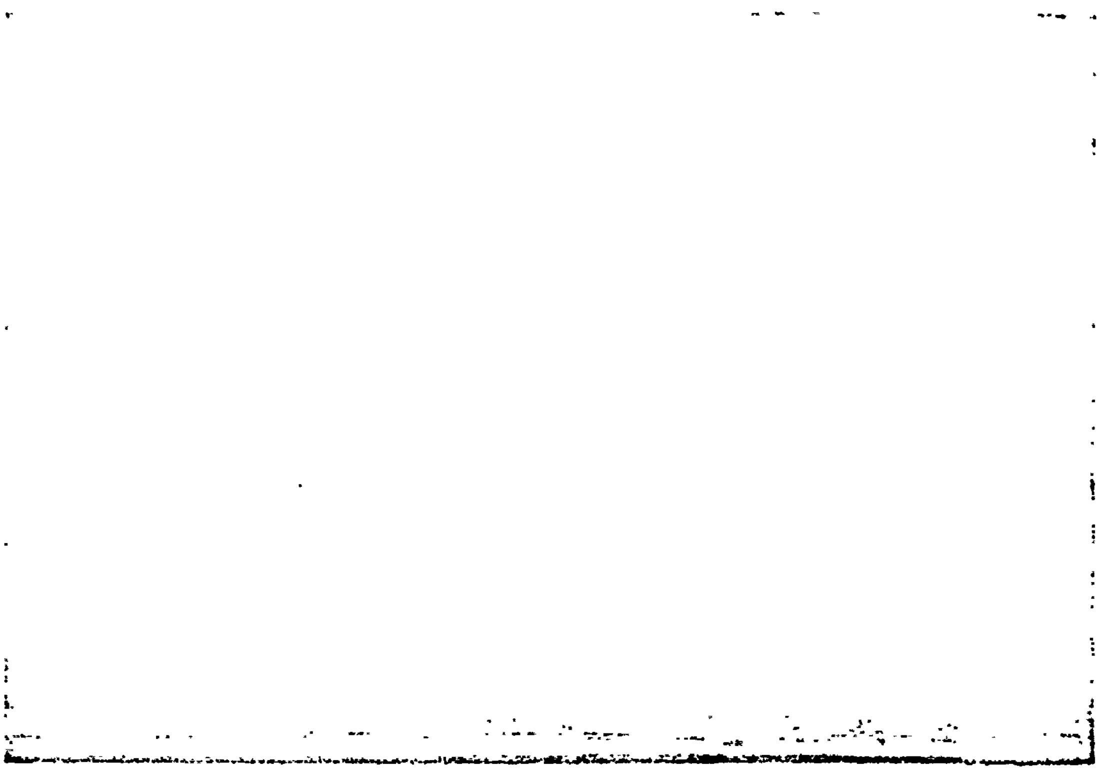
Test Item	Subgrade Material	Rated Subgrade CBR	No. Mat Runs in Item	Traffic Passes	Mat Breakage: End-Joint Failures	Mat Breakage: Planks with Core Failures	Mat Breakage: Planks with Longitudinal Weld Failures	Mat Breakage: Failed Planks	Max Mat Defl, in.: 1 ft from Joint	Max Mat Defl, in.: 1 ft from ℄ Plank	Rating of Item
1	Clay	6.4	15	0	0	0	0	0	0.6	0.4	
				100	0	0	0	0	0.6	0.5	
				300	0	1	0	1	0.6	0.5	
				616	2	1	1	3	---	---	Failed at about 616 passes
				954	4	1	2	4	0.7	0.6	
2	Clay	12.2	15	0	0	0	0	0	0.4	0.5	
				100	0	0	0	0	0.5	0.6	
				300	0	0	0	0	0.6	0.6	
				500	0	0	0	0	0.6	0.6	
				800	0	0	1	0	0.7	0.6	
				1200	0	0	2	0	0.6	0.6	Satisfactory
3	Clay	15.7	15	0	0	0	0	0	0.8	0.5	
				100	0	0	0	0	0.8	0.5	
				300	0	0	0	0	0.8	0.8	
				500	0	0	0	0	0.8	0.8	
				800	0	0	1	0	0.5	0.9	
				1200	0	0	1	0	1.0	0.6	Satisfactory
4	Rock	16.5	15	0	0	0	0	0	0.3	0.2	
				100	0	0	0	0	0.4	0.4	
				300	0	0	2	0	0.6	0.6	
				500	0	1	3	0	0.6	0.6	
				800	0	1	3	0	0.7	0.6	
				1200	0	1	4	1	0.7	0.7	Satisfactory
5	Sand	5.6	15	0	0	0	0	0	0.4	0.3	
				100	0	0	0	0	0.5	0.6	
				300	1	0	0	1	0.9	0.9	
				616	3	1	3	3	0.8	0.9	Failed
				750	4	1	3	4	0.8	0.9	



Photograph 1. Fenestra mat test section prior to traffic



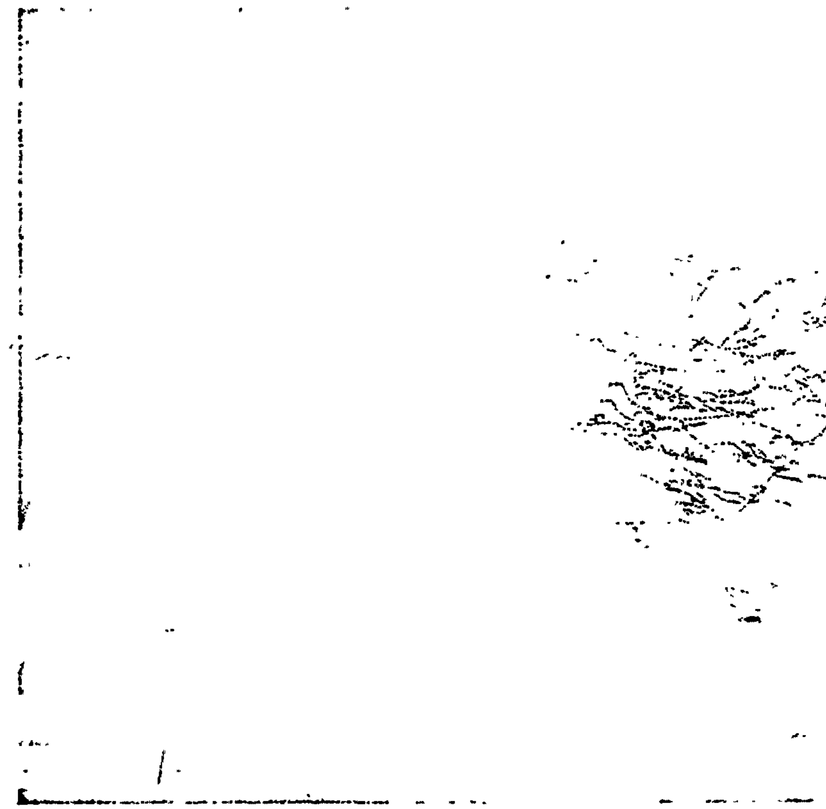
Photograph 2. Fenestra mat test section after 50 coverages of traffic with 17,000-lb single-wheel load



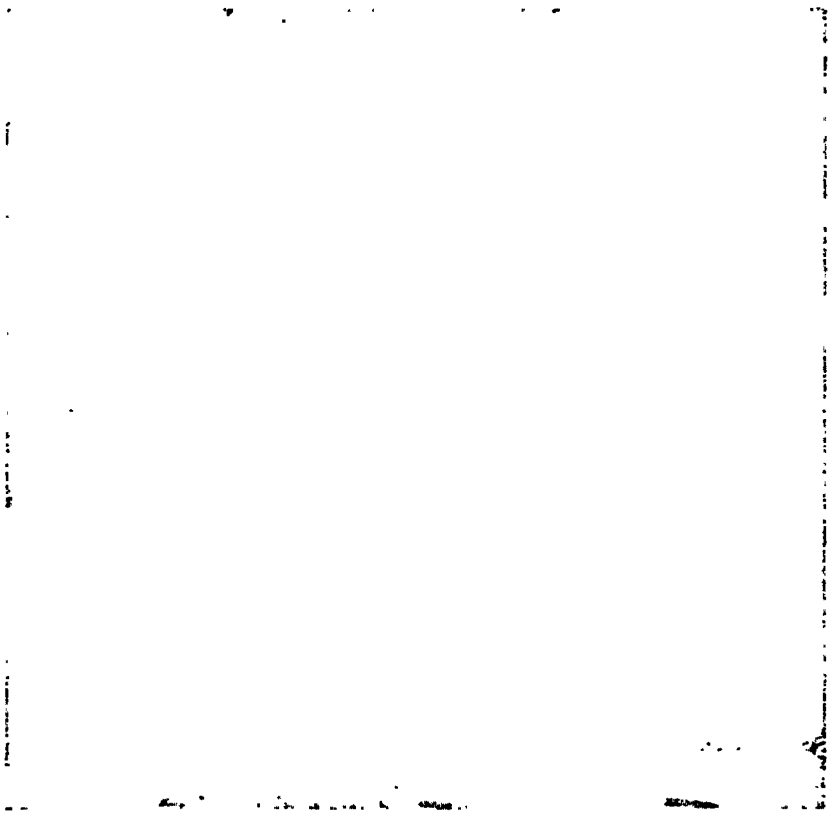
Photograph 3. Item 1 of Fenestra mat test section after 128 coverages of traffic with 27,000-lb single-wheel load

Photograph 4. AM1 mat test section after 188 coverages with 27,000-lb single-wheel load

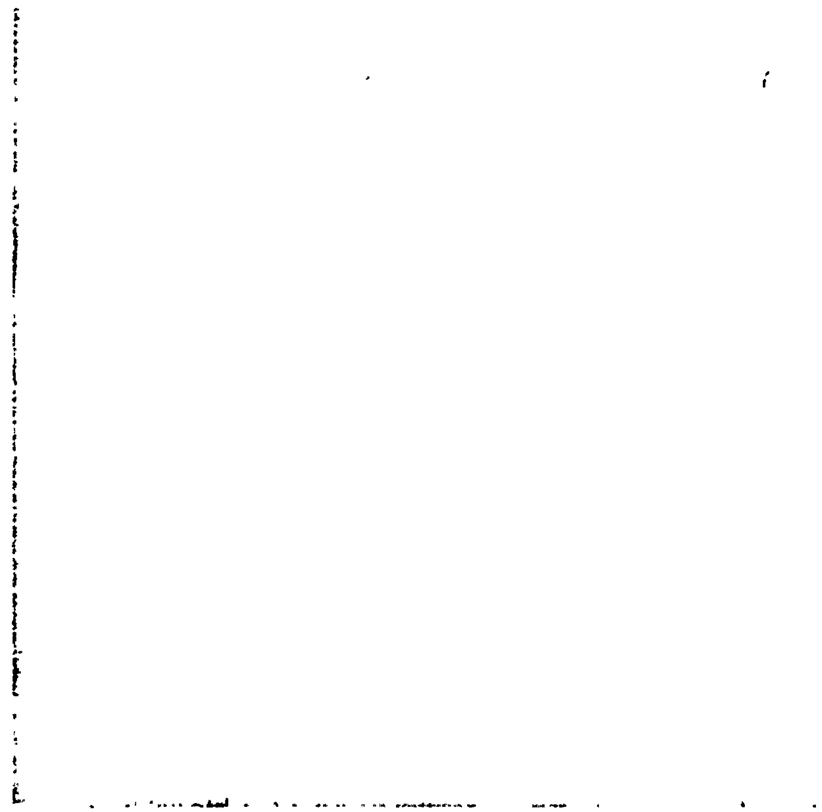
Photograph 5. AM1 mat item 1 after 500 passes of 39,000-lb single-wheel load



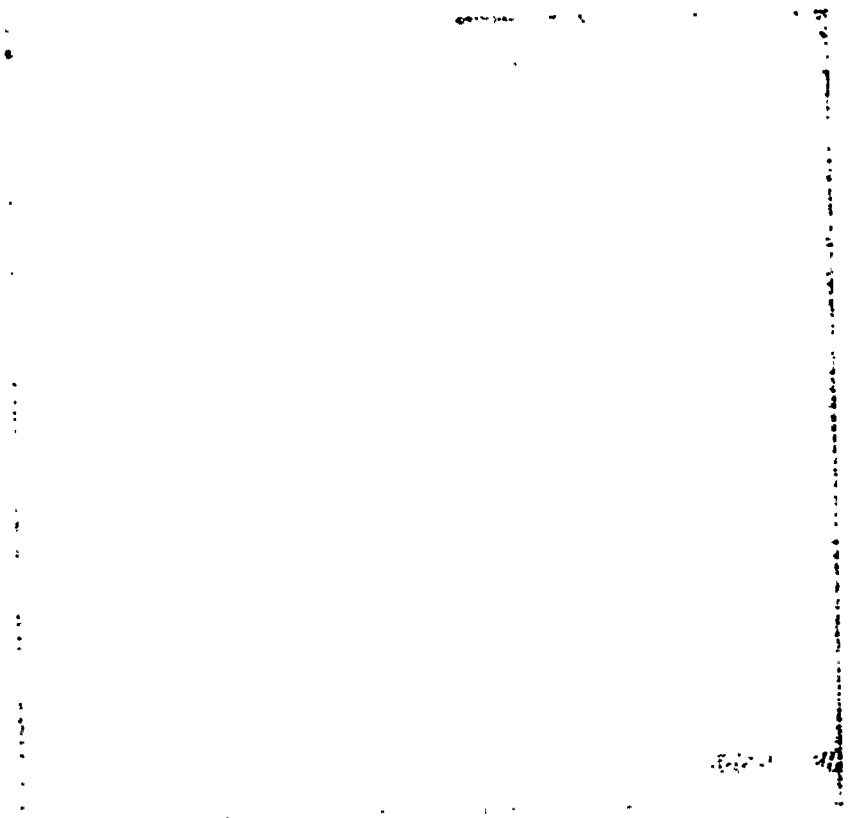
Photograph 6. AM1 mat item 2 after 500 passes of 39,000-lb single-wheel load



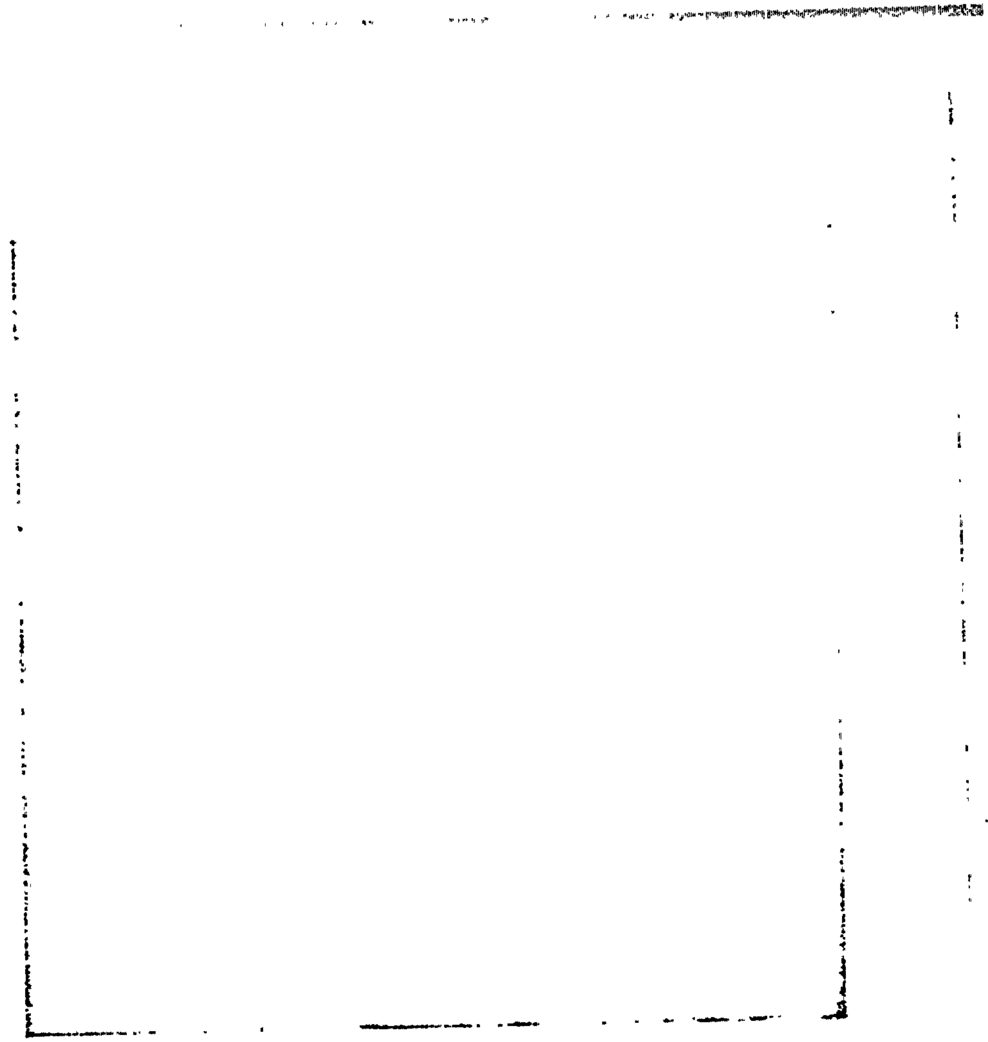
Photograph 7. AM1 mat item 3 after 500 passes of 39,000-lb single-wheel load



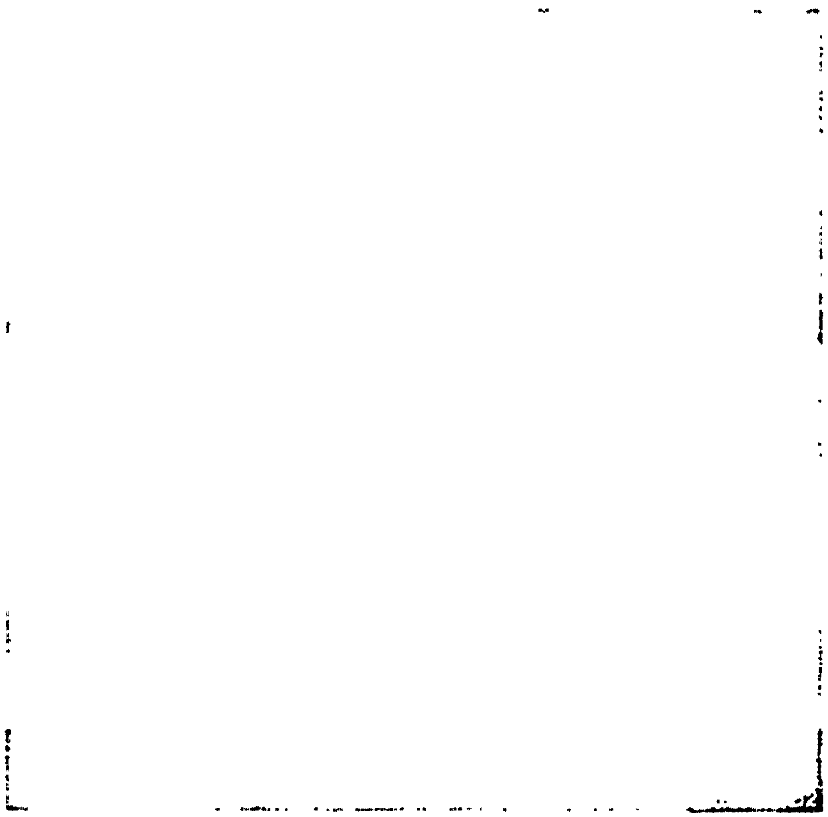
Photograph 8. AM1 mat item 4 after 500 passes of 39,000-lb single-wheel load



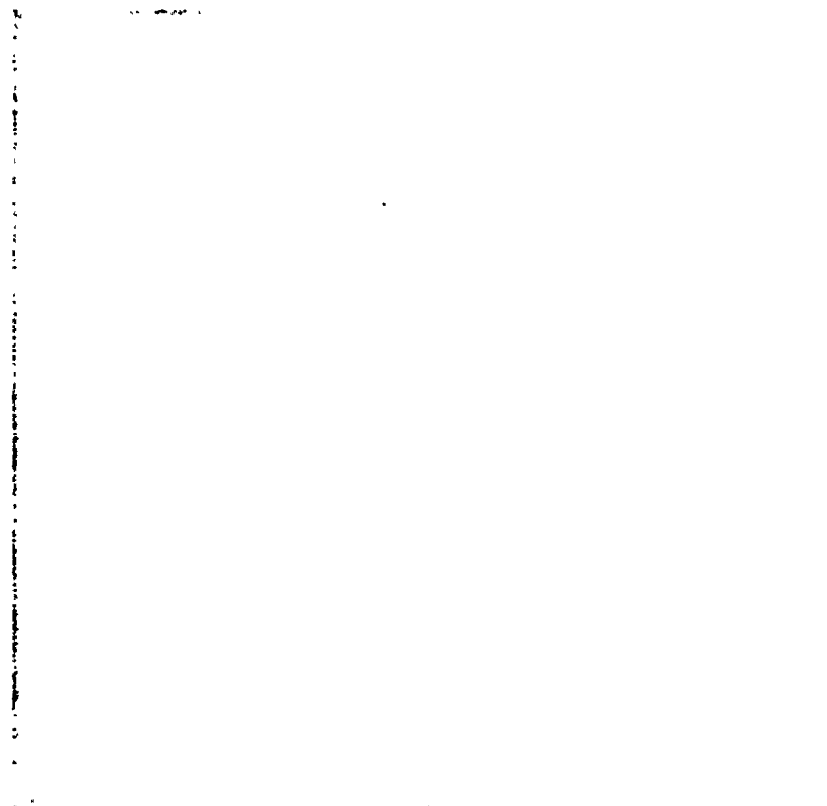
Photograph 9. AM1 mat item 5 after 500 passes of 39,000-lb single-wheel load



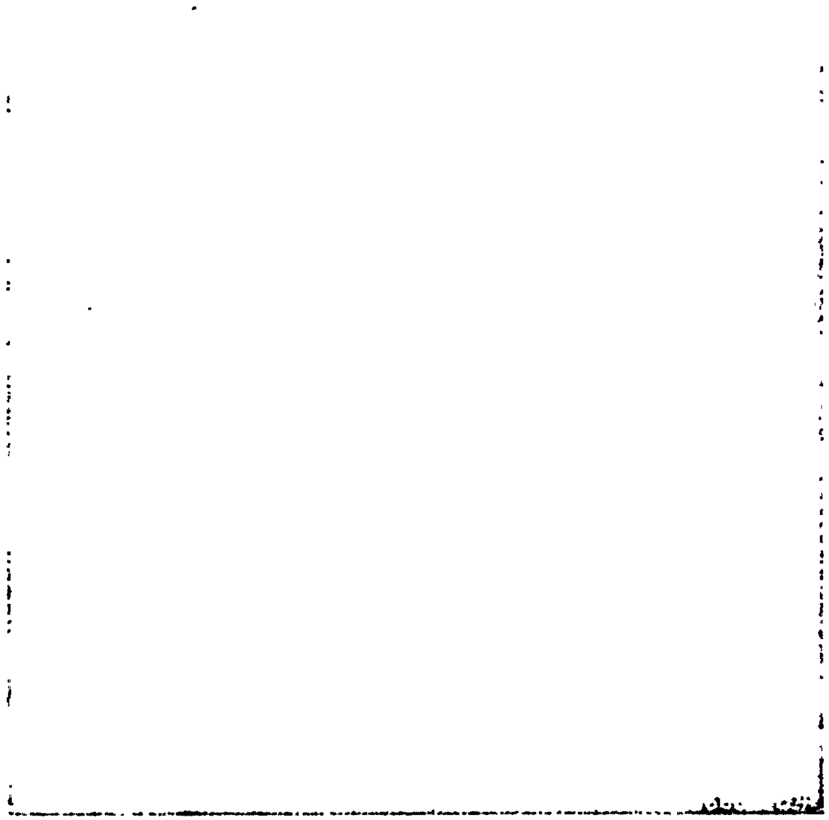
Photograph 10. AM1 mat item 1 after 954 passes of 39,000-lb single-wheel load



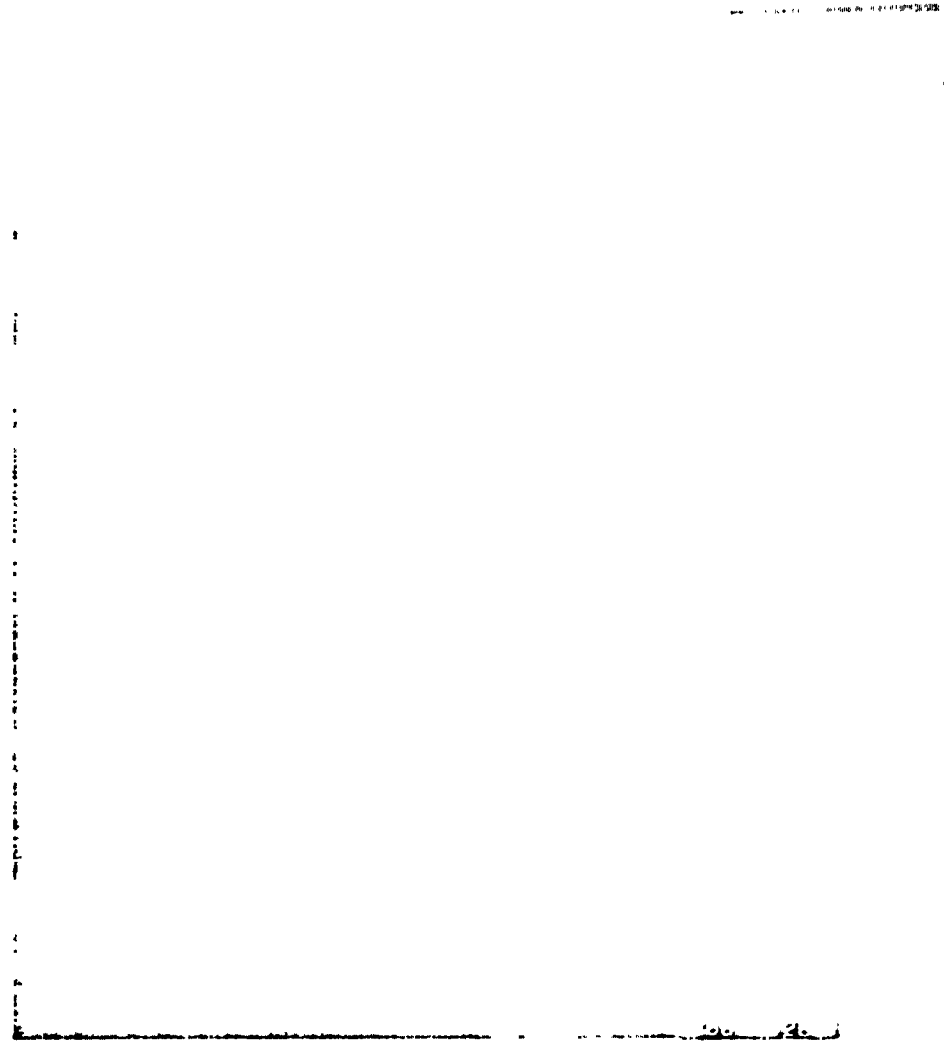
Photograph 11. AM1 mat item 2 after 1200 passes of 39,000-lb single-wheel load



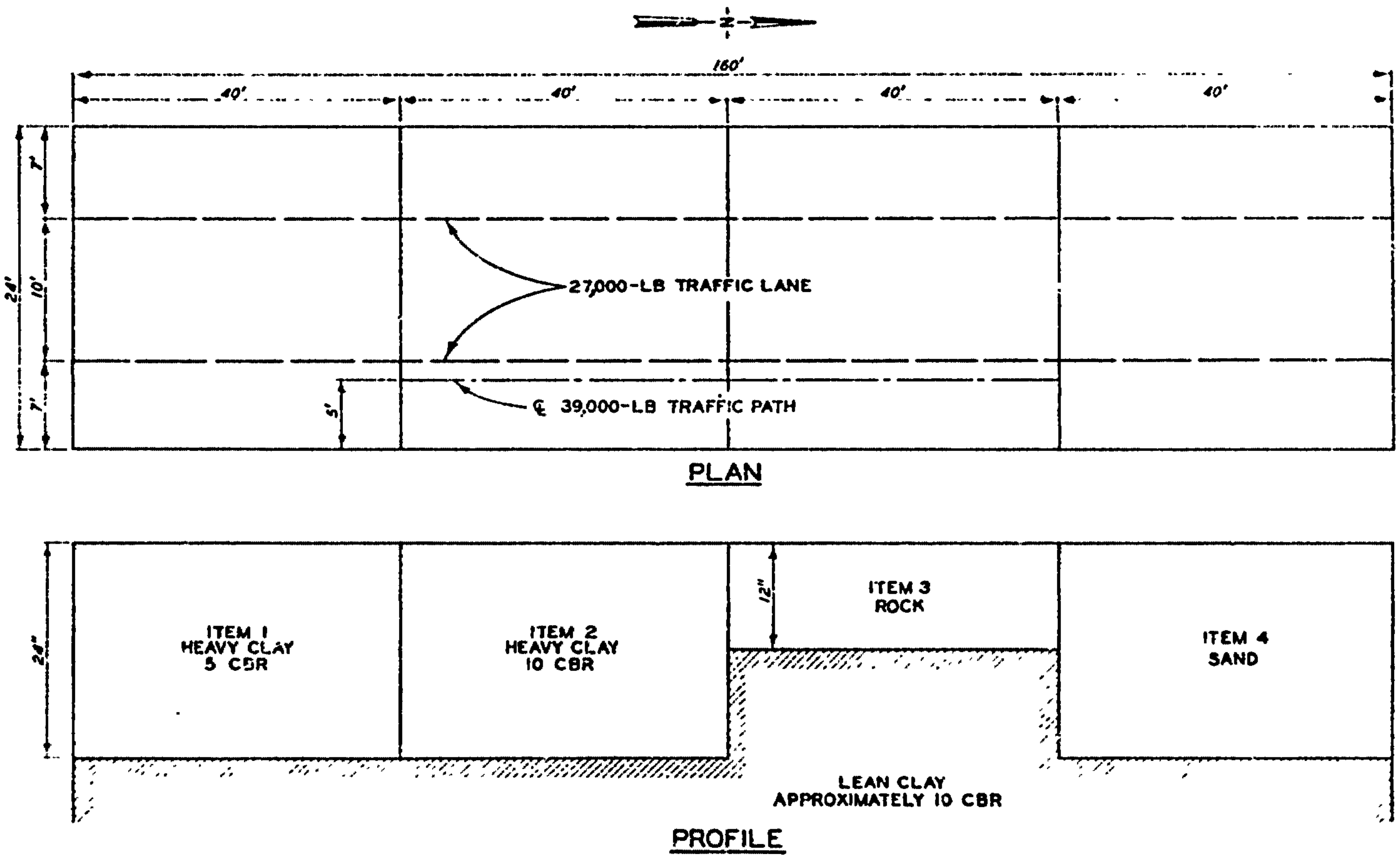
Photograph 12. AM1 mat item 3 after 1200 passes of 39,000-lb single-wheel load



Photograph 13. AM1 mat item 4 after 1200 passes of 39,000-lb single-wheel load



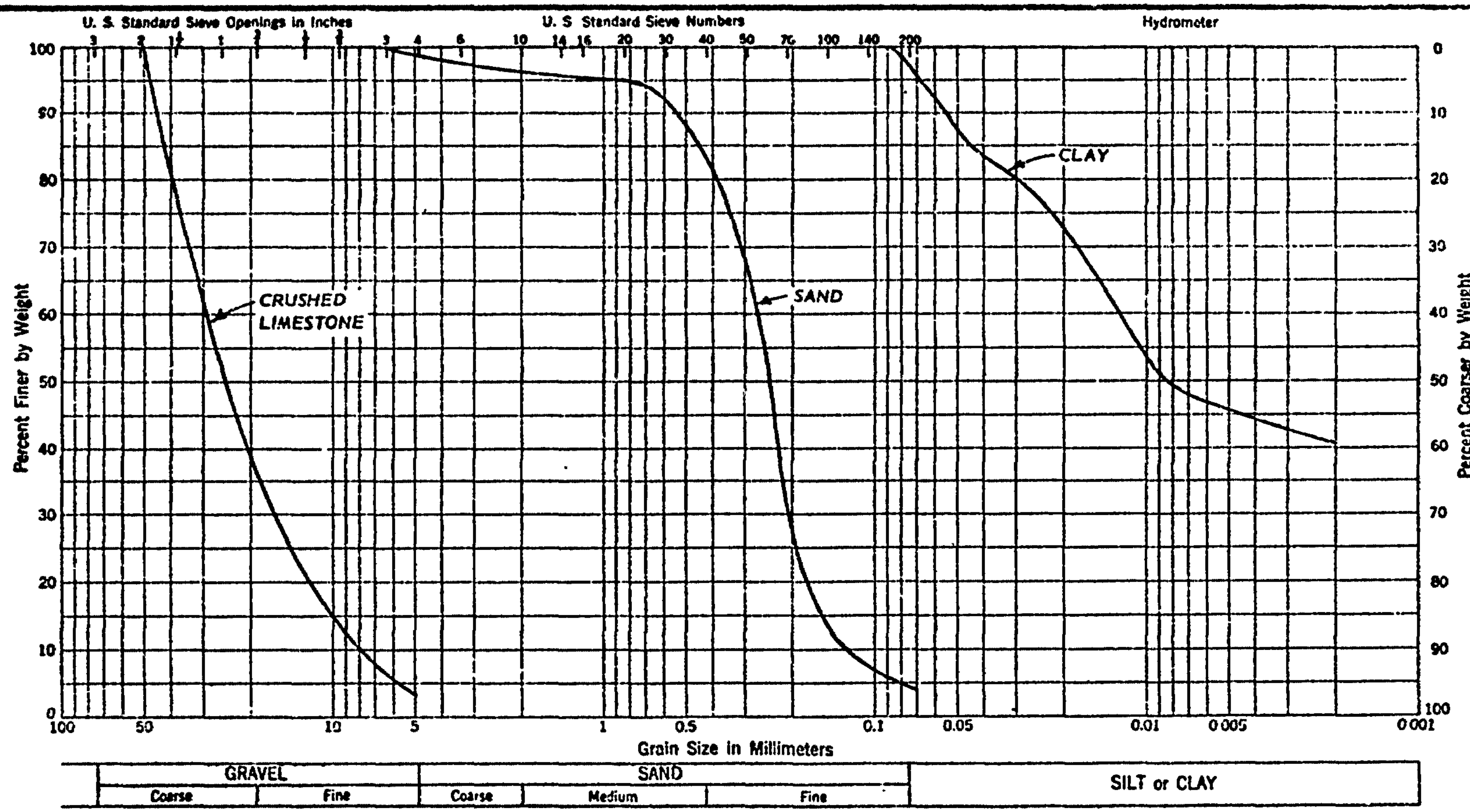
Photograph 14. AM1 mat item 5 after 750 passes of 39,000-lb single-wheel load



FENESTRA MARK III MAT

TEST SECTION LAYOUT

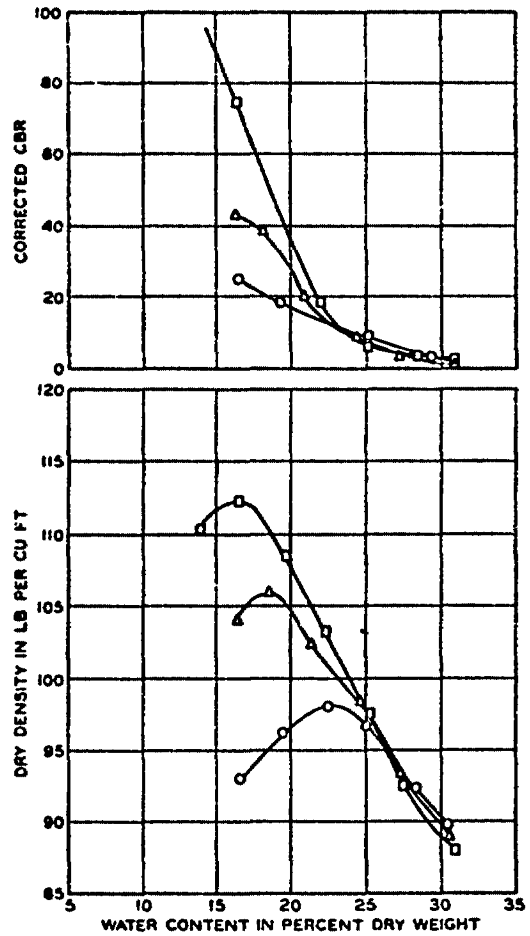
012153A



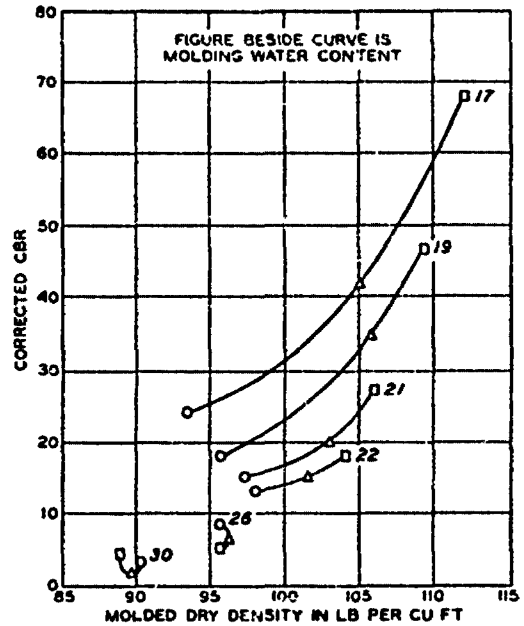
Number	Depth	Natural Moisture	L. L.	P. L.	P. I.	Classification
			56	23	33	HEAVY CLAY (BUCKSHOT), CH

CLASSIFICATION DATA
SUBGRADE MATERIALS

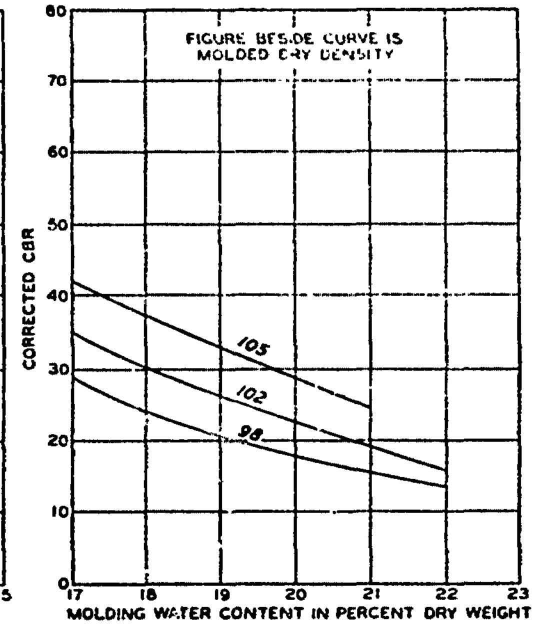
0121633



MOLDING WATER CONTENT VS DENSITY AND CBR



DENSITY VS CBR



WATER CONTENT VS CBR

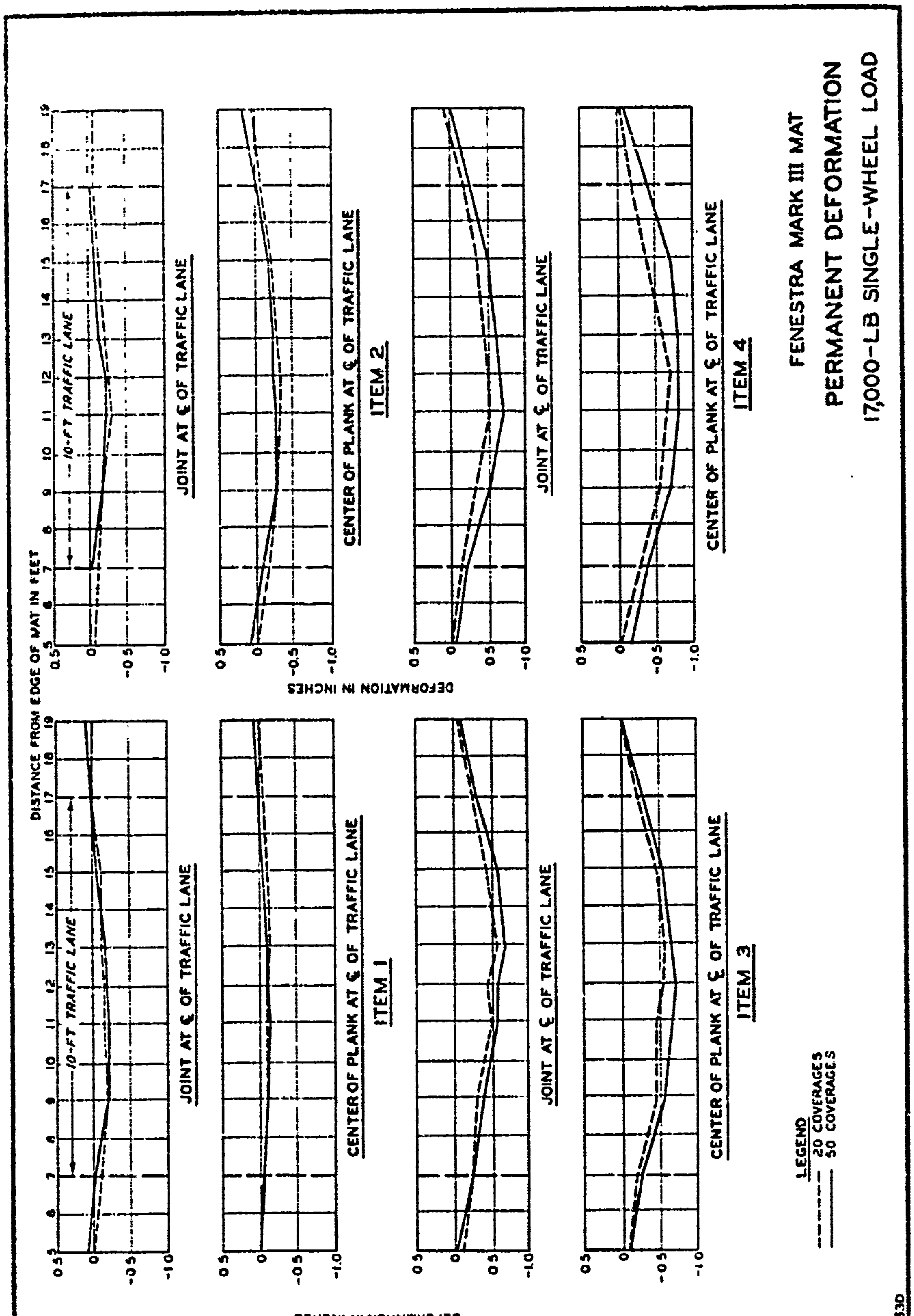
LEGEND

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

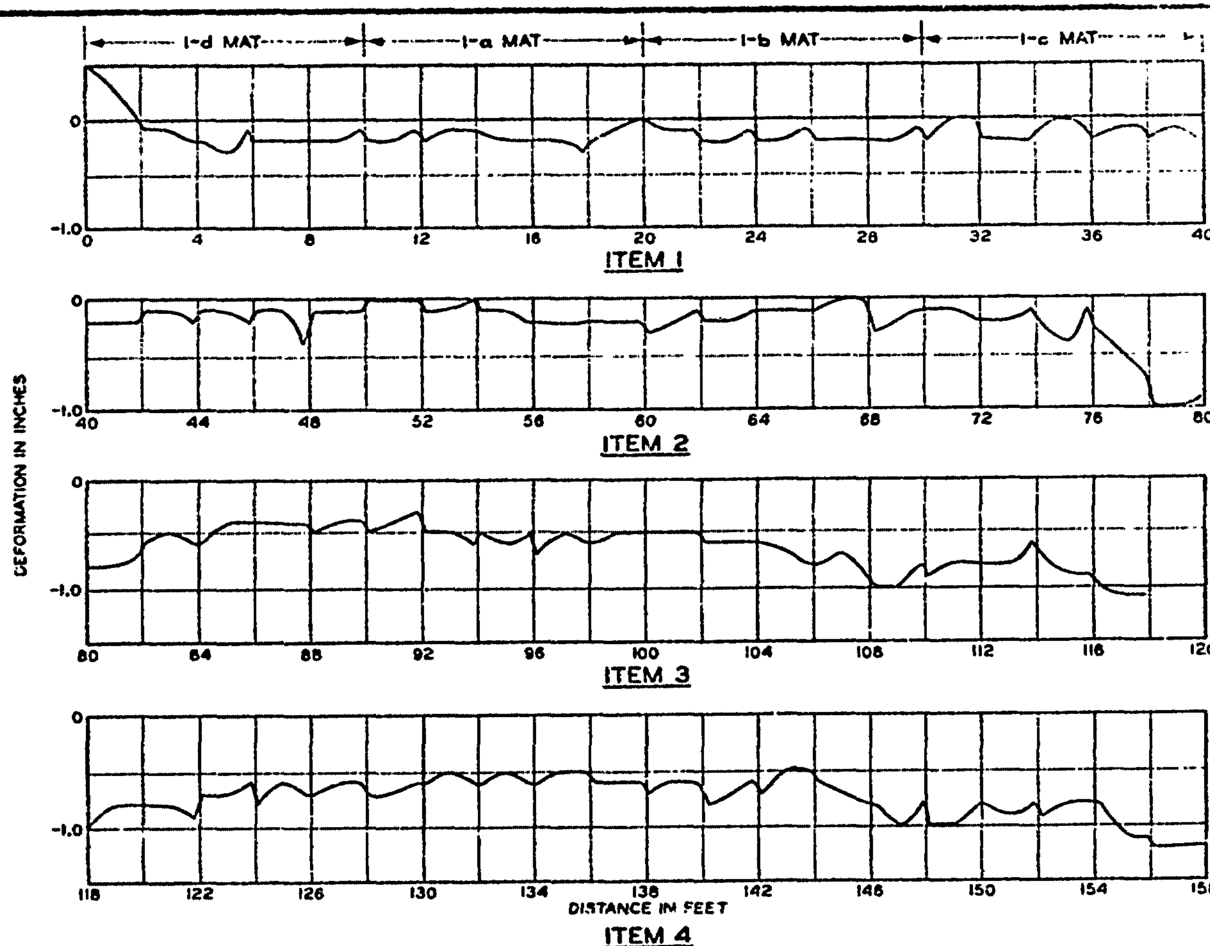
HEAVY CLAY (CH)
(UNSOAKED)

012163 C



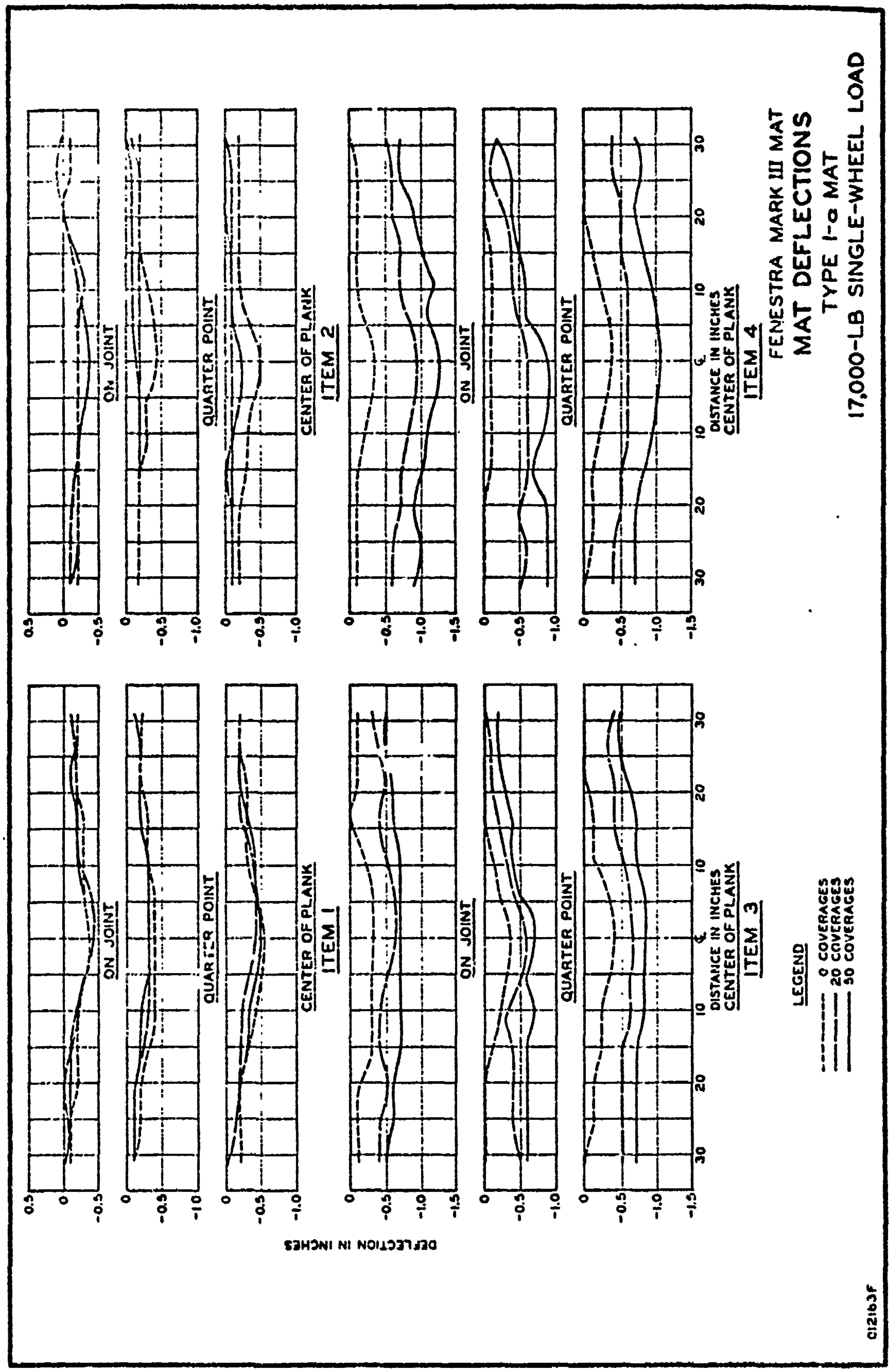
FENESTRA MARK III MAT
PERMANENT DEFORMATION
17,000-LB SINGLE-WHEEL LOAD
DISTANCE FROM EDGE OF MAT IN FEET
DEFORMATION IN INCHES
10-FT TRAFFIC LANE
JOINT AT ℄ OF TRAFFIC LANE
CENTER OF PLANK AT ℄ OF TRAFFIC LANE
ITEM 1
ITEM 2
ITEM 3
ITEM 4
LEGEND
20 COVERAGES
50 COVERAGES
012163D

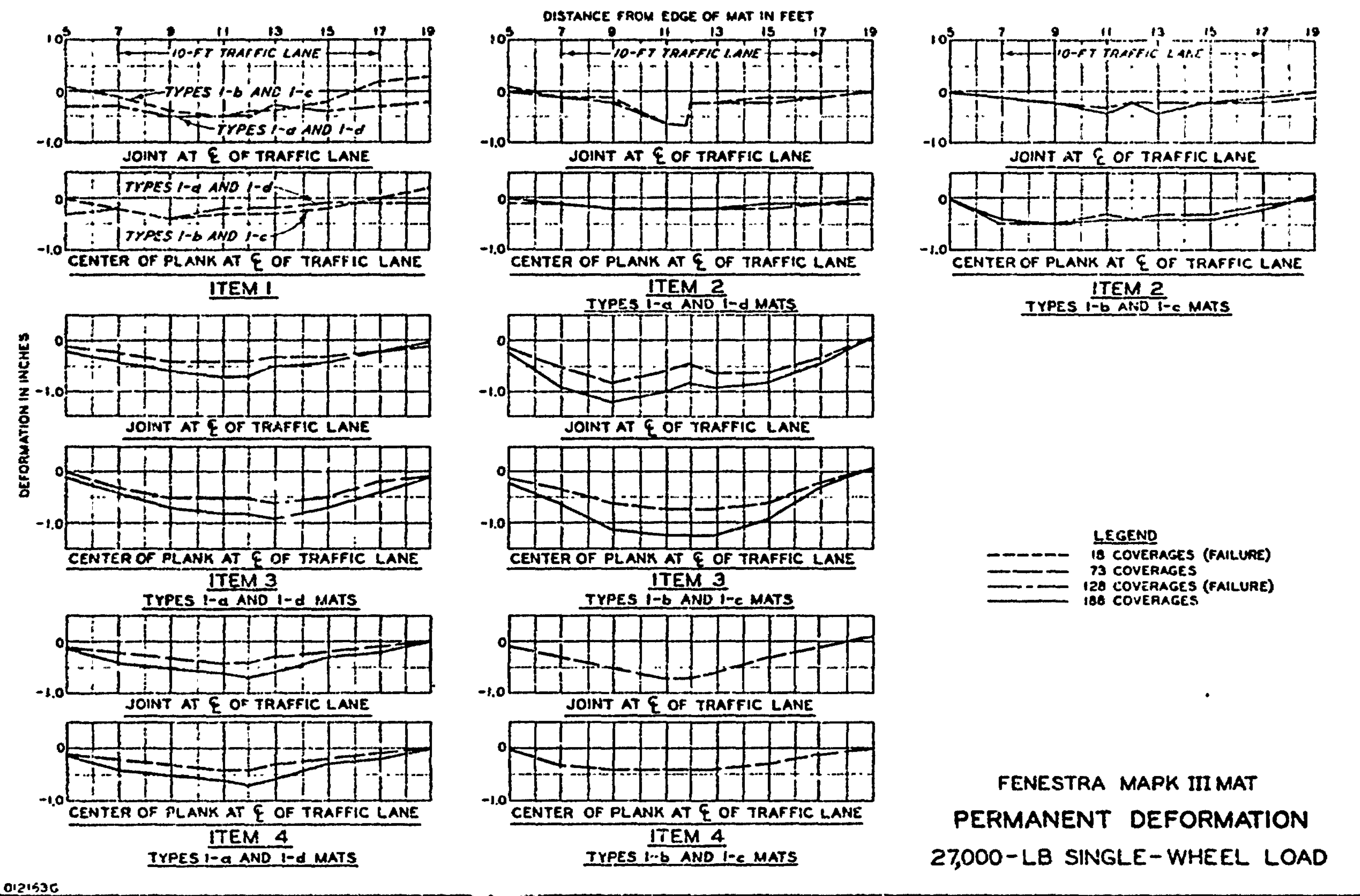
PLATE 4



FENESTRA MARK III MAT
CENTER-LINE PROFILES
17,000-LB SINGLE-WHEEL LOAD
50 COVERAGES

012163 E

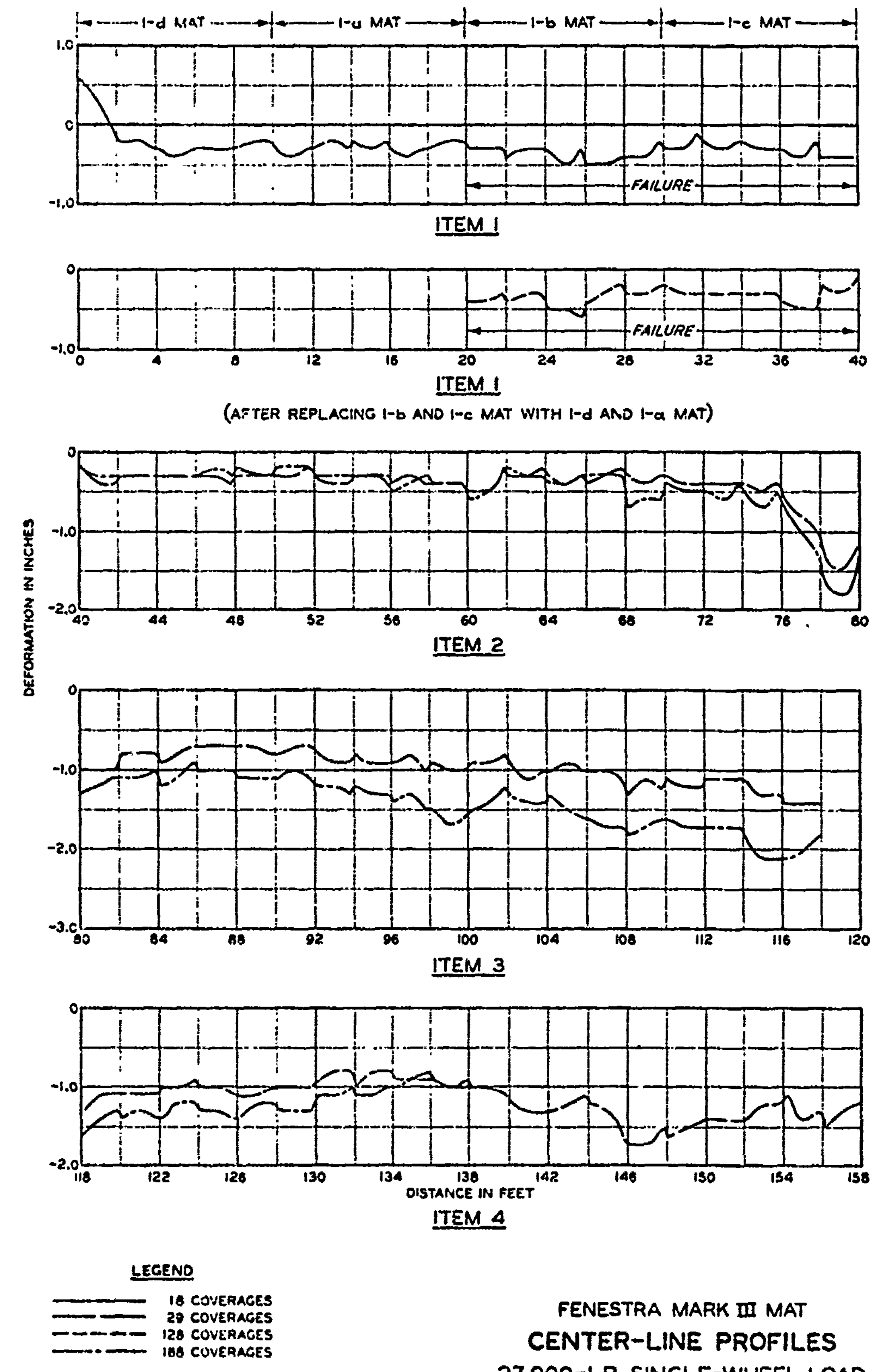

FENESTRA MARK III MAT
MAT DEFLECTIONS
TYPE I-a MAT
17,000-LB SINGLE-WHEEL LOAD
ON JOINT
QUARTER POINT
CENTER OF PLANK
ITEM 1
ITEM 2
ITEM 3
ITEM 4
DISTANCE IN INCHES
CENTER OF PLANK
DEFLECTION IN INCHES
LEGEND
0 COVERAGES
20 COVERAGES
50 COVERAGES
0.5
0
-0.5
-1.0
-1.5
30
20
10
℄
CI2163F



FENESTRA MAPK III MAT

PERMANENT DEFORMATION

27,000-LB SINGLE-WHEEL LOAD

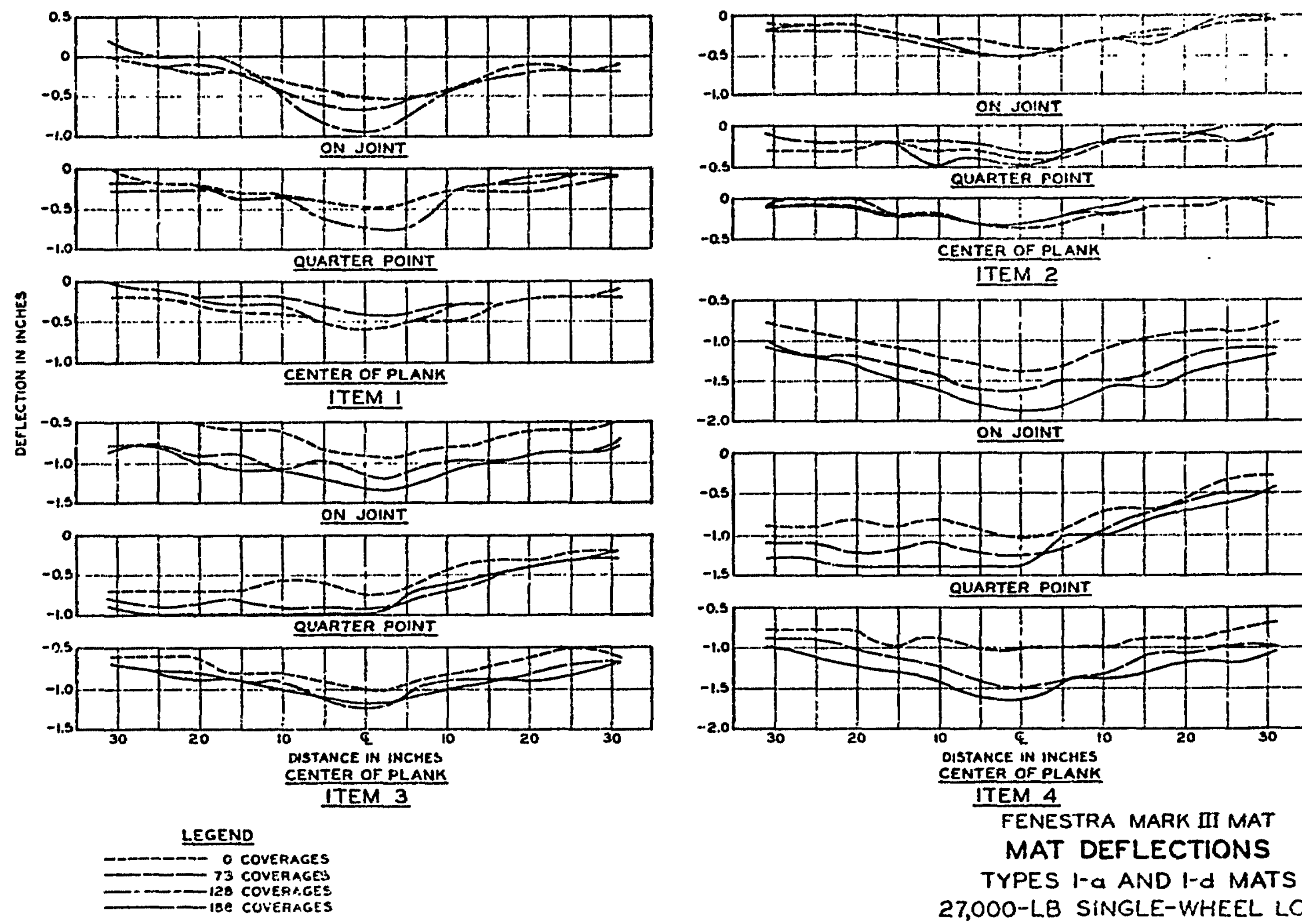


FENESTRA MARK III MAT

CENTER-LINE PROFILES

27,000-LB SINGLE-WHEEL LOAD

012163 H

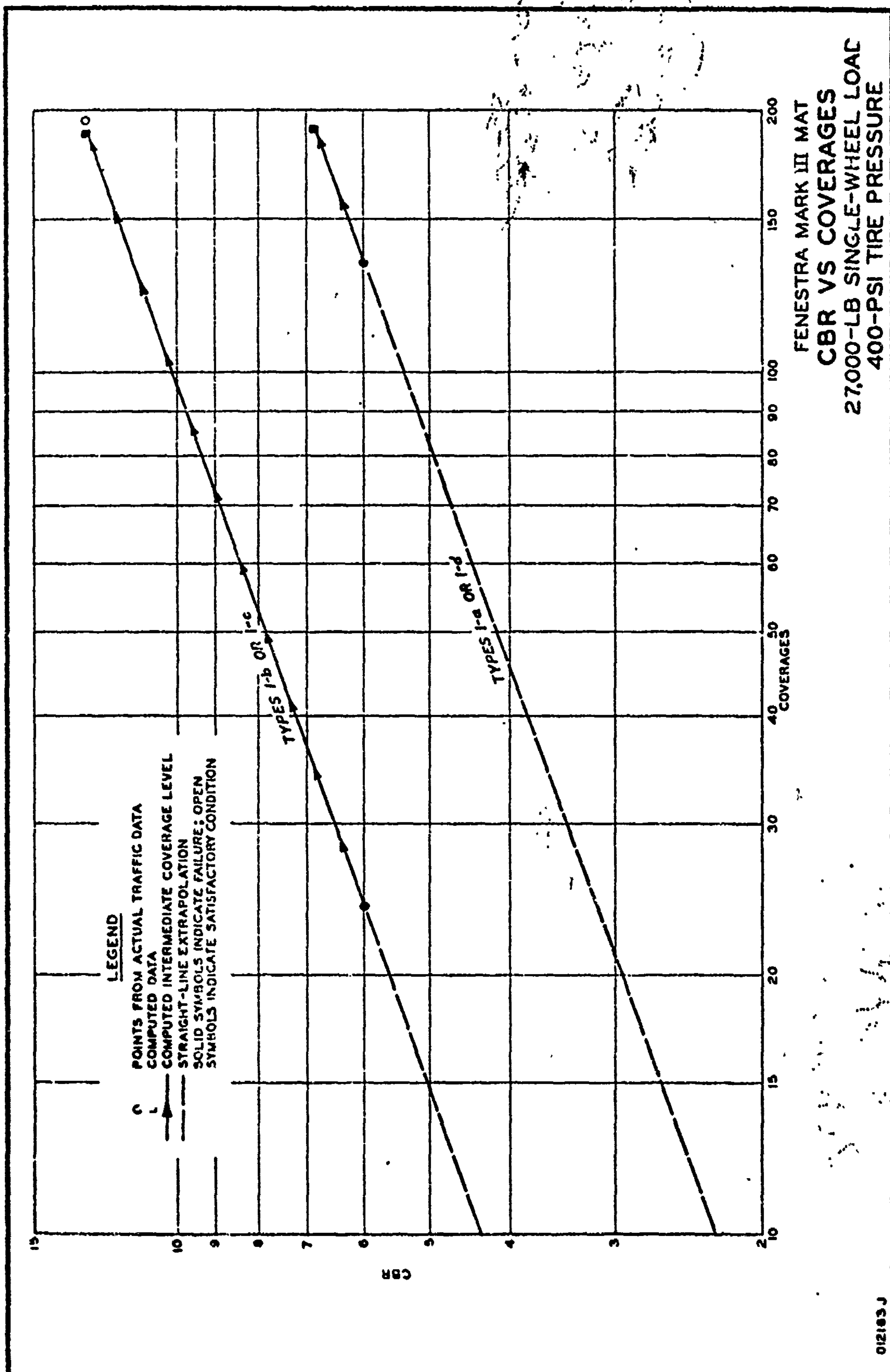


FENESTRA MARK III MAT

MAT DEFLECTIONS

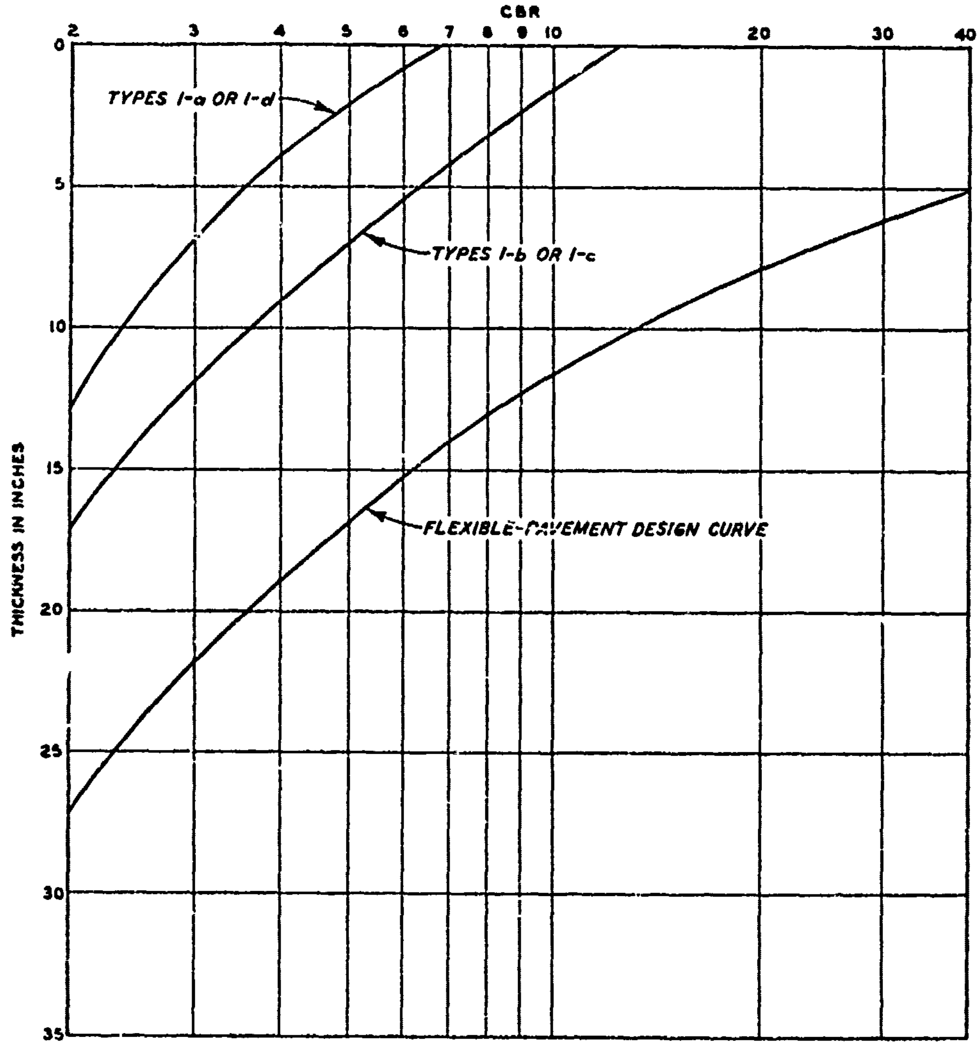
TYPES I-a AND I-d MATS

27,000-LB SINGLE-WHEEL LOAD



FENESTRA MARK III MAT
CBR VS COVERAGES
27,000-LB SINGLE-WHEEL LOAD
400-PSI TIRE PRESSURE
LEGEND
POINTS FROM ACTUAL TRAFFIC DATA
COMPUTED DATA
COMPUTED INTERMEDIATE COVERAGE LEVEL
STRAIGHT-LINE EXTRAPOLATION
SOLID SYMBOLS INDICATE FAILURE; OPEN SYMBOLS INDICATE SATISFACTORY CONDITION
TYPES I-b OR I-c
TYPES I-a OR I-d
CBR
COVERAGES
2
3
4
5
6
7
8
9
10
15
10
15
20
30
40
50
60
70
80
90
100
150
200
012183 J

PLATE 10



FENESTRA MARK III MAT

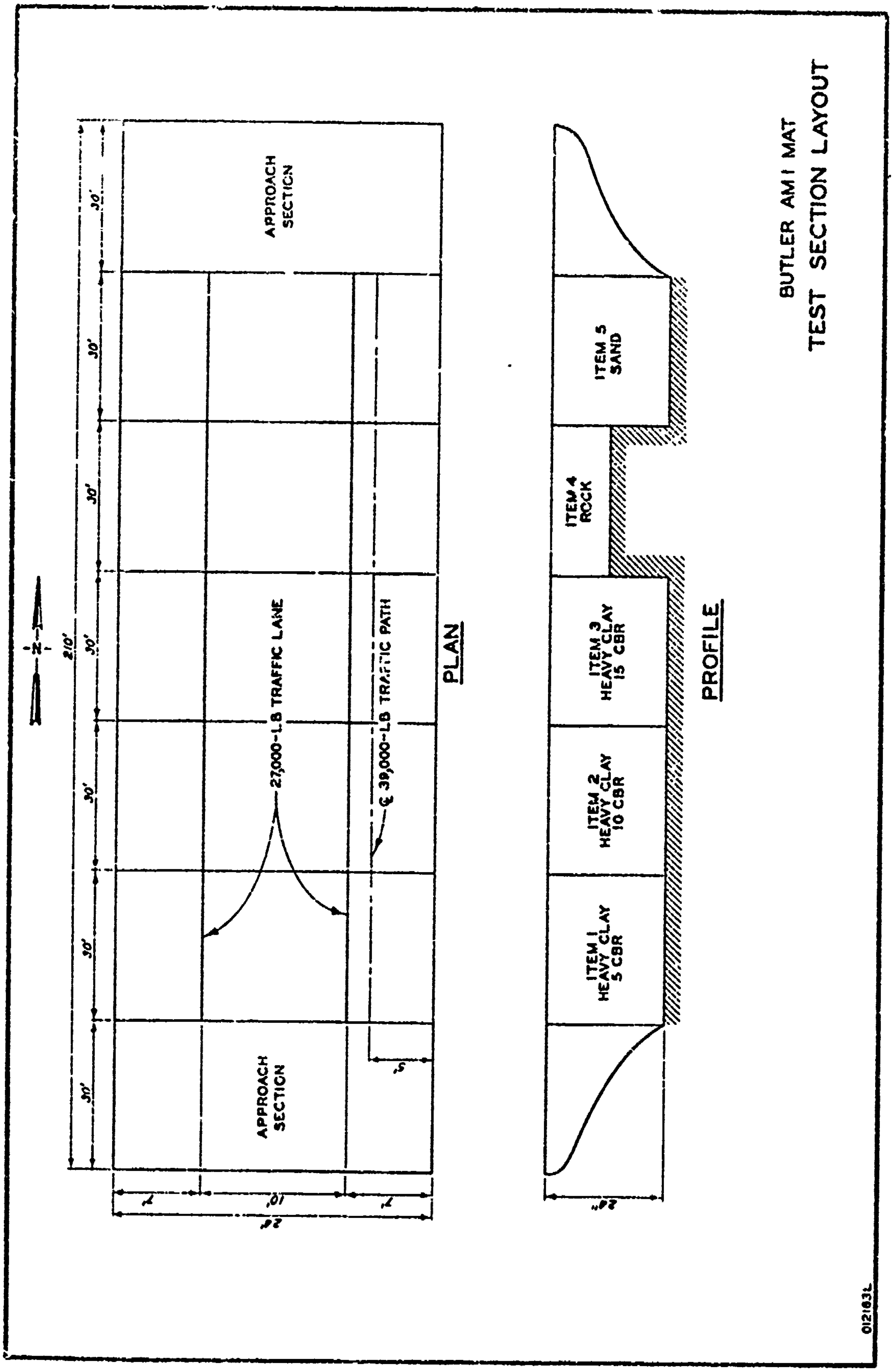
CBR DESIGN CURVES

27,000-LB SINGLE-WHEEL LOAD

400-PSI TIRE PRESSURE

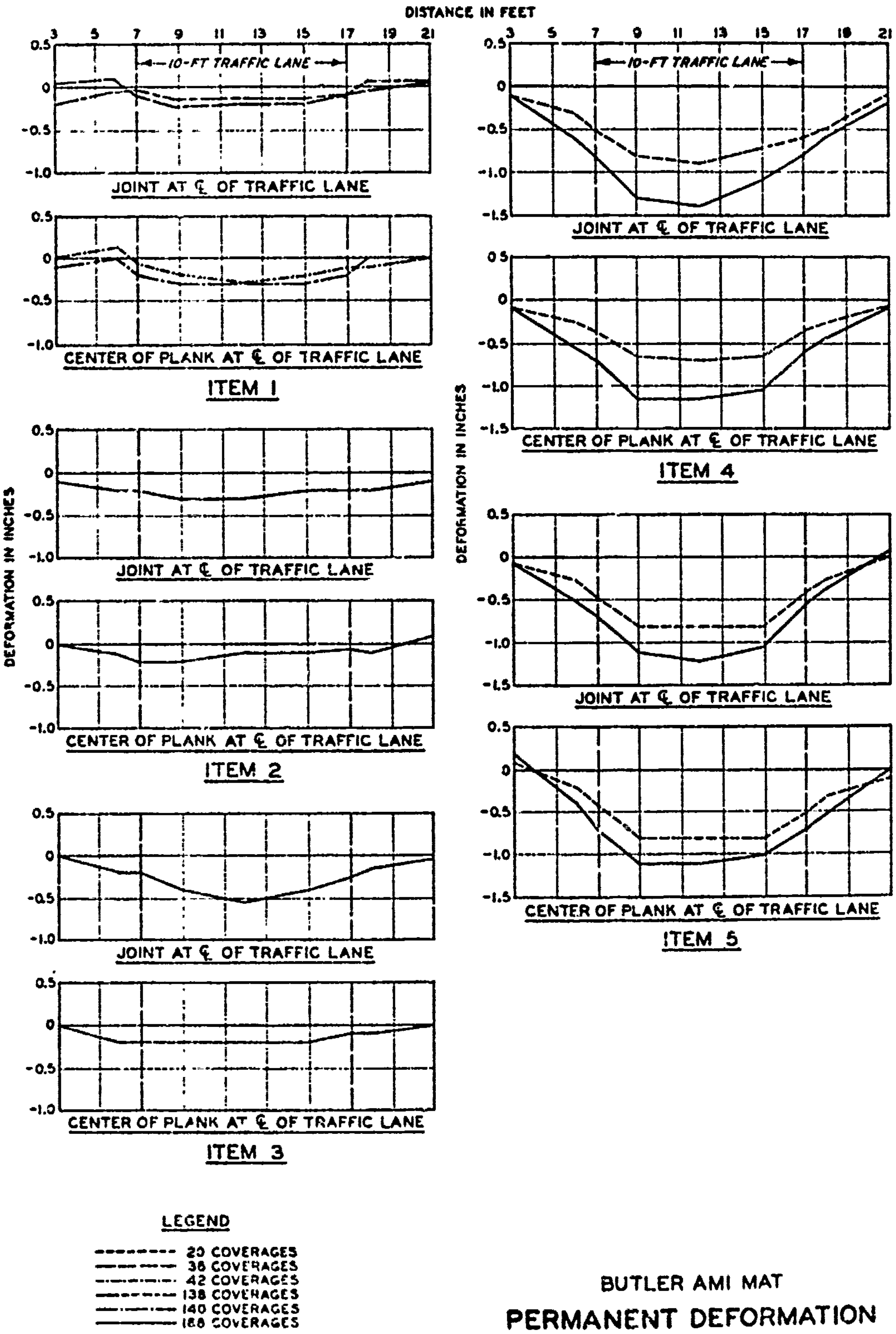
188 COVERAGES

012183K



BUTLER AM 1 MAT
TEST SECTION LAYOUT
APPROACH SECTION
27,000-LB TRAFFIC LANE
℄ 39,000-LB TRAFFIC PATH
PLAN
210'
30'
7'
10'
24'
5'
N
ITEM 1 HEAVY CLAY 5 CBR
ITEM 2 HEAVY CLAY 10 CBR
ITEM 3 HEAVY CLAY 15 CBR
ITEM 4 ROCK
ITEM 5 SAND
PROFILE
012183L

PLATE 12

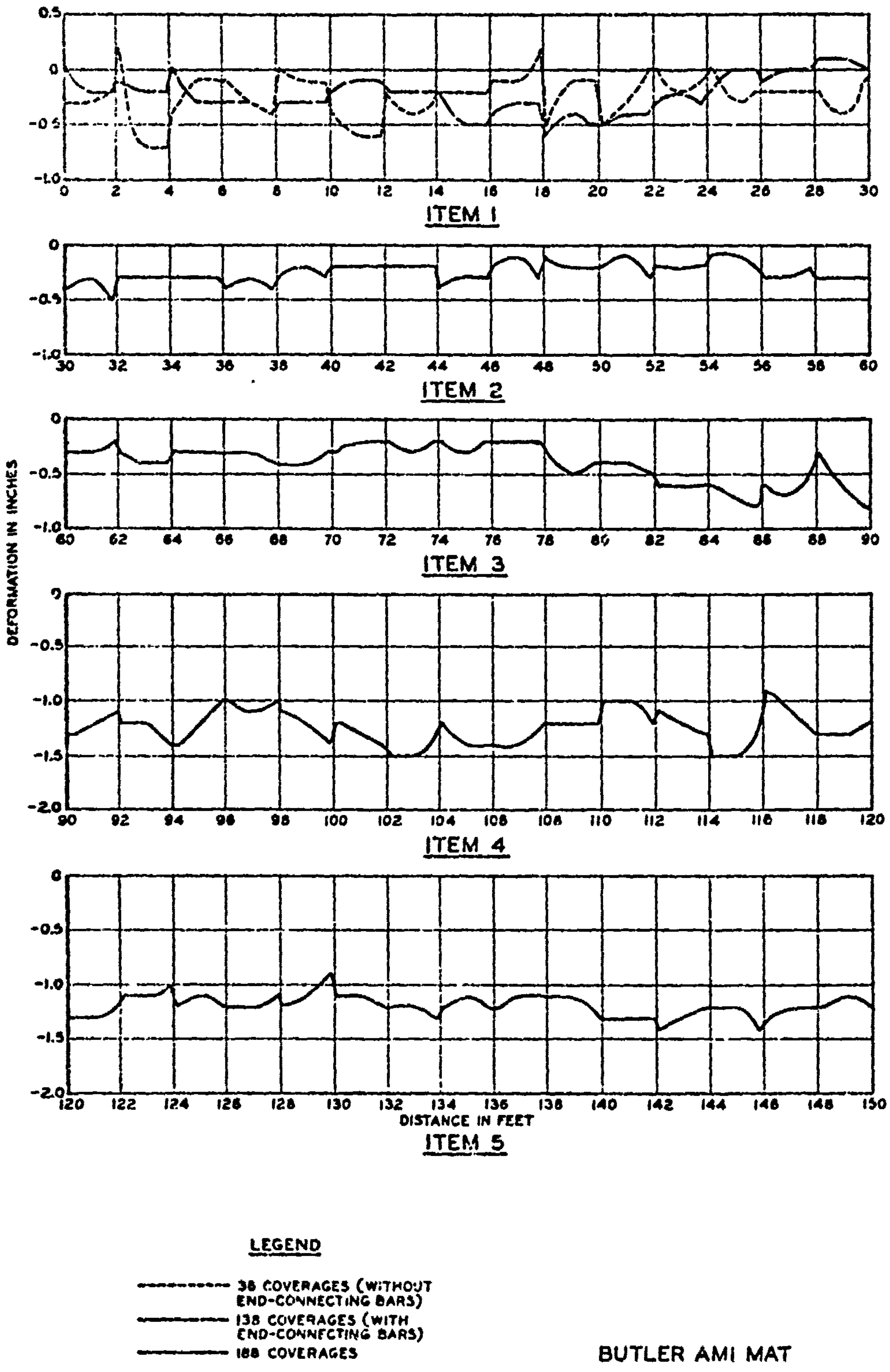


BUTLER AMI MAT

PERMANENT DEFORMATION

27,000-LB SINGLE-WHEEL LOAD

012163M

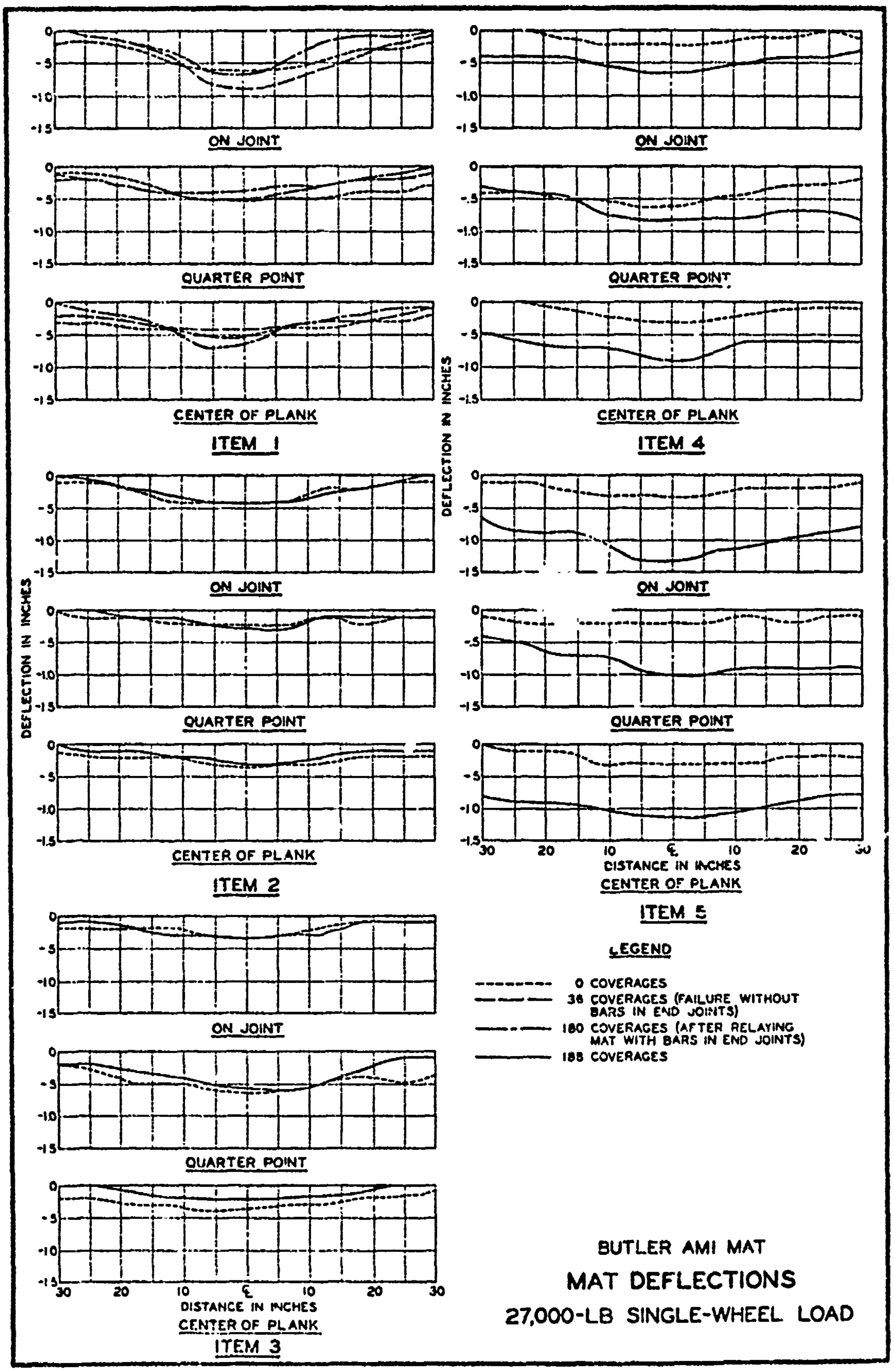


BUTLER AMI MAT

CENTER-LINE PROFILES

27,000-LB SINGLE-WHEEL LOAD

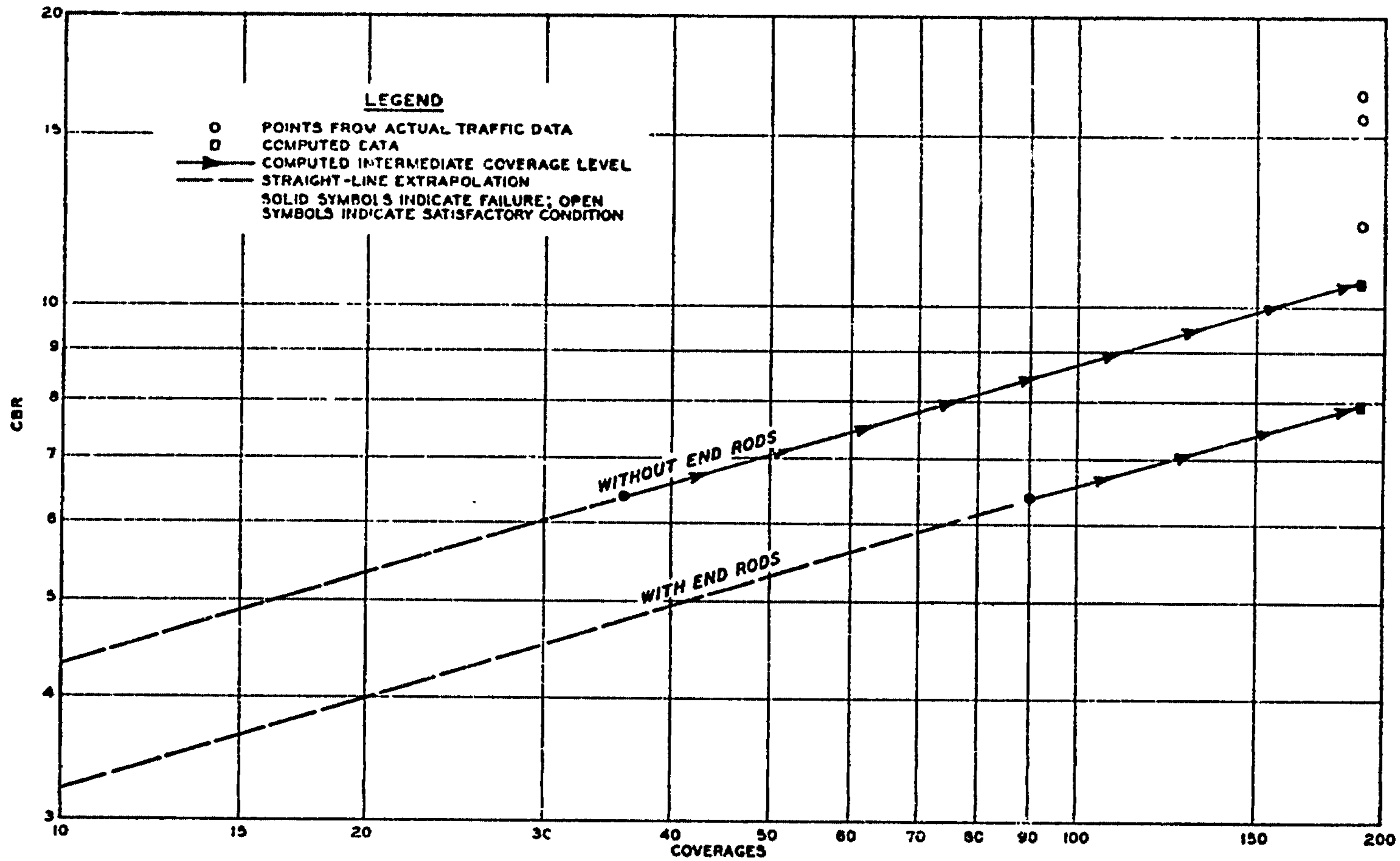
012163 N



BUTLER AMI MAT

MAT DEFLECTIONS

27,000-LB SINGLE-WHEEL LOAD

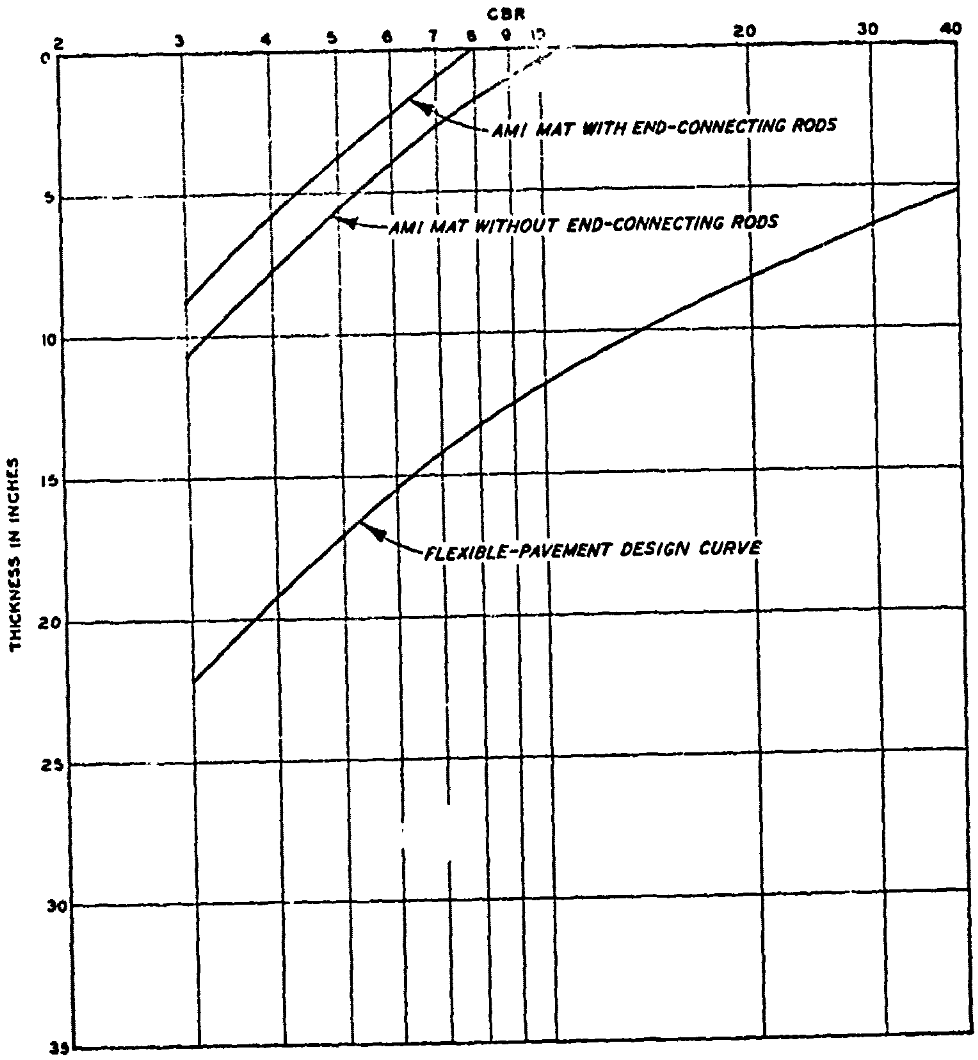


BUTLER AMI MAT

CBR VS COVERAGES

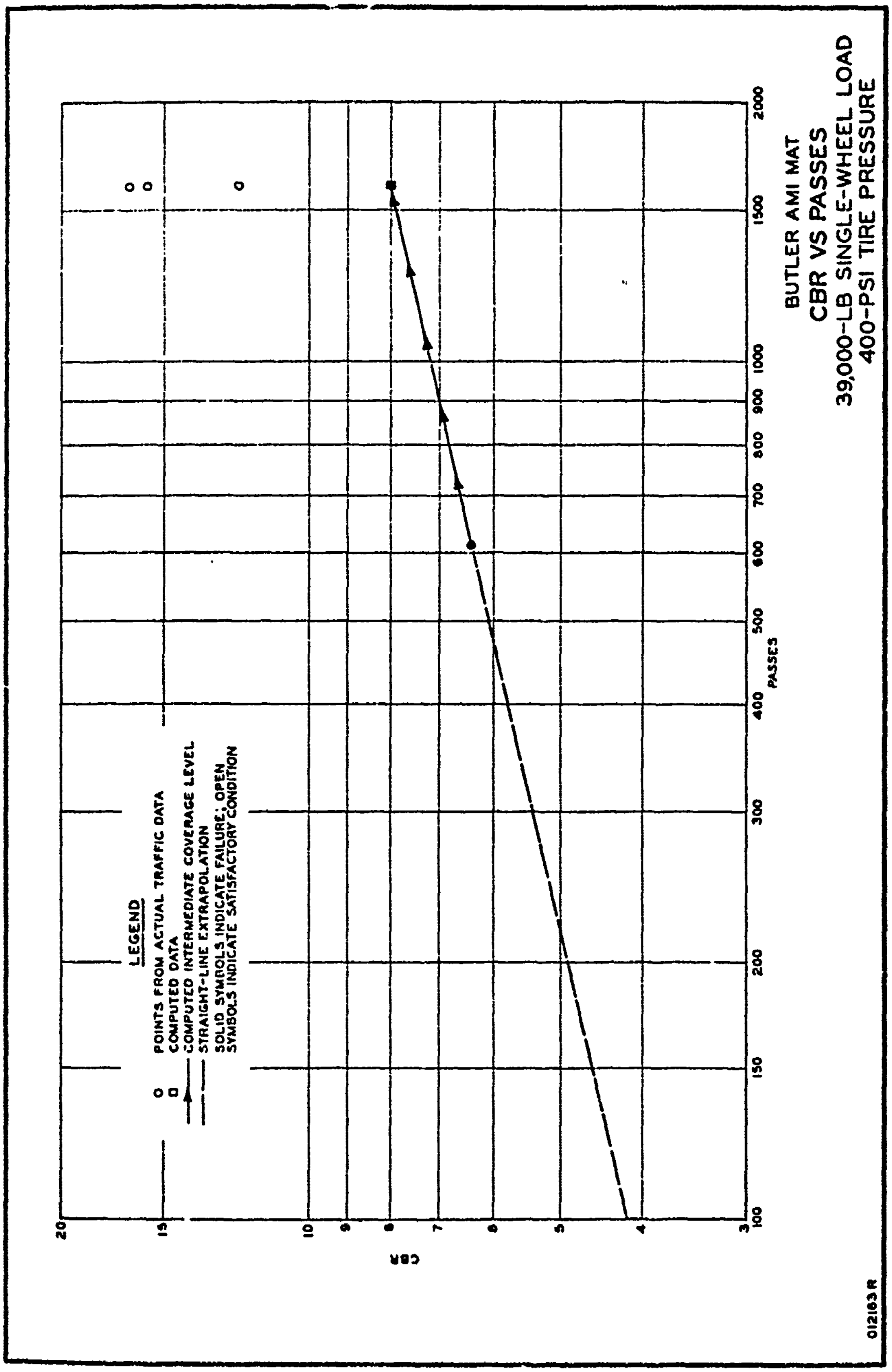
27,000-LB SINGLE-WHEEL LOAD
400-PSI TIRE PRESSURE

012163 P



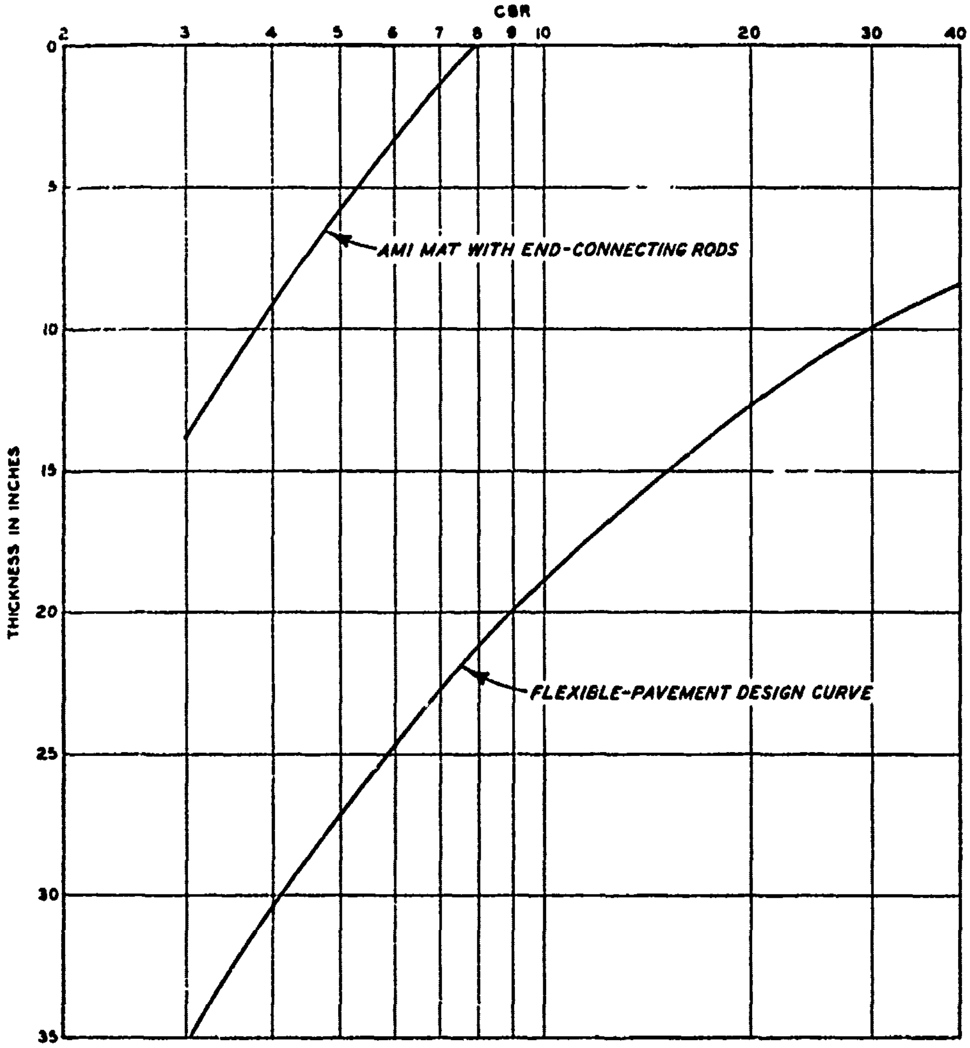
BUTLER AMI MAT
CBR DESIGN CURVES
27,000-LB SINGLE-WHEEL LOAD
400-PSI TIRE PRESSURE
188 COVERAGES

012183Q



BUTLER AMI MAT
CBR VS PASSES
39,000-LB SINGLE-WHEEL LOAD
400-PSI TIRE PRESSURE
LEGEND
POINTS FROM ACTUAL TRAFFIC DATA
COMPUTED DATA
COMPUTED INTERMEDIATE COVERAGE LEVEL
STRAIGHT-LINE EXTRAPOLATION
SOLID SYMBOLS INDICATE FAILURE; OPEN SYMBOLS INDICATE SATISFACTORY CONDITION
CBR
20
15
10
9
8
7
6
5
4
3
PASSES
100
150
200
300
400
500
600
700
800
900
1000
1500
2000
012163 R

PLATE 18



BUTLER AMI MAT

CBR DESIGN CURVES

39,000-LB SINGLE-WHEEL LOAD

400-PSI TIRE PRESSURE

1600 PASSES

0121635