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EVALUATION OF HARVEY ELECTRON BEAM WELDED AM2 LANDING MAT (AM2 MOD 2)

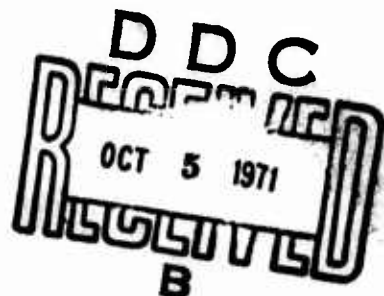
by

C. D. Burns

D. P. Wolf



April 1969



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Naval Air Engineering Center
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Conducted by

U. S. Army Engineer Waterways Experiment Station
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Vicksburg, Mississippi

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ASSOCIATED REPORTS

Report No.	Title	Date
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MP 4-581	Evaluation of M9M1 Landing Mat	July 1963
MP 4-599	Development of CBR Design Curves for AM1 Landing Mat	Sept 1963
MP 4-615	Development of CBR Design Curves for Harvey Aluminum Landing Mat (AM2)	Jan 1964
MP 4-655	Development of CBR Design Curve for Modified AM1 Landing Mat	June 1964
MP 4-656	Evaluation of Convair Landing Mat	June 1964
MP 4-747	Evaluation of Harvey Modified AM2 Landing Mat	Oct 1965
MP 4-753	Evaluation of Washington Aluminum Company AM2 Landing Mat	Jan 1966
MP 4-786	Evaluation of Various Sizes of Harvey Aluminum AM2 Landing Mat	Jan 1966
MP 4-787	Evaluation of Various Sizes of Butler AM1 Landing Mat	Jan 1966
MP 4-788	Evaluation of AM2 Landing Mat Replacement Panels and Keylock Assemblies	Jan 1966
MP 4-789	Evaluation of Butler AM2 Landing Mat	Feb 1966
MP 4-850	Evaluation of Guide Rail in Conjunction with Kaiser and Harvey Landing Mat (AM2)	Oct 1966
MP 4-852	Evaluation of Harvey Two-Piece Landing Mat (AM2)	Nov 1966
MP 4-886	Evaluation of Three-Piece AM2 Aluminum Landing Mat	Apr 1967
MP 4-954	Comparative Performance Tests of AM2 Mat from Various Extruders and Fabricators	Dec 1967
MP S-68-11	Evaluation of May Two-Piece AM2 Landing Mat	July 1968
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13. ABSTRACT The investigation reported herein was conducted to evaluate the performance of the electron beam welded AM2 landing mat fabricated by Harvey Aluminum, Inc., Torrance, California. A test section consisting of a heavy clay subgrade was constructed and surfaced with the electron beam welded AM2 mat, which will be known as AM2 mod 2. The test section was subjected to traffic representing 1600 operational cycles of an aircraft having a 60,000-lb gross weight with a single-wheel main-gear assembly load of 27,000 lb and a 30-7.7 tire inflated to 400 psi. Based on the results obtained in this investigation, it is concluded that: (a) the AM2 mod 2 mat will sustain 1600 cycles (188 coverages) of aircraft operations with a 27,000-lb single-wheel load and 400-psi tire inflation pressure when placed on a subgrade having a CBR of 3.6 or greater throughout the period of traffic, and (b) electron beam welding of the end connectors resulted in considerable improvement in performance of the AM2 mod 2 mat over that of AM2 mat tested previously.			

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FOREWORD

This report is the 19th in a series published on landing mat tests performed by the U. S. Army Engineer Waterways Experiment Station (WES) for the Naval Air Engineering Center (NAEC), Philadelphia, Pa. The investigation reported herein was authorized by the NAEC in Project Order No. 8-4050, dated 14 December 1967, and was conducted by the WES during March 1968.

Engineers of the WES Soils Division who were actively engaged in the planning, testing, analyzing, and reporting phases of this investigation were Messrs. R. G. Ahlvin, C. D. Burns, D. P. Wolf, and M. J. Mathews, under the general supervision of Messrs. W. J. Turnbull and A. A. Maxwell, Chief and Assistant Chief, respectively, of the Soils Division. This report was prepared by Messrs. Burns and Wolf.

COL John R. Oswalt, Jr., CE, and COL Levi A. Brown, CE, were Directors of the WES during the conduct of this investigation and the preparation of this report. Mr. J. B. Tiffany and Mr. F. R. Brown were Technical Directors.

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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

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

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
inches	2.54	centimeters
square inches	6.4516	square centimeters
feet	0.3048	meters
square feet	0.092903	square meters
pounds	0.45359237	kilograms
kip	453.59237	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
pounds per cubic foot	16.0185	kilograms per cubic meter

SUMMARY

The investigation reported herein was conducted to evaluate the performance of the electron beam welded AM2 landing mat, fabricated by Harvey Aluminum, Inc., Torrance, California. A test section consisting of a heavy clay subgrade was constructed and surfaced with the electron beam welded AM2 mat, which will be known as AM2 mod 2. The test section was subjected to traffic representing 1600 operational cycles of an aircraft having a 60,000-lb gross weight with a single-wheel main-gear assembly load of 27,000 lb and a 30-7.7 tire inflated to 400 psi.

Based on the results obtained in this investigation, it is concluded that:

- a.* The AM2 mod 2 mat will sustain 1600 cycles (188 coverages) of aircraft operations with a 27,000-lb single-wheel load and 400-psi tire inflation pressure when placed on a subgrade having a CBR of 3.6 or greater throughout the period of traffic.
- b.* Electron beam welding of the end connectors resulted in considerable improvement in performance of the AM2 mod 2 mat over that of AM2 mat tested previously.

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EVALUATION OF HARVEY ELECTRON BEAM WELDED AM2 LANDING MAT (AM2 MOD 2)

BACKGROUND

1. For several years the U. S. Army Engineer Waterways Experiment Station (WES) has been engaged in a study for the Naval Air Engineering Center (NAEC), Philadelphia, Pa., to evaluate various types of landing mats to be used in surfacing small airfields for tactical support (SATS) in combat air operations. A SATS has been defined as a small, quickly constructed, temporary, tactical-support airfield capable of sustaining operations of the Marine Corps' modern jet aircraft, which employ assisted takeoffs and arrested landings.

2. The service criterion established by NAEC for landing mat is that it remain in serviceable condition with minimum maintenance for at least 1600 aircraft operation cycles (one takeoff and one landing) during a 30-day period when supported on a subgrade having a CBR of 10 or less. The heaviest fighter aircraft utilizing SATS at the present time has a gross weight of 60,000 lb,* or a main-gear wheel load of 27,000 lb. The aircraft is equipped with 30-7.7, 18-ply tires with an inflation pressure of 400 psi. Test criteria established by NAEC are that a test section of the particular mat under consideration placed on a subgrade having a CBR of 10 or less remain serviceable with minimum maintenance for (a) 188 coverages (equivalent to 1600 cycles) of the test load applied uniformly over a 10-ft-wide traffic lane, and (b) 1600 passes of the test load applied in a single path (one tire print width). The uniform-coverage traffic simulates landings and normal takeoffs (takeoffs in which no catapult is used), and the single-line traffic simulates takeoff runs in which a catapult system is employed. Only uniform-coverage traffic was applied during this investigation because the primary objective was to evaluate a new fabrication feature, the electron beam welding of the end joints to the planks.

3. The test reported herein was conducted on AM2 mat with electron beam welded end joints. The planks were manufactured and fabricated by Harvey Aluminum, Inc. (hereinafter referred to as Harvey), Torrance, California.

OBJECTIVE AND SCOPE OF INVESTIGATION

Objective

4. The objective of this investigation, which was to evaluate the performance of AM2 mod 2 mat under accelerated traffic tests with loadings contemplated under the SATS concept, was accomplished by:

- a. Conducting accelerated traffic tests on a specially prepared test section surfaced with AM2 mod 2 mat.
- b. Measuring CBR's, densities, and water contents of subgrade materials before and after traffic.
- c. Observing the behavior of the mat and subgrade during trafficking and recording pertinent test data.

Scope

5. This report describes the landing mat used, the test section, the tests conducted, and the results obtained, and gives an analysis of the test data.

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

DEFINITION OF TRAFFIC TERMS

6. Various traffic terms used in this report are defined below:
- a. *Cycle*. One takeoff and one landing of an aircraft. For this test, a cycle is considered to be one round trip or two passes on a runway or taxiway.
 - b. *Pass*. One traverse of a load wheel along a given length of runway, taxiway, or test section surface. Load repetitions applied in a single path (one tire print width) are referred to as passes.
 - c. *Coverage*. One application of the wheel of an aircraft or test load vehicle over the entire area within the limits of the test lane being subjected to traffic. Since the traffic is applied incrementally in passes and the width of each of the passes is equal to one tire print width, the number of passes required to complete one coverage is equal to the test lane width divided by the tire print width.

TEST SECTION

Location

7. The traffic tests were conducted at the WES on a special test section that was constructed and trafficked under shelter in order that water content and strength of the subgrade soil could be controlled.

Description

8. A layout of the test section is shown in plate 1. The test section was approximately 40 ft long and 24 ft wide. The subgrade was constructed of a heavy clay soil. Classification data for the subgrade soil are shown in plate 2.

Subgrade Construction

9. The test section was constructed to a total thickness of 24 in. The existing material at the test site was excavated to a depth of 24 in. below finished grade, and the excavation was backfilled with the special test soil. The soil below the excavation was a lean clay having a CBR value of approximately 10. The subgrade was to be constructed of the heavy clay at water contents that would result in CBR values of approximately 4 after compaction. The soil was processed to the desired water content, hauled to the test site by truck, spread, and compacted in 6-in.-thick lifts. Each lift was compacted by application of eight coverages of a nine-wheel, rubber-tired roller loaded to 45,000 lb with its tires inflated to 90 psi. The CBR, density, and water content of each lift were checked after compaction. The surface of each lift was scarified prior to the placement of the next lift. After placement and compaction of the final lift, the surface of the subgrade was fine-bladed to grade by a motor grader.

MAT

Description

10. The AM2 mod 2 mats were received at the WES in four bundles, each weighing approximately 1590 lb. Full and half planks were packaged in each bundle. The mat planks, approximately 2 ft wide, were fabricated from one extrusion to which end connectors were then electron beam welded. (Electron beam welding is a new process being applied by Harvey.) The formed planks were 12.08 and 6.08 ft long for the full and half planks, respectively, with an average thickness of 1.5 in. The top surface of the planks

was smooth, as the mat was not coated with an antiskid material. The average dimensions and weights of the mat planks were as follows:

	Width ft	Length ft	Thickness in.	Height in.	Weight	
					lb	Lb per Sq ft of Placing Area
Plank:						
Full	2.08	12.08	1.5	--	140.3	5.6
Half	2.08	6.08	1.5	--	70.5	5.6
Bundle:	2.36	12.08	--	20	1590	--

A mat bundle is shown in fig. 1, and a whole and a half plank are shown in fig. 2.

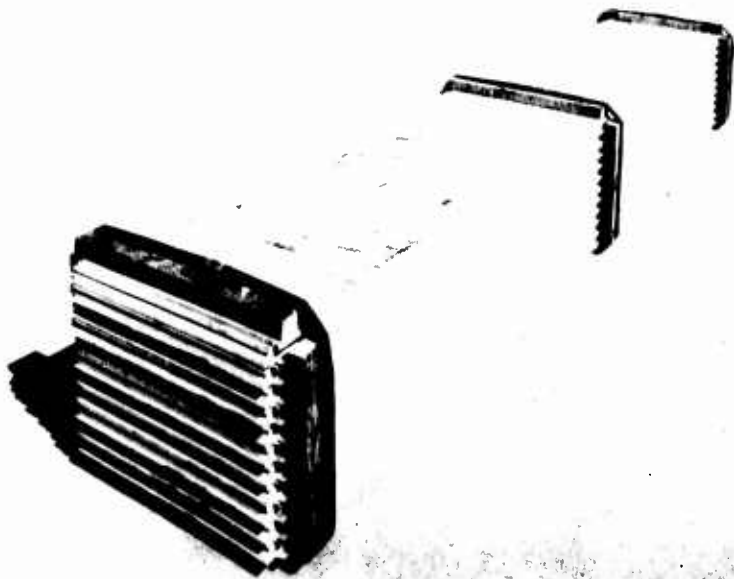


Fig. 1. Bundle of mat as received for testing

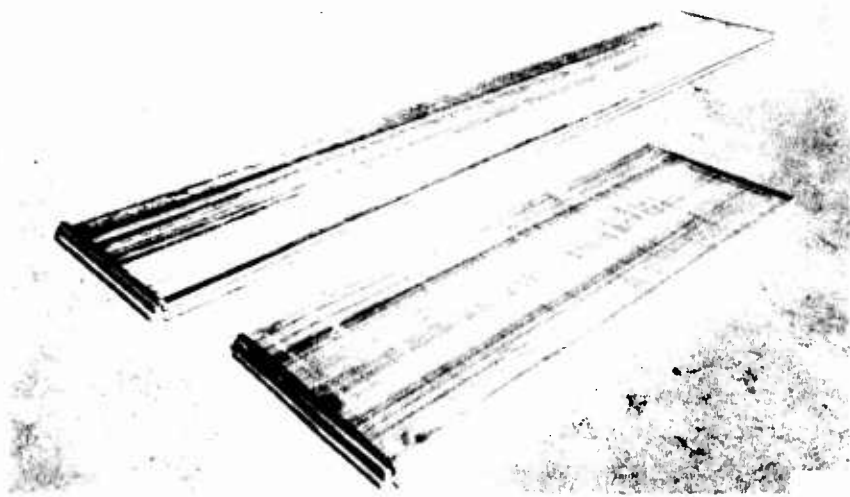


Fig. 2. View of mat showing half plank in foreground

Placement Procedures

11. The mat was placed on the test section by a crew of experienced laborers under the supervision of a foreman. The mat bundles were placed along the test section with a forklift, and the individual planks were carried about 30 ft by laborers and placed in position. One laborer inserted end-connecting bars between the planks at the end joints. The placement rate for the test section was approximately 450 sq ft per man-hour.

12. The entire test section was surfaced with AM2 mod 2 mat placed with the long axis perpendicular to the direction of traffic (plate 1). The surfaced test section was approximately 24 ft wide. The first run of mat consisted of one full plank in the center with half planks on both ends, and the second run consisted of two full planks placed end to end. This alternating pattern was continued throughout the test section for 20 runs, or approximately 40 ft, and provided the staggered joint configuration shown in plate 1.

TEST LOAD CART

13. A specially designed single-wheel test cart (fig. 3) loaded to 27,000 lb was used in the traffic tests. It was equipped with an outrigger wheel to prevent overturning and was powered by the front half of a four-wheel-drive truck. The load cart was equipped with the specified 30-7.7 18-ply rating tire inflated to 400 psi. For the 27,000-lb wheel load, the tire had a contact area of about 82 sq in. and an average contact pressure of 330 psi.

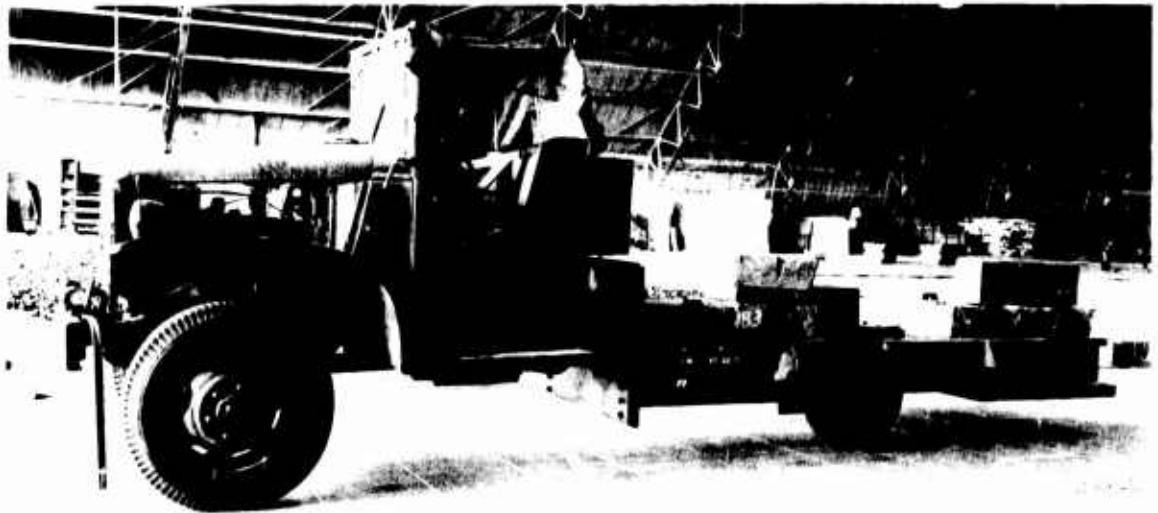


Fig. 3. Load cart used in traffic tests: 27,000-lb single-wheel load, 400-psi tire pressure, and 82-sq-in. tire contact area

TRAFFIC TESTS

14. As stated in paragraph 2, the objective of the uniform-coverage traffic was to simulate a main landing-gear wheel traversing a mat surface during landings and normal takeoffs. Therefore, a 10-ft-wide traffic lane was laid out along the center of the test section, as shown in plate 1. Lead weights were used along the edges of the mat for anchoring and to simulate the weight of the wider section of the mat that would be normally laid on a runway (photograph 1). Traffic was applied by driving the load cart forward

and then backward over the length of the test section, then shifting the path of the cart laterally about 7.3 in. (one tire print width) and applying another two passes. This procedure resulted in two complete coverages of traffic on the test lane each time the load cart was maneuvered from one side of the test lane to the other. Traffic was applied until failure of the mat in the test section had occurred.

SOIL TESTS AND MISCELLANEOUS OBSERVATIONS

15. Water content, density, and in-place CBR tests were conducted prior to and at the end of traffic. These tests were made at 0-, 6-, and 12-in. depths, and at least three tests were made at each depth. The data obtained from the tests are summarized in table 1. The values listed in table 1 corresponding to the various depths are averages of the values measured at each particular depth.

16. Visual observations of the behavior of the test section and other pertinent data were recorded throughout the traffic test period. These observations were supplemented by photographs. Level readings were taken on the mat prior to trafficking, at intervals during traffic, and at the end of traffic to show the development of permanent mat deformation and deflection of the mat under the wheel load.

FAILURE CRITERIA

17. The criteria for mat failure were the same as those used in previous tests of this series, and are based primarily on mat breakage. It was assumed that a certain amount of maintenance would be performed in the field during actual usage and that minor metal or weld breaks could be easily repaired. It is considered feasible to replace up to 10 percent of the AM2 planks with new mat during the design service life of a runway; however, replacement in excess of 10 percent of the planks is not considered practical. Therefore, in this test, it was assumed that up to 10 percent of the mat planks could be replaced, and when an additional 10 percent of the planks had failed (a total of 20 percent failed), the entire test section was considered failed.

BEHAVIOR OF MAT UNDER TRAFFIC

Visual Observations

18. A general view of the test section prior to traffic is shown in photograph 1. Mat breakage was first noted at 10 coverages, with hairline weld cracks developing along the underlapping end connector at the C-rail corner. At 40 coverages, eight planks were damaged in this manner, and the length of the cracks averaged about 5/8 in. Weld cracks had also developed in the same location along the overlapping end connector in five planks and averaged about 3/8 in. in length. The weld cracks progressed very little after 40 coverages, and at 188 coverages had increased to about 3/4 in. in length. Curling of the overlapping end-connector corner was observed in six planks, but neither the weld cracks nor the curling was considered a hazard to aircraft operations. A view of typical curl and weld cracks at 188 coverages is shown in photograph 2. The mat in the traffic lane was considered in good condition at 188 coverages (photograph 3).

19. Traffic was continued to determine how many coverages would be required to fail the entire section. The first sign of major distress occurred at 238 coverages, with an underlapping end-connector failure and a top skin tear on plank 32, as shown in photograph 4. The plank was replaced, and traffic was resumed. Similar breaks developed in six more planks and had become so severe at 346 coverages that the test section was considered failed. Photograph 5 shows skin tears along the C-rail side at both the overlapping

and underlapping end connectors. Six planks also showed signs of internal rib failure. Photograph 6 shows a cross section of a plank with interior damage along the C-rail connector. A general view of the test section at failure is shown in photograph 7.

20. An inspection of the mat after removal from the section revealed the C-rail had split in five planks, as shown in photograph 8. These breaks averaged about 10-1/2 in. in length. The C-rail was also damaged at the corner of the overlapping and underlapping end connectors in 15 planks. These breaks averaged about 15 in. in length. Bottom skin tears, averaging 3/4 in., were also noted in six planks. A typical view of these breaks is shown in photograph 9.

Permanent Deformation

21. Plots showing permanent mat deformation as determined from level readings taken prior to and at intervals during traffic are shown in plate 3. The cross sections were taken at several locations, and the results shown in plate 3 are averages of all the readings. Two types of locations were measured: one with the center of a plank at the center line of traffic, and the other with a plank joint at the center line of traffic. These data indicate that the greatest average deformation, about 0.65 in., occurred at a plank joint after 346 coverages. A plot of deformation along the center line of the traffic lane is shown in plate 4.

Elastic Mat Deflection

22. Elastic deflections of the mat surface prior to and after traffic are shown in plate 5. These plots indicate the elastic deflection, or rebound, of the mat as the wheel load moved over the surface. The data for the first plot were taken with the load wheel centered on the midpoint of a plank, and the data for the second plot were taken with the wheel centered on the joint of two planks. In both cases, the load wheel was positioned in the center of the traffic lane.

23. The plots indicate that the change in elastic deflection over the trafficking period was negligible. The maximum deflection, about 0.80 in., occurred at the plank joint after 346 coverages. At 0 coverages the deflection at the same point averaged about 0.65 in.

ANALYSIS OF RESULTS

24. The test results are summarized in table 2. Included in the table are the rated subgrade CBR, mat breakage and deflection data taken at various stages of traffic, and the performance rating of the test section based on the failure criteria described in paragraph 17. The rated CBR is based on the numerical average of the CBR values measured at 0-, 6-, and 12-in. depths prior to and at the end of the traffic period (table 1). The soil strength of the test section was rated at 4 CBR.

25. The test section performed satisfactorily through 188 coverages and met the service criterion outlined in paragraph 2. Although several planks had developed small hairline weld cracks and some curling of plank corners was noted, the condition of the test section was not considered a hazard to aircraft operations at this time. Traffic was continued to determine the number of coverages required to fail the test section. After 346 coverages had been completed, the test section was considered failed due to internal rib failures and excessive breakage of the top skin.

26. A plot of CBR versus coverages is shown in plate 6. The rated CBR value listed in table 2 for the clay subgrade was plotted at the corresponding number of coverages at the end of traffic. From previous tests on landing mats, it has been established that the CBR-coverage relation for landing mat is essentially

a straight line when plotted to a log-log scale. By the use of the CBR equation,* the CBR versus coverages plot in plate 6 was obtained by extrapolation from the known failure point at 346 coverages. Therefore, the linear projection indicates the CBR required to support the test load for various coverage levels. The indicated CBR required to support 188 coverages is about 3.6.

27. Plate 7 shows a CBR design curve 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 curve for the Harvey mat was developed as follows. In plate 6 it is shown that a subgrade with a CBR of 3.6 will support the 27,000-lb wheel load for 188 coverages when surfaced with AM2 mod 2. It can be seen from plate 7 that a flexible pavement design based on a subgrade CBR of 3.6 will require 20.2 in. of base course. In prior similar studies, CBR design curves have been developed by merely reducing standard curve thicknesses by the thickness pertaining to the 188-coverage service life (20.2 in. in this case). This is assuming that the effective thickness of a mat plus a strengthening layer beneath it will be equal to the total thickness of an equivalent pavement structure. However, studies of soil thickness requirements beneath landing mat being conducted by WES indicate the effective thickness of the mat plus the strengthening layer is only 80 to 85 percent of the simple sum of the two thicknesses. Therefore, the CBR design curve for the AM2 mod 2 mat, also shown in plate 7, was obtained by establishing the layer thickness required so that when the total thickness of the underlying layer plus the effective mat thickness was reduced by 20 percent, it yielded a satisfactory effective combined thickness. The curve is presented tentatively pending the outcome of further study of strengthening layers under landing mat.

DISCUSSION OF RESULTS

28. The electron beam welding of the end connectors to the plank extrusion resulted in a considerable improvement in the performance of the AM2 mod 2 mat in comparison with Harvey AM2 mat previously tested. Although weld cracks were noted, failure of the mat at 346 coverages was due primarily to internal damage and excessive breakage of the top skin, whereas in previous tests on AM2 mat most failures were due to end-joint weld failures.

CONCLUSIONS

29. Based on the data presented in this report, the following conclusions are believed warranted:
- a. The Harvey electron beam welded AM2 will sustain 1600 cycles (188 coverages) of aircraft operations with a 27,000-lb single-wheel load and 400-psi tire inflation pressure when placed on a clay subgrade having a CBR of 3.6 or greater throughout the period of traffic.
 - b. Electron beam welding of the end connectors resulted in considerable improvement in the performance of the AM2 mod 2 mat over that of AM2 mat previously tested.

* U. S. Army Engineer Waterways Experiment Station, CE, "Development of a Set of CBR Design Curves," Instruction Report No. 4, Nov 1959, Vicksburg, Miss.

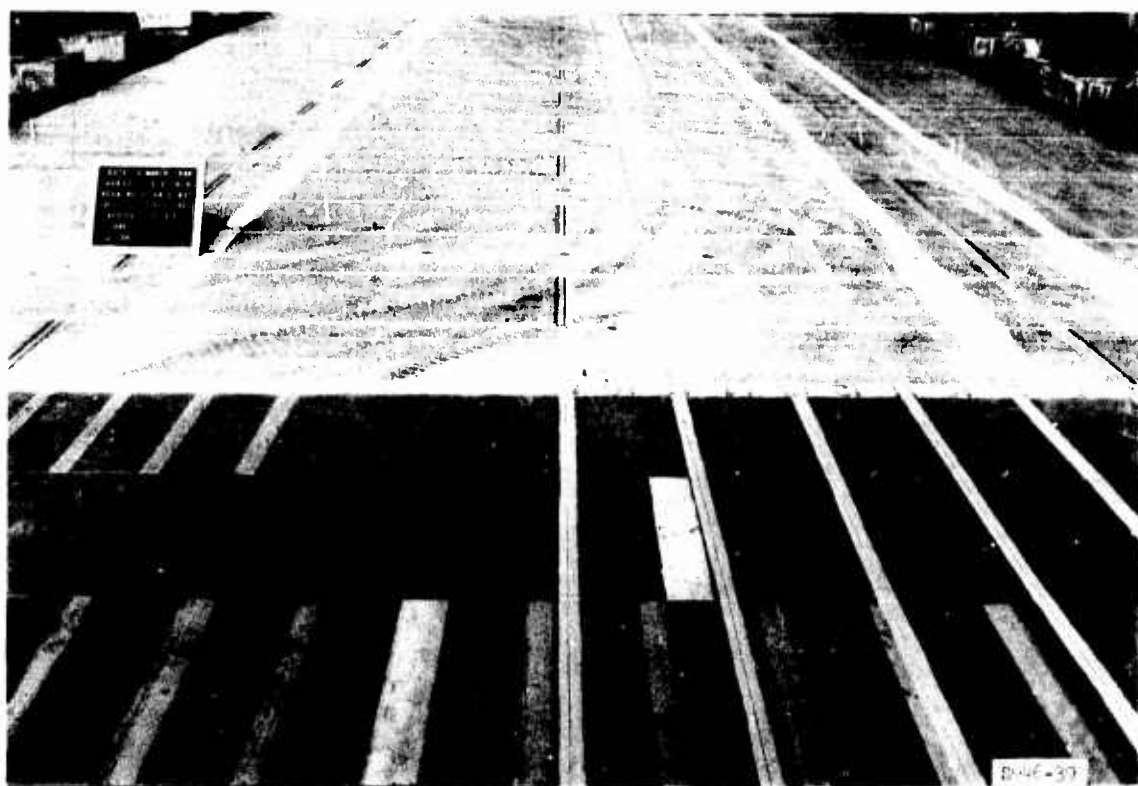
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Table 1
Summary of CBR, Water Content, and Dry Density Data

<u>Subgrade Material</u>	<u>Traffic Coverages</u>	<u>Depth in.</u>	<u>CBR</u>	<u>Water Content, %</u>	<u>Dry Density pcf</u>
Heavy clay	0	0	3.3	31.2	86.4
		6	4.0	29.7	87.6
		12	4.4	28.8	90.4
	346	0	3.6	31.2	87.3
		6	4.4	29.8	89.4
		12	4.0	29.9	88.4

Table 2
Summary of Traffic Test Results

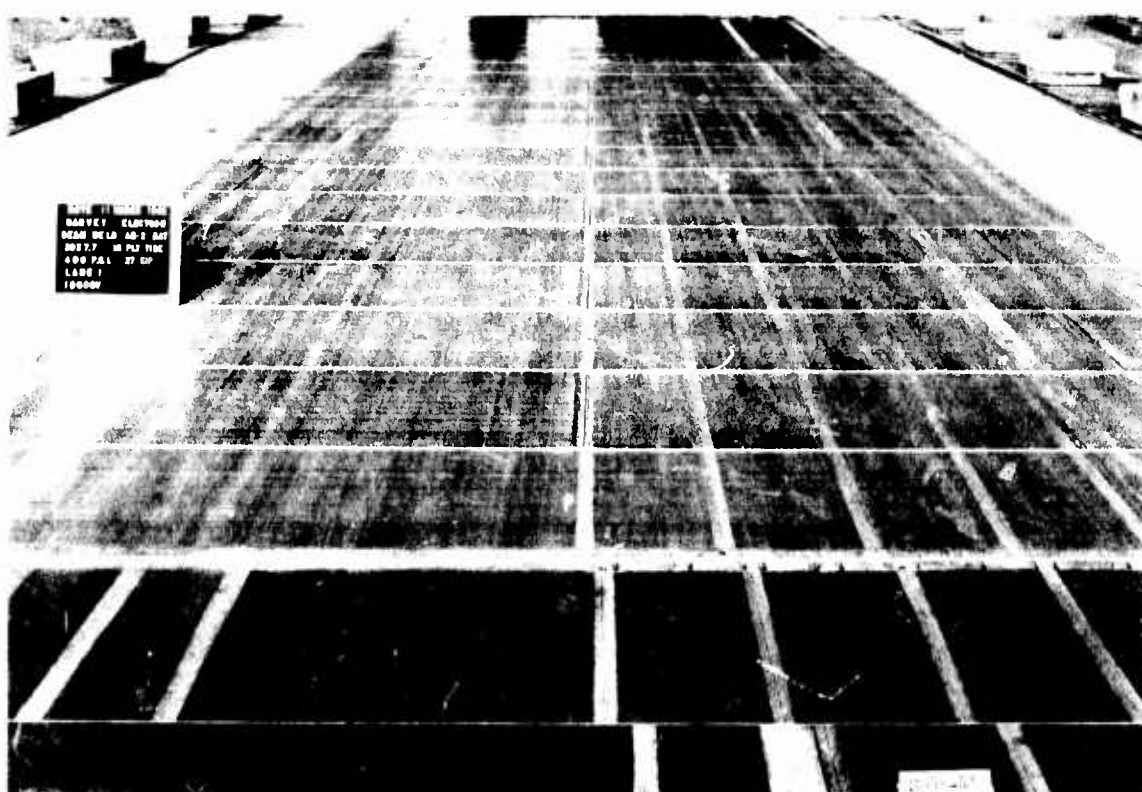
Subgrade Material	Rated Sub-grade CBR	Number Planks in Traffic Lane	Joints in Traffic Lane	Traffic Cover-ages	Mat Breakage										Mat Deflection in.		Rating of Test Section
					End-Connector Weld Breaks				Top Skin Tears	Bottom Skin Tears	Core Damage	C-Rail Breaks		Under-lapping Corner			
					Under-lapping Connector	Over-lapping Connector	Over-lapping Connector	Plank Center				Over-lapping Corner	Under-lapping Corner				
Heavy clay	4.0	30	20	0	0	0	0	0	0	0	0	0	0.65	0.60	Failed		
				40	8	5	3	0	0	0	0	0	--	--			
				188	9	8	4	0	0	0	0	0	0.80	0.70			
				346	10	10	13	6	7	5	5	10	0.80	0.75			



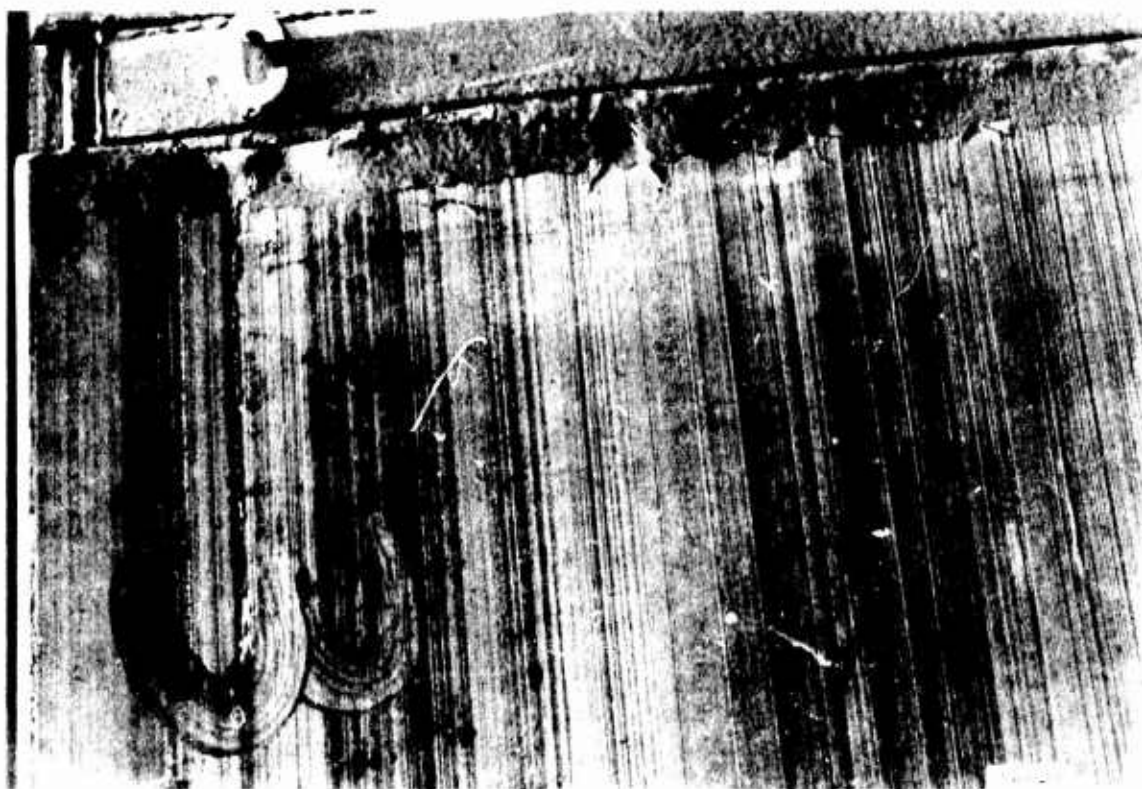
Photograph 1. Test section prior to traffic



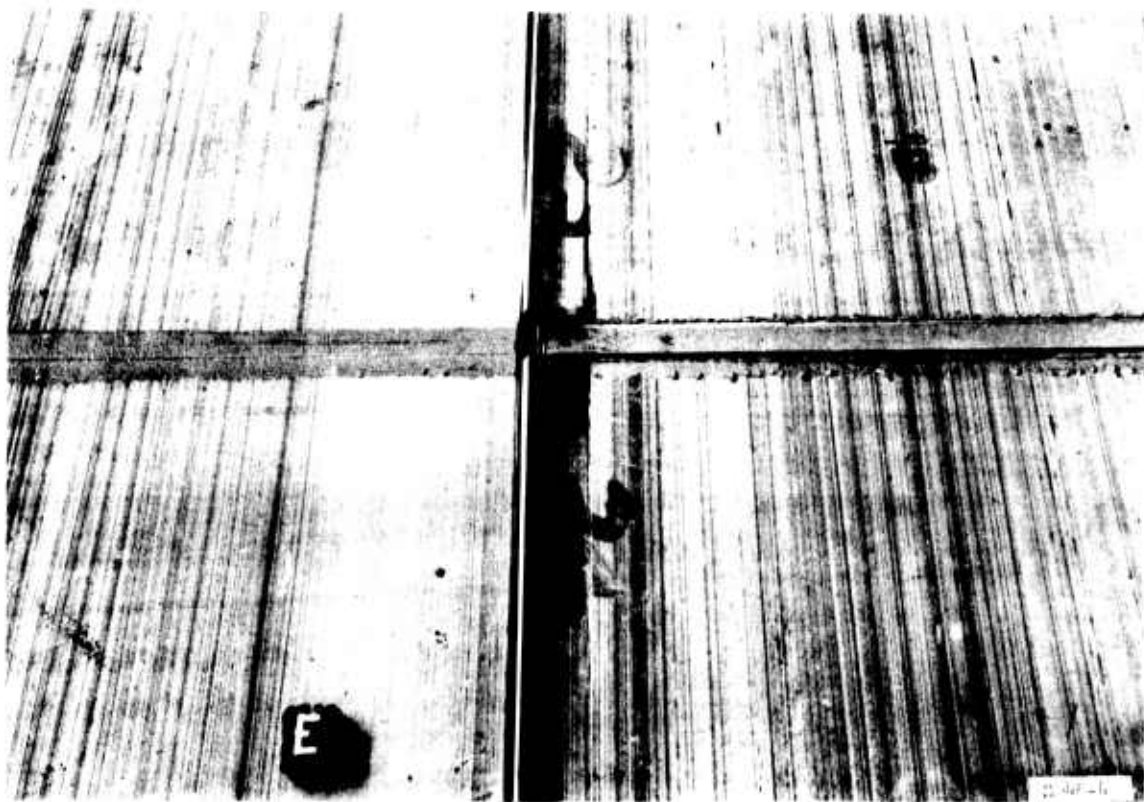
Photograph 2. Corner curl and weld cracks along overlapping and underlapping end connectors



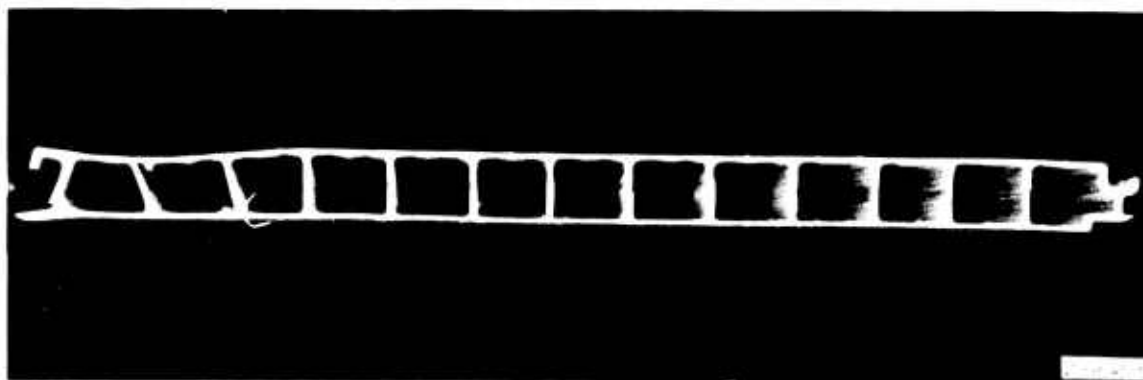
Photograph 3. Test section after 188 coverages



Photograph 4. Top skin tear and underlapping end-connector failure at 238 coverages



Photograph 5. Typical top skin tears at 346 coverages (failure)



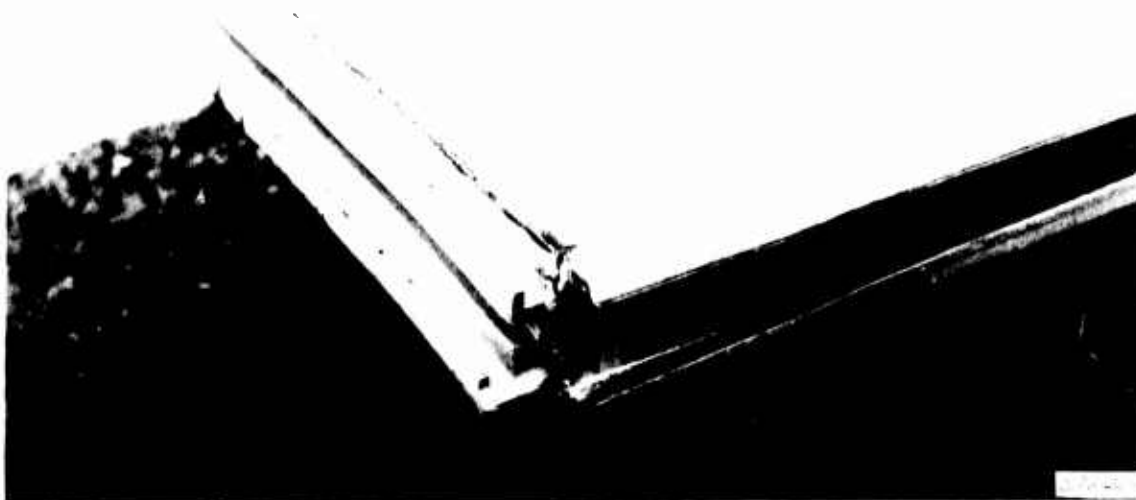
Photograph 6. Cross section of plank showing rib failure at 346 coverages



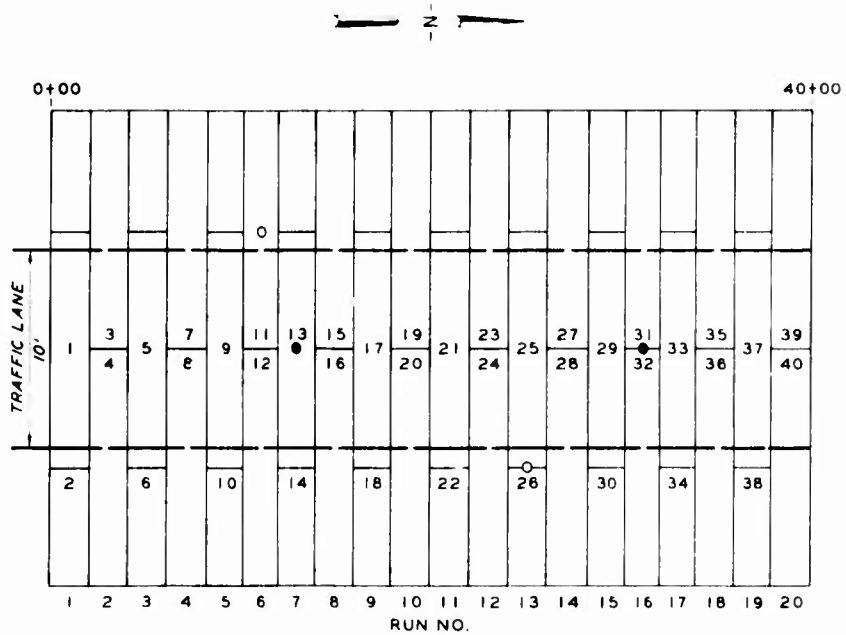
Photograph 7. Test section after 346 coverages (failure)



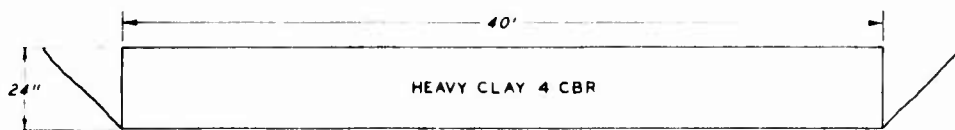
Photograph 8. C-rail split at plank center after 346 coverages



Photograph 9. Weld crack, bottom skin tear, and C-rail split after 346 coverages



PLAN



PROFILE

NOTE: NUMBERS INSIDE PLANKS
INDICATE PLANK NUMBERS

CBR PITS

- 0 COVERAGES
- 346 COVERAGES

PLAN AND
SUBGRADE PROFILE

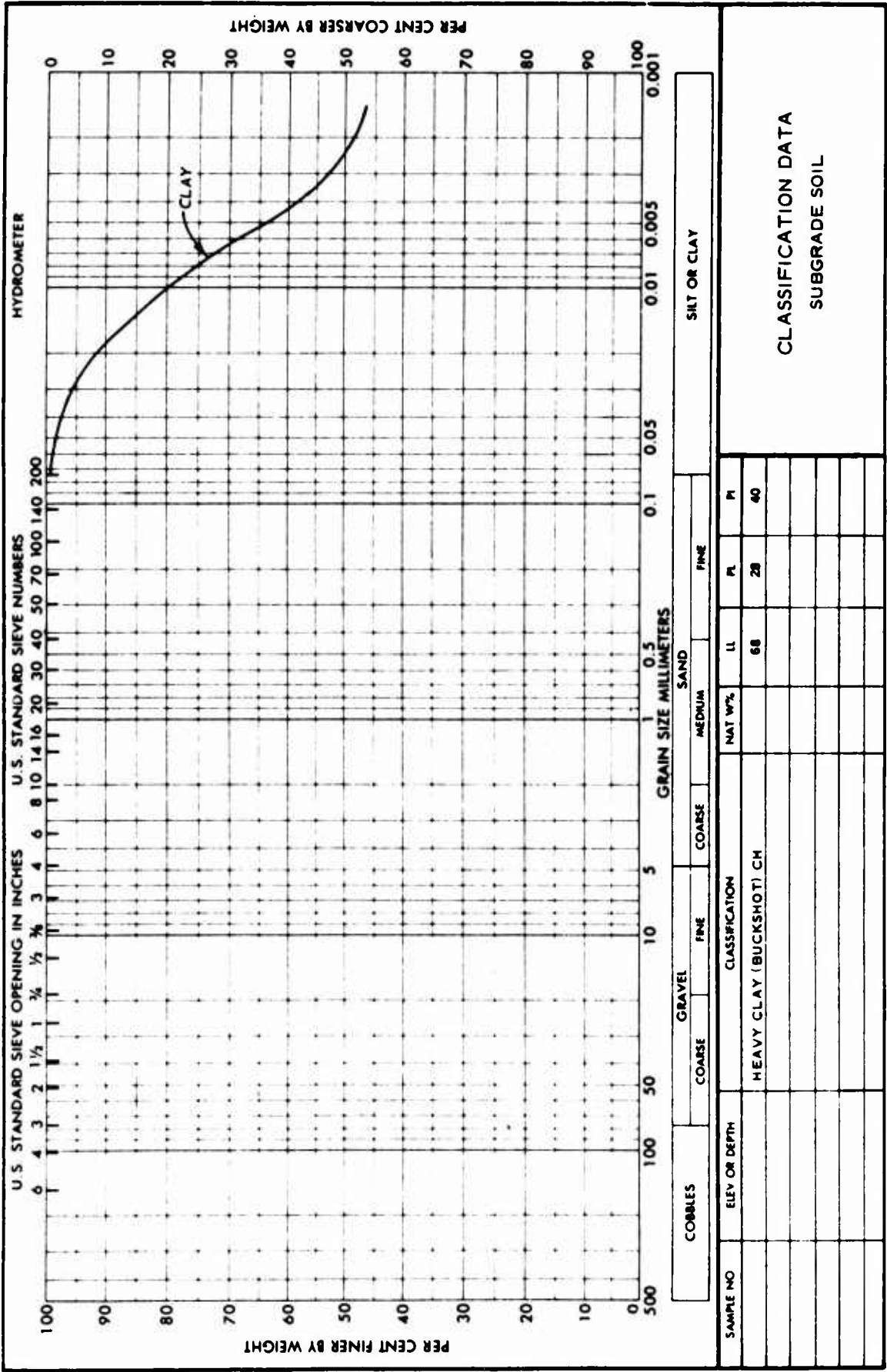
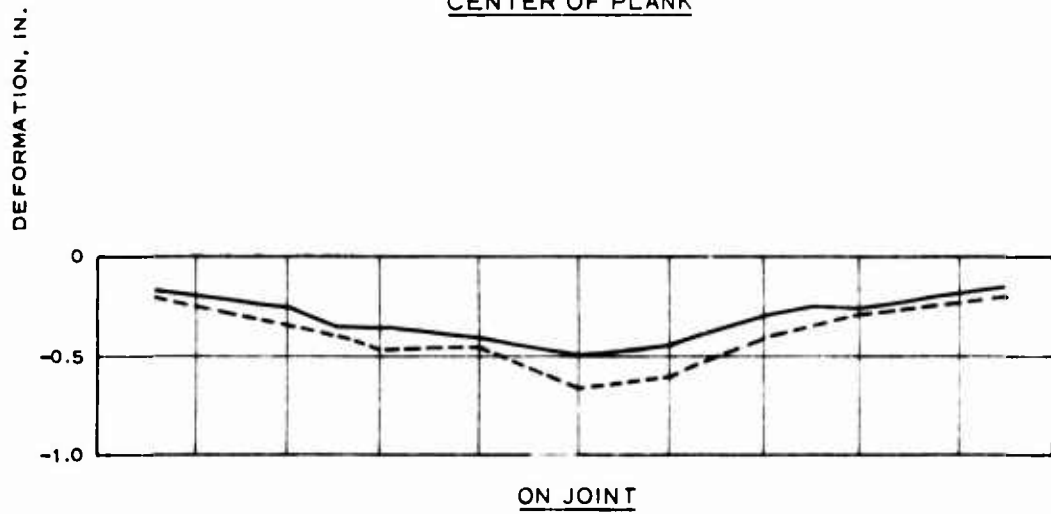
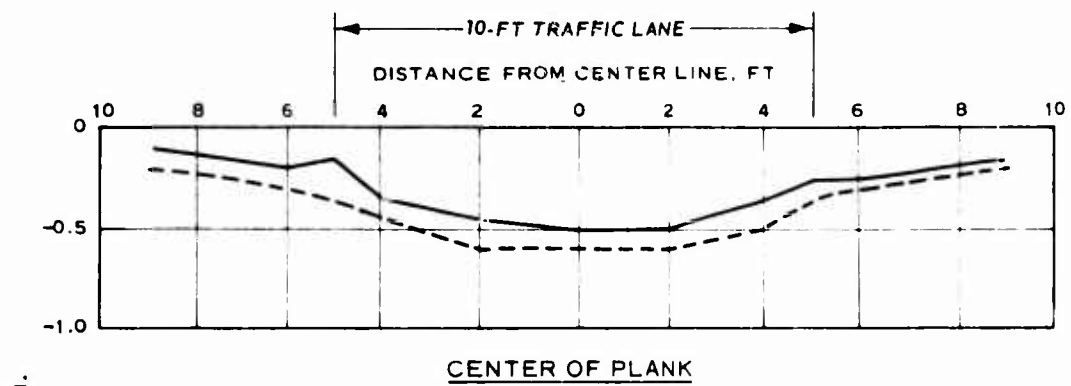


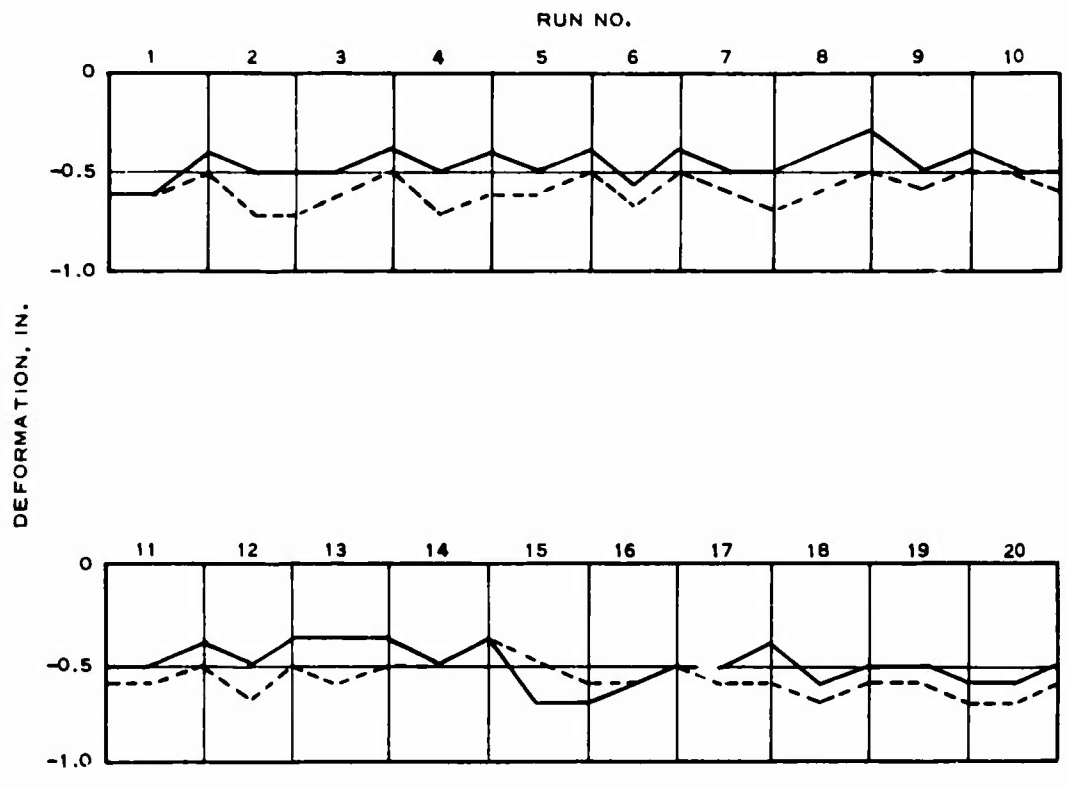
PLATE 2



LEGEND

- 188 COVERAGES
- 346 COVERAGES

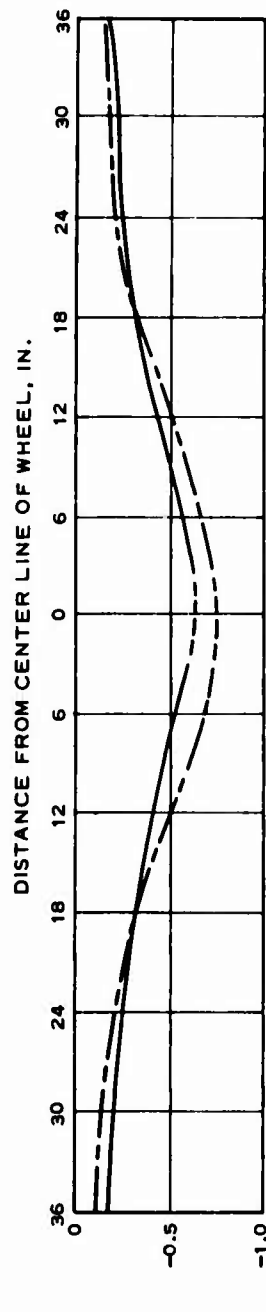
PERMANENT
MAT DEFORMATION



LEGEND

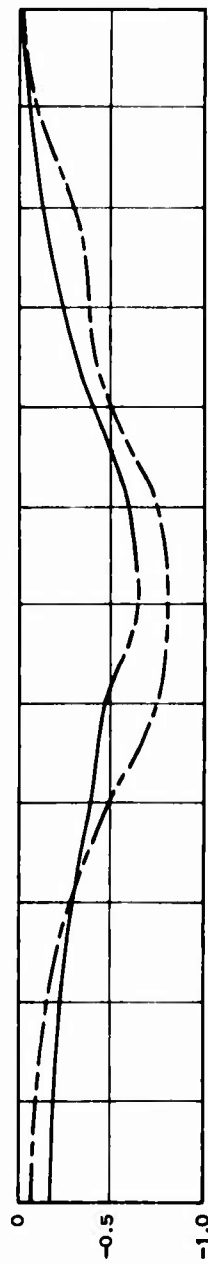
- 188 COVERAGES
-- 346 COVERAGES

CENTER-LINE PROFILE



CENTER OF PLANK

DEFLECTION, IN.



ON JOINT

LEGEND

- 0 COVERAGES
- - - 346 COVERAGES
- . - . - EXTRAPOLATED

ELASTIC DEFLECTION OF MAT

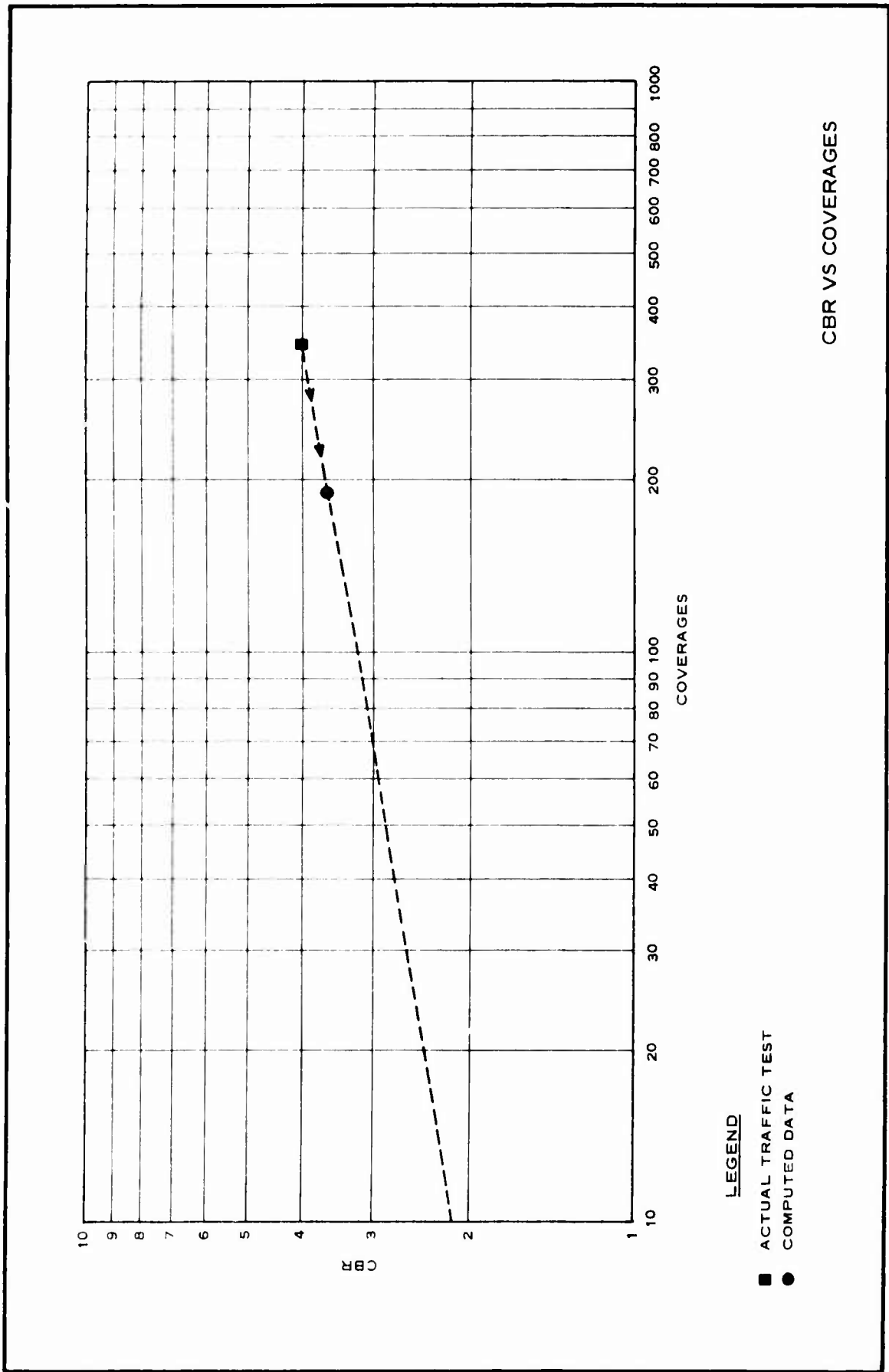


PLATE 6

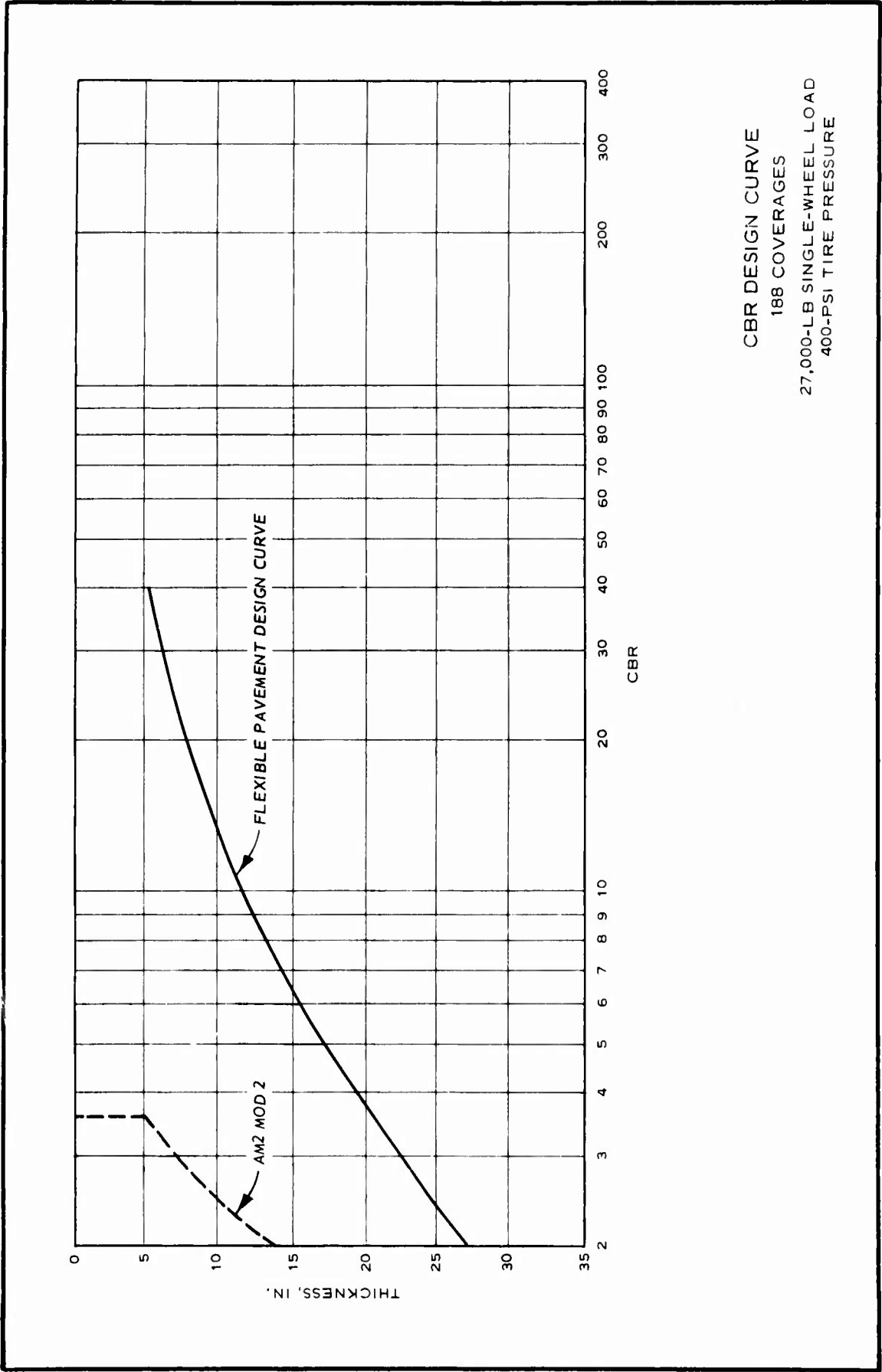


PLATE 7