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INTERIM REPORT OF FIELD TEST OF EXPEDIENT PAVEMENT REPAIRS (TES--ETC(U)
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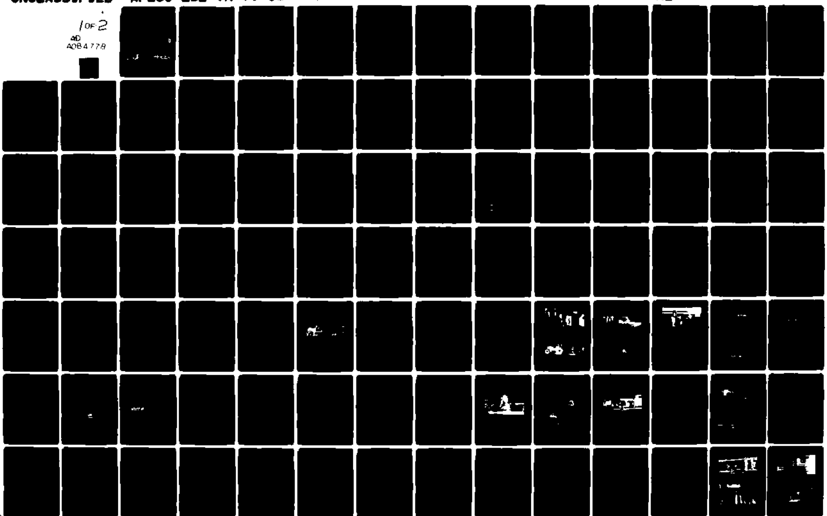

AFESC-ESL-TR-79-08

LEVEL 2

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INTERIM REPORT OF FIELD TEST OF EXPEDIENT PAVEMENT REPAIRS (TEST ITEMS 1-15).

RAYMOND S. ROLLINGS
ENGINEERING RESEARCH DIVISION

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Fast Setting Cements
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Asphaltic Materials
Soil Compaction
Landing Mat

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

This report describes field tests of fifteen materials that showed potential for use in temporary, expedient repair of bomb craters in runways. The test facility consisted of a concrete surface placed over a crushed limestone base which in turn lay over a weak clay subgrade. Three 20-foot by 20-foot square sections were left open in the concrete to serve as test pits. The test facility was so constructed to allow for simulation of small bomb craters in a typical North Atlantic Treaty Organization runway. The test materials were used to

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) repair the "craters" in the pavement. Upon completion of each repair, the resulting surface was tested with a load cart constructed to give the same load that would be experienced from taxiing of a modern fighter aircraft. This report describes the result of each of the tests and identifies areas requiring further research.

PREFACE

This report was prepared by the Air Force Engineering and Services Center, Engineering and Services Laboratory at Tyndall AFB, Florida, under Job Order Number 21042B22 Bomb Damage Repair Materials Field Test. The results of this study were used to assist in writing technical guidance to the field users in an earlier technical report. Data from these tests combined with data from subsequent tests will be used to write a comprehensive Small Crater Repair Manual.

This report discusses field tests of previously identified small crater repair materials. Fifteen materials were used for repairs of small craters constructed to simulate bomb craters in a typical NATO runway.

This report discusses the use of fifteen materials for bomb damage repair. The report does not constitute an indorsement or rejection of these products for the Air Force nor can it be used for advertising a product.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public including foreign nationals.

This report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

Recent improvements in weapon technology and increased use of hardened aircraft shelters have made attacks against runway pavements an effective method of reducing the effectiveness of enemy air power. The US Air Force base civil engineering squadron, supplemented with any available RED HORSE or Prime BEEF resources, has the primary responsibility for temporary, expedient airfield repairs to maintain combat operations (References 1, 2, and 3). The Air Force has developed and tested a technique of rapid bomb damage repair for runways which uses debris for the crater backfill, a limited thickness of select fill as a base course, and an AM-2 landing mat patch for the repair surface (References 1, 2, 4, 5, and 6). This technique is oriented primarily toward the simultaneous repair of several relatively large, conventional bomb craters.

This existing landing mat repair technique may not be adequate for repair of relatively small craters due to the potential roughness problem associated with multiple short mats (Reference 7). Also as the size of the repair area becomes smaller, the use of mats becomes less efficient. Increasing numbers of ramps and anchors are required, and the ratio of mat area to damage area increases rapidly if an entire 50-foot width of a repair strip must be covered by mats. The use of landing mat material for repair of numerous small craters will result in lengthy assembly and anchoring times, will require large volumes of mat, and will pose a potential severe roughness problem.

In 1976 Detachment 1 (Civil and Environmental Engineering Development Office), Armament Development Test Center, began a project to develop new techniques for expedient airfield pavement repair for small craters and spalled areas. Laboratory tests and accelerated F-4 load cart trafficking of spalls up to 5 feet in diameter provided preliminary information on repair materials (References 8 and 9). This report describes further traffic testing of repair materials and designs over soft clay subgrades representative of weak crater backfill materials. The objectives of this study are:

1. To evaluate performance of candidate repair materials under F-4 load cart traffic.

2. To identify construction and design problems associated with use of these repair materials and construction of repairs.

SECTION II

TEST DESCRIPTION

A permanent facility was constructed at Tyndall AFB, Florida, by the Air Force Civil Engineering Center, Directorate of Field Technology, to allow accelerated traffic tests of various pavement repair materials and designs. A clay core 60 feet wide, 220 feet long, and 6 feet deep was placed and compacted at a high water content to provide a weak test subgrade. Twelve inches of crushed limestone was placed as a base course followed by a 10-inch thick portland cement concrete pavement. Three 20-foot by 20-foot square sections were left open in the concrete to serve as test pits. The local dune sand was stabilized with oyster shells to construct a sand fill around the test site, and a 10-foot wide asphalt berm was placed on top of this fill around the test site. The local water table fluctuates and during wet seasons is at approximately the surface of the natural sand subgrade. Figures 1 and 2 provide plan and cross section views with dimensions of the test site.

The 20-foot test pits provide a location to construct representative pavement repairs. The depth to the clay subgrade can be varied by adding or removing clay as necessary. Following traffic on any test repair, the repair materials can be removed and a different repair constructed in the same pit.

The test pits are not an attempt to duplicate the crater repair problem. Because of the many variations in crater types and sizes and their very erratic geometry (Reference 10), attempts to construct models representing craters would be futile. Instead, the dimensions of the test pits were selected to provide a controlled test of the juncture between the pavement and the repair and to test the repair performance over a soft subgrade with a minimum effect from edge conditions.

Portable covers were constructed to protect the test pits from rain, but it was necessary to supplement these with rubber seals glued into shallow saw cuts approximately 6 inches from the edge of the test pit. A "snow fence" was also erected around the test pad to reduce problems with blowing and drifting sand. Future plans call for erecting a prefabricated building over the site to allow testing during inclement weather.

The clay used for the test subgrade was a local clay, classified as CH by the Unified Soil Classification System (Reference 11), obtained from near Wewahitchka, Florida. Table 1 shows physical properties and Table 2 minerological composition of the clay. Figure 3 is a representative gradation of the material, and Figure 4 shows a plot of the material on a plasticity chart. This clay was placed at an average moisture content of 27 percent and a California Bearing Ratio (CBR) of 4. This strength was selected as a representative lower bound for crater debris backfill based on eight previous crater repair field tests (Reference 9).

TABLE 1. PHYSICAL PROPERTIES OF WEWAHITCHKA CLAY

Property	Range	Average
Liquid Limit	57 - 79 percent	65 percent
Plastic Limit	21 - 30 percent	25 percent
Plasticity Index	30 - 52 percent	41 percent
Specific Gravity	2.58 - 2.67	2.61
CE-55 Optimum Dry Density	110 - 115 pcf[1]	113 pcf
Optimum Moisture	13 - 15 percent	14.5 percent
CE-26 Optimum Dry Density	105 - 109 pcf	107 pcf
Optimum Moisture	13 - 16.5 percent	14.5 percent
CE-12 Optimum Dry Density	98 - 102.5 pcf	99.0 pcf
Optimum Moisture	11.5 - 18 percent	15.0 percent

[1]Pounds per cubic foot.

Each repair was subjected to simulated F-4 traffic. The load cart, shown in Figure 5, applied a 27,000-pound main gear load at a 265 pounds per square inch (psi) tire pressure. Traffic was applied in an approximately normal distribution over a 10-foot traffic lane as shown in Figure 6. The load cart was pulled forward and then backed up in the same wheel path. Consequently, a total of 96 passes of the load were placed on the test item to obtain 10 coverages of the traffic in the center lane with 8 coverages in the adjacent lanes and 2 coverages in the outside lanes. A normal distribution is representative of actual aircraft traffic distribution on a runway and avoids introducing a sharp discontinuity between trafficked and untrafficked areas (Reference 12).

Data collected on each test item generally included profiles at various traffic levels, CBR, modulus of subgrade reaction, density (see Appendix A), moisture content from various sections of the repair, as well as appropriate laboratory test results on different surfacing materials. Profiles were taken with a self-leveling level and a survey rod with accuracy of 0.01 foot. The other tests were conducted in accordance with appropriate sections of References 13, 14, and 15.

TABLE 2. *MINEROLOGICAL COMPOSITION OF WEWAHITCHKA CLAY*

Mineral Constitutents	Relative Sample Content[1]
Clay	
Kaolinite	Intermediate
Smectite	Common
Clay-mica	Common
Non Clays	
Quartz	Intermediate
Feldspars	Rare

[1]Based on the following:

Abundant	> 50 percent
Intermediate	25 - 50 percent
Common	10 - 25 percent
Minor	5 - 10 percent
Rare	< 5 percent

SECTION III

TEST CRITERIA

The word "expedient" has been defined for military operations as "any paving or surfacing operation that must be completed quickly and whose end result is temporary in nature" (Reference 16). This is an adequate description of the task of rapidly repairing damaged airfield pavements. Any repair done rapidly, hence an expedient repair, implies that the result is only temporary, will require maintenance, and will have to be replaced or upgraded relatively soon after placement.

The length of time the repair must last has never been established by the Air Force. Earlier tests have used traffic capacity criteria ranging from 16 to 100 passes, but generally it is believed higher capacities are needed. The previous laboratory and spall repair tests used 100 passes and 10 coverages (86 passes), respectively, as the minimum acceptable levels of traffic by an F-4 (References 8 and 9). In the past only tactical aircraft have been considered, and cargo aircraft have been ignored. For the purpose of this field test, 12 coverages and 150 coverages by an F-4 have been used to identify the minimum acceptable repair capacity and the maximum required repair capacity for an expedient repair. Assuming a 70-inch wander distance and a normal distribution of channelized traffic similar to a runway are representative of traffic in a repair strip, the pass to coverage ratio is 8.58 (Reference 12). This gives a minimum acceptable repair capacity of 103 passes of an F-4 (27,000 pounds with 265 psi tire pressure), and 1287 passes of an F-4 as the maximum required repair capacity to be used in this field test. The Air Force needs to establish specific required levels of traffic and loading for repairs. The selection of loading and traffic level for this test has been essentially arbitrary.

The failure criteria of test items for expedient repairs are very difficult to establish. Although a section may crack and show signs of overstressing, it may still be functional for emergency operations. Table 3 summarizes the failure criteria used by the Corps of Engineers in past accelerated traffic field tests. These criteria are not directly applicable to the problem of expedient patches. Long after a patch has failed by engineering or conventional pavement standards, it may remain usable for emergency operations. Possible failure criteria will be discussed individually.

TABLE 3. CORPS OF ENGINEER FAILURE CRITERIA

Surface	Criteria
Flexible	1-inch deformation and rutting
	0.25-inch deflection
	Severe cracking, surface no longer waterproof
Rigid	Initial failure: First crack
	Shattered slab: Slab cracked into 6 pieces
	Complete failure: Slab cracked into 35 pieces
Unsurfaced	3-inch deformation and rutting
	1.5-inch deflection
Landing mat	20 percent of panels showing breakage

Permanent deformation and rutting are evidence of consolidation and shear deformation of material under traffic. Reference 17 defines rutting and depressions on airfield surfaces as light for depths of 0.25 to 0.50 inch, medium for 0.50 to 1 inch and high for over 1 inch. Existing unsurfaced soil criteria allow ruts up to 3 inches deep, but this is based on tests with cargo aircraft which may not be applicable at all to tactical aircraft. The C-130 aircraft has successfully operated during takeoff with ruts of 3 to 6 inches and landed with ruts of 4 to 8 inches (Reference 18). A C-141 successfully operated with ruts up to 4.5 inches (Reference 19). Operation with tactical aircraft on unsurfaced surfaces appear to be limited to a test of an F-5 on a high CBR subgrade with negligible rutting (Reference 20). There is no evidence that the 3-inch rut criterion for unsurfaced soil is acceptable for tactical aircraft though it appears to be conservative for cargo type aircraft. Lacking any better criteria, this study will use the conventional criteria of a 1-inch permanent deformation in a paved test item and a 3-inch rut (measured from top to bottom of the wheel depression) for unsurfaced soil materials.

Deflections are limited to 0.25 to 1.5 inch for paved and unsurfaced areas in Table 3. Generally, deflection limits are based on empirical correlations of excessive deflections with predefined failure criteria (Reference 21) and are not cause for functional failure by themselves. The subgrade accounts for 70 to 95 percent of the surface deflection which can be limited by reducing subgrade stress through thicker or more rigid pavements (Reference 21). The resilient, or recoverable, deflection of a subgrade is strongly influenced by soil type, number of stress cycles, aging before stress loading, stress intensity, compaction methods, density, and moisture content (Reference 22). The clay subgrade for these tests has relatively low density and high moisture content and is subjected to relatively few repetitions of high stress. This condition is thought to be representative of the subgrade condition of craters backfilled with clay debris. Resilient deflections can be expected to be large under these conditions. However, since deflection is not a functional failure in itself, no deflection failure criteria will be used for this study.

Cracking in a pavement structure is evidence that the material has been overstressed. This may be due to either load or environmental conditions. Cracking may result in increased water infiltration with consequent weakening of the subgrade, in spalling and surface deterioration, and in increased roughness. In this test, formation of tight cracks will not be considered failure until surface deterioration occurs which would impede aircraft operation. This is a subjective evaluation.

Under traffic the repair patch is likely to settle so that there is a differential elevation at the joint between the pavement and repair. This may result in damage to aircraft structure and tires and increased roughness. Reference 17 defines high severity faulting for runways and taxiways as a difference in elevation of a half inch; for aprons this is increased to one inch. Computer simulation studies (presently unvalidated by field tests) also indicate a potential roughness problem with tactical aircraft when they must traverse several 1.5-inch elevation changes (Reference 7). This test uses 1-inch differential elevation between the repair and original pavement as the failure criterion.

Spalling, raveling, and scaling are forms of surface distress which offer potential foreign object damage (FOD) by ingestion of particles in jet aircraft engines. No criteria have been developed in this area to determine acceptable levels or actual seriousness of the potential FOD problem.

Maintenance may keep a repair usable long after it has originally failed. In the past, only tests with landing mat have taken possible maintenance into account. The Corps of Engineers has assumed that 10 percent of the landing mat in a test section may be replaced for maintenance, and failure occurs after another 10 percent of the panels fail. This gives the 20 percent failure criterion shown in Table 3. Although maintenance will be a part of expedient repair, it is not clear how to take this into account in the testing, and no maintenance criterion will be included in this testing.

Table 4 summarizes the failure criteria used for this testing. Improved failure criteria need to be developed, but the criteria shown in Table 4 provide a point where aircraft operation can be considered hazardous.

TABLE 4. TEST FAILURE CRITERIA

Failure Mode	Paved Test Item	Unsurfaced Test Item
Permanent Deformation and Rutting	1 inch	3 inches
Deflection	None	None
Cracking	Open cracks leading to surface deterioration judged to affect aircraft operations	Not applicable
Differential Elevation Between Repair and Pavement	1 inch	1 inch
FOD	Subjective	Subjective

SECTION IV

TEST RESULTS

1.0 Item 1 - Future Patch®

Item 1 consisted of 13 inches of aggregate base course over the clay subgrade. The item was surfaced with a 1-inch thick layer of Future Patch®, a proprietary asphalt patching material. Laboratory test results, spall repair field tests, and more detailed information on Future Patch® may be found in References 8 and 9. The base course aggregate was a crushed, well graded limestone from Alabama with the gradation shown in Figure 7. The aggregate is nonplastic with an apparent specific gravity of 2.83 and a bulk specific gravity of 2.73 as determined by the procedures of Reference 13. The CE-55 optimum density was 148.7 pcf, and the optimum moisture content was 5.4 percent. The CE-55 compaction curve is shown in Figure 8.

Item 1 was placed using only a hand vibratory plate compactor (Figure 9), a towed, 4000-pound static weight, vibratory roller (Figure 10), and a 12-ton tandem steel wheel roller (Figure 11). This equipment is representative of the compaction equipment normally available to Air Force base civil engineering squadrons. The base course was installed in two lifts. The first lift was compacted with the hand vibratory plate compactor, and the second lift used both the hand compactor and the towed vibratory roller. The Future Patch® was emptied from 55 gallon drums, spread by hand, and then compacted with eight coverages of the steel wheel roller.

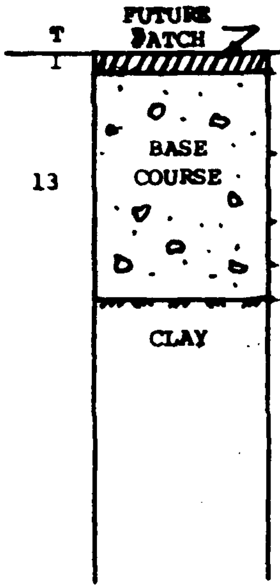
This equipment was unable to provide the required densities in the base course. Under traffic, the base course failed in shear in two passes (Figure 12). Results of testing are shown in Table 5. Tests run in the traffic lane were inside the tire paths away from the shear failure.

2.0 Item 2 - Base Course Aggregate

Item 2 consisted of 14.5 inches of unsurfaced base course aggregate. The aggregate was placed and compacted in 3-inch lifts. A gasoline powered, hand operated, impact compactor (Figure 13) was used with the vibratory plate for compaction. The impact compactor was effective in obtaining density in the aggregate but was slow. No surfacing was applied to this item.

Deflection of the test item surface under traffic was readily visible from the first pass. Rutting of about 1.5 inches began on the second coverage. After the third coverage, rutting had reached a maximum of 2.5 inches and was occurring over most of the traffic lane. Traffic was discontinued after three coverages. Table 6 shows the results of testing item 2 after trafficking.

TABLE 5. ITEM 1 TEST RESULTS



TRAFFIC 2 PASSES

	IN TRAFFIC					OUT OF TRAFFIC					
d	CBR	d	%	MC	d	CBR	d	%	MC	k
1	42	145.0	98	2.0	1	67	146.6	99	1.6	180
5½	61	+	+	+	5½	61	+	+	+	+
9½	14	145.0	98	2.0	9½	18	139.1	94	2.4	+
12	4	+	+	+	12	6	+	+	+	+
14	4	97.5	86	25.4	14	4	+	+	+	+

LEGEND

T - thickness of material (inches)
d - depth below surface (inches)
CBR - California Bearing Ratio
d - Dry density, See Appendix A for detailed discussion
MC - Moisture Content (percent)
k - Modulus of subgrade reaction, pounds per cubic inch (pci)
% - Percent of CE-55 density
+ - not measured

TABLE 6. ITEM 2 TEST RESULTS

T	Unsurfaced	In traffic: d	CBR	d	%	MC	Out of traffic: d	CBR	d	%	MC	k
							0	89	147.6	99	3.3	200
14½	BASE COURSE	4½	67	149.0	100	2.9	4	81	151.0	102	3.6	+
		7	63	149.0	100	2.4	7	85	151.2	102	2.6	+
		12	14	152.0	107	1.9	12	21	145.2	98	2.0	+
		14½	6	103.0	91	24.4	14½	5	96.2	85	25.0	+
	CLAY											

TRAFFIC 3 COVERAGES

LEGEND

T - thickness of material (inches)
d - depth below surface (inches)
CBR - California Bearing Ratio
d - Dry density, See Appendix A for detailed discussion
MC - Moisture Content (percent)
k - Modulus of subgrade reaction, pounds per cubic inch (pci)
% - Percent of CE-55 density
+ - not measured

3.0 Item 3 - Darex 240®

Item 3 consisted of 3 inches of magnesium phosphate cement with an 11-inch aggregate base course over the clay. The magnesium phosphate cement used for this testing was Darex 240® produced by W. R. Grace and Company under license from the Republic Steel Corporation. Results of laboratory testing, field tests for spall repairs, and more detailed information may be found in References 8 and 9. The base course was placed in three lifts and compacted with the impact compactor.

This type of magnesium phosphate cement is provided in 50-pound bags of magnesium aggregate with 1 gallon of a liquid phosphate solution in a separate container. A pallet contains 32 one-gallon phosphate containers and 32 fifty-pound bags of aggregate. A total of eight pallets were used in this testing. According to directions received with the materials, specific runs or lots of the phosphate solution must be mixed with matching lots of magnesium aggregate. Unless lot numbers should happen to match, a phosphate solution from one pallet cannot be mixed with an aggregate from another pallet.

The magnesium phosphate cement used in this testing had been stored for approximately 18 months. A white solid had precipitated from the phosphate solution during this time. Most of this precipitate could be put back in solution by stirring or vigorous shaking. A large number of the containers were leaking or had been broken during this extended storage (storage area was indoors but not heated). The magnesium aggregate also exhibited a warehouse pack due to extended storage, but this was readily broken up by dropping and rolling the sacks of magnesium aggregate.

The magnesium aggregate and phosphate liquid were mixed in a 15-cubic foot, towed concrete mixer borrowed from the 823rd RED HORSE Squadron. This type of equipment is not usually available to the base level civil engineering squadron. Using construction joints, the repair area was formed into four pour lanes, each 5 feet wide, 20 feet long, and 3 inches deep (Figure 14). Original plans called for two pours per lane from the 15-cubic foot mixer; however, due to the thickness of the magnesium phosphate cement and the design of the blades in the mixer only about half of the material in the mixer could be emptied. After each pour the concrete mixer had to be washed out. The cement set about 5 minutes after the liquid was added to the aggregate; thus, very rapid mixing, pouring, and screeding were required. Ammonia vapors were a chemical by-product of the mixing but, while unpleasant, did not hinder the field crews.

After two pours with the mixer, the engine stalled during washing, and excess material set up in the mixer before the engine could be restarted. Futher attempts to mix the magnesium phosphate cement with the towed concrete mixer were abandoned because of the poor production rate and difficulty in handling the cement. The remainder of the slab was mixed and placed by hand from wheelbarrows. Placement of a 20-foot by 20-foot by 3-inch deep slab requires about 4 hours when done by hand in this manner.

Six sample beam specimens were cast at different times during the placement of the cement. Four beams were broken after 2 hours of curing and had an average flexural strength of 494 psi. This was in good agreement with the results of strength tests in Reference 9. The remaining two beams were air cured for 24 hours and gave an average flexural strength of 676 psi. Previous tests with magnesium phosphate cement in reference 9 indicated that there was little change in strength between 2 and 24 hours of curing, but the results of the beams collected in this field test contradicted this conclusion.

Trafficking with the F-4 load cart began 2.5 hours after the last pour. An elastic deflection of the surface was visible during traffic. After four coverages tight surface cracks had appeared along joint pour lines; and two cracks, probably due to shrinkage, appeared in the untrafficked zone. On the sixteenth coverage audible cracking could be heard, and the bond between two pour lanes was broken so that the more heavily trafficked pour was displaced downward approximately 0.25 inch. By 40 coverages spalling was severe along this joint (Figure 15). Spalling and crazing (tight network of cracks) increased throughout the traffic lane until, after 60 coverages, it was severe (Figure 16). Traffic was continued to 100 coverages at which time scaling and spalling at the surface (Figure 17) and severe spalling along joints and edges of the slab (Figure 18) resulted in a heavy layer of potential FOD. Figure 19 shows the surface profiles under varying levels of traffic. Maximum permanent deformation was 0.50 inch. Tabulated test results are presented in Table 7.

4.0 Item 4 - Base Course Aggregate

Item 4 consisted of 25 inches of well compacted aggregate over the clay subgrade. No surfacing was used for this item. The aggregate was placed and compacted with the gasoline powered, hand impact compactor in two lifts, each approximately 6 inches, followed by three 4-inch lifts. As shown in the out of traffic test results in Table 8, this method of placement and compaction gave better than 95 percent CE-55 density throughout the lift.

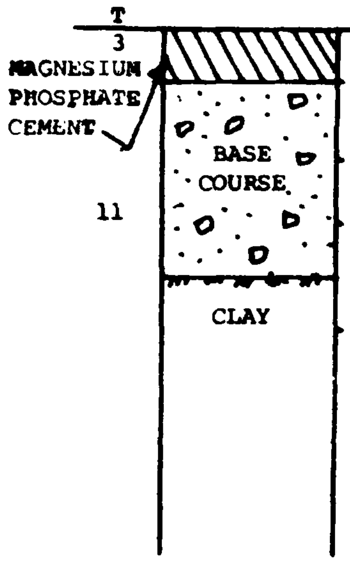
The surface rutted under initial traffic until, at the end of 10 coverages, ruts (measured from top of upheaved material to bottom of the rut) reached a maximum of 2.5 inches (Figure 20). Further traffic began densifying the material (Figure 21) until it became a very smooth hard surface (Figure 22). The increase in maximum permanent deformation (difference between original untrafficked elevation and elevation after traffic at a point) with increasing coverages is shown in Figure 23, and surface profiles measured along the center line perpendicular to traffic are shown in Figure 24. Traffic was discontinued at 150 coverages, short of the 3-inch failure criterion (Figure 23) for unsurfaced operation. If a 1-inch criterion for paved surfaces had been used, failure would have been at 60 coverages.

5.0 Item 5 - Uniform and Graded Aggregate

Item 5 consisted of 6 inches of base course aggregate with an 18-inch subbase of 3-inch uniform aggregate. No surfacing was placed on the base course.

The uniform aggregate was rained into place with a 5-foot free fall from a front end loader bucket. Some limited data indicate that this technique of placement can result in a relative density of about 80 percent for cohesionless soils (Reference 23). No other compaction was applied to the uniform aggregate subbase.

TABLE 7. ITEM 3 TEST RESULTS



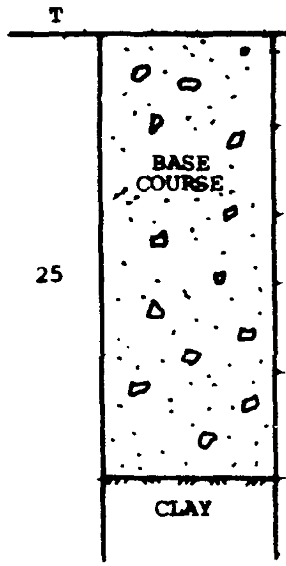
TRAFFIC 100 COVERAGES

IN TRAFFIC					OUT OF TRAFFIC					
d	CBR	d	%	MC	d	CBR	d	%	MC	k
3	87	145.4	98	2.2	3	97	149.1	100	1.6	380
					6	81	147.7	99	1.6	+
7½	135	146.8	99	2.4						
11	57	146.1	98	2.7	11	72	147.9	100	1.9	+
					14	5	97.6	86	24.2	74
17	5	96.1	85	25.2						

LEGEND

T - thickness of material (inches)
d - depth below surface (inches)
CBR - California Bearing Ratio
d - Dry density, See Appendix A for detailed discussion
MC - Moisture Content (percent)
k - Modulus of subgrade reaction, pounds per cubic inch (pci)
% - Percent of CE-55 density
+ - not measured

TABLE 8. ITEM 4 TEST RESULTS



T	IN TRAFFIC d	CBR	d	%	MC	OUT OF TRAFFIC d	CBR	d	%	MC	k
	0	106	148.2	100	2.8	0	107	144.9	97	1.6	400
	5	132	146.4	98	2.4	5	148	144.5	97	2.1	+
	10	127	146.5	98	2.6	10	110	148.4	100	2.6	+
25	14	126	143.3	96	3.2	14	90	147.9	99	3.3	+
	19	70	146.9	99	4.2	20	71	143.9	97	5.5	+
	25	4	96.2	85	26.8	25	4	99.4	88	25.3	95

TRAFFIC 150 COVERAGES

LEGEND

T - thickness of material (inches)
d - depth below surface (inches)
CBR - California Bearing Ratio
d - Dry density, See Appendix A for detailed discussion
MC - Moisture Content (percent)
k - Modulus of subgrade reaction, pounds per cubic inch (pci)
% - Percent of CE-55 density
+ - not measured

The base course aggregate was compacted with 10 passes of a hand vibratory plate compactor and 10 passes of a gasoline powered, hand impact compactor. This level of compaction provided a dry density of 143.9 pcf (97 percent of CE-55 density) and a CBR of 88. Moisture content was 2.2 percent. A plate load test on the surface of the base course gave a modulus of subgrade reaction of 260 pounds per cubic inch (pci).

Under the F-4 load cart the surface began working on the third pass, and the load cart was unable to get out of its own rut on the tenth pass. Traffic was attempted again in an untrafficked zone, and results were the same.

6.0 Item 5A - Uniform and Graded Aggregate

Item 5 was reconstructed to provide a 12-inch subbase of uniform aggregate and a 12-inch base course of well graded crushed aggregate. As before, no surfacing was placed on the base course. The base course was compacted in two 6-inch lifts with 4 and 10 coverages with the hand impact compactor on the lower and upper lifts, respectively.

Rutting began under the F-4 load cart on the sixteenth pass. By the thirtieth coverage the surface had densified, and a general settlement of the repair surface was noticeable. Table 9 shows the progressive increase in maximum permanent deformation and lip height (difference between elevation of concrete and adjacent repair surface). Figure 25 shows the surface profiles along axes at the quarter, centerline, and three-quarter points perpendicular to the traffic and along the longitudinal centerline of the traffic lane.

TABLE 9. LIP AND DEFORMATION MEASUREMENTS FOR ITEM 5A

Number of Coverages	Lip Height (inches)	Maximum Permanent Deformation (inches)
0	0.12	0
30	0.84	1.8
60	1.08	2.5

The item was considered failed at 60 coverages because of the lip height. This lip was sufficient to cause a considerable number of surface cuts on the F-4 tire of load cart. The permanent deformation reached 2.5 inches, still short of the 3-inch rut depth failure criterion for unsurfaced operation. Table 10 shows the results of testing after traffic for item 5A.

7.0 Preliminary High Alumina Cement Tests.

Previous laboratory studies described in Reference 9 showed that concretes made with high alumina cement and accelerated with small additions of lithium carbonate could reach 400 psi flexural strengths in 2 hours. Prior to construction and trafficking of test items of this material, a limited laboratory study and several trial field pours were conducted.

TABLE 10. ITEM 5A TEST RESULTS

T	Layer	In Traffic d	In Traffic CBR	In Traffic d	In Traffic %	In Traffic MC	Out of Traffic d	Out of Traffic CBR	Out of Traffic d	Out of Traffic %	Out of Traffic MC	Out of Traffic k
	BASE COURSE	0	63	147.1	99	1.9	0	99	141.1	95	1.1	375
		6	105	146.6	99	2.1						
12							8	79	142.5	96	1.7	+
12	UNIFORM AGGREGATE											
		24	8	99.6	88	24.9						
	CLAY						26	6	102.9	91	21.4	72

TRAFFIC 60 COVERAGES

LEGEND

T - thickness of material (inches)
d - depth below surface (inches)
CBR - California Bearing Ratio
d - Dry density, See Appendix A for detailed discussion
MC - Moisture Content (percent)
k - Modulus of subgrade reaction, pounds per cubic inch (pci)
% - Percent of CE-55 density
\+ - not measured

Flexural beam samples were prepared and tested in accordance with ASTM C-78 to determine the effect of lithium carbonate concentration on flexural strength. The gradation of the aggregate used in this mix is shown in Figure 26. An eight sack per cubic yard mix, proportioned 1:1.21:2.65 cement to sand to coarse aggregate by weight, was used for these tests. The water/cement ratio was 0.4. Figure 27 shows the results of this testing. The curve indicates that there may be a point at which strength decreases due to over acceleration, but insufficient data exist to reach a final conclusion. Previous tests indicated little difference between strengths at accelerator contents of 0.03, 0.06, and 0.10 (Reference 9). Technicians, while preparing the test samples, also noted the mix grew stiffer and harder to mix as the accelerator content increased.

Normal Air Force civil engineering squadrons do not have access to any sizable concrete mixers. Portable towed concrete mixers were not considered feasible because of the quantity of material to be handled and the difficulties encountered with this equipment during the item 3 tests. Air Force RED HORSE squadrons will eventually be equipped with Concrete-Mobiles® which are trailer mounted, self-contained, batching and mixing units. Conversations with C. L Rone and G. Hammitt about tests with fast setting regulated set cements conducted at the US Army Engineer Waterways Experiment Station indicated difficulty in recharging this equipment and overall slow production rates. The technical representative of the high alumina cements manufacturer felt that the mixing time of the Concrete-Mobile® was too short for this product.

The remaining alternative for mixing the accelerated high alumina concrete was to use conventional transit mix trucks. At the present time only one RED HORSE squadron is authorized transit mix trucks. This technique has been used with some success with another fast setting cement (Reference 24). However, there are several practical problems such as the potential for the concrete to set up in the truck and the requirement to wash and dry the truck before it can be reused. A transit mix truck was borrowed from an Air Force RED HORSE civil engineering squadron for these tests.

A 1.5 cubic yard trial pour was attempted with the same eight sacks per cubic yard mix used in the laboratory and with a water/cement ratio of 0.38. Accelerator content was 0.04 percent by weight of cement. Aggregate and cement temperature was 67°F, and the ambient and water temperature was 72°F. The sand, coarse aggregate, and cement were placed and mixed in the transit mix truck first. Then the water and finally the lithium carbonate in a water solution were added. The concrete was mixed for about 18 minutes, but the mix stiffened and had to be washed out.

A second trial pour was attempted the next day. The water/cement ratio was increased to 0.42. Temperature of aggregate, cement, and water ranged from 70°F to 75°F, and the ambient temperature was 80°F. The materials were mixed for 3 minutes. As dumping began it was apparent the cement was rapidly stiffening. Additional water was added to the mix, but it had no effect. The concrete mix had to be washed out of the truck to prevent damage.

New mixes were tested in the laboratory to provide a very fluid, pourable mix. A 10-sack per cubic yard mix, 1:0.95:1.76 cement:sand:course aggregate by weight, was selected for further testing. The water/cement ratio was 0.4. This mix provided a 300 psi flexural strength with 0.03 percent lithium carbonate and a 292 psi flexural strength with 0.04 percent lithium carbonate.

A third trial pour was conducted with the 10-sack per cubic yard mix and with 0.03 percent lithium carbonate. Aggregate and ambient temperatures at mixing were 64 to 67°F. The water, cement, and aggregate were mixed for 1.5 minutes; then the lithium carbonate in 5 gallons of water was added and mixed for 40 seconds. This mix was very fluid. The entire 1.5-cubic yard batch was placed and finished prior to hardening. The concrete reached a peak exotherm temperature of 144°F in 57 minutes. Beam samples prepared from this mix had flexural strengths of 170, 270, and 287 psi at 2,3, and 4 hours, respectively.

Because no scales were available for field mixing, all batching had to be done on a volumetric basis. This was a crude method which did not provide accurate mix proportioning. An error was discovered in the volumetric batching which resulted in all trial pours having a lower sand content than the intended mix porportions.

8.0 Item 6 - High Alumina Cement

Item 6 consisted of a 12-inch base course under a 4-inch cap of accelerated high alumina cement. The base course aggregate was placed and compacted with a mechanical impact compactor. Table 11 shows results of testing on the base course during construction.

TABLE 11. ITEM 6 BASE COURSE TEST RESULTS

	CBR	Dry Density (pcf)	Percent CE-55	Moisture Content (percent)
Top Lift	61	139.3	94	2.9
Bottom Lift	19	139.7	94	3.5

A 5.5-cubic yard mix of high alumina concrete was prepared for the 20-foot x 20-foot x 4-inch deep slab for item 6. The 10-sack per cubic yard mix with 0.03 percent lithium carbonate and 0.4 water/cement ratio was used.

The aggregate and cement were placed in the transit mix truck and mixed dry. Water was added and mixed for 3 minutes, 9 seconds. Next, 1.55 pounds of lithium carbonate in 15 gallons of water was added and mixed for 38 seconds. The mix was then poured and immediately screeded with a vibratory screed (Figure 28). The mix was initially very fluid and easily handled. After 1 minute, 33 seconds, the mix hardened so rapidly that pouring had to be discontinued; after 2 minutes, 36 seconds, screeding became impossible. Only one half of the test item could be screeded relatively level, and it had an exceedingly rough and coarse surface (Figure 29). Beam samples were prepared during pouring, and the test results are shown in Table 12.

TABLE 12. FLEXURAL STRENGTH OF HIGH ALUMINA CONCRETE, ITEM 6

Cure Time	Flexural Strength (psi)	Aggregate Breakage (percent)
2 hours	170	0
3 hours	227	0
4 hours	236	15
3 days	298	20
7 days	248	20

Sand was spread over a portion of the test item to prevent damage to the load cart tire, and trafficking began 3 hours after pouring. Traffic could be applied in a 40-inch wide lane because of the limited level area of the repair. After 136 passes a crack formed in the cap. Traffic was discontinued after 200 passes.

9.0 Item 7 - AM-2 Mat and Uniform Aggregate

Items 7 and 8 had originally been prepared for testing with high alumina concrete, but further testing with the material was discontinued due to the difficulties encountered in handling item 6. It was decided to use these already prepared items to examine performance of landing mat repairs.

Item 7 consisted of a 14-inch base course of 3-inch uniform aggregate placed in the same manner as item 5. The surface was an 18-foot wide by 20-foot long AM-2 landing mat patch. One foot of the 20-foot by 20-foot item was left uncovered parallel to the load cart traffic (Figure 30). It proved impossible to level the large uniform aggregate to provide a patch truly flush with the surrounding pavement. After the mat was placed on the test item, it was settled onto the surface by driving a front end loader over it. The mat was not anchored in any manner.

The mat panels freely rotated about their edge connections so that a bow wave formed ahead of the load cart wheel. An attempt to measure the rise of the mat panels in the bow wave with dial gages failed because of inadequate dial gage capacity. The difference in elevation between leading and trailing edges of one mat panel as the load wheel approached was estimated to be in excess of 0.75 inch. After 4 coverages the item was considered failed because the base course under the mat had rapidly settled and a 1.8-inch lip had formed between the mat and pavement. The mat panels did not conform exactly to the underlying surface and bridged over some depressions. The mat would be depressed under the load tire and then would rebound when the load was removed. The mat surface settled a maximum of 1.32 inches under traffic. Profiles of the mat surface before and after traffic are shown in Figure 31. All profiles are from the unloaded surface.

The clay subgrade for this item had a CBR of 8, a dry density of 103.3 pcf (91 percent CE-55 density), a moisture content of 22.4 percent and a modulus of subgrade reaction of 105 pounds per cubic inch (pci).

10.0 Item 8 - AM-2 Mat and Base Course Aggregate

Item 8 consisted of a 6-inch base course of well graded aggregate with an AM-2 mat surfacing. The base course was compacted with a mechanical impact compactor. The AM-2 mat used in item 7 was lifted intact and repositioned on item 8 with a front end loader equipped with a fork attachment (Figure 32). This test pit was approximately 0.25 inch too short for the mat patch, so the north end of the mat was allowed to lie over the edge of the concrete (Figure 33).

As in item 7, the mat formed a bow wave ahead of the F-4 tire of the load cart. The maximum rise and fall of the mat was estimated to be in excess of 0.75 inch. Profiles on the mat, base course, and clay are shown in Figures 34 through 37. There was very little change in the profiles on the mat surface between 40 and 120 coverages, so only 0 and 120 coverages are shown in the figures. The lateral quarter point profiles and stations 0 through 5 of the longitudinal profiles cannot be considered as representative profiles because of the effect of the mat lying over the concrete.

Under the F-4 load cart traffic, the mat surface and the base course surface settled approximately 1 inch in the traffic lanes. The upheaval of the base course surface outside the traffic lane is evidence that repetitive shear deformation (plastic flow without volume change) occurred. The clay profiles do not show a shear deformation pattern.

The mat along the concrete edge of the test item did not conform to the base course surface and would rise up to near its original position after the load wheel moved onto the concrete. Figure 37 shows that at the 20-foot station the mat surface settled only 0.06 foot under traffic while the base course surface at the same point settled 0.10 foot. A visual observation of the mat surface would not reveal nearly as much lip at the edge as actually existed. The actual lip encountered at the edge of the test item by the load wheel was measured by taking readings on a rod held by the wheel on the frame of the truck while the wheel was on the last AM-2 mat panel and again while it was on the edge of the concrete. This method of measurement is affected by any flexing in the tire, by the difficulty of positioning the load cart tire at the point to be measured, and also by any resilient deflection in the subgrade. These measurements gave a lip height of 0.12 foot at 40 coverages with an erratic variation up to 0.15 foot at 120 coverages. The base course at this point had only a 0.10 foot change between 0 and 120 coverages.

Traffic was discontinued at 120 coverages. Only one crack appeared in an AM-2 panel. The crack was in a panel located at the north end of the patch that was subjected to considerable bending stress due to overlapping the edge of the concrete. The patch surface settled a maximum of approximately 1 inch within the first 40 coverages and remained relatively unchanged for another 80 coverages.

A lip at the south end of the test item apparently increased about 0.36 inch between 40 and 120 coverages and reached a maximum, judging from the base course settlement, of 1.2 inches. Test results on the clay and base course are shown in Table 13.

TABLE 13. ITEM 8 TEST RESULTS

T	Material	In Traffic d	In Traffic CBR	In Traffic d	In Traffic %	In Traffic MC	Out of Traffic d	Out of Traffic CBR	Out of Traffic d	Out of Traffic %	Out of Traffic MC	Out of Traffic k
1½	AM-2	1½	59	145.8	98	6.6	1½	109	143.7	97	2.1	143
6	BASE COURSE						7½	7	99.4	88	21.2	109
	CLAY											

NOTE: k=89 at d=1½

TRAFFIC 120 COVERAGES

LEGEND

T - thickness of material (inches)
d - depth below surface (inches)
CBR - California Bearing Ratio
d - Dry density, See Appendix A for detailed discussion
MC - Moisture Content (percent)
k - Modulus of subgrade reaction, pounds per cubic inch (pci)
% - Percent of CE-55 density
+ - not measured

11.0 Item 9 - Hot Mix Asphaltic Concrete

The 4-inch thick slab of high alumina concrete in item 6 was removed, and the existing base course was reworked for item 9. Item 9 consisted of 4 inches of hot mix asphaltic concrete over a 12-inch thick base course of crushed, well graded aggregate.

The hot mix asphaltic concrete was obtained from a local plant and met Florida Department of Transportation specification S-1. The aggregate gradation for this mix is shown in Figure 38.

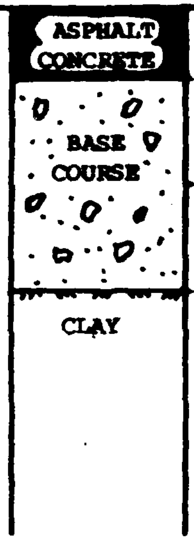
No prime coat was used on the base course. The asphaltic concrete was dumped directly into the repair area and spread by hand. The entire 4-inch lift was placed at one time. Placement began at 0845 and was completed at 0930. During placement, temperature of the hot mix asphaltic concrete ranged from 235°F to 280°F.

A 12-ton tandem steel wheel roller was used for breakdown roll. The roller was applied about 1 hour after placement when the asphaltic concrete temperature ranged from 171°F to 212°F. The mix shoved and puckered under the roller. High quality mixes such as S-1 can be successfully rolled at temperatures of 250°F. The shoving and puckering of this mix under the roller at these temperatures suggests that the mix contained an excess of asphalt cement. A total of eight coverages were made with the 12-ton roller at various times as the asphalt concrete cooled to 152°F. This was followed with 21 coverages with a 13-wheel pneumatic roller with 65 psi tire pressure at asphalt temperature range of 133°F to 147°F. The final density after compaction measured with a nuclear gage in the backscatter mode was 142.1 pcf. Figure 39 shows the temperature and density measurements for various levels of compaction. Density in the asphalt was not obtained until considerable cooling had occurred. Temperature appeared to have more influence on density than the amount of compaction with the steel wheel and pneumatic rollers.

The hot mix was unstable under the rollers while it was hot, so no attempt was made to traffic the item until the day after the placement and compaction. Figure 40 shows the average temperatures of the asphaltic concrete from placement at 0845 on 25 April 1978 until traffic began at 0830 on 26 April 1978.

A total of 150 coverages of F-4 load cart traffic was applied to item 9. Tight alligator cracking was apparent after 60 coverages. By 150 coverages, tight alligator cracks covered the entire trafffic lane; several cracks had appeared; some aggregate was exposed; and permanent deformation had reached 1 inch. Profiles of the surface of the asphalt, base course, and clay are shown in Figures 41 through 44. The surface upheaval alongside the traffic lane in Figures 41 through 43 indicates a shear deformation failure. Although the original clay subgrade profile was not recorded, the clay profile does match the final surface profiles to some extent as can be seen in Figures 41 through 43 and is seen to be particularly close in Figure 44. This suggests that the clay subgrade was being overstressed. A plot of maximum permanent deformation and traffic coverage is shown in Figure 45. Results of soil testing on item 9 are shown in Table 14.

TABLE 14. ITEM 9 TEST RESULTS



T		IN TRAFFIC					OUT OF TRAFFIC					
	d	CBR	d	%	MC	d	CBR	d	%	MC	k
4	4	92	151.0	102	1.4	4	149	145.3	98	0.9	180
12	10	56	147.9	99	1.1	10	90	148.1	100	0.7	+
	16	3	100.8	89	22.4	16	4	97.4	86	23.0	54

TRAFFIC 150 COVERAGES

LEGEND

T - thickness of material (inches)
d - depth below surface (inches)
CBR - California Bearing Ratio
d - Dry density, See Appendix A for detailed discussion
MC - Moisture Content (percent)
k - Modulus of subgrade reaction, pounds per cubic inch (pci)
% - Percent of CE-55 density
+ - not measured

The resilient deflection of the surface was readily visible. To try to measure this resilient deflection, elevations were measured at various points around the tire while it was at the center of the test item. The elevations were remeasured after the load cart was removed from the test item. These measurements were made at 2, 100, and 150 coverages. The surface rebound after the load was removed was a maximum of 0.25 inch directly alongside the tire and did not change for different coverage levels. The depression basin around the tire extended horizontally 30 to 36 inches.

Figure 46 shows the average density of asphalt concrete at various levels of compaction achieved by the steel wheel roller, the pneumatic roller, and the F-4 load cart. All measurements were with a nuclear gage in the backscatter mode. The points for the steel wheel and pneumatic rollers consisted of one to three measurements, and for the F-4 they were the average of four measurements.

Three cores of asphaltic cement were removed from within the traffic lane, and three cores were removed from outside the traffic lane. Results of testing on these cores are presented in Table 15 and show more compaction under traffic than indicated by the nuclear density measurements.

TABLE 15. LABORATORY TESTING ON ASPHALTIC CONCRETE CORES FROM ITEM 9

Test	Traffic Lane	Out of Traffic Lane
Asphalt Content (Percent of Sample Weight)	5.9	5.9
Apparent Specific Gravity	2.378	2.343
Maximum Theoretical Specific Gravity	2.461	2.438
Voids Total Mix (Percent)	3.4	3.9
Voids Filled (Percent)	79.9	77.3
Unit Weight (pcf)	148.4	146.2
Marshall Stability	3054	2475
Flow (1/100 inch)	12	13
Penetration of Asphalt Cement[a]	b	42

[a]Extraction by centrifuge method with trichloroethelene solvent which generally decreases penetration.

[b]Not measured.

12.0 Item 10 - Future Patch®

Item 10 consisted of 1 inch of Future Patch® over 23 inches of well graded, crushed stone base course. Future Patch® is a premixed asphalt patching material provided in 55 gallon drums. More detailed information on Future Patch® is available in References 8 and 9. The base course was placed and compacted in four 6-inch lifts. The bottom two lifts received 5 coverages each with an impact type compactor; the next lift received 7 coverages; and the final top lift received 5 coverages.

Slightly over five barrels of Future Patch® were placed in the repair area and compacted with 4 coverages of the unballasted tandem steel wheel roller (9 tons), 4 coverages with the ballasted tandem steel wheel roller (12 tons), and 4 coverages with the 13-wheel pneumatic roller with 65 psi tire pressure. The Future Patch® material did not compact but puckered and shoved under the rollers.

A total of 20 coverages of traffic were applied to item 10, but the surface rutted, shoved, and broke up under traffic from the initial pass. This item was considered unacceptable because of shoving, rutting, and breakup of the surface. Results of soil tests are shown in Table 16.

13.0 ITEM 11 - Amalgapave®

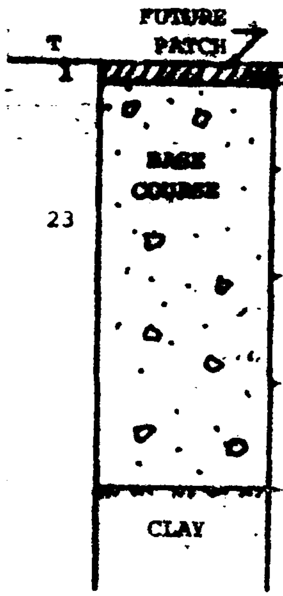
Item 11 consisted of 1.75 inches of Amalgapave® over 23 inches of a well graded, crushed stone base course. Amalgapave® is a commercial cold mix asphalt patching material. More information on Amalgapave® is available in References 8 and 9.

The base course was compacted in 6-inch lifts with the impact compactor and rolled on the surface with 12 coverages of the 12-ton steel wheel roller. Amalgapave® is provided in 50-pound bags, which were broken and spread by hand (Figure 47). A total of 111 bags were placed. The Amalgapave® was compacted by 6 coverages of the 12-ton steel wheel roller, 1 coverage of the 9-ton unballasted steel wheel roller, and 4 coverages of the 13-wheel pneumatic roller with 65 psi tire pressure. The Amalgapave® shoved during all compactions.

A total 20 coverages of F-4 load cart traffic was applied to the item. During traffic the Amalgapave® shoved and rutted badly (Figure 48) and worked out of the repair area (Figure 49.) This item was considered unusable under traffic because of low stability.

A nuclear gage with a source probe was used to measure the density of the upper 12 inches of base course after traffic. The results of this testing are shown in Table 17. The dry density was calculated from the nuclear wet density by using a moisture content from oven dried samples. The density given is the average density for the material between the depth of the probe and the surface.

TABLE 16. ITEM 10 TEST RESULTS



TRAFFIC 20 COVERAGES

	IN TRAFFIC					OUT OF TRAFFIC					
d	CBR	d	%	MC	d	CBR	d	%	MC	k
1	[illegible]	[illegible]	[illegible]	1.9	1	112	146.1	98	2.0	370
6	133	148.5	100	0.8	6	116	146.6	99	1.0	+
12	120	146.8	99	1.1	12	96	144.2	97	0.8	+
18	71	144.6	97	1.4	18	29	143.9	97	1.3	+
24	3	98.4	87	22.8	24	4	98.2	87	23.7	105

LEGEND

T - thickness of material (inches)
d - depth below surface (inches)
CBR - California Bearing Ratio
d - Dry density, See Appendix A for detailed discussion
MC - Moisture Content (percent)
k - Modulus of subgrade reaction, pounds per cubic inch (pci)
% - Percent of CE-55 density
+ - not measured

TABLE 17. TESTS ON ITEM 11, BASE COURSE

	In Traffic Lane		Out of Traffic Lane	
Depth (Inches)	Dry Density (pcf)[a]	Percent CE-55	Dry Density (pcf)[b]	Percent CE-55
2	147.4	99	148.0	100
4	147.0	99	146.0	98
6	147.0	99	145.2	98
8	147.8	99	147.2	99
10	147.8	99	146.0	98
12	152.5	103	147.0	99

[a]Oven-dried moisture 0.6 percent

[b]Oven-dried moisture 0.8 percent

14.0 Item 12 - Zor-x®

The Amalgapave® surface of item 11 was removed, and the base course surface was rolled twice with the 12-ton steel wheel roller for item 12. The surface for item 12 was ' inch of Zor-x®, a commercial cold mix asphaltic patching material. More details on Zor-x® can be found in References 8 and 9.

Zor-x® is provided in 55 gallon drums. A fork lift was used to handle the drums, and the material was spread and leveled by hand (Figure 50). The Zor-x® surface was rolled with four coverages of the 12-ton steel wheel roller, four coverages with the 13-wheel pneumatic roller, and 2 additional coverages with the 12-ton steel wheel roller.

The surface was unstable under the rollers and rutted under initial traffic of the F-4 load cart. A total of 14 coverages of traffic was applied. The Zor-x® worked out of the ends of the repair area (Figure 51) was soft and easily removed by hand (Figure 52). This item was considered unacceptable because of unstable surfacing.

15.0 Item 11A - Amalgapave®

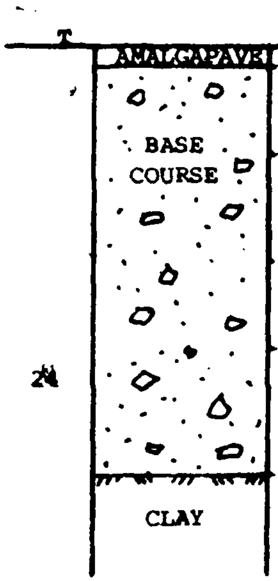
The Zor-x® surface for item 12 was removed and replaced with Amalgapave® for item 11A. The thickness of Amalgapave® was reduced to less than 1 inch for item 11A in comparison to the 1.75 inches used in item 11. A total of 53 bags of Amalgapave® were placed for item 11A. The surface was compacted with 6 coverages of the 12-ton steel wheel roller and 6 coverages of the 13-wheel pneumatic roller.

The Amalgapave® was unstable under the F-4 load cart traffic. A total of 24 coverages of traffic were applied to the item, but the surface was judged to be unsuitable due to shoving and rutting under initial traffic. The Amalgapave® did not work out of the repair area as it did in item 11. The surface of item 11A after 20 coverages is shown in Figure 53. Table 18 shows the results of soil tests for item 11A. The density for the base course was determined from a nuclear gage wet density with the source probe at a 6-inch depth, and moisture contents were determined from oven dried moisture samples. In addition to item 11A, this same base course had been used for items 11 and 12 and was subjected to 58 coverages of traffic. Profiles of the clay subgrade in item 11A after traffic were unchanged from profiles made before traffic in Item 11.

16.0 Item 13 - Base Course Aggregate

Item 13 consisted of a 24-inch well graded, crushed stone base course without any surfacing. The upper 6-inch lift was used for a compaction study which will be discussed later. The lower 18 inches were placed in 6-inch lifts and compacted with an impact compactor.

TABLE 18. ITEM 11A TEST RESULTS



IN TRAFFIC					OUT OF TRAFFIC					
d	CBR	d	%	MC	d	CBR	d	%	MC	k
1	153+	148.8	100	0.6	1	151+	146.4	99	0.5	350
6	143+	148.6	100	0.5	6	130+	146.6	99	0.3	+
12	133	142.3	96	1.0	12	148	146.7	99	0.8	+
17	76	142.6	96	0.9	17	81	141.8	95	0.8	+
24	3	99.0	88	22.6	24	5	97.1	86	22.4	57

TRAFFIC 24 COVERAGES

LEGEND

T - thickness of material (inches)
d - depth below surface (inches)
CBR - California Bearing Ratio
d - Dry density, See Appendix A for detailed discussion
MC - Moisture Content (percent)
k - Modulus of subgrade reaction, pounds per cubic inch (pci)
% - Percent of CE-55 density
+ - not measured

Two coverages of the F-4 load cart resulted in a 1.75-inch rut (measured top of edge of rut to bottom of rut), and 8 coverages resulted in a 3.5-inch rut (Figure 54). Traffic was discontinued at this point. Density of the upper 12 inches of base course in and out of the traffic lane was determined with a nuclear gage. Results are shown in Table 19.

TABLE 19. BASE COURSE DENSITY, ITEM 13

Depth (inches)	Out of Traffic Dry Density[a] (pcf)	Percent CE-55	In Traffic Dry Density[b] (pcf)	Percent CE-55
4	143.6	97	139.3	94
8	141.6	95	138.9	93
12	141.1	95	137.7	93

[a]Moisture content by nuclear gage: 4.7 percent
Moisture content by oven dried sample: 4.75 percent

[b]Moisture content by nuclear gage: 5.5 percent

17.0 Item 13A - Base Course Aggregate

Item 13 was releveled and compacted with 20 coverages of the 12-ton steel wheel roller for item 13A. A total of 150 coverages of F-4 load cart traffic was applied to this test item.

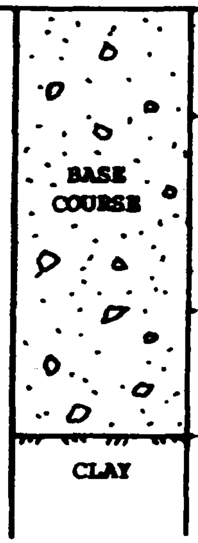
After 70 coverages the surface of the item was soaked until water was standing in low spots. Samples from the surface had moisture contents of 4.7 and 5.2 percent. Traffic was immediately continued on the wet surface. No difference in performance of the item was seen due to this excess moisture.

Profiles of the clay subgrade and base course surface at various levels of traffic are shown in Figures 55 through 58. The lack of upheaval at the edge of the traffic lane indicates densification rather than shear deformation was the cause of the surface settlement. Maximum deformation reached 1 inch at 150 coverages. The maximum deformation at various levels of traffic is shown in Figure 59. Results of soil tests are shown in Table 20. Densities were determined from a nuclear gage wet density with the source probe at a depth of 6 inches, and moisture contents were determined from oven dried moisture samples.

18.0 Item 14 - Sand Bag Subbase

Item 14 consisted of a 12-inch base course of well graded, crushed stone and a 12-inch subbase of sandbags. No surface was used on this item. Results of testing are shown in Table 21.

TABLE 20. ITEM 13A TEST RESULTS



T	IN TRAFFIC d	CBR	d	%	MC	OUT OF TRAFFIC d	CBR	d	%	MC	k
	0	113	154.6	104	1.0	0	148	147.9	99	1.1	290
	6	147	148.5	100	1.3	6	143	141.9	95	1.1	+
24	17	138	148.9	100	1.6	18	80	143.9	97	1.1	+
	24	3	102.4	91	20.9	25	5	99.7	88	21.7	81

TRAFFIC 150 COVERAGES

LEGEND

T - thickness of material (inches)
CBR - California Bearing Ratio
d - Dry density, See Appendix A for detailed discussion
MC - Moisture Content (percent)
k - Modulus of subgrade reaction, pounds per cubic inch (pci)
% - Percent CE-55 density
+ - not measured

TABLE 21. ITEM 14 TEST RESULTS

T	IN TRAFFIC d	CBR	d	%	MC	OUT OF TRAFFIC d	CBR	d	%	MC	k
12	0	42	+	+	+	0	88	+	+	+	+
	4	+	140.3	94	1.9	4	+	146.3	98	1.6	+
	8	+	142.9	96	1.8	8	+	144.3	97	1.6	+
	10	85	+	+	+	10	83	+	+	+	+
	12	+	143.4	96	1.8	12	+	146.2	98	1.5	+
12						24	5	+	+	+	+

TRAFFIC 6 COVERAGES

LEGEND

T - thickness of material (inches)
d - depth below surface (inches)
CBR - California Bearing Ratio
d - Dry density, See Appendix A for detailed discussion
MC - Moisture Content (percent)
k - Modulus of subgrade reaction, pounds per cubic inch (pci)
% - Percent of CE-55 density
+ - not measured

Initial traffic on this item caused some visible resilient deflection but no other visible distress. By four coverages the resilient deflection had become more pronounced, and some minor rutting had begun. On the sixth coverage rutting had reached 4 inches, and traffic was discontinued.

19.0 Item 15 - Dune Sand Subbase

Item 15 consisted of a 6-inch base course of well graded, crushed stone and an 18-inch subbase of a local dune sand. The gradation of the sand is shown in Figure 60. A CE-55 compaction curve and a CBR curve are shown in Figure 61.

The dune sand subbase was placed in two 9-inch lifts with 8 coverages by a vibratory plate hand compactor. The base course was rolled with 36 coverages of the 12-ton steel wheel roller. The density of the base and upper lift of the subbase were recorded during construction and are shown in Table 22. A shear failure occurred in the sand subbase on the third pass of the load cart (Figure 62).

TABLE 22. DENSITY RESULTS, ITEM 15

Depth[a] (inches)	Material	Dry Density[b] (pcf)	Percent of CE-55	Moisture Content[b] (percent)
2	Base	145.7	98	4.6
4	Base	145.8	98	4.4
6	Base	144.5	97	4.4
2	Subbase	92.5	94	18.1
4	Subbase	95.0	97	17.3
6	Subbase	97.9	100	16.0
8	Subbase	98.5	101	15.9

[a]Depth of radioactive source probe below surface of material.

[b]Dry Density and moisture content determined with nuclear gage.

20.0 Compaction Tests

The final 6-inch lift of well graded base course aggregate of item 13 was used for a comparative evaluation of compaction equipment for crater repair. The vibratory plate hand compactor (Figure 9), gasoline powered, hand operated impact compactor (Figure 13), the 12-ton steel tandem wheel roller (Figure 11), and the 13-wheel pneumatic roller with 65 psi tire pressure (Figure 63) used previously in test item construction were evaluated. In addition a larger model of the hand impact compactor (Figure 64) and a hydraulically operated impact compactor attached to a backhoe (Figure 65) were tested. The two rollers were used to compact 7-foot wide and 20-foot long sections; and the hand operated and backhoe compactors were used in 5-foot square sections. Manufacturers' data on the impact compactors is included in Appendix B.

Density was recorded with a nuclear gage after 0, 2, 4, 8, 16, and 24 coverages of each piece of compaction equipment. Density and moisture content were recorded with the radioactive source probe at a 6-inch depth. Results are shown in Figure 66.

The backhoe compactor was capable of obtaining the highest densities (98.8 percent of CE-55); however, this piece of equipment was very slow and awkward to use. The plate is lowered into position, and then the hydraulic impact device is cut on. This allows a hydraulically compressed spring to impact a weight on the plate (at about 3.5 impacts per second). For comparison purposes, the results of the backhoe have been graphed with 5 seconds of impact operation being equal to 2 coverages, 10 seconds equal to 4 coverages, etc. This equipment was so slow and cumbersome that compaction of any sizable area was out of the question.

Of the two hand impact compactors, the smaller compactor (impactor 2 in Figure 66) obtained better results. However, this compactor was also compacting material closer to the optimum moisture content (moisture content shown in parentheses in the legend of Figure 66) which may account for this difference.

In general it does not appear that it will be possible to obtain above 95 percent CE-55 density with this equipment within any kind of reasonable coverage level.

SECTION V

ANALYSIS

1. SUMMARY

Table 23 summarizes the results of testing. Only two items met the maximum criterion of 150 coverages: item 9, 4 inches of hot mix asphaltic concrete over a 12-inch base course; and item 13A, unsurfaced 24-inch base course. Three other items exceeded the minimum criterion of 12 coverages: item 3, 3 inches of magnesium phosphate cement over 12 inches of base course; item 4, unsurfaced 24-inch base course; and item 8, AM-2 mat over 6 inches of base course.

There were four failures due to unstable surfacing materials (items 10 through 12 and 11A); one failure due to surfacing material being too difficult to handle (item 6); two shear failures in the base or subbase (items 1 and 15); two failures due to surface rutting (items 2 and 13); one failure due to surface deterioration (item 3); three failures due to unstable base or subbase (items 5, 7, and 14); two failures due to shear deformation in the base or subgrade (items 8 and 9); and three failures due to densification (items 4, 5A, and 13A).

2. ASPHALTIC MATERIALS

Four asphaltic products were tested as surfacing materials. The three commercial cold mix patching products (Future Patch®, Zor-x® and Amalgapave®) recommended for testing in Reference 9 proved unsuitable for surfacing. Although these products reportedly performed adequately in repairs up to 5 feet in diameter, they were unsuitable in the larger repairs. The densities of the base course in Table 18 indicate little change between trafficked and untrafficked sections, so improved compaction of base material will not solve the problems of these materials. These cold mix patching products should be limited to expedient spall repair only.

Hot mix asphaltic concrete performed well, but time requirements for heating and cooling the mix are excessive. Figure 40 indicates that 11.5 hours would be required to cool the hot mix in item 9 to 120°F. This test item and results of tests in Reference 25 confirm that, although conventional hot mix asphalt concrete is structurally adequate, considerable cooling times are required before tactical aircraft can operate on the surface. Some shortening of the cooling time may be possible by limiting the initial temperature of the mix, carefully controlling aggregate gradation, and limiting asphalt content; however, the cooling time and hot mix plant requirements remain serious limitations.

3. FAST SETTING CEMENTS

Two fast setting cements, magnesium phosphate cement and high alumina cement accelerated with lithium carbonate, were tested. Item 3 demonstrated the feasibility of using fast setting cements in thin sections over base course to withstand the necessary loads. Other tests at Waterways Experiment Station have demonstrated the feasibility of using thicker slabs directly over a clay or debris subgrade.

TABLE 23. SUMMARY OF TEST ITEMS

Item	Thickness (inches)	Surface	Capacity (Coverages)	Failure Mode
1	13	1 inch Future Patch®	0.2	Shear in base
2	14.5	Unsurfaced	3	Rutting
3	14	3 inches Magnesium Phosphate Cement	100	Surface deterioration
4	24	Unsurfaced	60[a]	Densification
5	24	Unsurfaced	1.2	Unstable subbase
5A	24	Unsurfaced	<30[b]	Densification
6	16	4 inches high alumina cement	-	Surfacing material
7	13.5	AM-2 Mat	<4	Unstable base
8	7.5	AM-2 Mat	120[b]	Shear deformation in base
9	16	Asphalt Concrete	150	Shear deformation in subgrade
10	24	1 inch Future Patch®	0	Unstable surfacing
11	25	1 3/4 inch Amalgapave®	0	Unstable surfacing
11A	25	1 inch Amalgapave®	0	Unstable surfacing
12	25	1 inch Future Patch®	0	Unstable surfacing
13	24	Unsurfaced	8	3 inch rut
13A	24	Unsurfaced	150	Densification
14	24	Unsurfaced	6	Unstable subbase
15	24	Unsurfaced	0.3	Shear in subbase

[a]Interpolated from Figure 23 for 1-inch criterion.

[b]Based on 1-inch maximum deformation.

The problem with fast setting cements is an equipment and materials handling problem rather than a purely materials problem. Various fast setting cements, such as magnesium phosphate cements, accelerated high alumina and portland cements, gypsum cements and regulated set cements (see Reference 9 for discussion of various fast setting cements), can achieve the necessary strengths. Probably all of these can be successfully used for expedient repairs if a way can be found to store, transport, proportion, mix, dispense, and finish the concrete. Conventional transit mix trucks and slurry pumps have been used in past tests without any successful field usable technique being developed.

Emphasis on rapid strength gain has been stressed in past studies to the virtual exclusion of field handling requirements. This has resulted in numerous clogged pumps, lines, and mixers and rough repair surfaces. The same problems reoccurred in items 3 and 6. If cure times of 6 to 24 hours would be acceptable, a number of usable materials would become available. If the requirement for cure times of 30 minutes to 2 hours remains valid, fast setting cements have a potential for repair of small spalls and craters such as those repairs discussed in Reference 9.

4. LANDING MAT

The landing mat is the conventional military solution to the problem of expedient airfield repairs. It is used for this purpose by the United States, United Kingdom, Norway, Germany, and Korea. The landing mat is insensitive to the environment, has high load capacity, can be used by relatively unskilled personnel, and requires only simple support equipment.

Item 8 showed that densification will occur under the landing mat. Consequently, some provision must be made for periodic removal of the landing mat and repair of the base to bring the underlying surface back to grade.

A major hurdle in development of a flush mounted mat repair system is cutting the pavement and sizing the repair area. Other problems include developing an anchoring technique capable of adjusting to the bow wave in the mat and a method of releveling the base after it densifies under traffic.

Objections to the current method of placing AM-2 landing mats on top of the surface of the pavement surrounding the repair have centered on the potential roughness of a multiple mat repair strip. However, after 15 years of research, the landing mat repair systems remain the only dependable, field usable, rapid crater repair system deployed in the world. The pretraffic longitudinal profiles of several test items show variations which approximate elevation change of a 1.5-inch thick AM-2 mat repair. When small repairs are done by hand the results are inefficiency and construction tolerances which approximate the AM-2 repair profile. If landing mats can be placed on top of the pavement, repairs in 2 to 4 hours may be reasonable.

5. UNSURFACED REPAIRS

Items 4 and 13A demonstrated that an unsurfaced, well graded crushed aggregate is capable of being used for repair. This material is relatively insensitive to the environment. Excess moisture on the surface did not lead to rutting on item 13A. Tests by the Waterways Experiment Station indicate that, if plasticity index is below 5 and less than 10 percent of the material passes the number 200 sieve, well graded aggregate is not affected by excess moisture during compaction or trafficking (Reference 26).

Foreign object damage to aircraft engines is a concern if unsurfaced repairs are used. In a review of recent Air Force aircraft accident reports and discussion with various Air Force safety and aircraft engine development personnel, Captain M. McNerney at AFESC has concluded that the most serious FOD problem in an unsurfaced repair would be from rocks and debris kicked up by the aircraft tires. The problems might be minimized by proper aircraft spacing and development of an FOD cover using heavy duty membranes; or using materials such as liquid asphalts, polymers, or other cementing agents to form a nonstructural surface to eliminate the FOD concerns.

Good compaction is the key to the crushed aggregate repair technique and will be discussed in more detail separately. Inadequate compaction was the key factor, or strong contributing factor, in the success or failure of items 1, 2, 4, 5A, 13, 13A, and 15. In items 1 and 15 attempts to construct repairs using only available Air Force compaction equipment were unsuccessful. Items 13 and 13A demonstrated that the unsurfaced repairs can be accomplished even if compaction is initially inadequate.

6. COMPACTION

Adequate compaction provides shear strength to a soil and reduces densification of the soil under traffic. The Corps of Engineers has established standard levels of compaction for soil components under flexible pavements to prevent densification under traffic based on a survey of densities in various airfield pavements and test sections (Reference 27). The compaction requirement for a 60,000-pound gross load F-4 on cohesionless soil is shown in Figure 67 with data from items 4, 9, 13 and 13A. Only the lower sections of items 4 and 13A met the compaction requirements. Items 4, 9, and 13A all gave satisfactory performance, but their initial densities were not much greater than that of item 13 which failed. It can be concluded that the compaction requirements can be reduced somewhat, but there is only a narrow range for error. Considering the expedient nature of these repairs, Figure 67 suggests that compaction requirements for the upper foot of the repair can be relaxed to 100 percent of CE-55 density for 150 coverages of an F-4.

Once compaction requirements are agreed upon, rapid compaction to high density is often difficult to achieve. Compaction inside a crater is greatly complicated by the problem of working in a hole. Several different approaches appear possible and will be discussed separately.

6.1 Compact Material From Inside Crater.

This is the technique used in items 1, 2, 4, 13, and 13A. Using the gasoline powered, hand operated impact compactors it was possible to construct a successful repair, but it was extremely time consuming. The compaction test indicated that it was possible to obtain up to 97 percent CE-55 density with this equipment. The most effective of the hand operated compactors was the impact type compactor, but when used to compact material to high density the compactor required considerable maintenance and repair. Compaction of the final surface lift can be done with conventional compaction equipment such as the steel wheel roller because it is no longer necessary to get into the hole. All of the equipment listed in Figure 66 required a large number of coverages (and hence large amount of time) to reach the required density.

Large vibratory plate compactors have proven capable of compacting cohesionless materials to high density (Reference 28). It may be possible to use such equipment suspended from a crane to obtain rapid compaction down inside a crater. In tests at Eglin AFB in 1965 vibratory plate compactors were attached to a tracked vehicle to compact fill below the surface of the crater (Reference 4). Access and movement of other compaction equipment inside the crater appears very difficult and impractical.

Another approach is to drop a large weight to compact material down in the crater. This technique is used to consolidate loose natural fill deposits (Reference 29). It may prove possible to adapt existing Air Force cranes to perform this task.

6.2 Compact Material From Surface Only

If equipment existed which could compact the entire required depth by rolling the surface, the compaction problem would be solved. Large pneumatic proof rollers on the order of 50 tons or more can compact base course aggregate to 105 percent density in thin lifts but compaction falls off rapidly with depth (Reference 26 and 28). Large vibratory rollers have considerable potential for compacting cohesionless material at depth, and compaction of dune sands in excess of 5 feet and crushed stone to 20 inches has been reported (References 28, 30, 31 and 32).

6.3 Rapidly Compacted Subbase

Techniques of compacting from the surface only were used in items 5, 5A, 7, 14, and 15 to try to reduce compaction time. Uncompacted uniform aggregate, sand bags, and sand were used as subbases to avoid having to use the impact compactor to slowly compact the crushed stone to the required density. Item 5A, using a uniform aggregate subbase, was moderately successful, and the sand subbase could also be expected to be relatively successful if it had had a thicker base course above it, rather than the 6 inches used in item 15. However, equipment capable of compacting the 12-inch base course above the uniform aggregate or sand is still needed.

6.4 Membrane Reinforcement

A number of engineering fabrics are being marketed which have been successfully used in expedient construction of roads across poor subgrade soils. These fabrics have variously been claimed to provide tension reinforcement, to improve compaction characteristics of materials placed on them, and to prevent migration of fines into bases and subbases. They may be useful in construction of unsurfaced repairs and should be tested.

6.5 Stabilized Subbases

A fast setting cement could be used to stabilize a subbase. The subbase would still require compaction, but the cementing of the soil may allow a lower level of compaction. A limited laboratory study examined the stabilization of the dune sand used in item 15, but no field test was attempted. The results are shown in Table 24. A gypsum base cement (Duracal®), Type I portland cement, and high alumina cement were all tested for stabilization. It appears possible to obtain compressive strengths in excess of 100 psi in 2 hours, but field testing is required to evaluate this approach further.

TABLE 24. SAND STABILIZATION RESULTS

Cement type	Cement[a] (percent)	Water[b] (percent)	Cure (hours)	Strength[c] (psi)
Gypsum	50	36	2	702
"	25	12	2	173
"	25	12	3	175
"	25	12	4	170
"	21	12	2	125
"	21	12	3	100
"	21	12	4	110
"	20	15	2	82
"	20	15	3	95
"	20	15	4	95
"	20	12	2	118
"	20	12	3	113
"	20	12	4	130
"	20	10	2	93
"	20	10	3	100
"	20	10	4	121
"	18	12	2	125
"	18	12	3	121
"	18	12	4	105
"	15	12	2	85
"	15	12	3	83
"	15	12	4	80
"	10	12	6	0
"	10	12	21	10
"	10	5	4	0
Type I, Portland	10[d]	12	4	0
"	10[d]	12	8	0
"	10[d]	12	24	35
High Alumia	10	12	4	0
"	10	12	8	0
"	10	12	24	290
"	10[e]	12	2	120
"	10[e]	12	3	123
"	10[e]	12	4	120

[a]By weight of sand
[b]By combined weight of cement and sand
[c]Two inch compression cubes
[d]With 2 percent $COCl_2$ accelerator (by weight of cement)
[e]With 0.06 percent Li_2CO_3 accelerator (by weight of cement)

7. REPAIR BASE THICKNESS

The current method of debris backfill for craters results in a weak, compressible subgrade. Figure 68 shows the influence of thickness of the base course on the modulus of subgrade reaction. A 6-inch base had little influence, and 20 to 25 inches of base were required to raise the modulus to high levels.

SECTION VI

CONCLUSIONS

1. The fastest, most dependable and practical crater repair method using existing Air Force equipment and existing technology is placement of landing mats on top of the pavement as specified in AFR 93-2 for large craters. If the roughness associated with this method can be tolerated, it is doubtful if any other method within existing technology can be used to carry out repairs as rapidly or dependably.

2. Unsurfaced repairs using a high quality, well graded, crushed aggregate offer the most promising alternative to landing mat for expedient repair.

3. Hot mix asphaltic concrete offers another alternative to landing mat; but hot mix asphalt plants must be available, cool down time for the asphalt concrete surface is necessary, and a well compacted base is still required.

4. Current Air Force equipment is only adequate for repairs with landing mat.

5. Addition of small impact compactors to the Air Force rapid runway repair equipment package would allow construction of unsurfaced repairs or asphaltic concrete repairs but compaction time would be lengthy.

6. Improved methods of compaction in and around craters must be tested.

7. Cold mix asphaltic patching materials should be limited to expedient spall repairs where no additional strength is required.

8. Fast setting cements that can gain the required structural strengths in 2 to 3 hours cannot be handled in sufficient quantity for 20 by 20-foot or larger repairs with existing equipment. Any future work in this area should concentrate on the problems of materials handling and placement.

SECTION VII

RECOMMENDATIONS

1. Evaluate and test new methods of compaction and construction in the crater to include:

1.1 Effectiveness of large vibratory rollers on the order of 8500 to 20,000 pounds static drum weight for effectiveness in construction of unsurfaced repairs.

1.2 Effectiveness of rapid stabilization of materials in the crater to reduce compaction requirements.

1.3 Effectiveness of membrane reinforcing within unsurfaced repairs.

1.4 Effectiveness of dynamic compaction of materials within the crater.

2. Examine methods of preventing FOD through use of membranes or surface stabilization.

3. Examine material handling in further work with fast setting cement rather than material development.

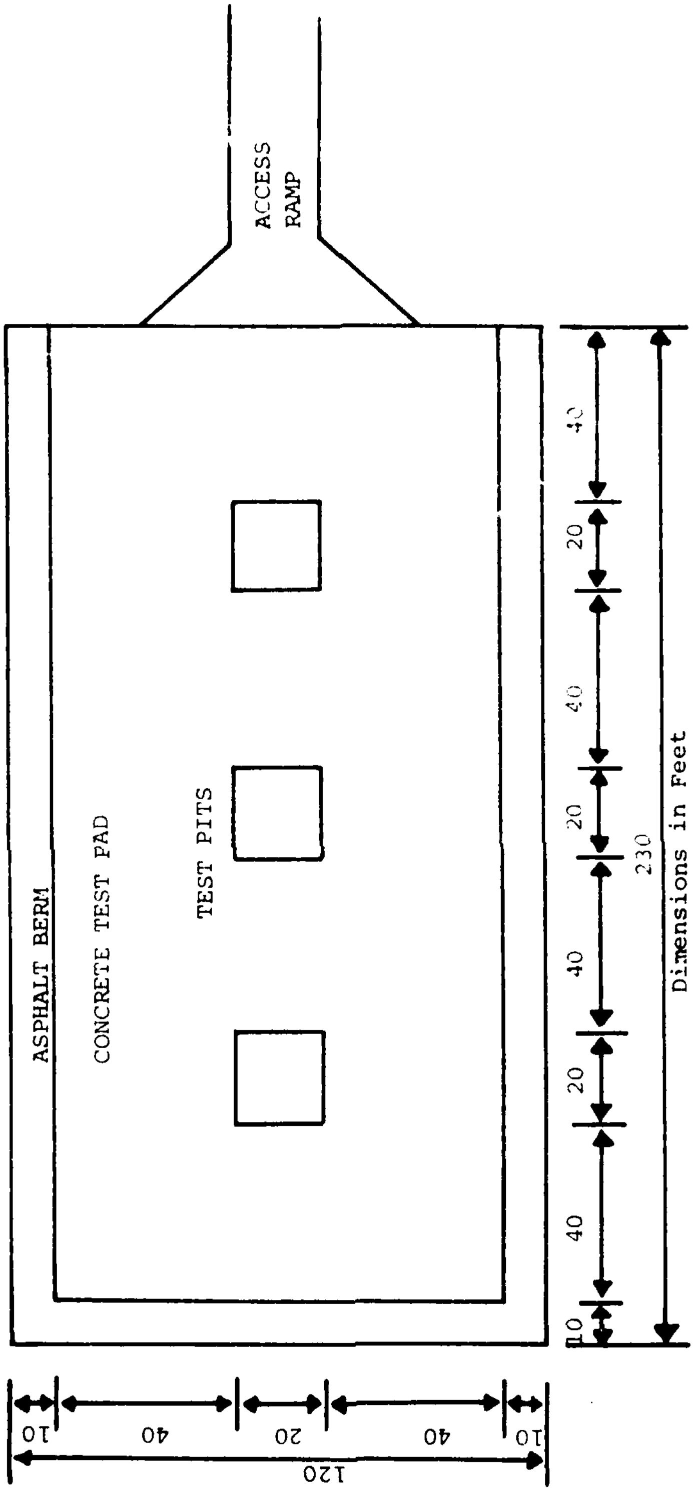


Figure 1. Plan View of Test Site

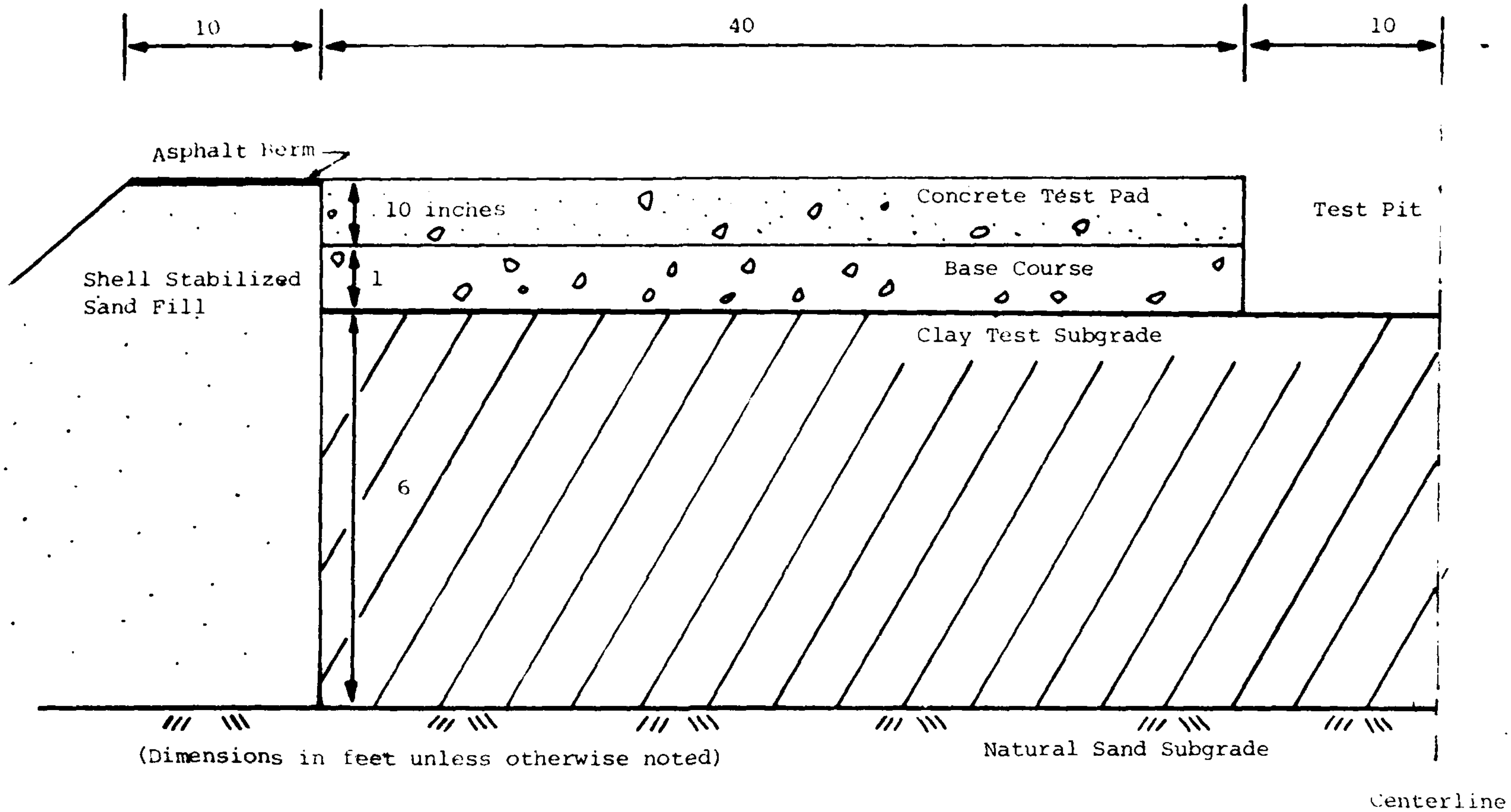


Figure 2. Test Pad Cross Section

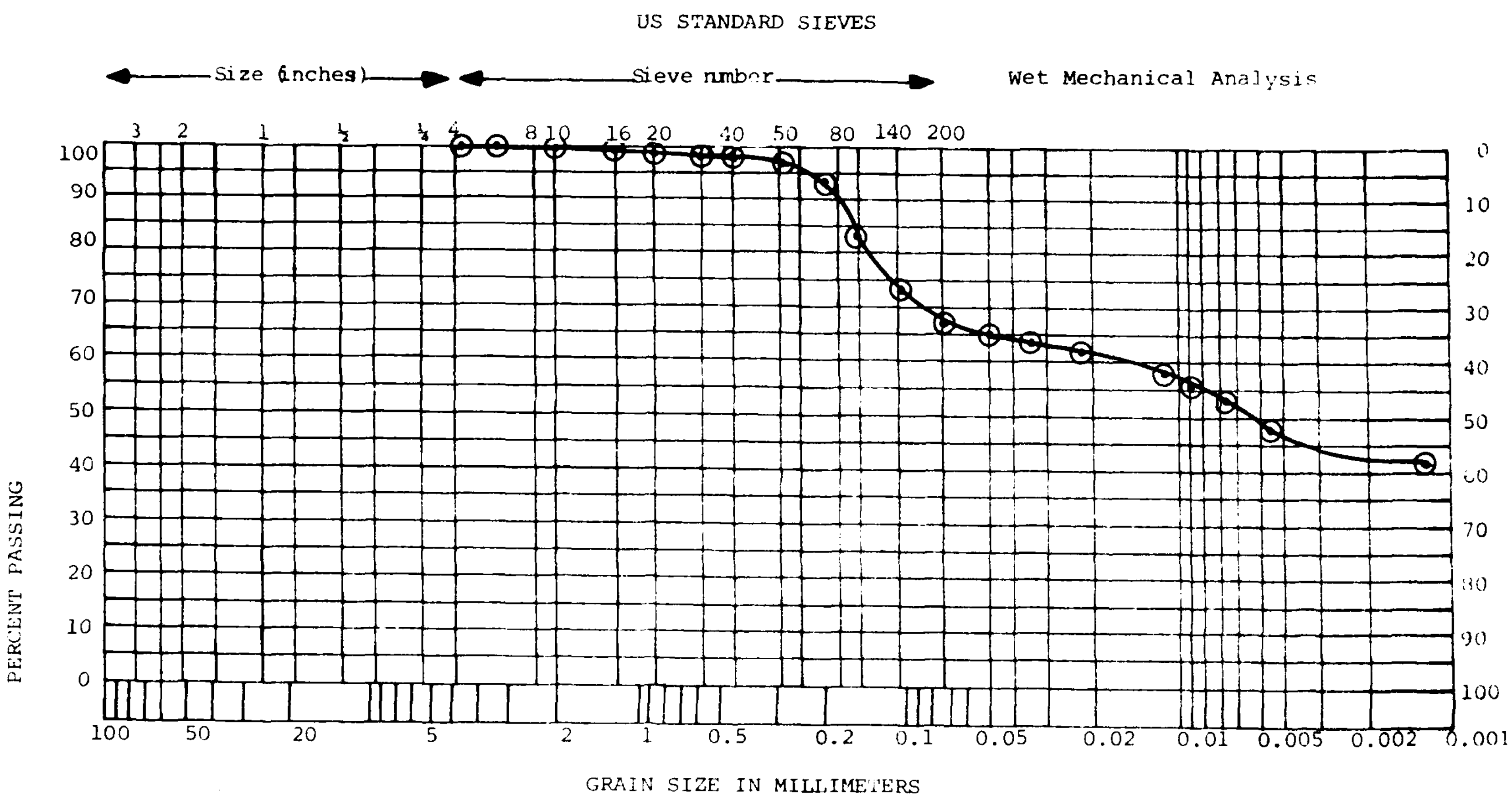


Figure 3. Gradation of Wewahitchka Clay

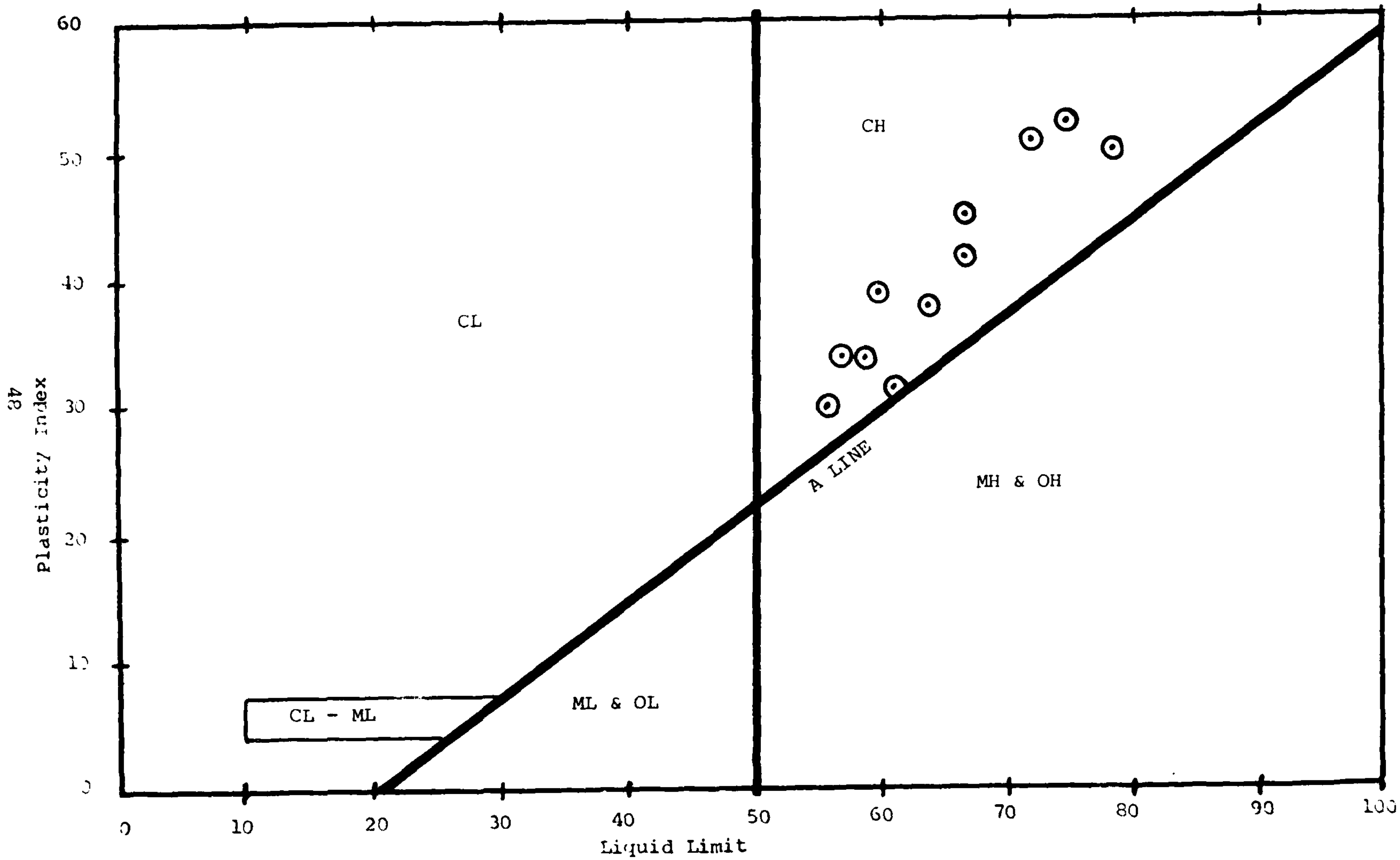


Figure 4. Plot of Wewahitchka Clay on Plasticity Chart

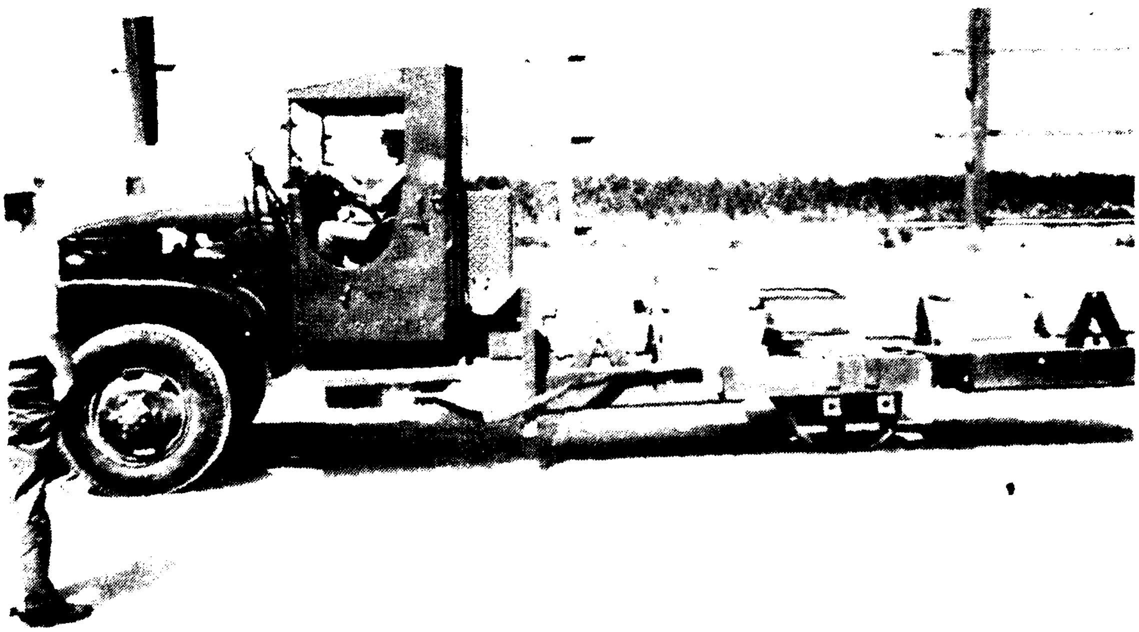


Figure 5. F-4 Load Cart

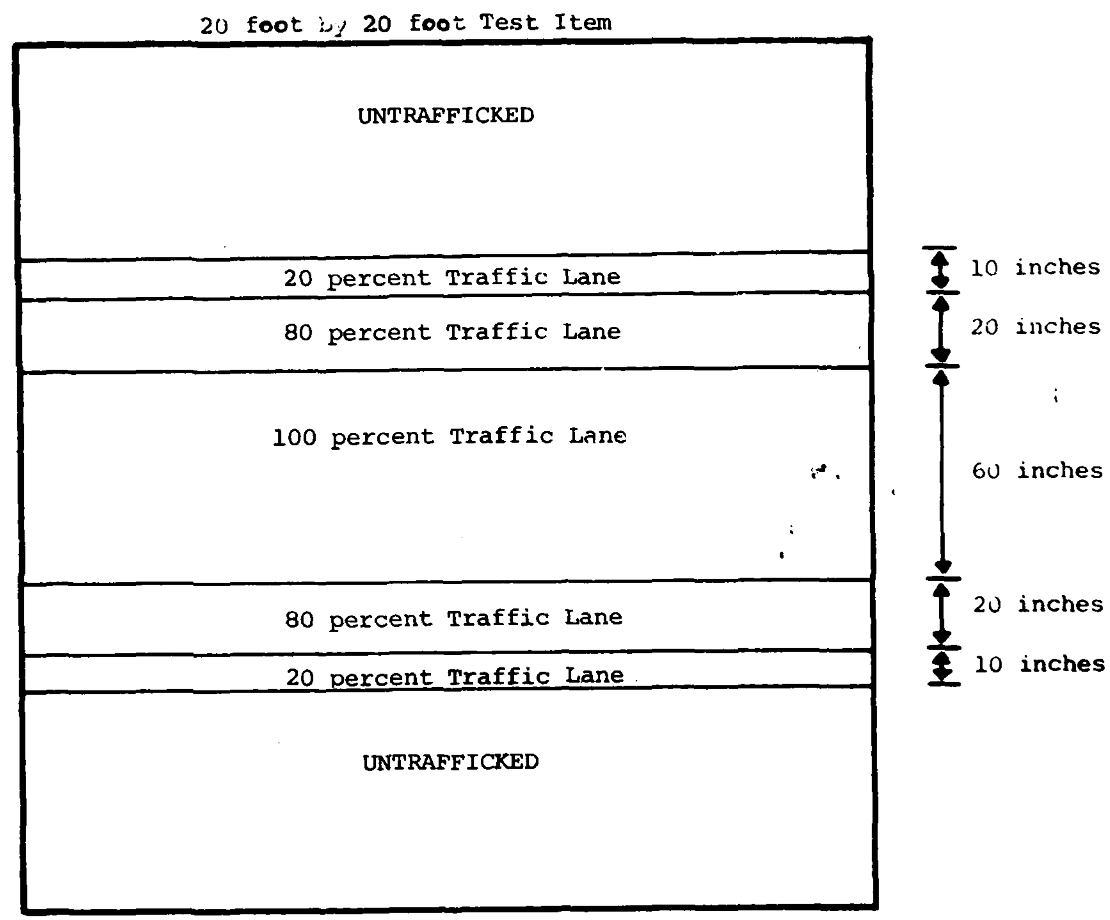


Figure 6. Traffic Pattern for F-4 Load Test

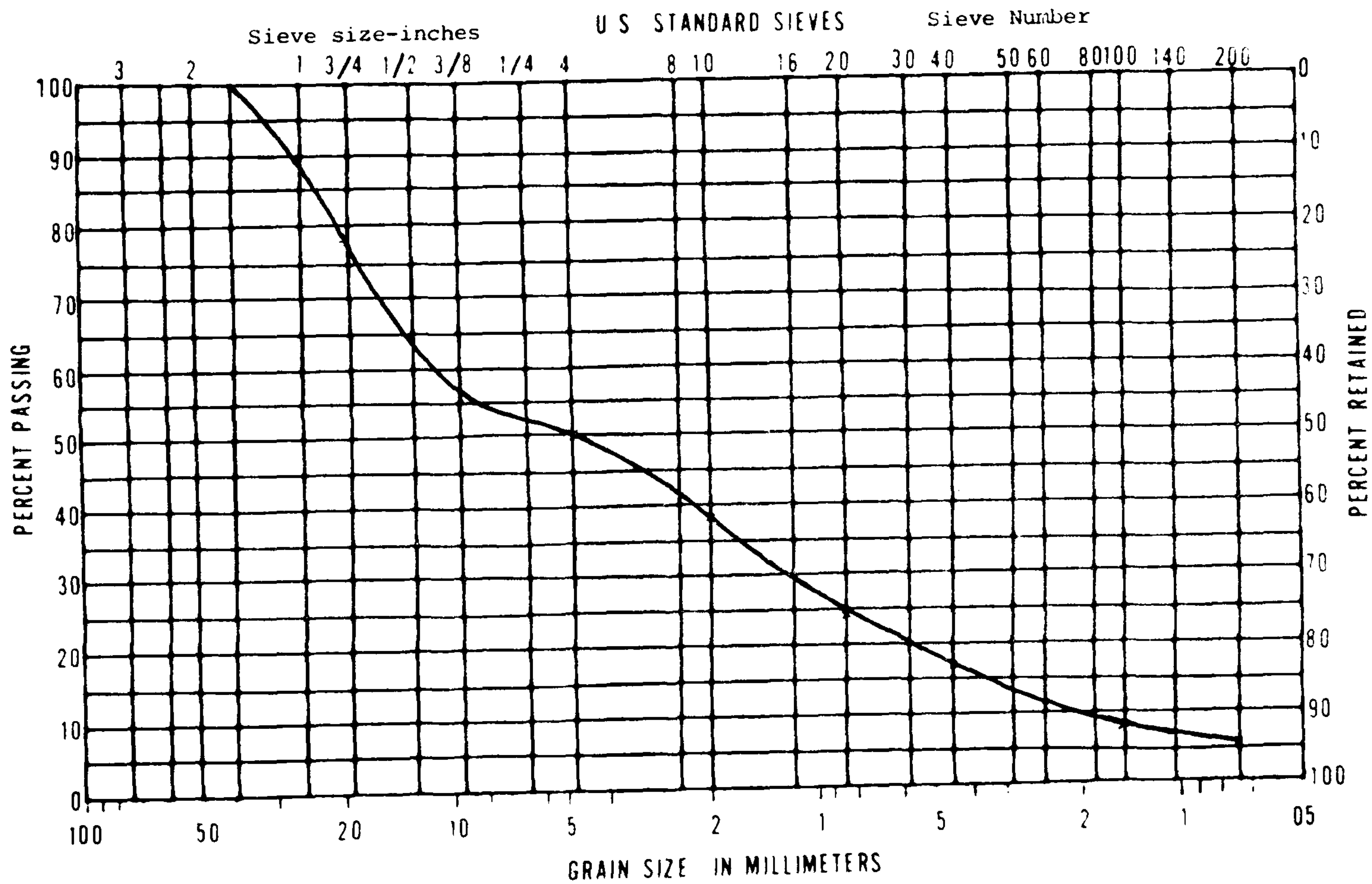


Figure 7. Base Course Aggregate Gradation

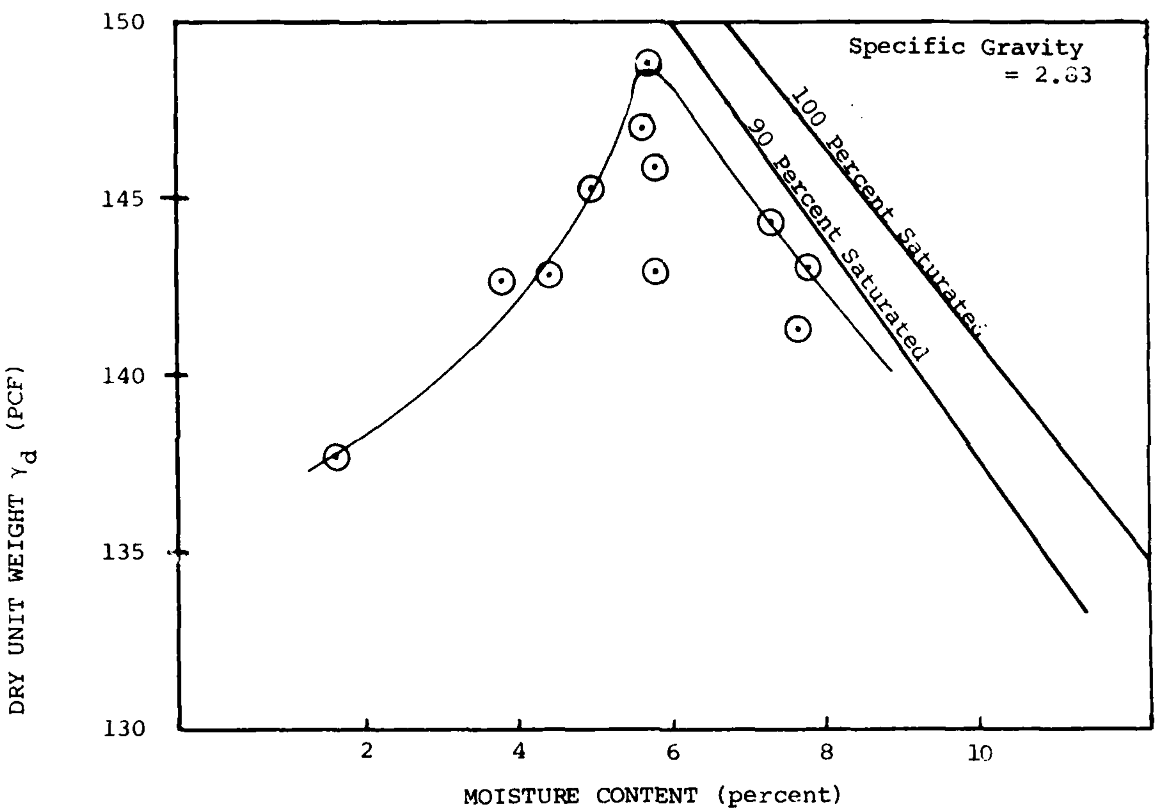


Figure 8. CE-55 (Modified AASHTO) Compaction Curve for Base Course Aggregate

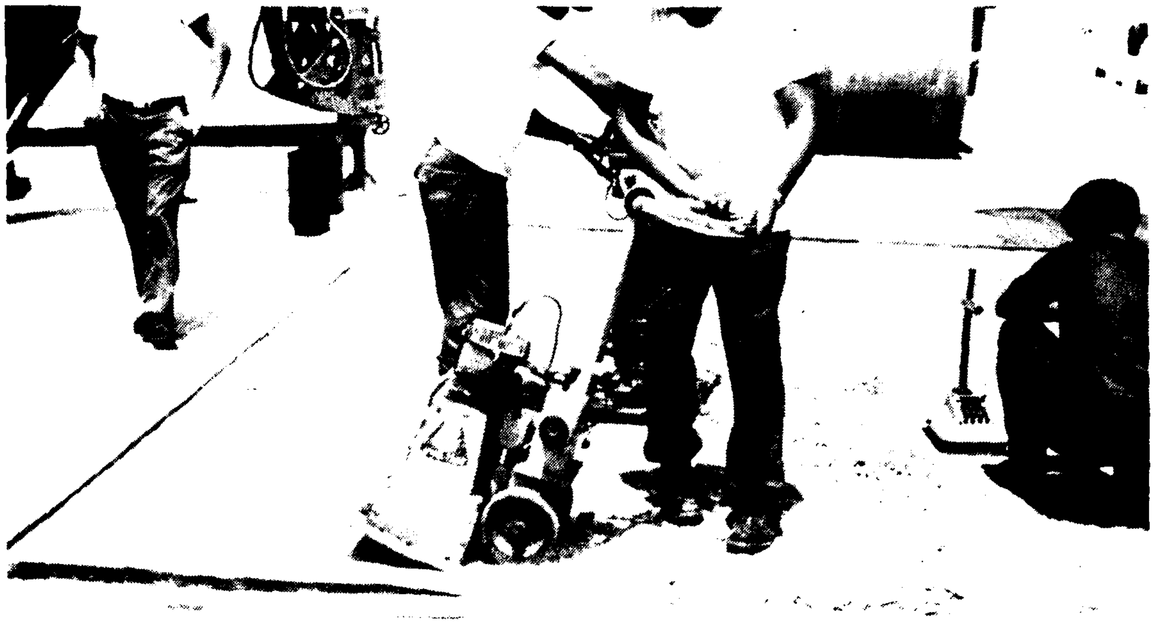


Figure 9. Hand Vibratory Plate Compactor

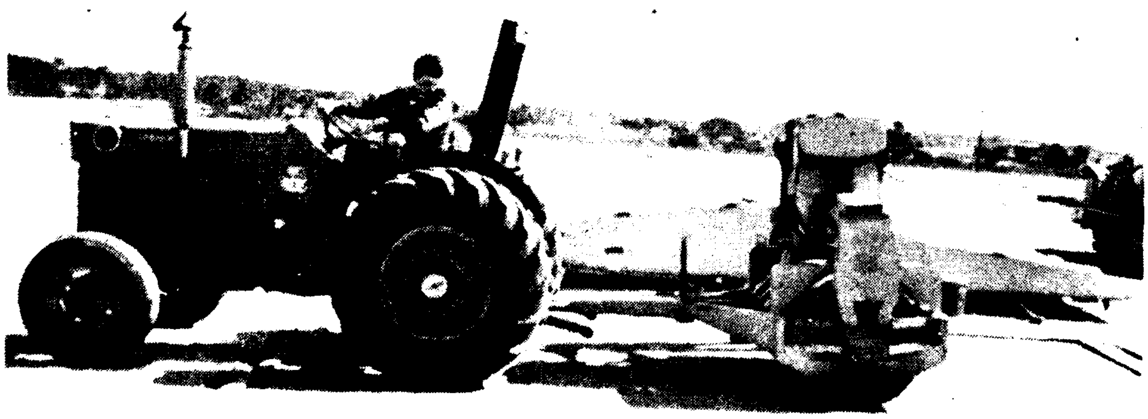


Figure 10. Light Towed Vibratory Roller

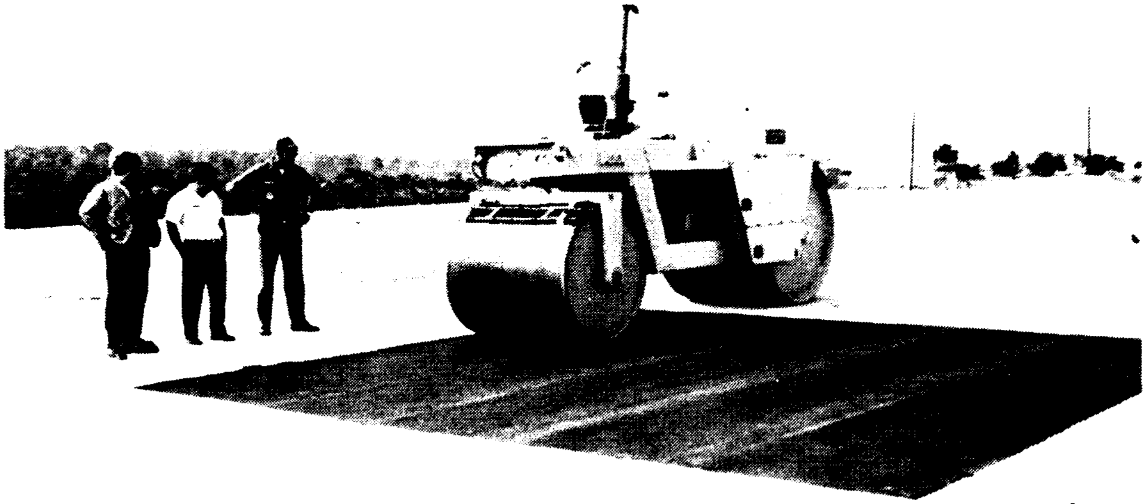


Figure 11. Twelve-Ton Tandem Steel Wheel Roller

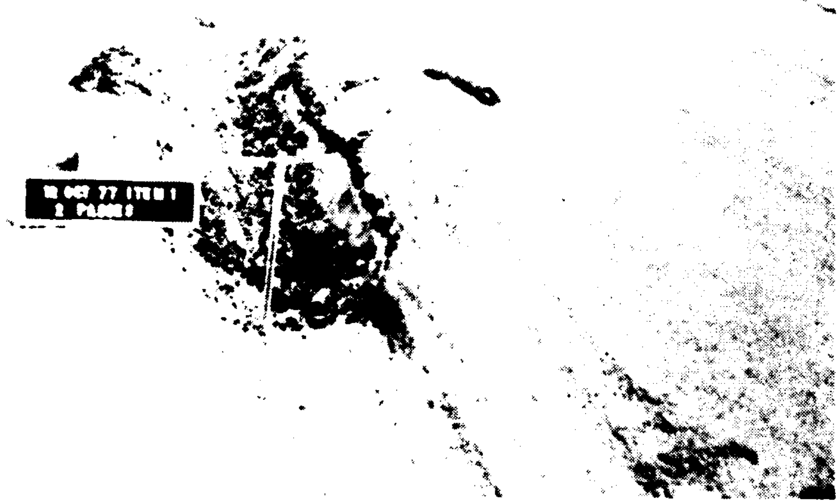


Figure 12. Base Course Shear Failure, Item 1

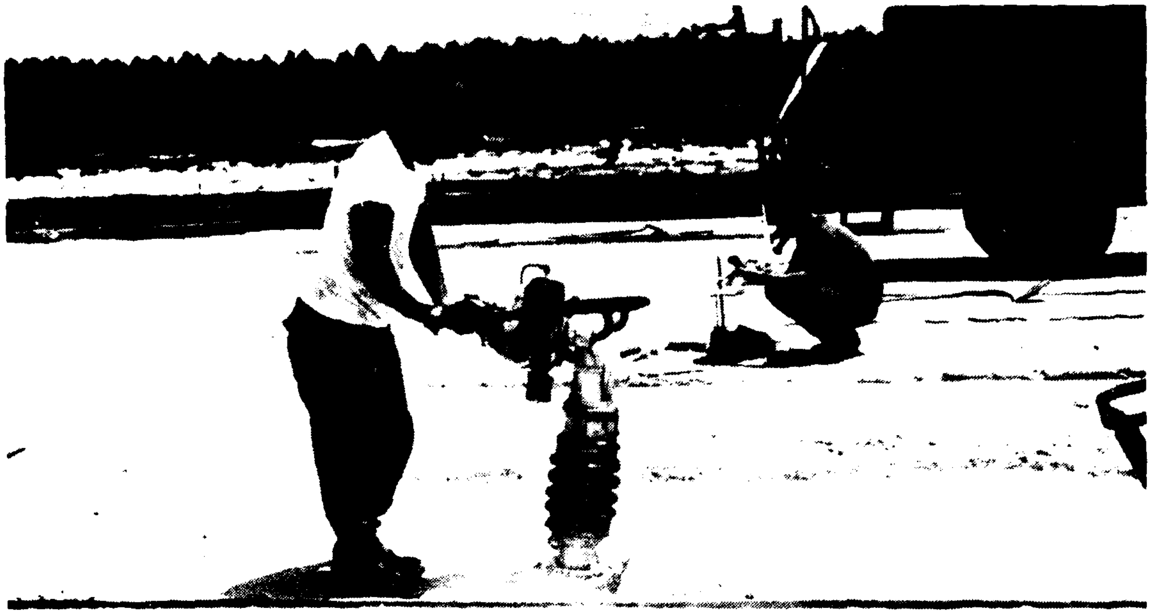


Figure 13. Gasoline Powered, Hand Operated Impact Compactor Model GVR 151Y

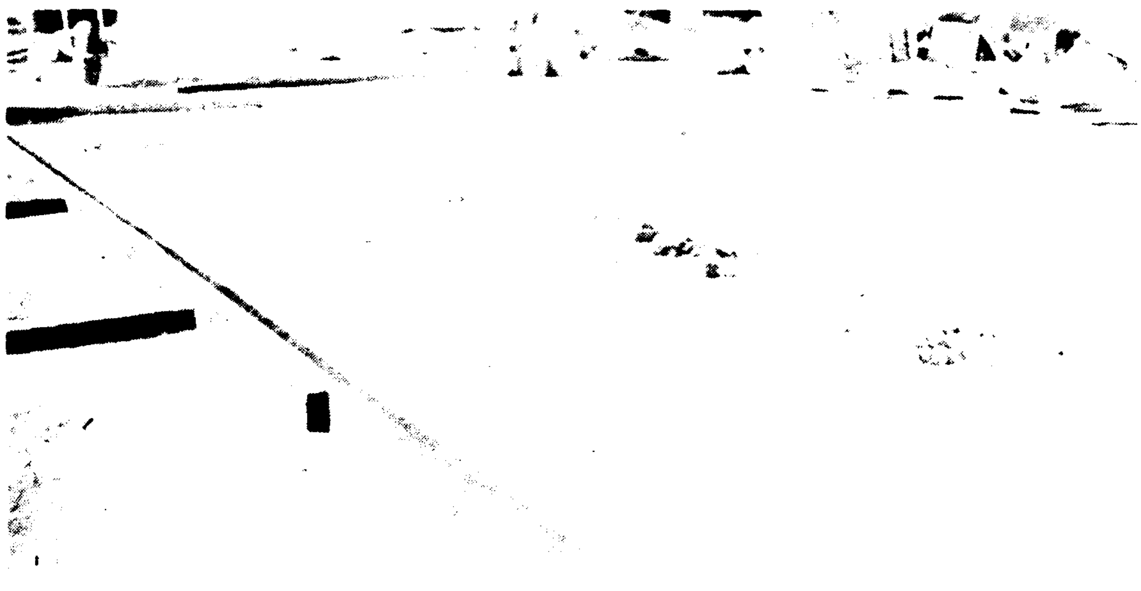


Figure 14. Construction Joints for Magnesium Phosphate Cement, Item 3

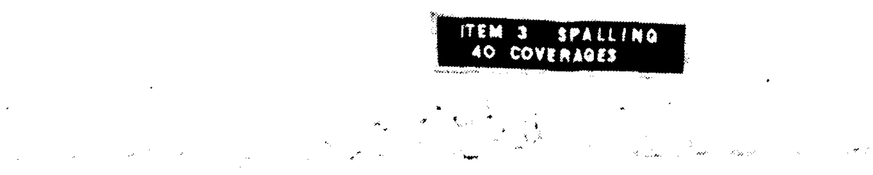


Figure 15. Spalling Along Construction Joint After 40 Coverages, Item 3

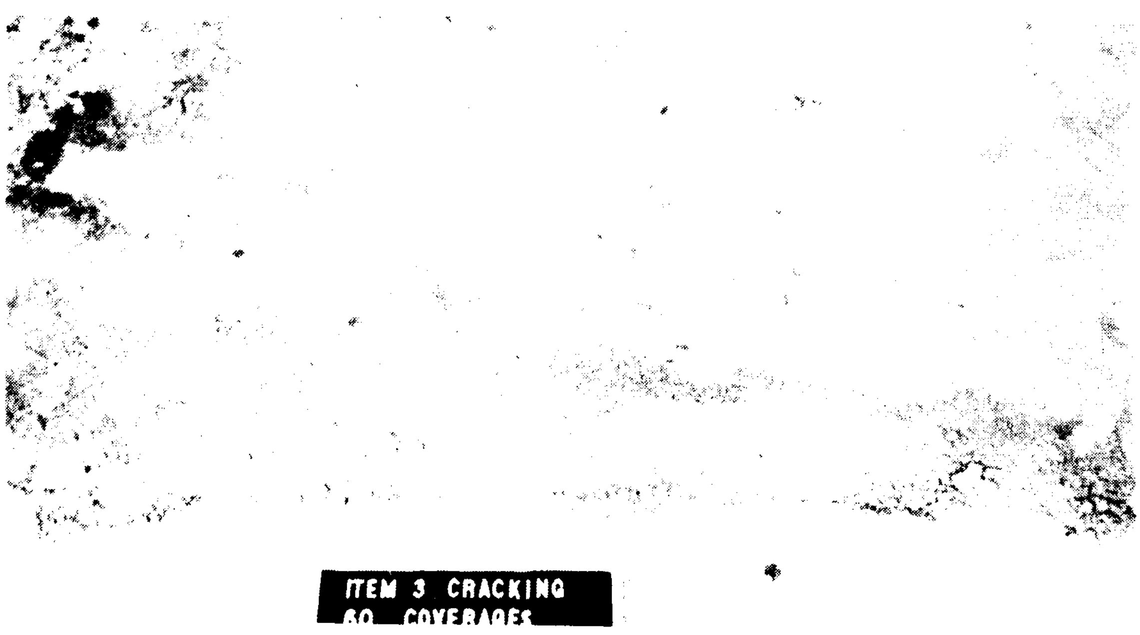


Figure 16. Severe Cracking and Spalling After 60 Coverages, Item 3

Figure 17. Surface Scaling and Spalling After 100 Coverages, Item 3

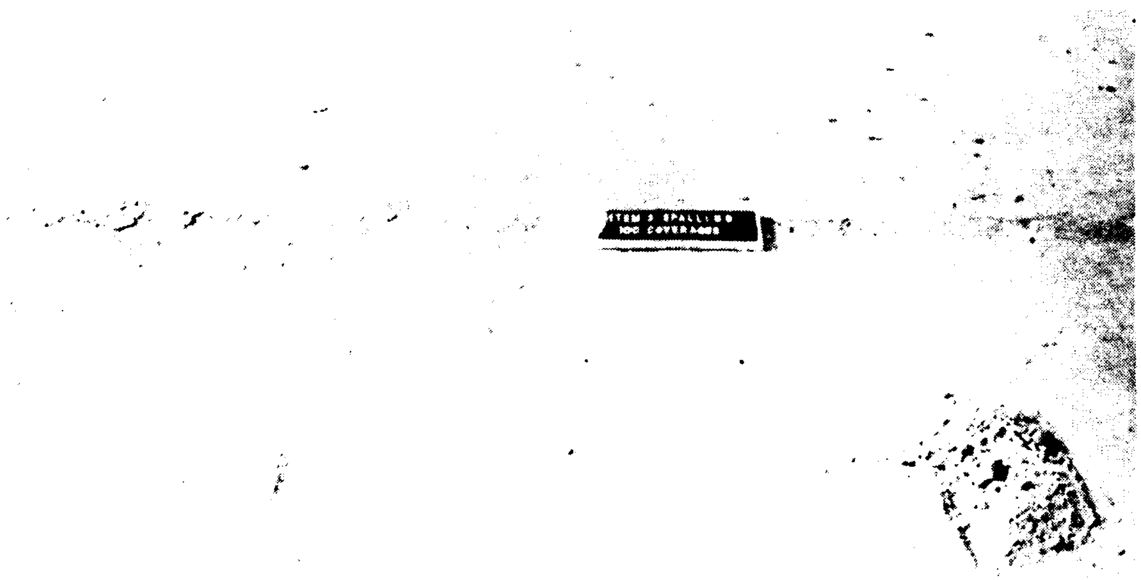


Figure 18. Spalling at Edge of Repair After 100 Coverages, Item 3

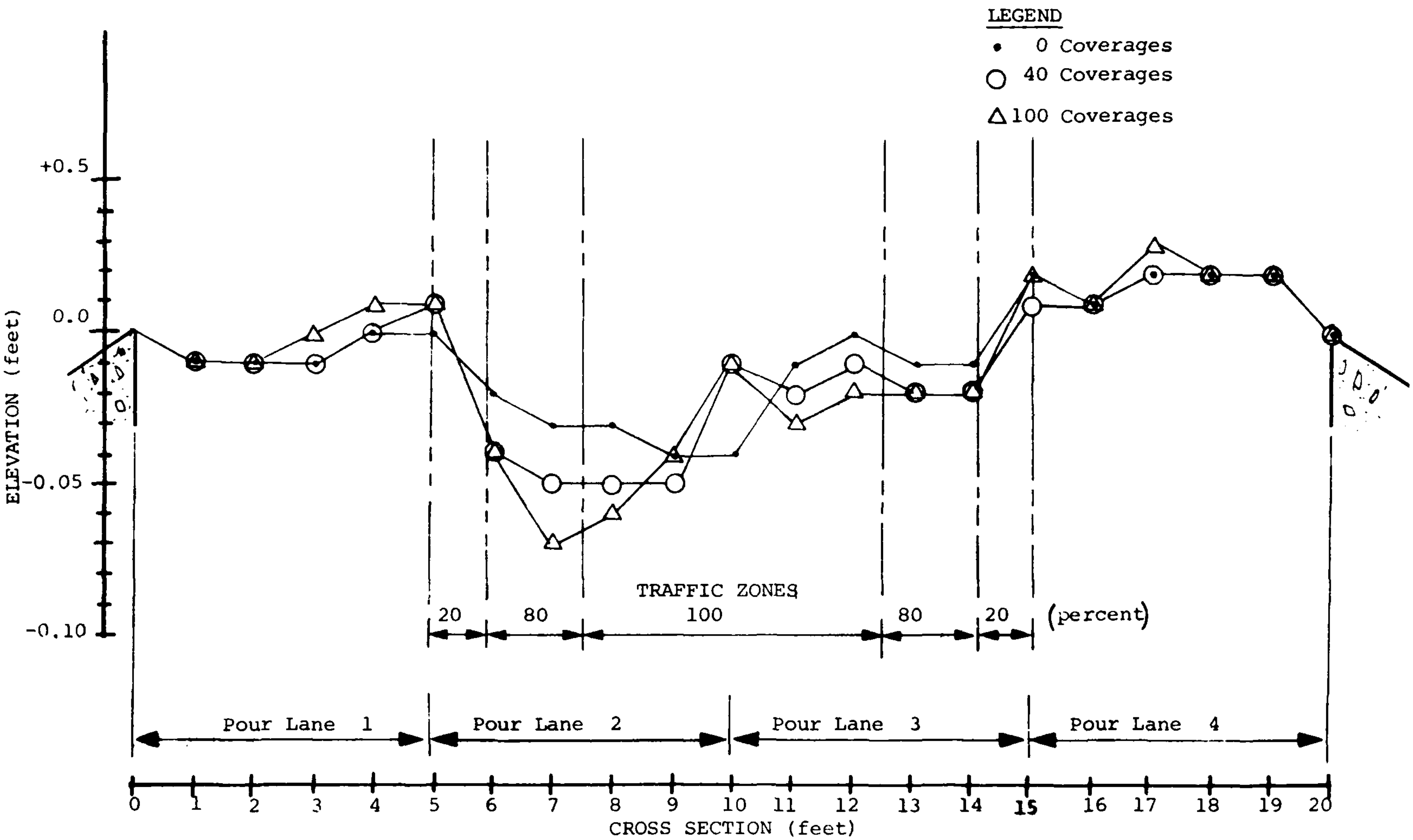


Figure 19. Surface Profiles, Item 3

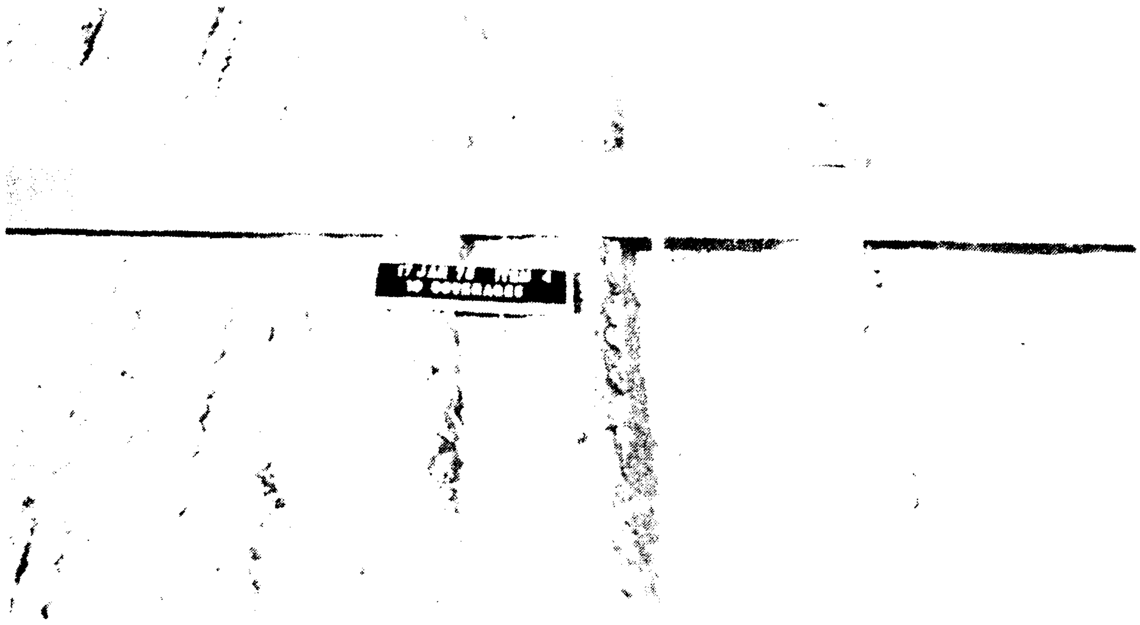


Figure 20. Rutting After 10 Coverages, Item 4

Figure 21. Surface Item 4, 40 Coverages

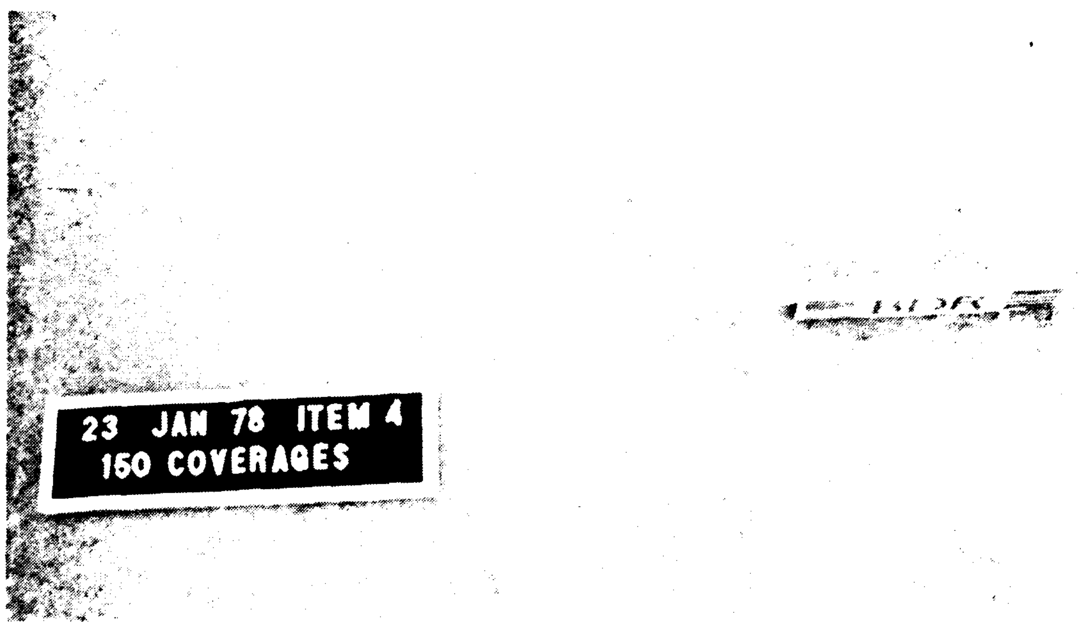


Figure 22. Surface Item 4, 150 Coverages

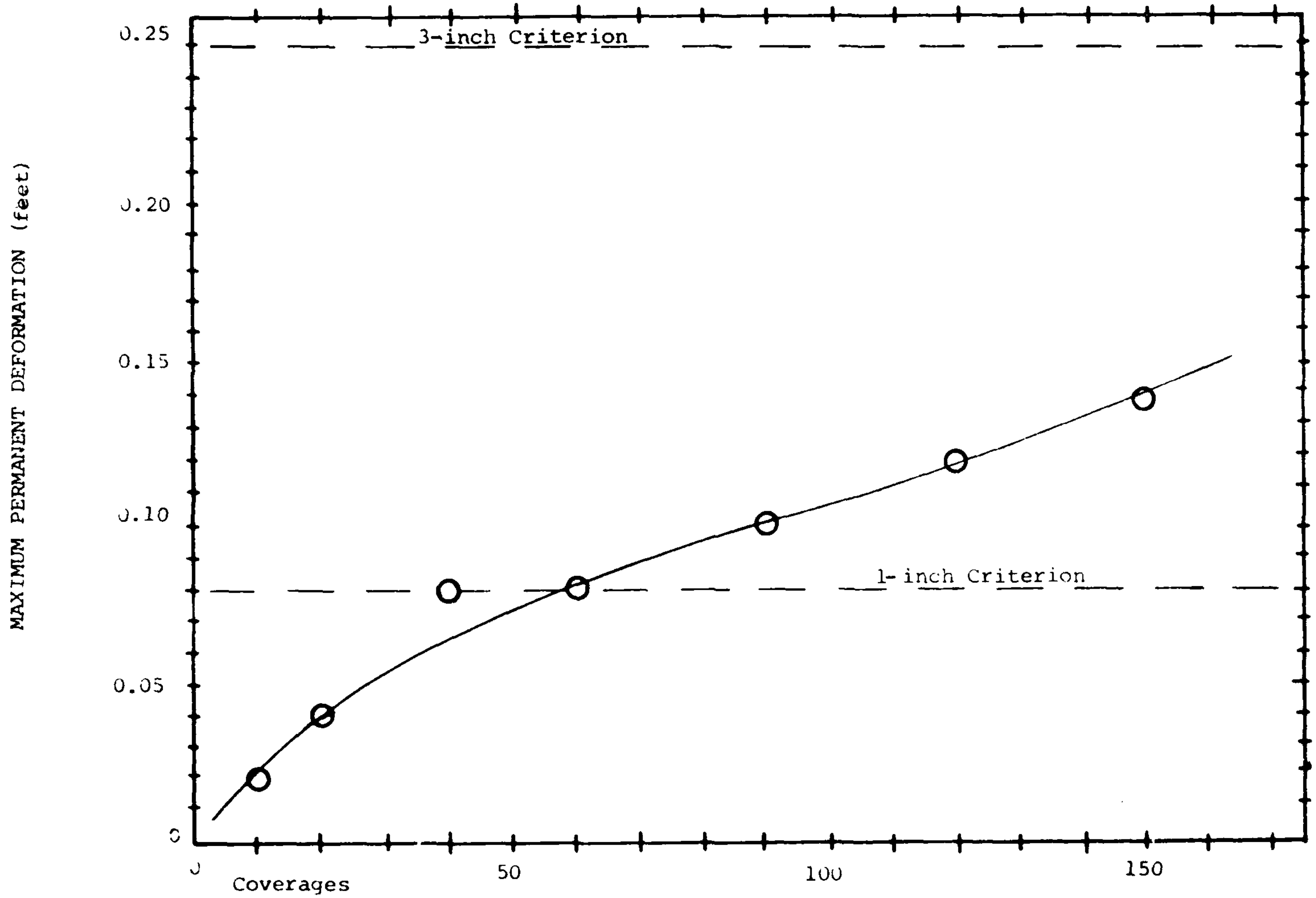


Figure 23. Coverage and Deformation Relationship, Item 4

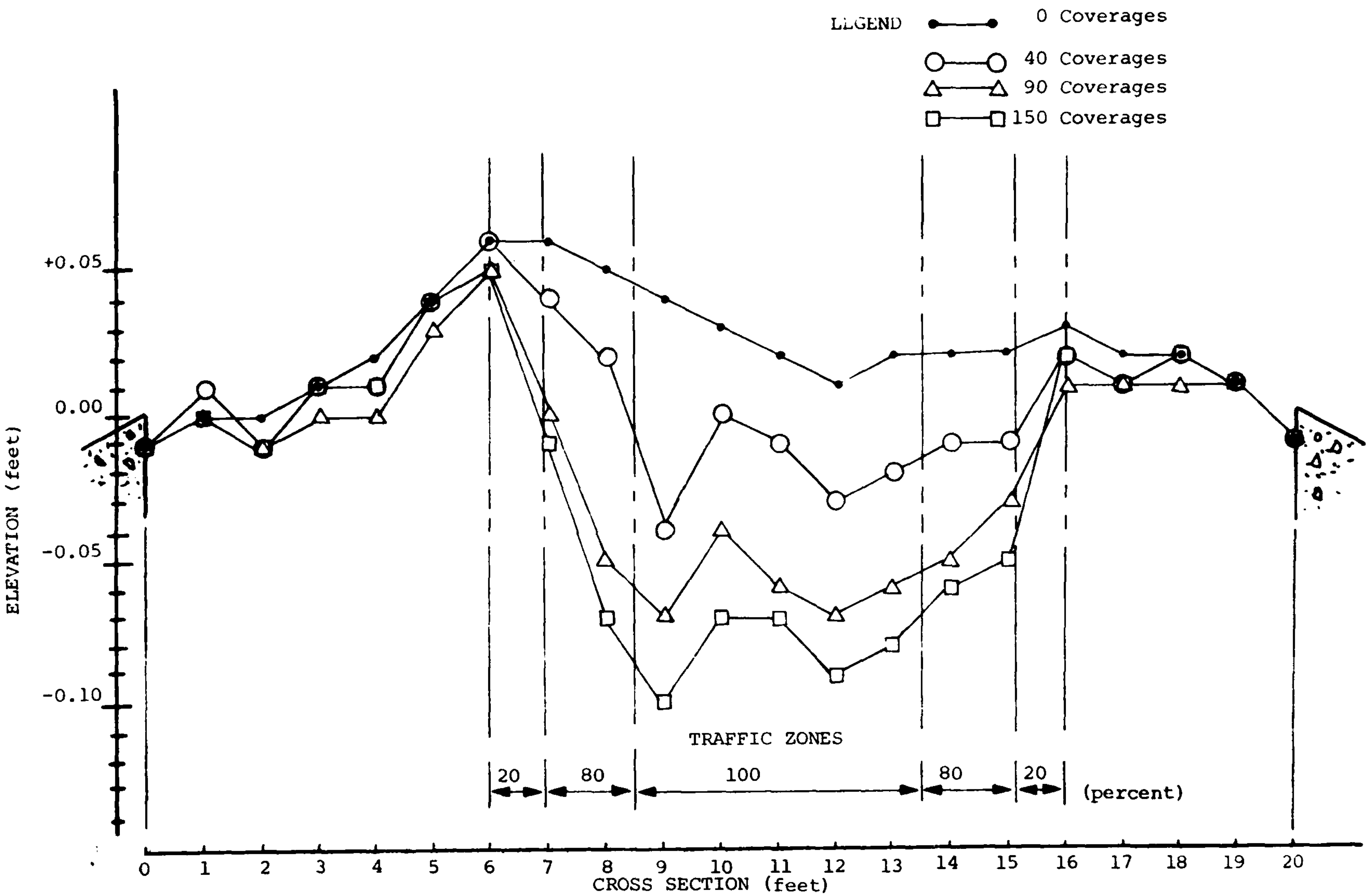


Figure 24. Surface Profiles, Item 4

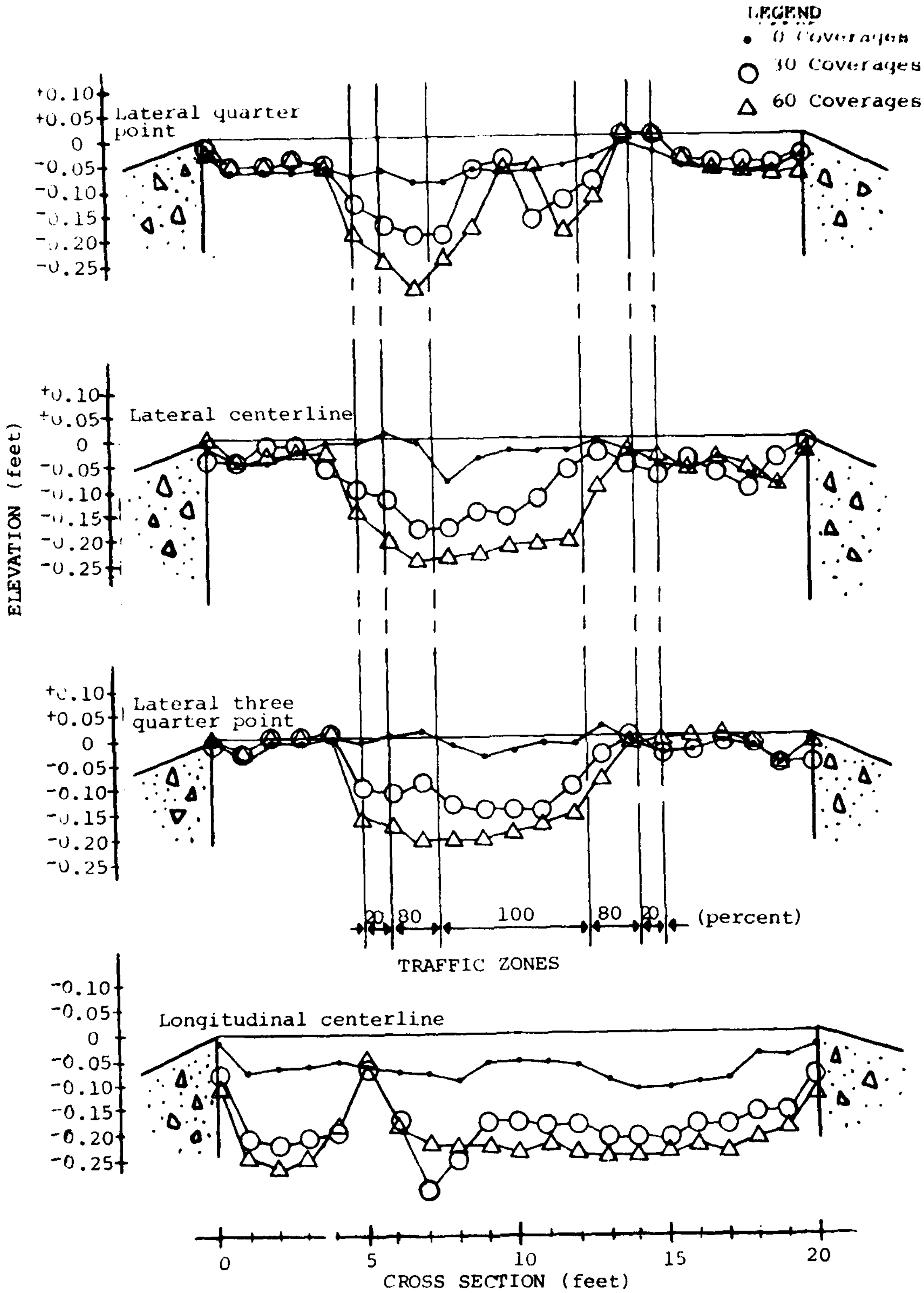


Figure 25. Surface Profiles, Item 5A

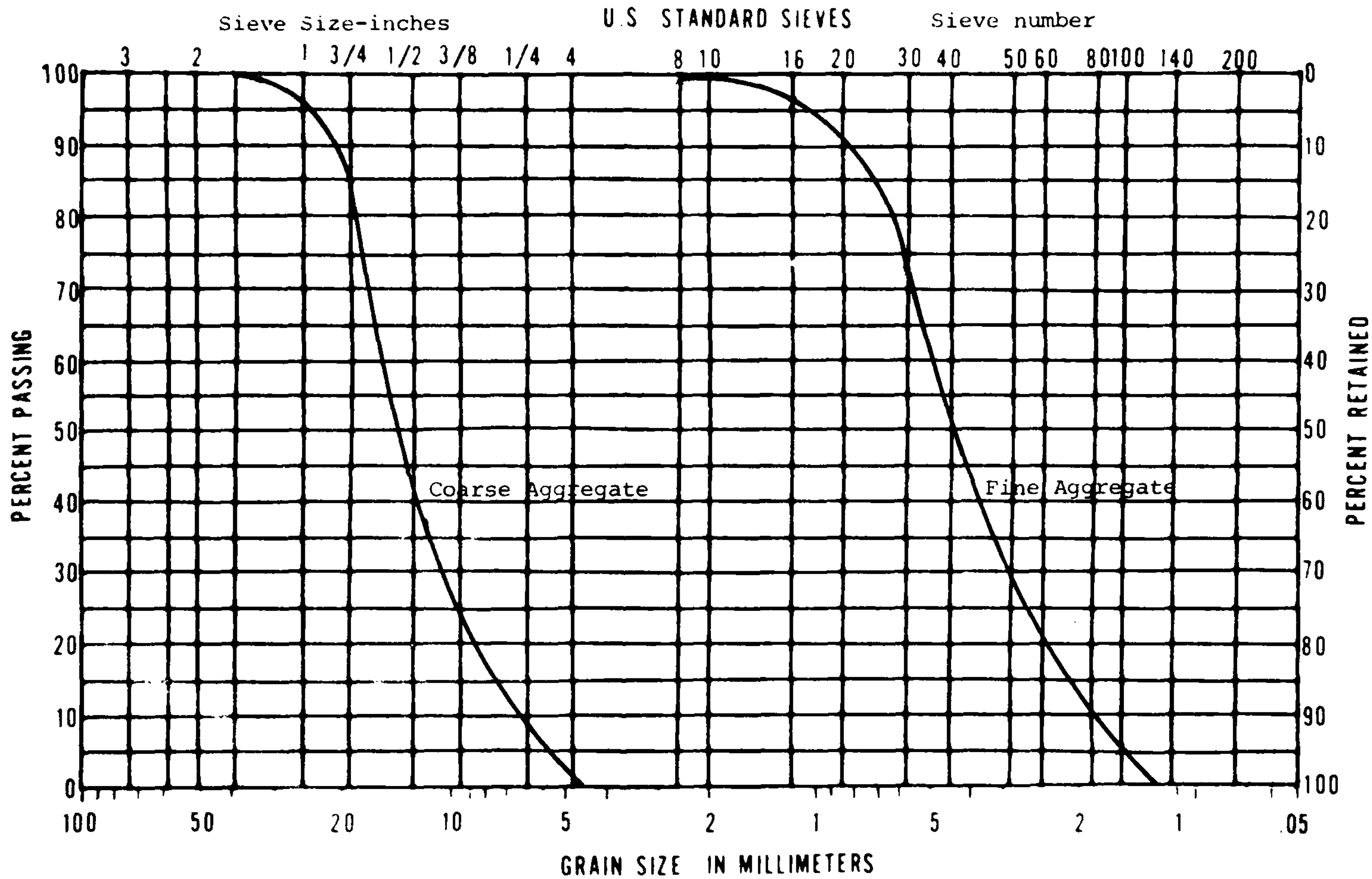


Figure 26. Gradation of Concrete Aggregate, Item 6

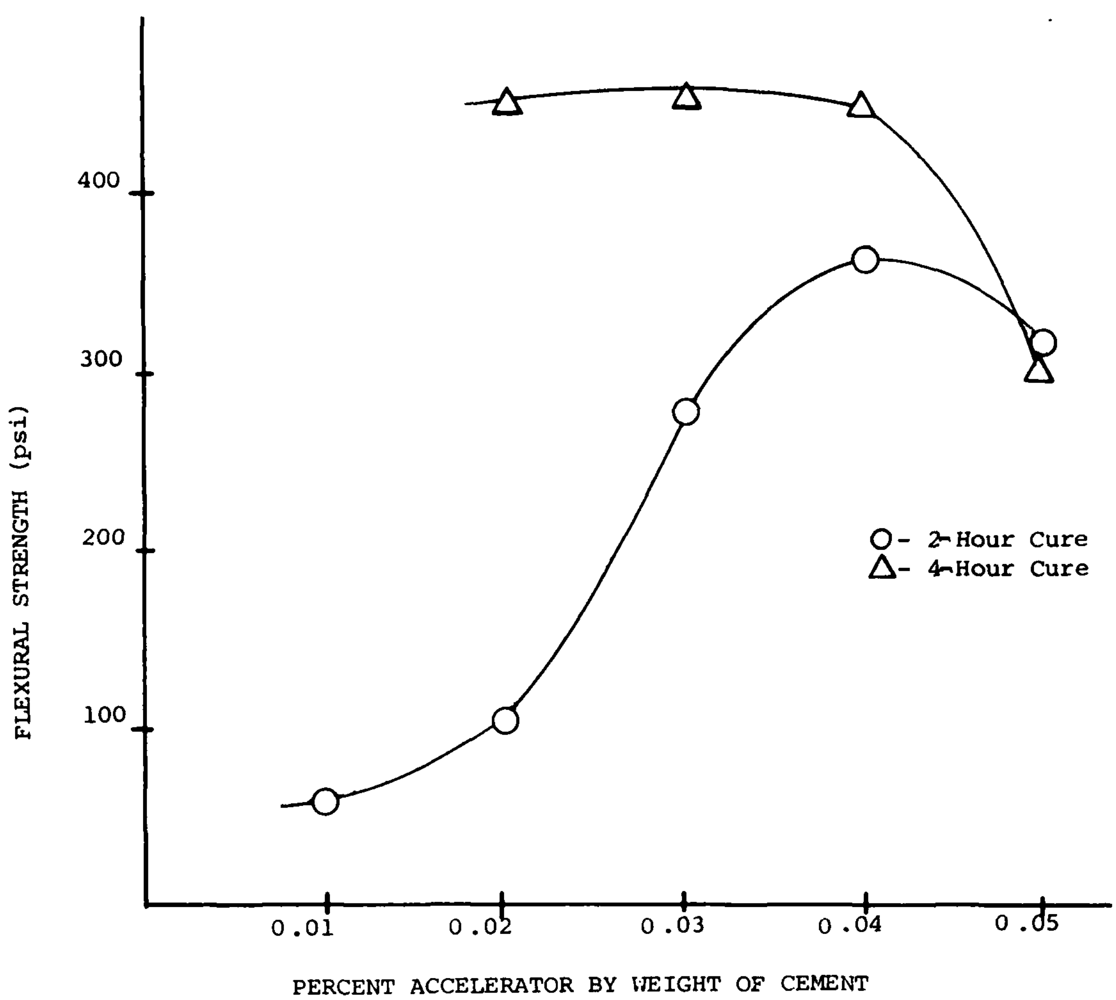


Figure 27. Effect of Accelerator Content on Flexural Strength of High Alumina Concrete

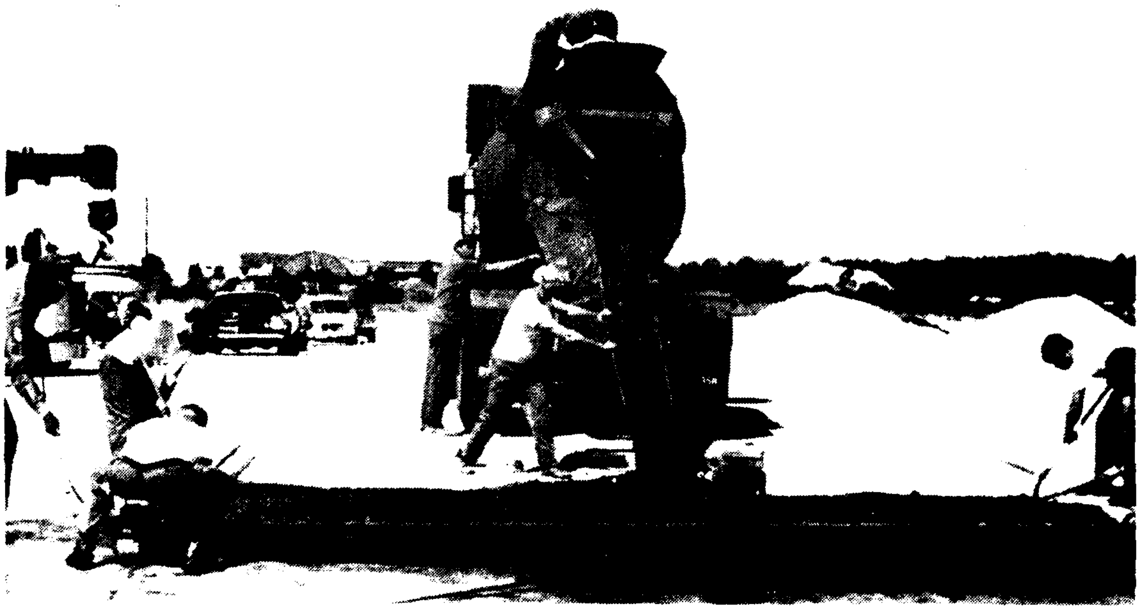


Figure 28. Pouring High Alumina Concrete, Item 6

Figure 29. High Alumina Concrete Surface Texture, Item 6

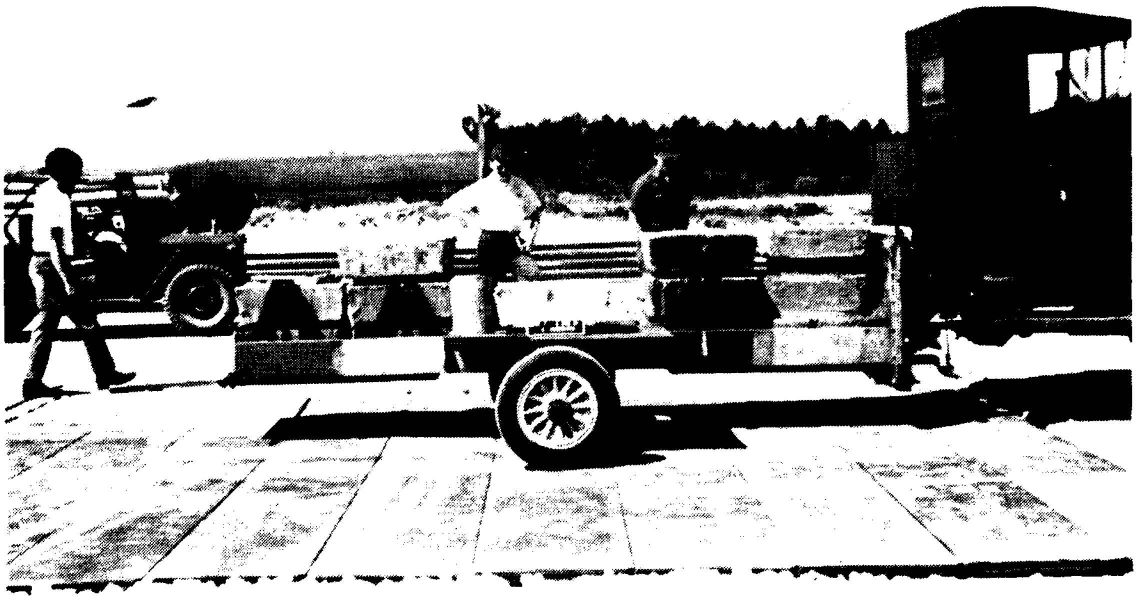


Figure 30. AM-2 Mat, Item 7

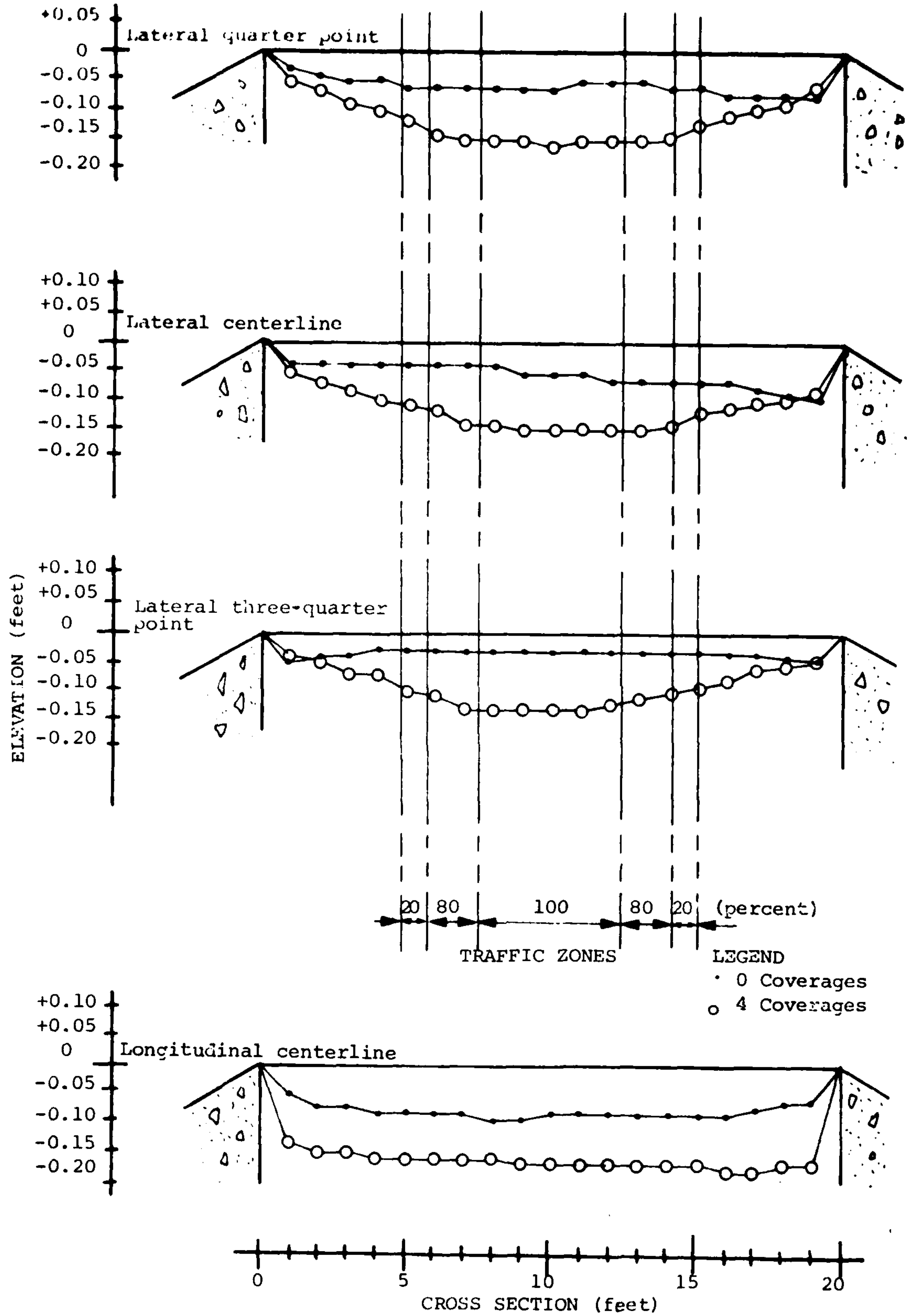


Figure 31. Surface Profiles, Item 7

Figure 32. Positioning AM-2 Mat for Item 8

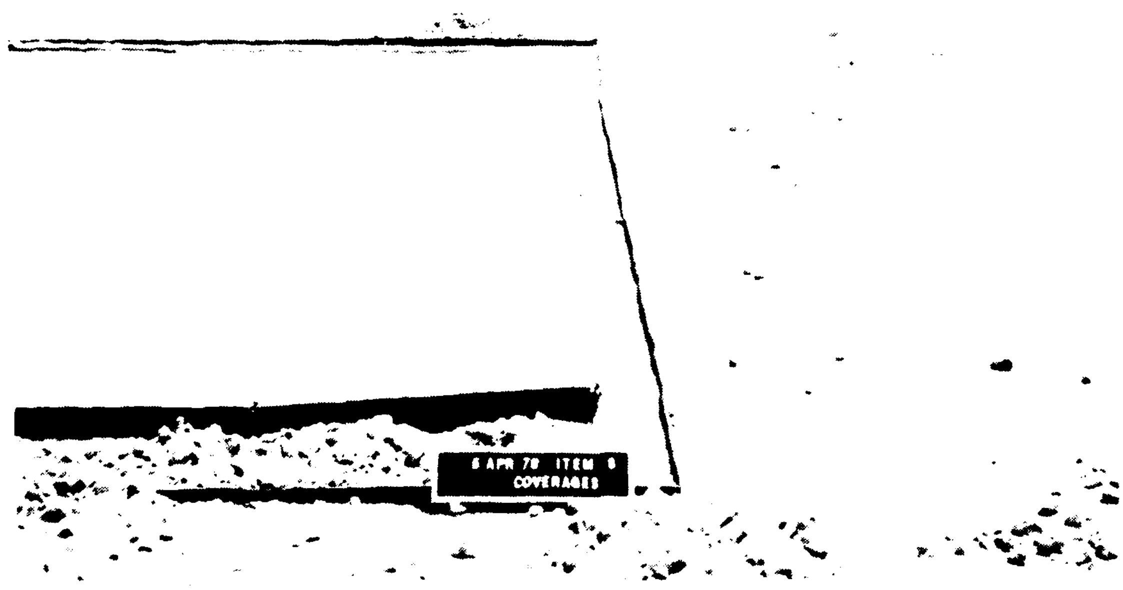


Figure 33. AM-2 Mat Panel Overlying Concrete, Item 8

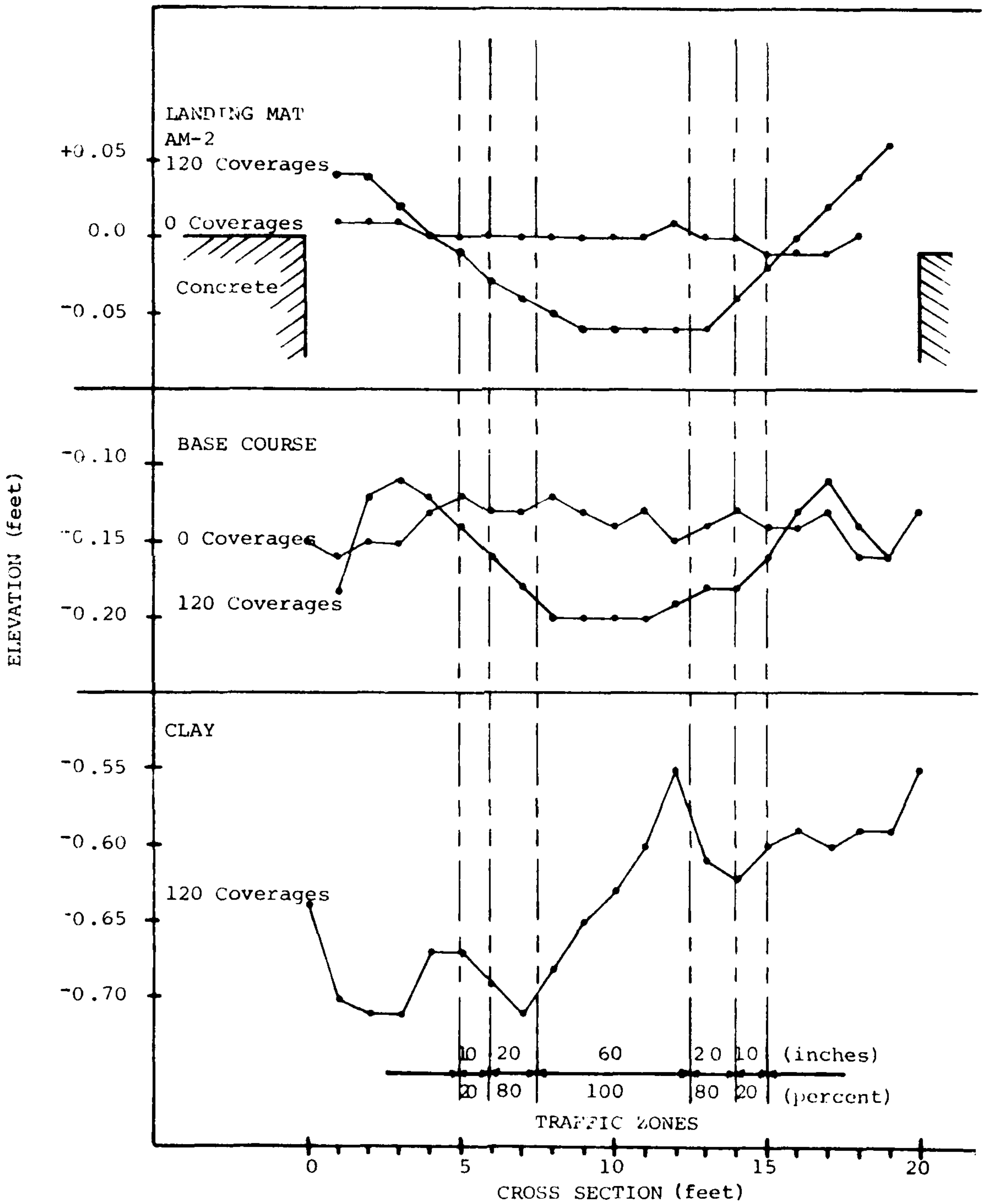
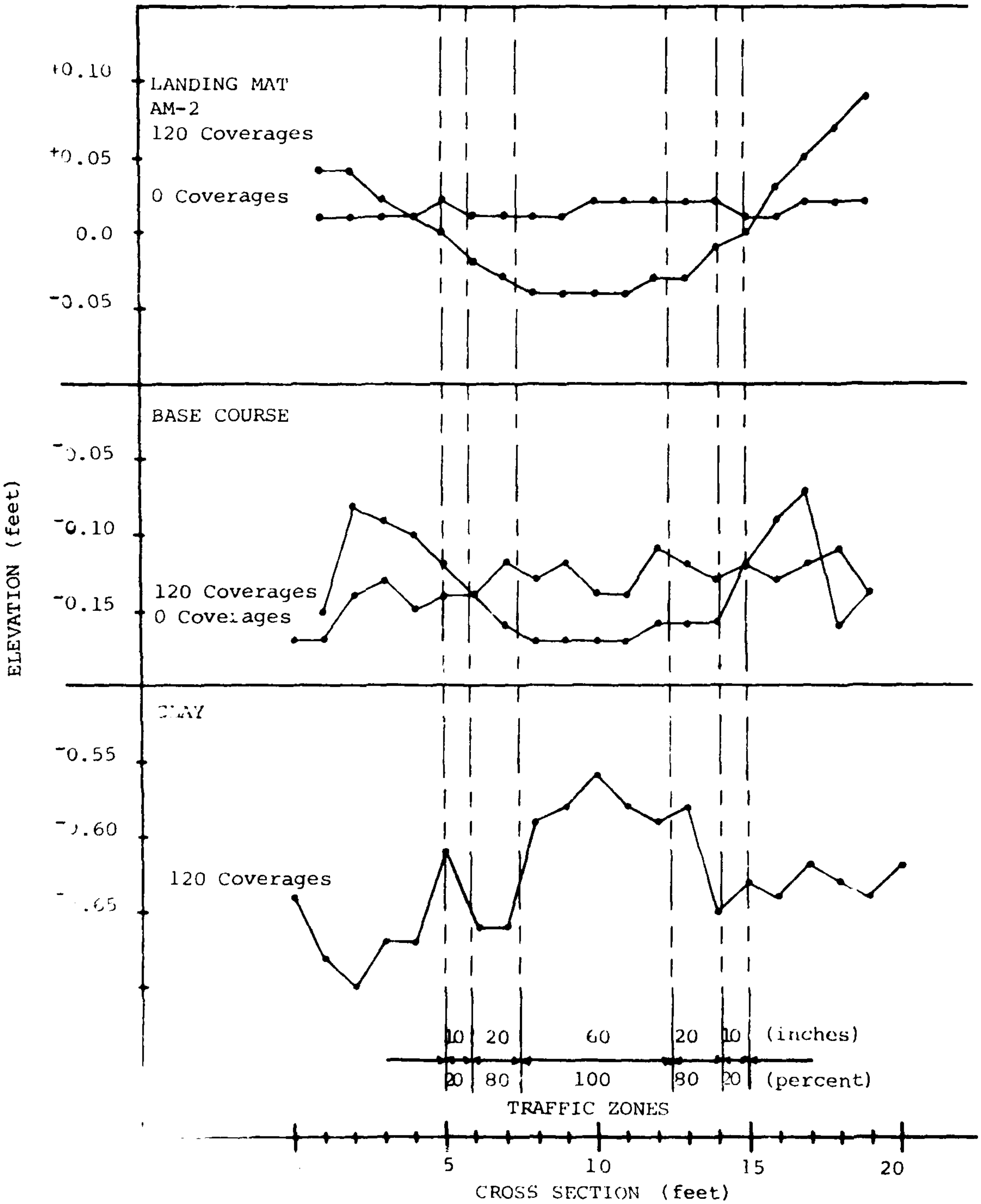


Figure 34. Lateral Quarter Point Profiles, Item 8



Lateral Centerline Profiles, Item 8

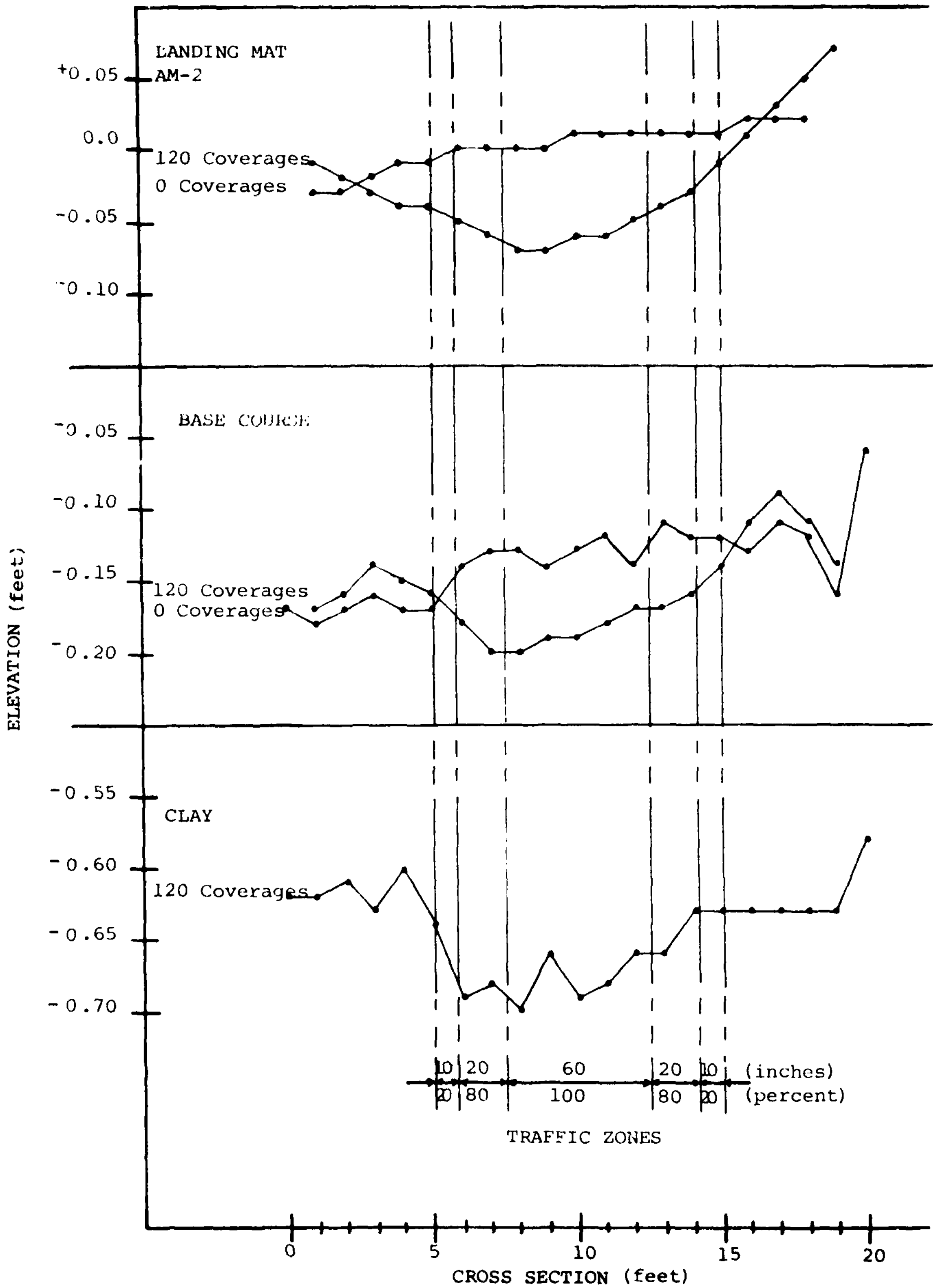


Figure 36. Lateral Three-Quarter Point Profiles, Item 8

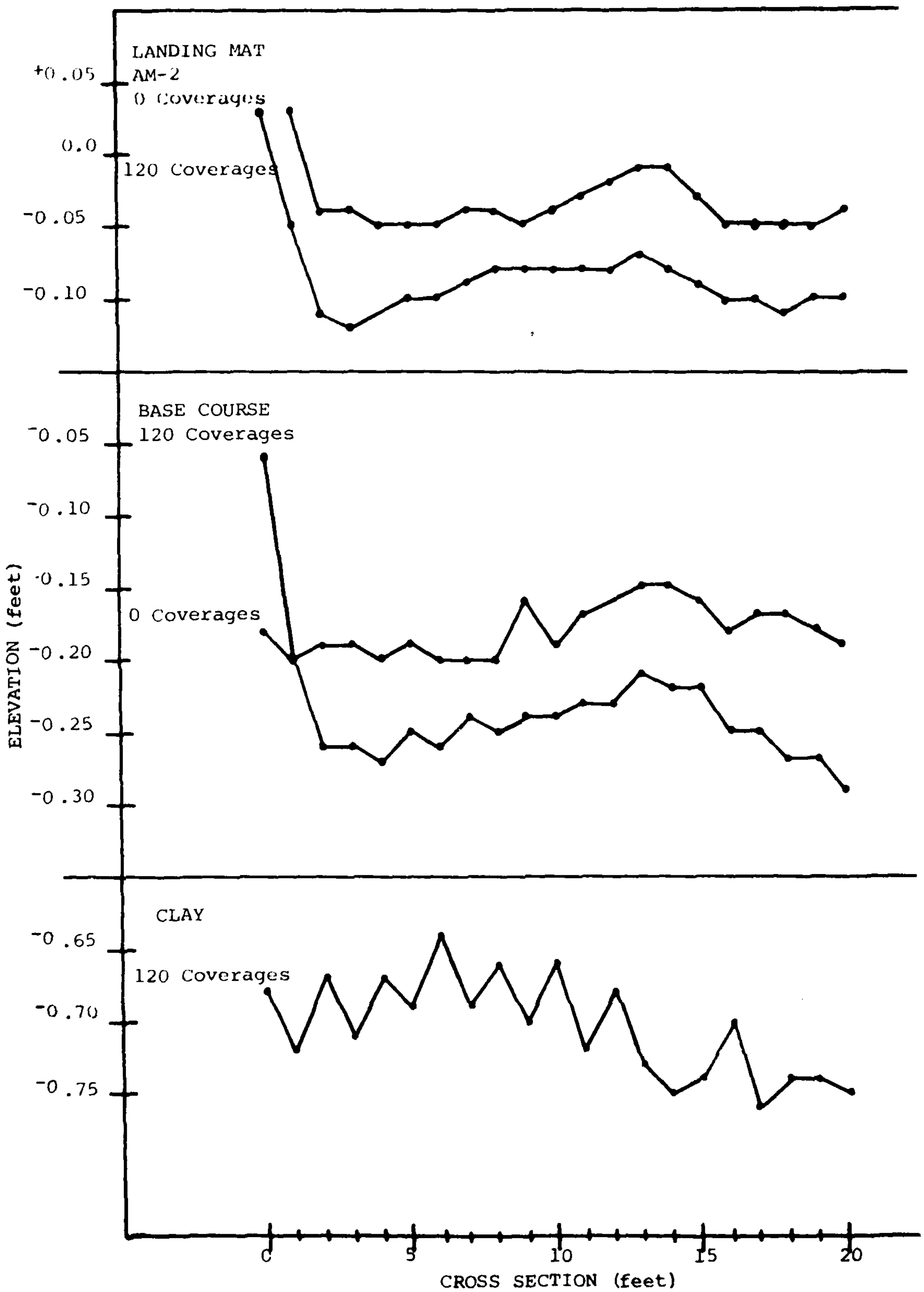


Figure 37. Longitudinal Centerline Profiles, Item 8

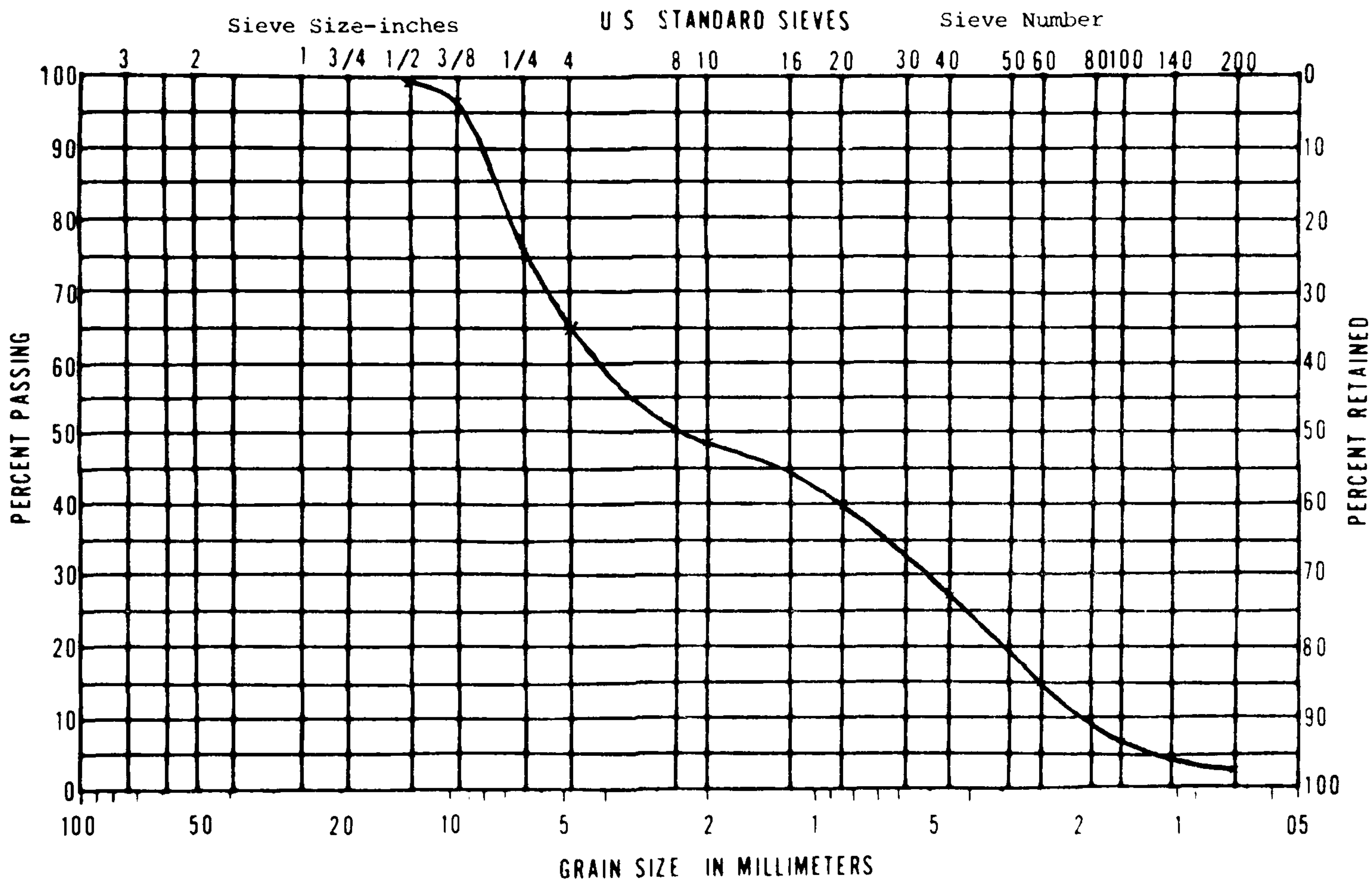


Figure 38. Aggregate Gradation of Hot Mix Asphaltic Concrete, Item 9.

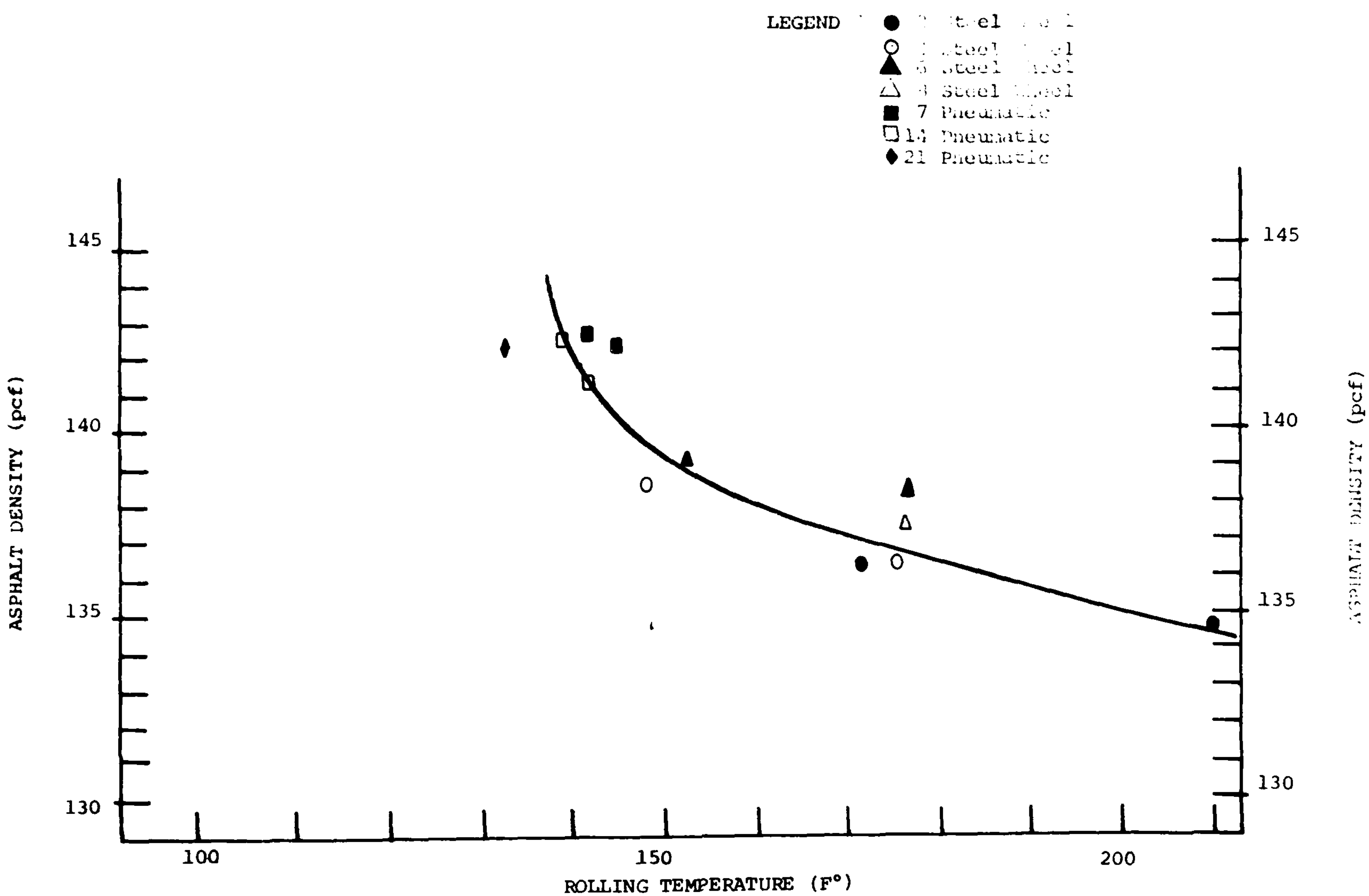


Figure 39. Asphalt Density, Rolling Temperature, and Compaction Relationships

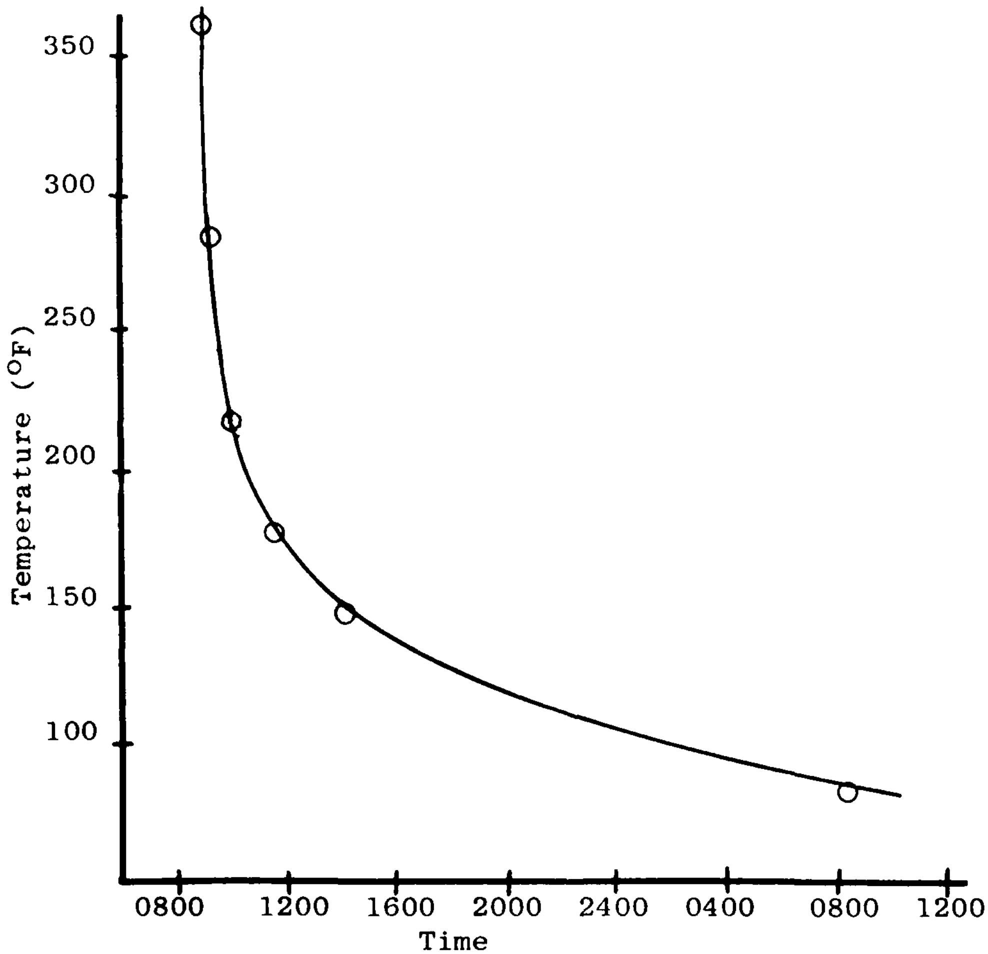


Figure 40. Temperature of Asphaltic Concrete, Item 9

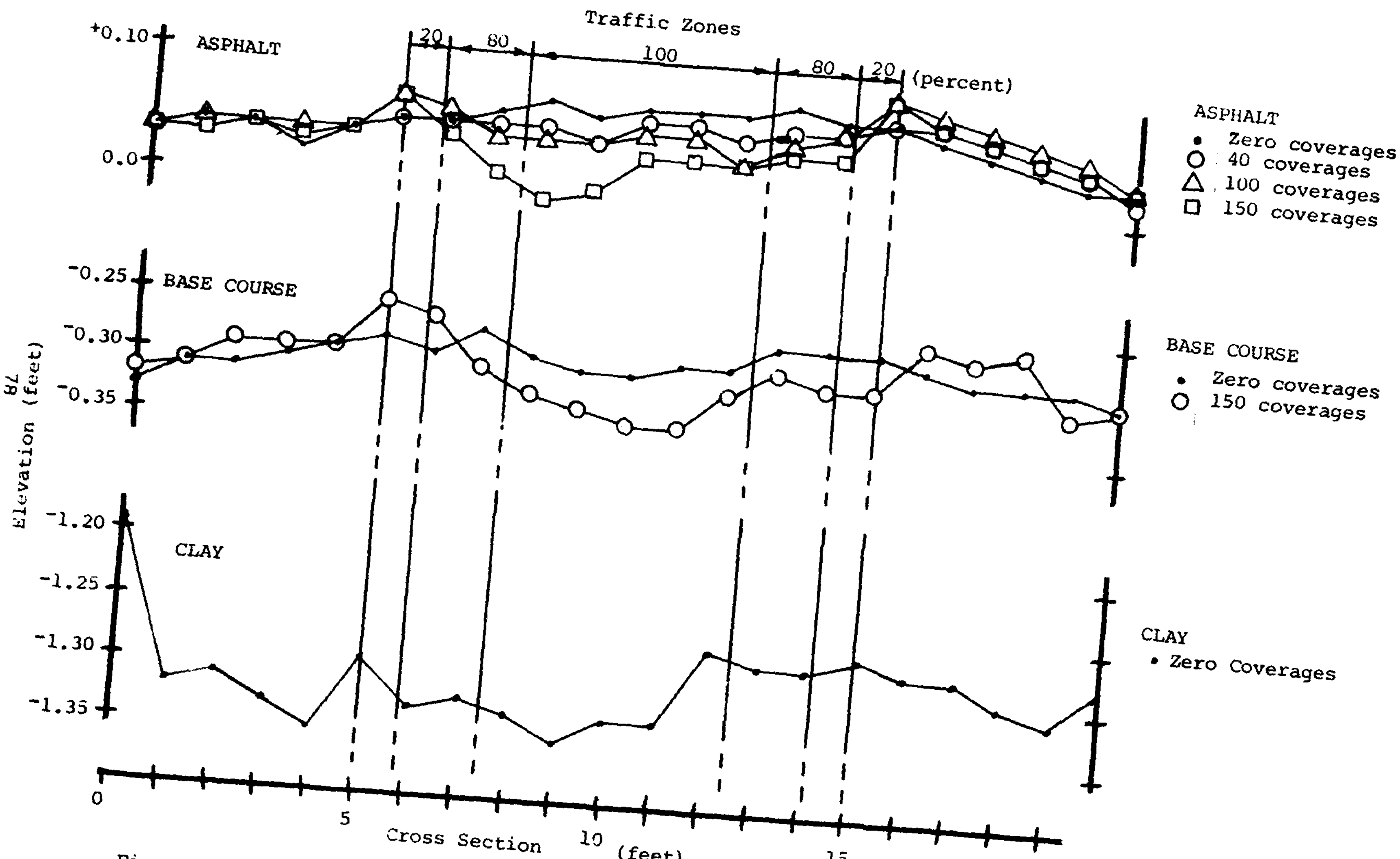


Figure 41. Lateral Quarter Point Profiles, Item 9.

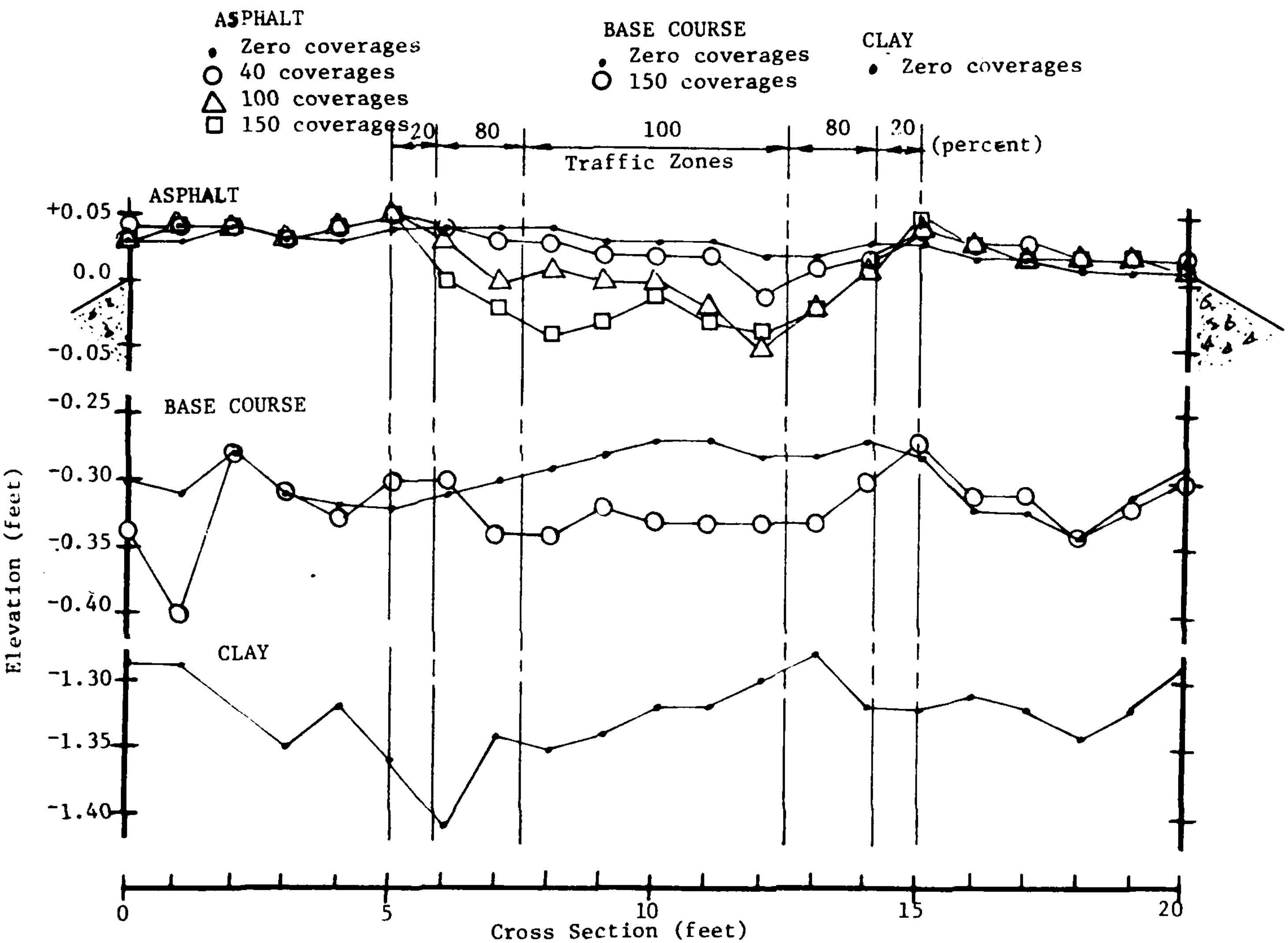


Figure 42. Lateral Centerline Profiles Item 9

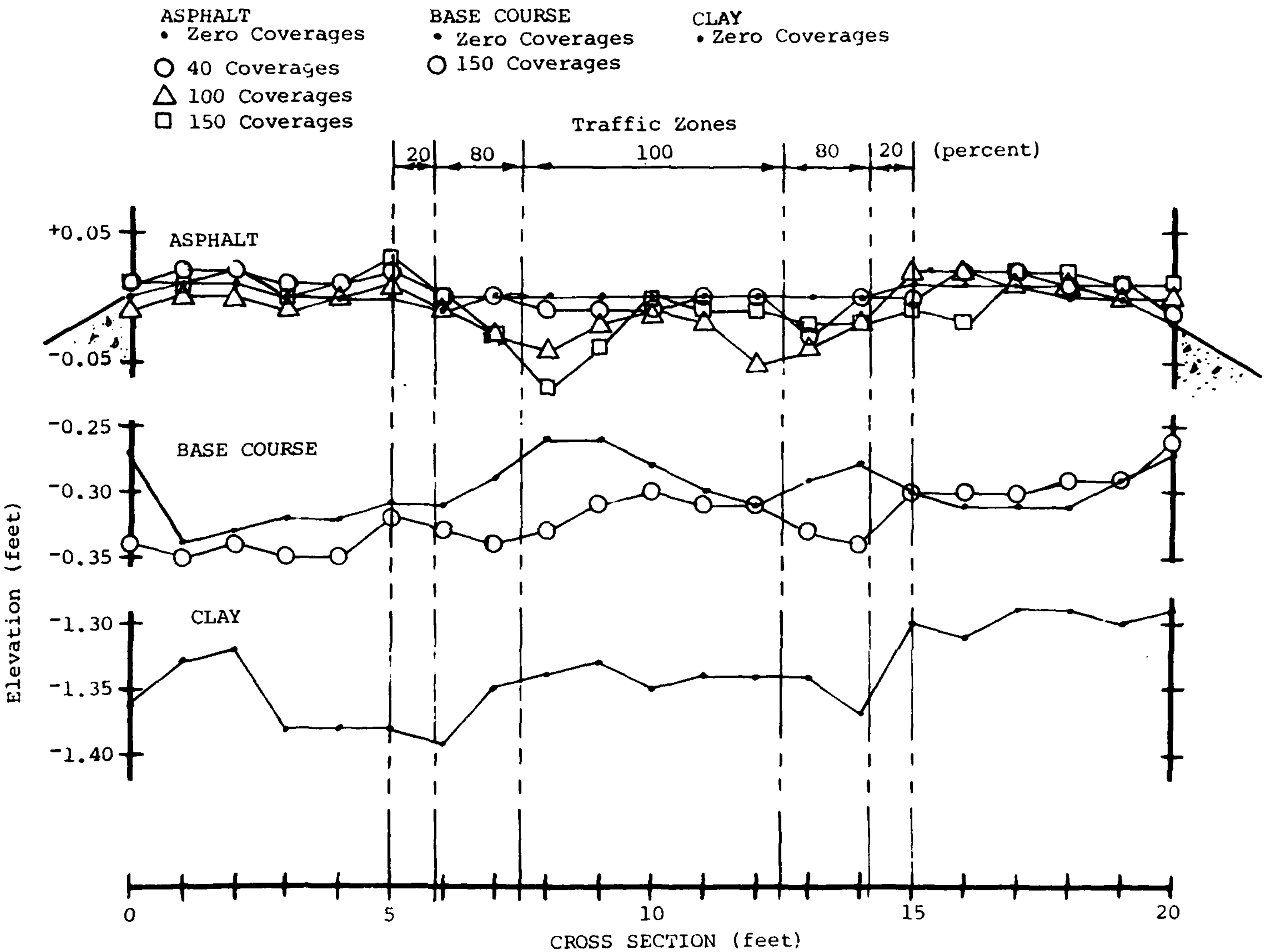


Figure 43. Lateral Three-Quarter Point Profiles, Item 9

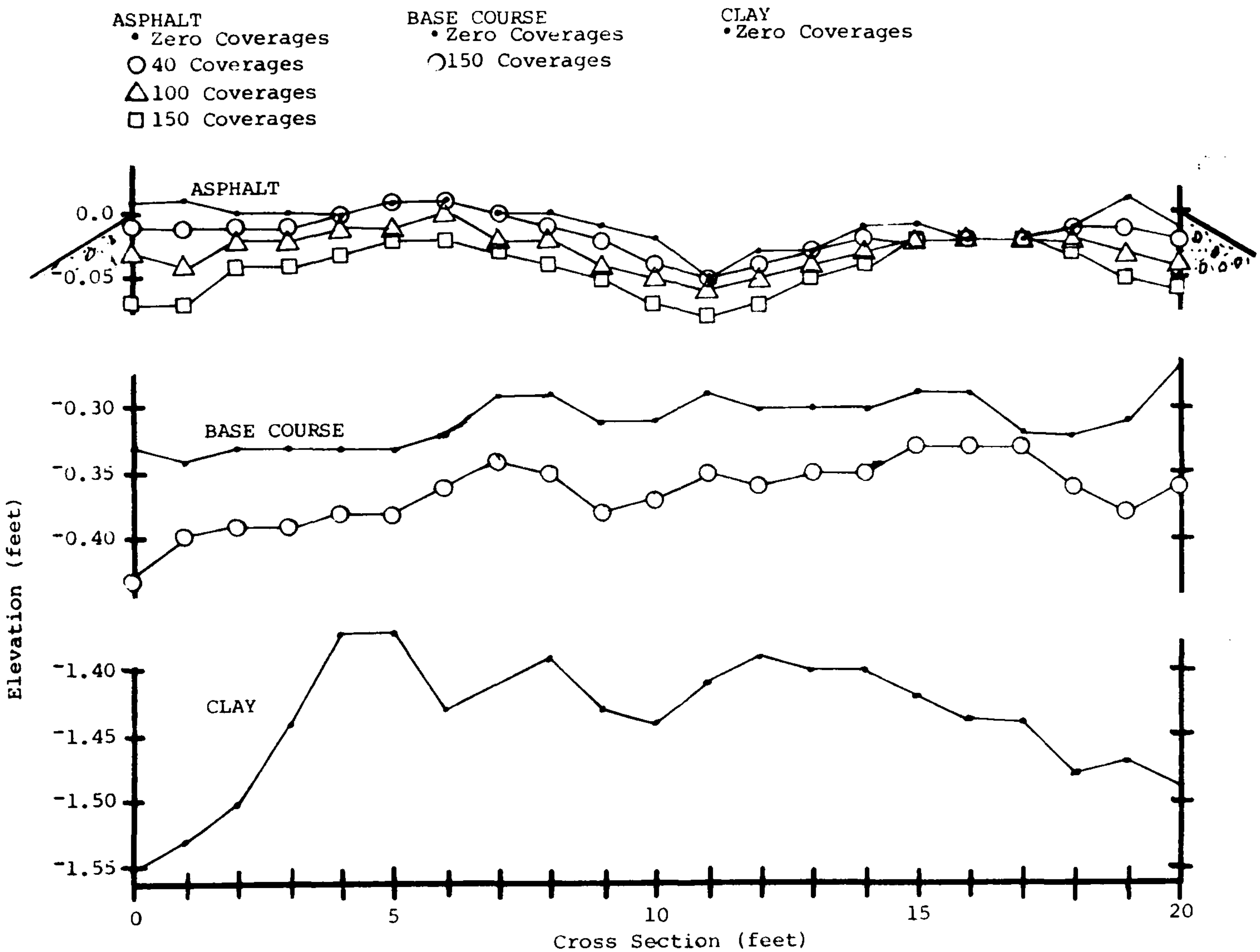


Figure 44. Longitudinal Centerline Profiles, Item 9

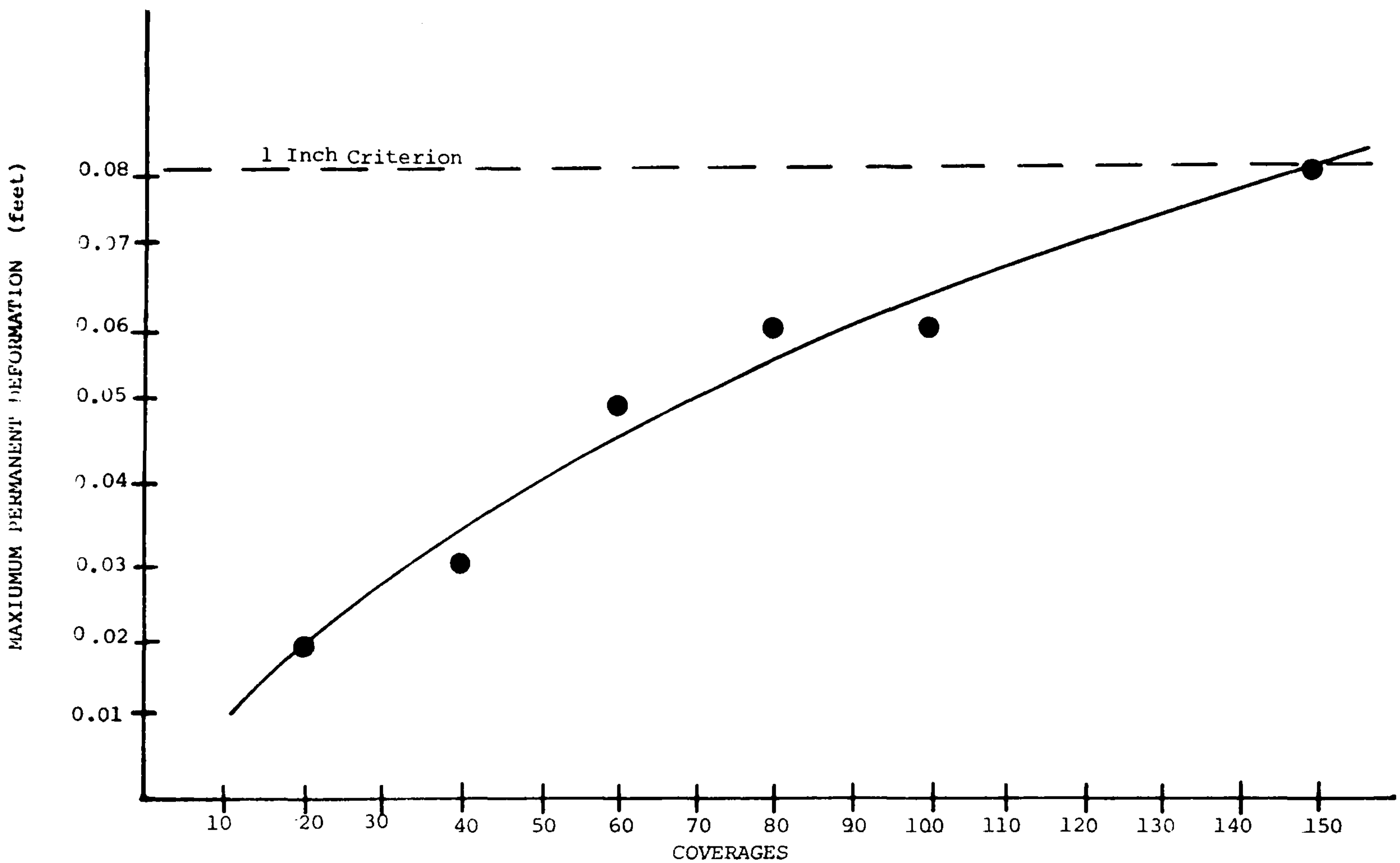


Figure 45. Coverage and Deformation Relationship, Item 9

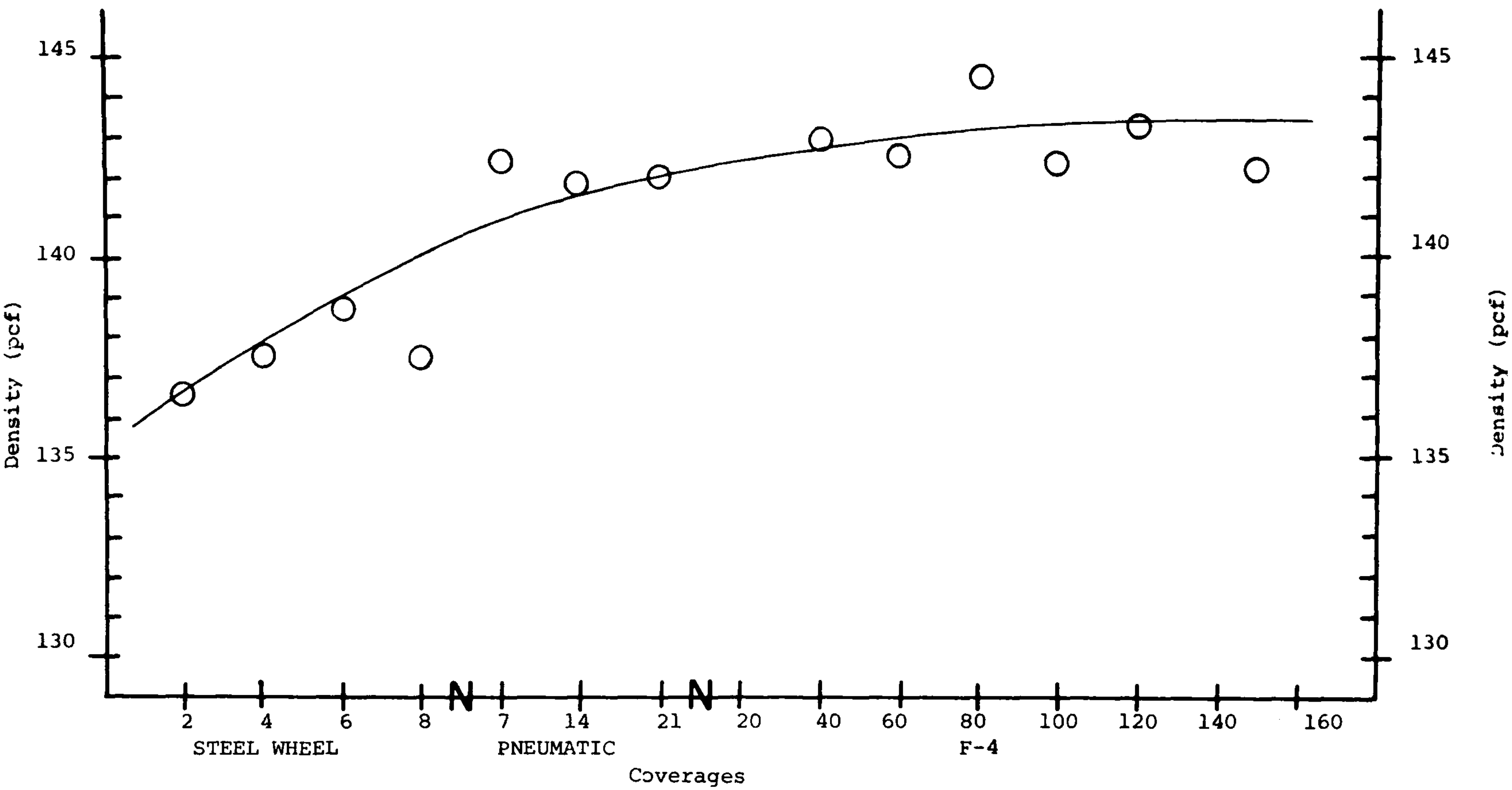


Figure 46. Asphalt Concrete Density at Various Compaction and Traffic Levels

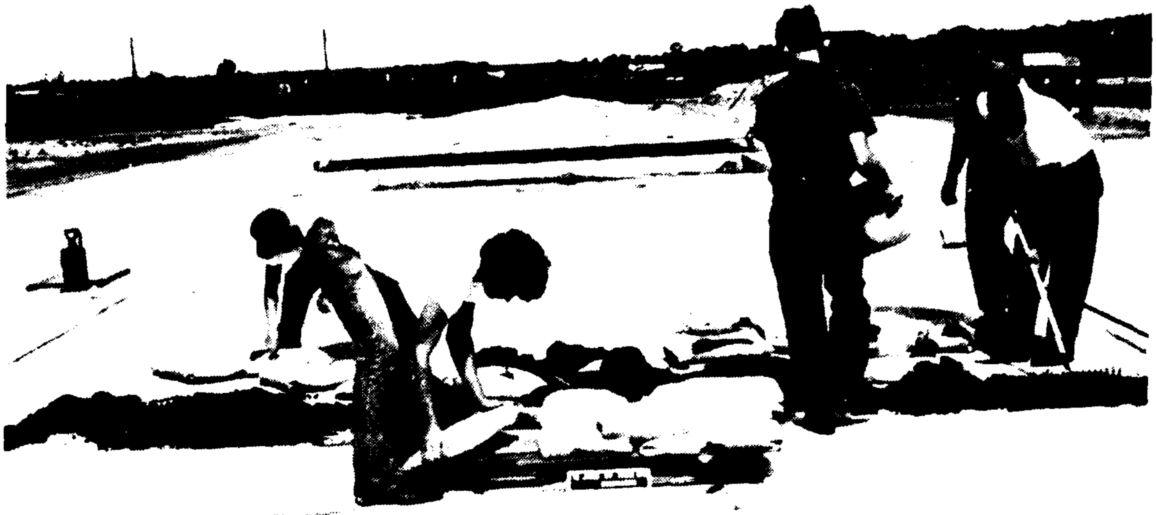


Figure 47. Placement of Almalgapave®, Item 11

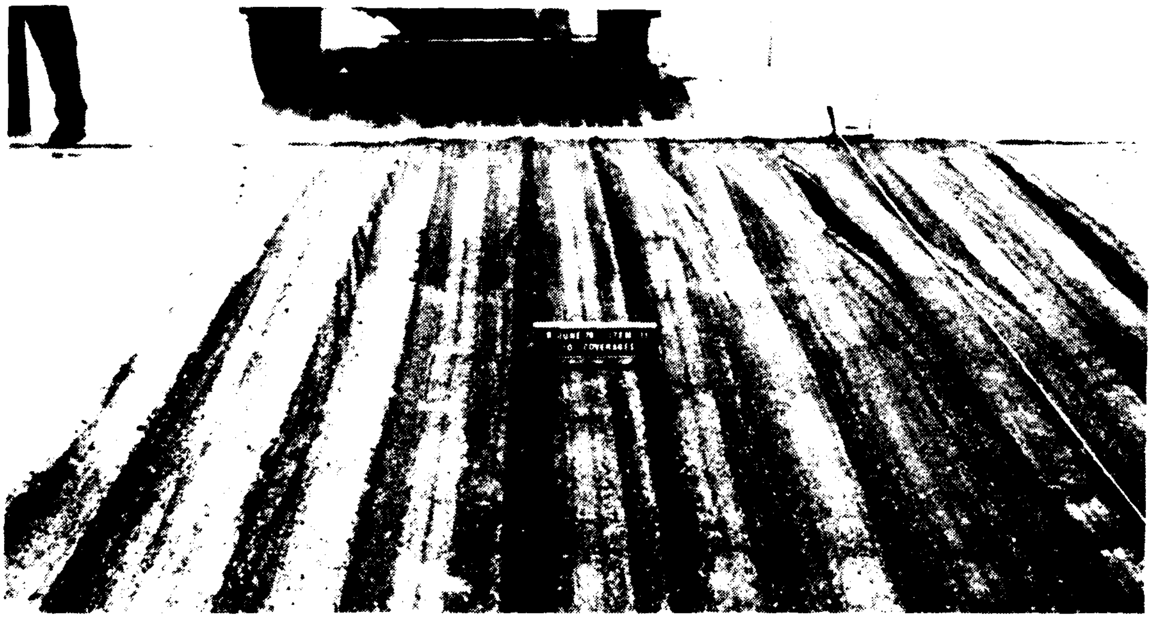


Figure 48. Rutting in Almalgapave® Surface, Item 11

Figure 49. Amalgapave® Working out of Repair Area, Item 11

Figure 50. Placement of Zor-x®, Item 12

AD-A084 778 AIR FORCE ENGINEERING AND SERVICES CENTER TYNDALL AF--ETC F/G 1/5
INTERIM REPORT OF FIELD TEST OF EXPEDIENT PAVEMENT REPAIRS (TES--ETC(U)
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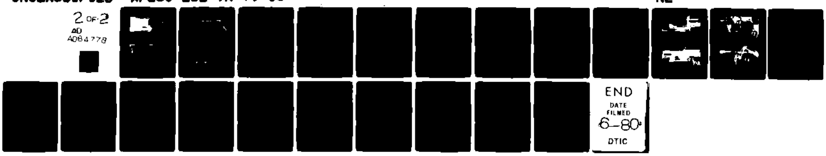


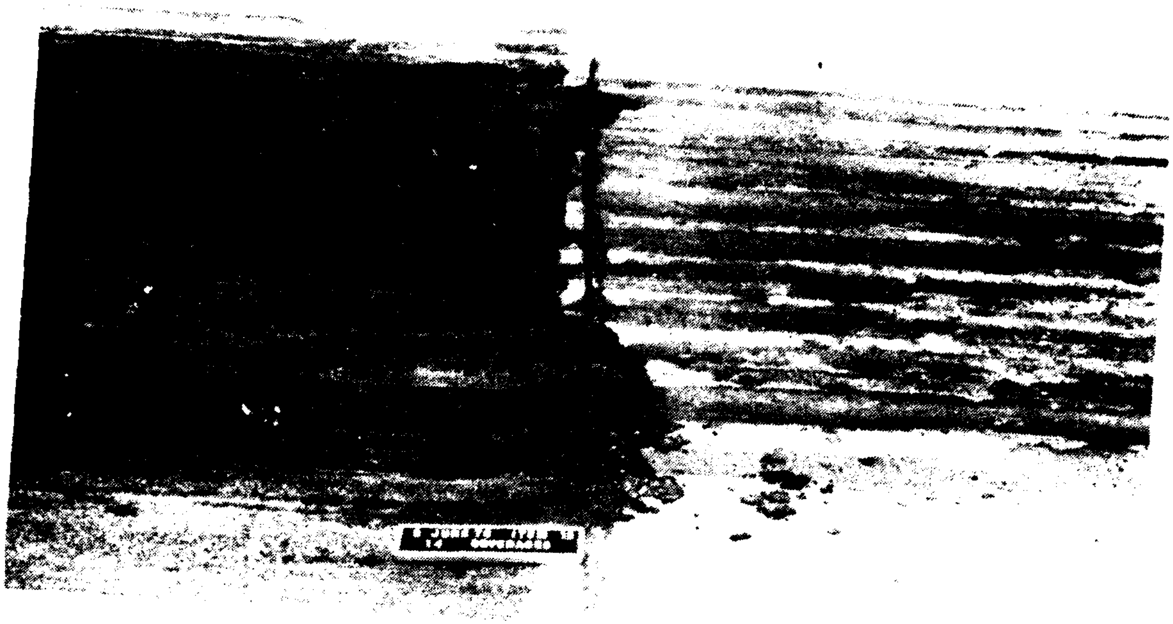


Figure 51. Zor-x® Working out of Repair Area, Item 12

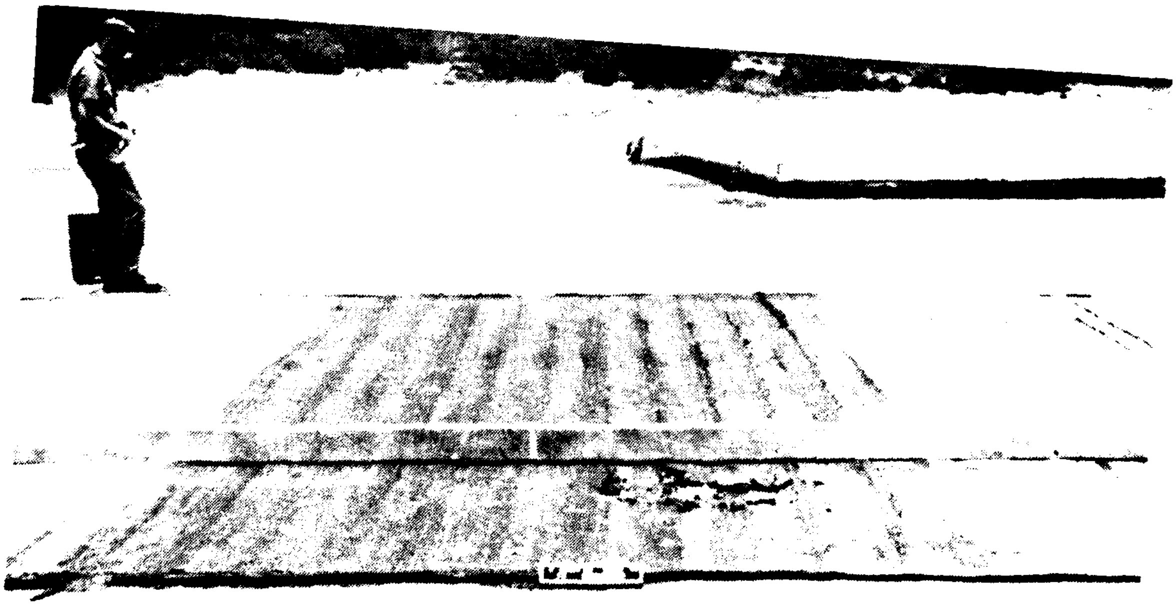


Figure 52. Zor-x® Surface After Traffic, Item 12

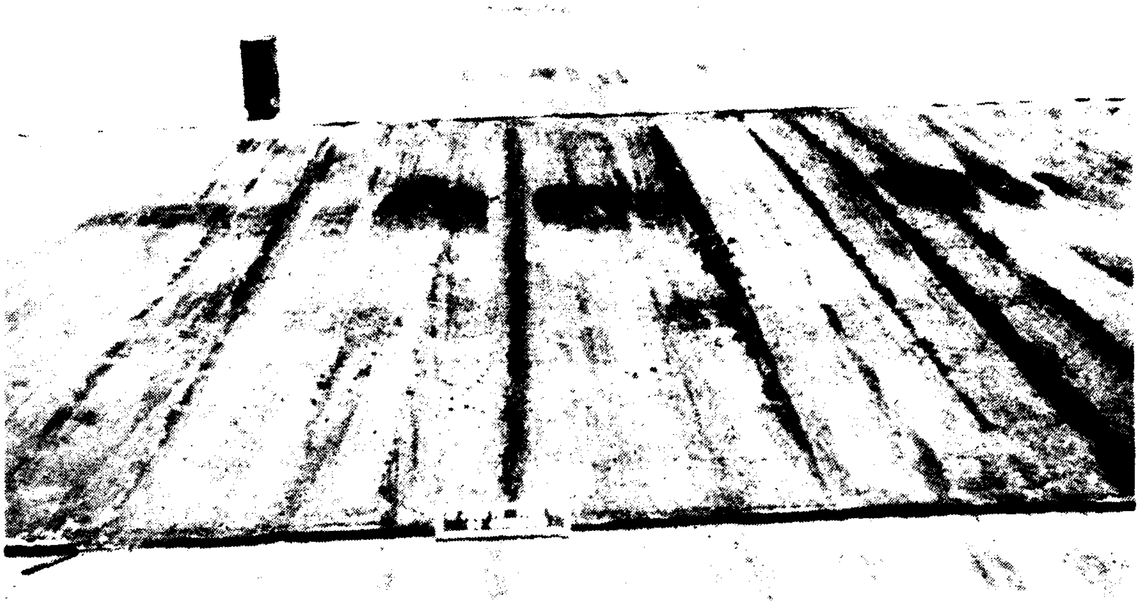


Figure 53. Almalgapave® Surface After 20 Coverages, Item 11A

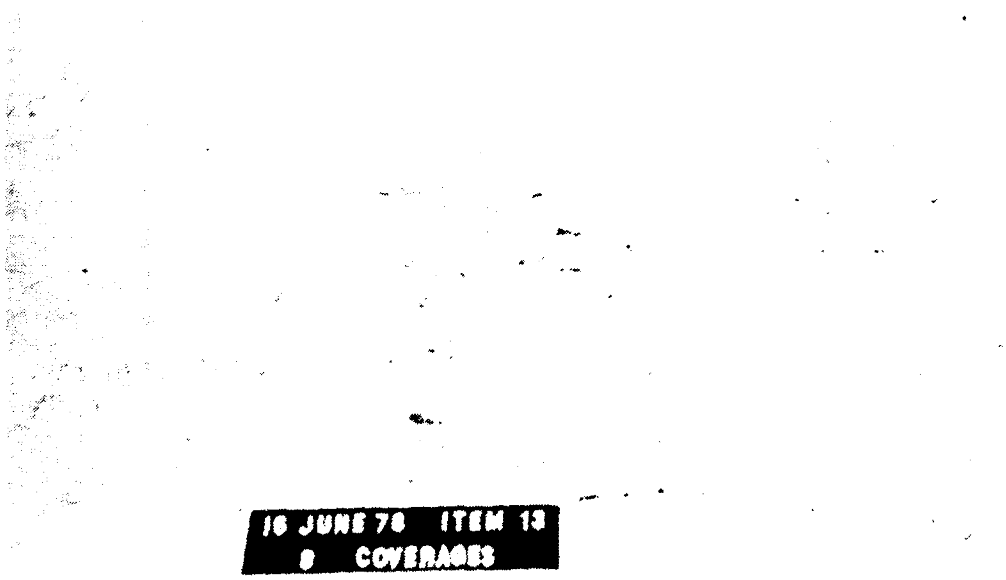


Figure 54. Surface After Traffic, Item 13

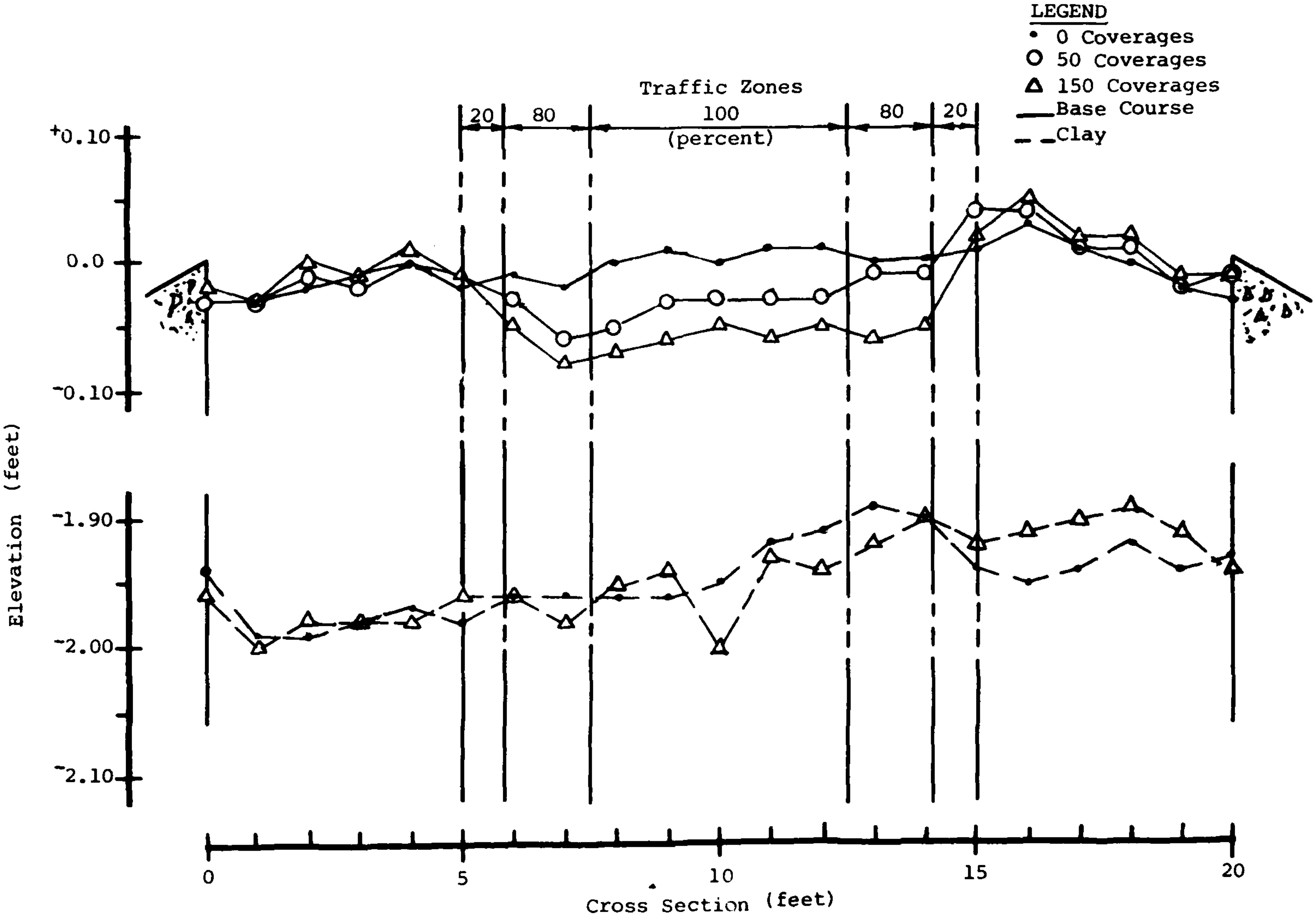


Figure 55. Lateral Quarter Point Profiles, Item 13A

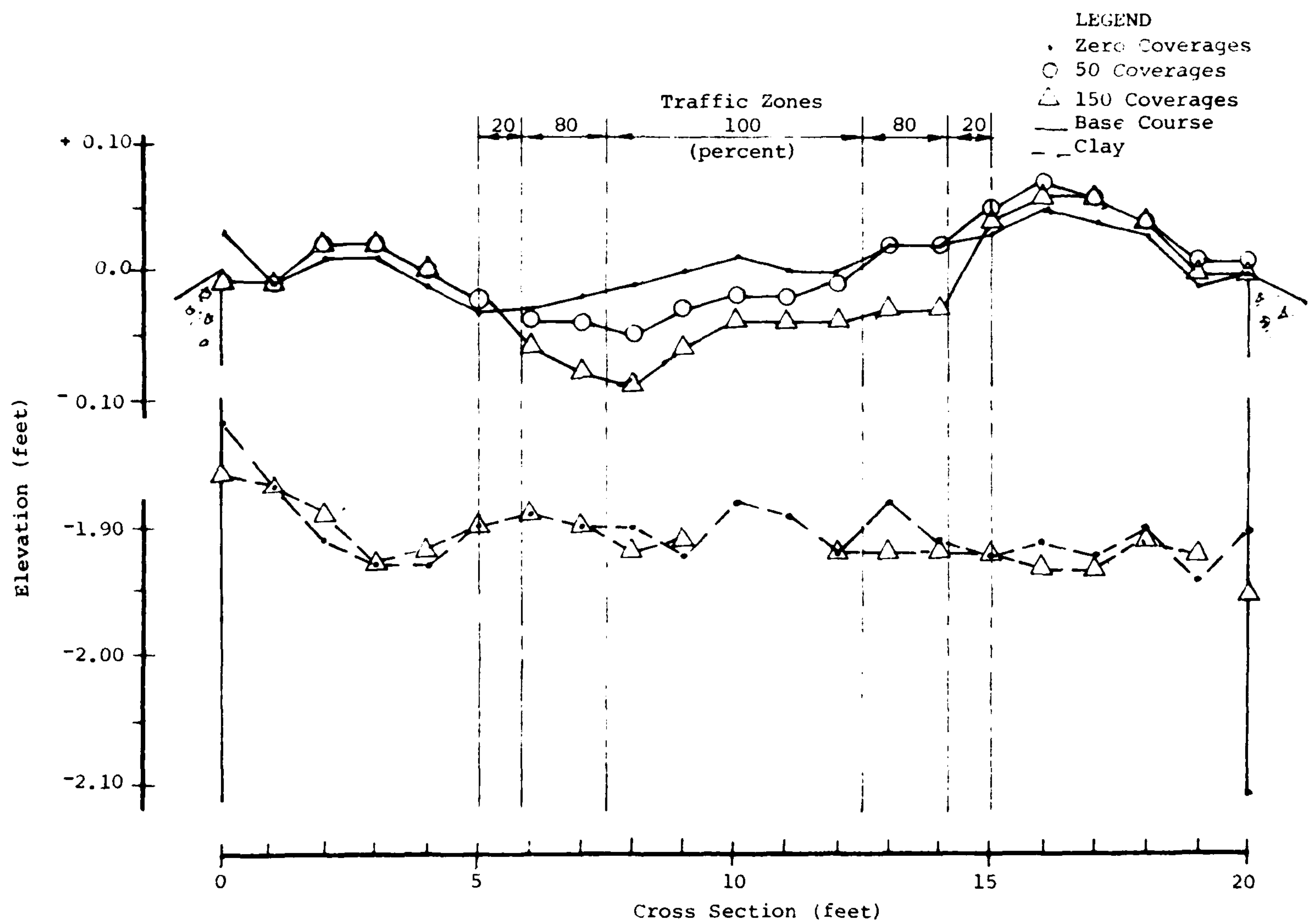


Figure 56. Lateral Centerline Profiles, Item 13A

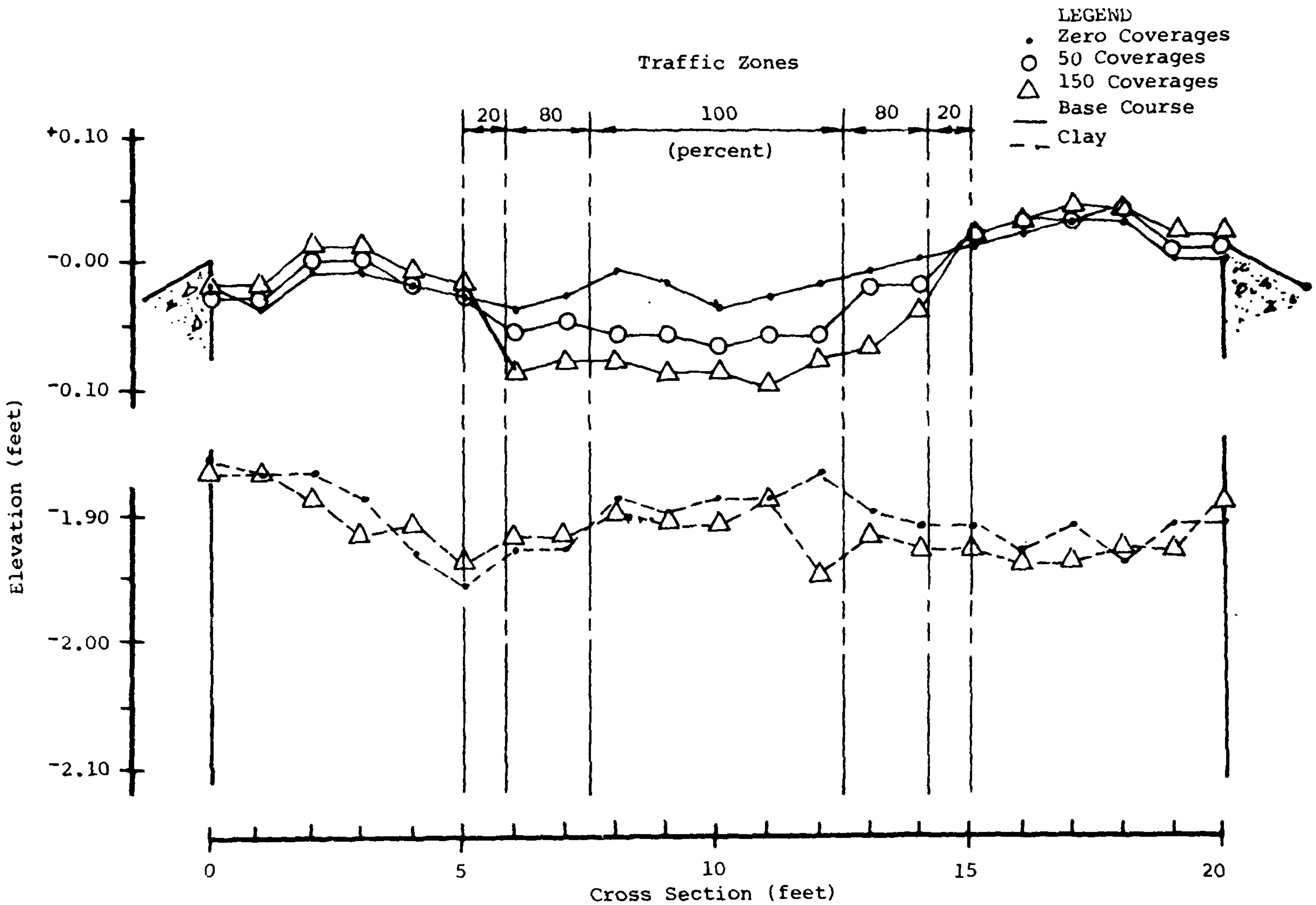


Figure 57. Lateral Three-Quarter Point Profiles, Item 13A

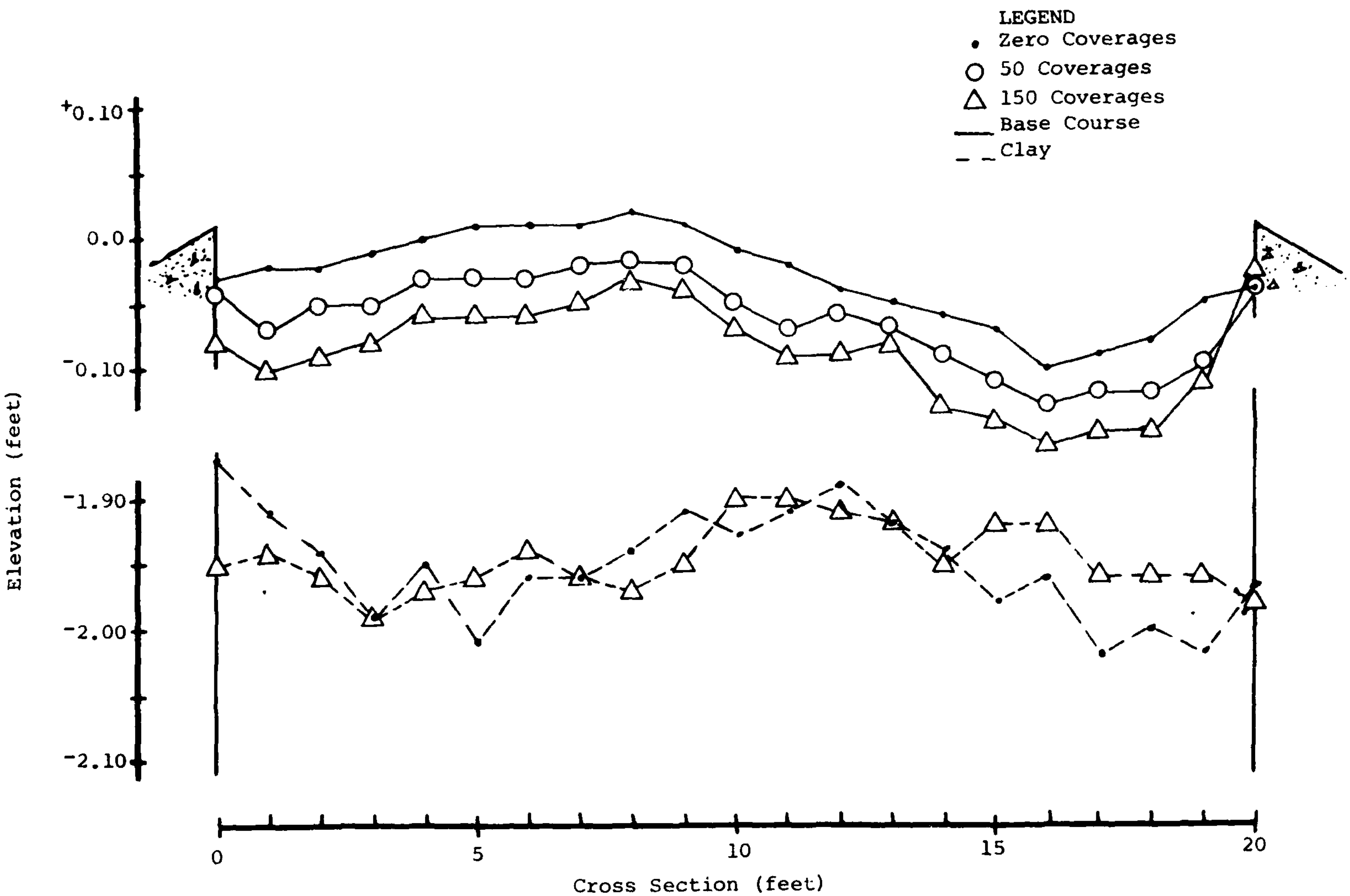


Figure 58. Longitudinal Centerline Profiles, Item 13A

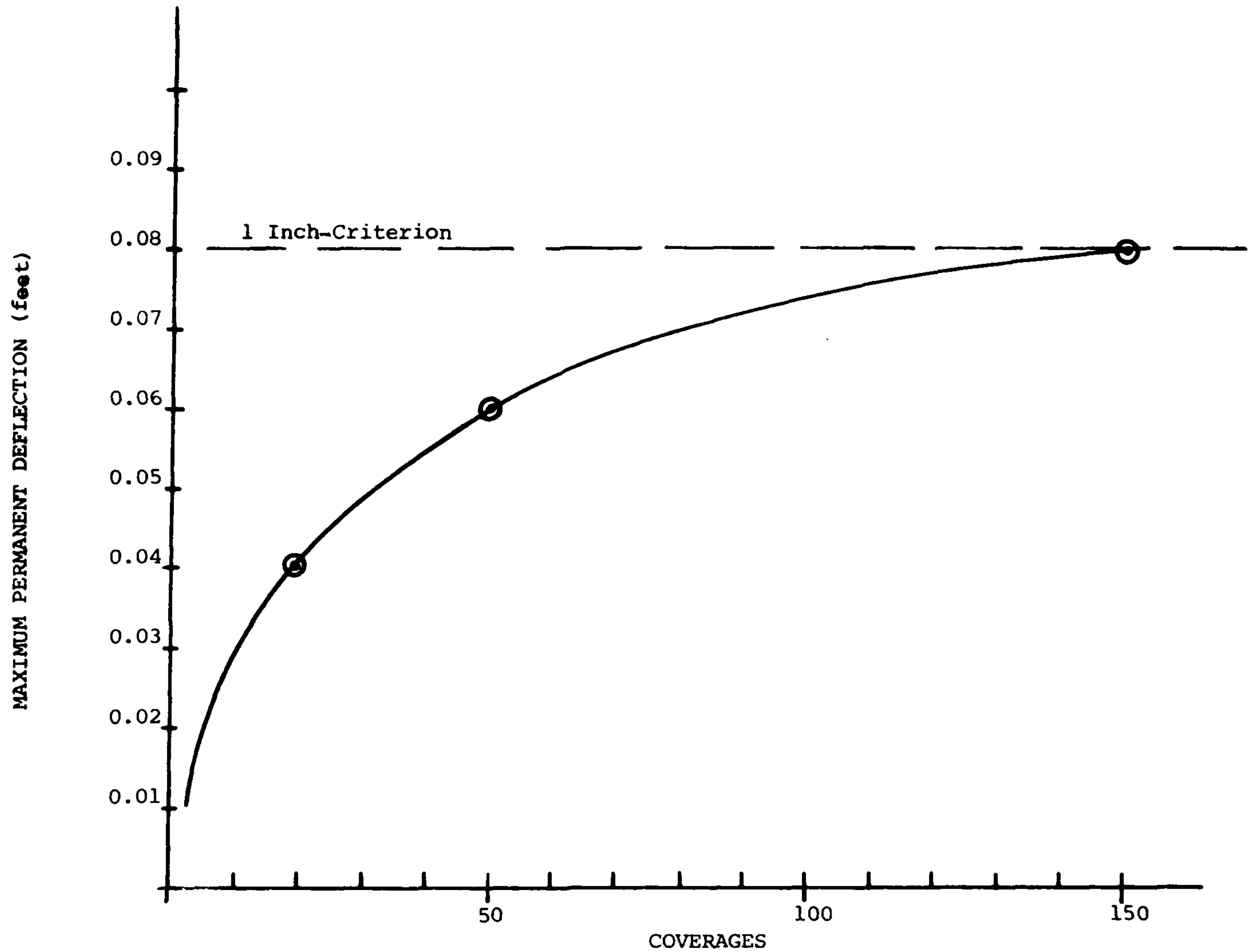


Figure 59. Load Cart Coverage and Deformation Relationship, Item 13A

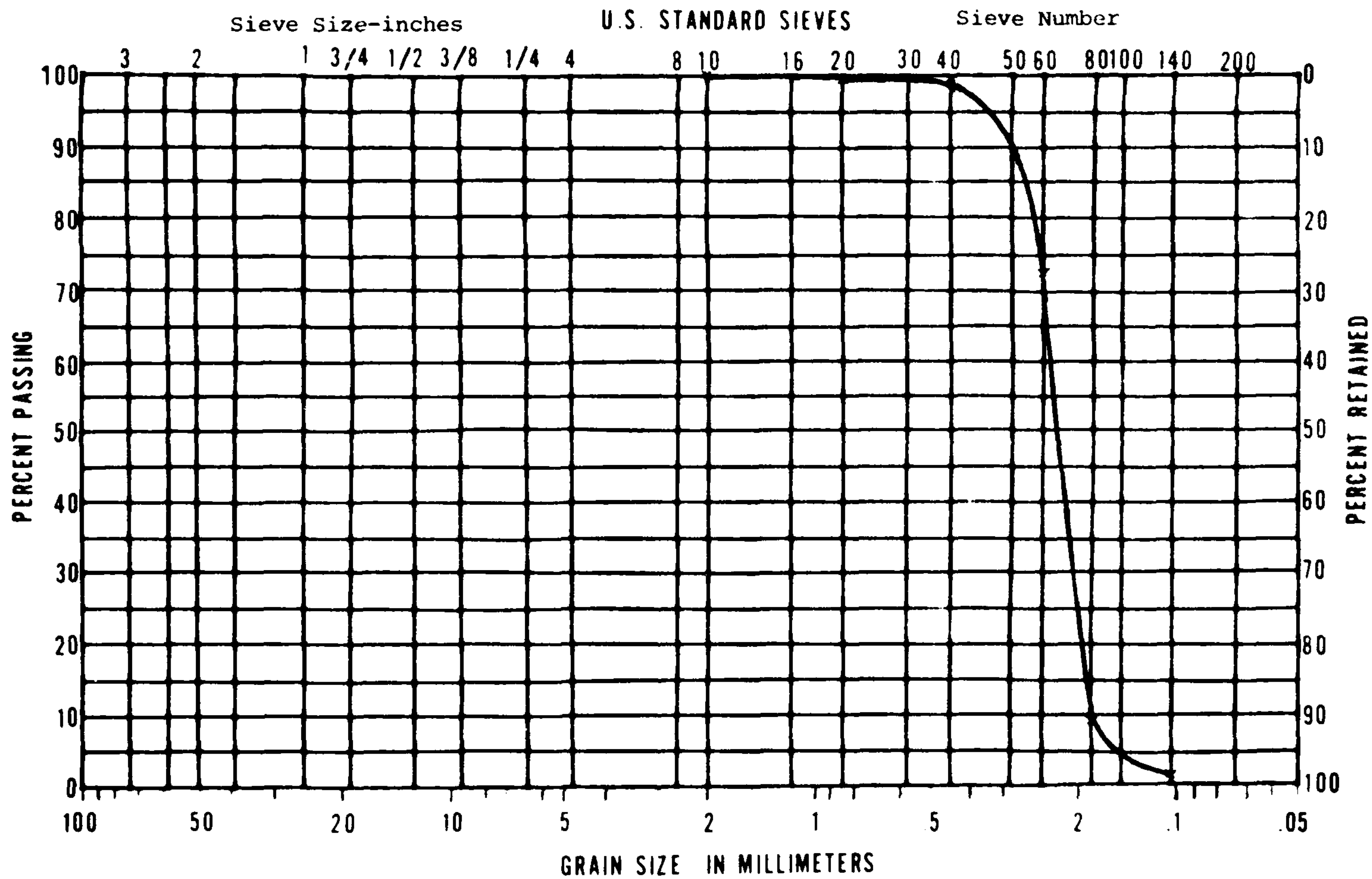
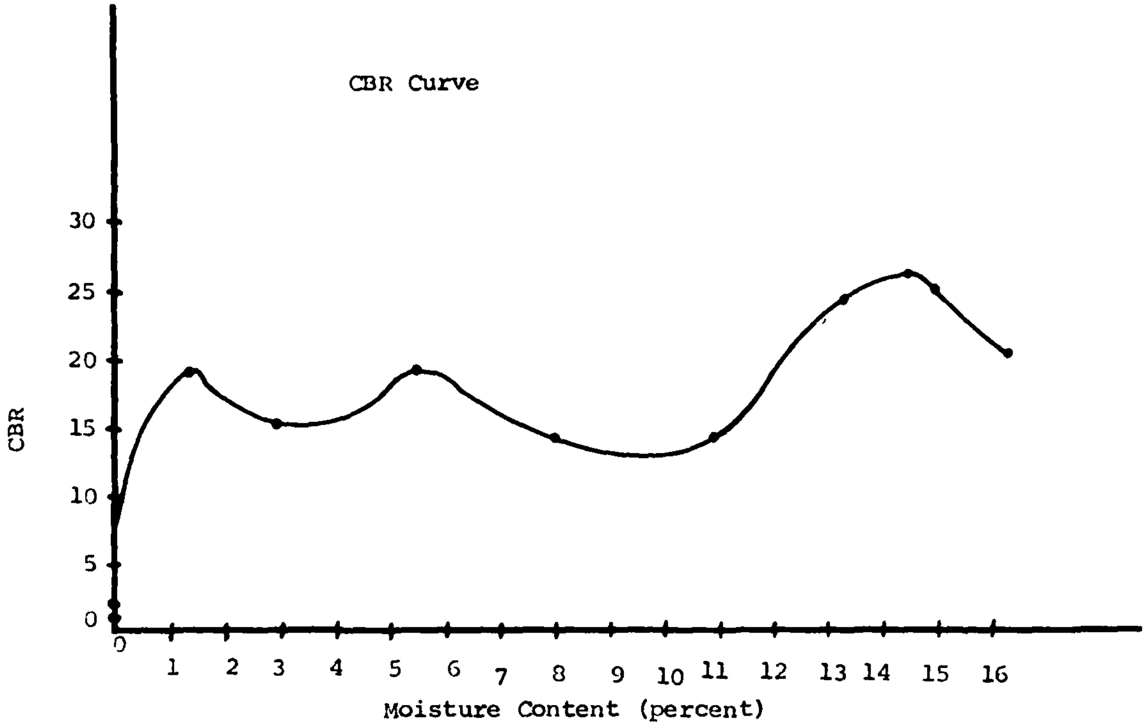


Figure 60. Gradation of Dune Sand, Item 15



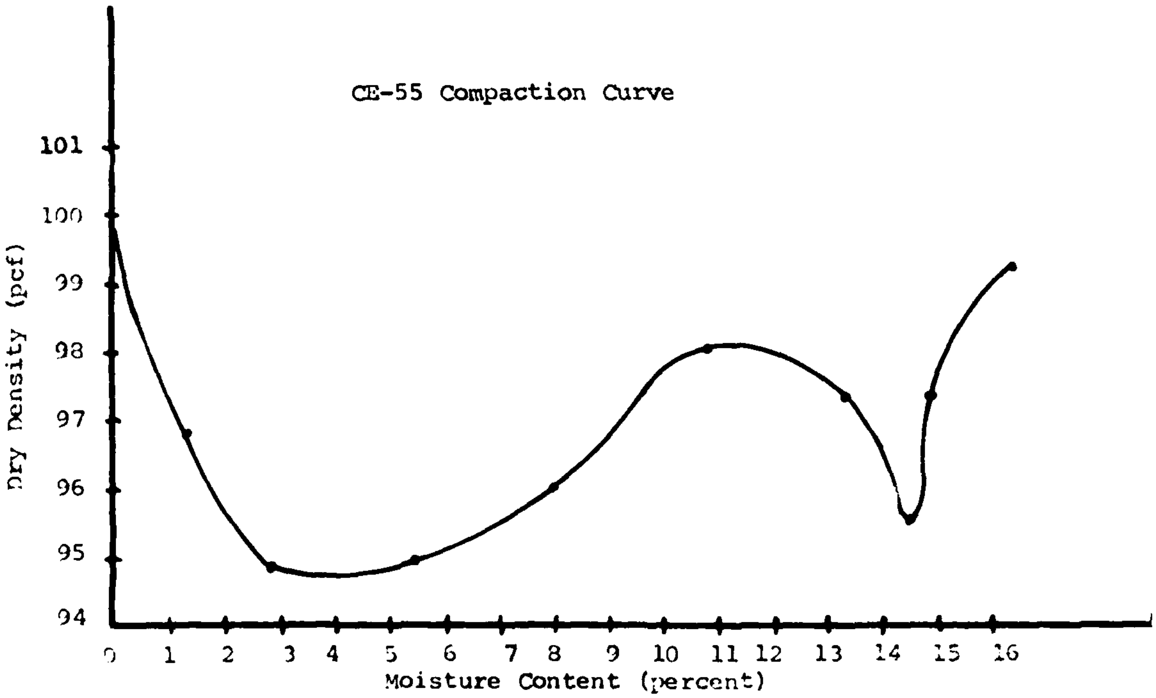


Figure 61. CE-55 Compaction Curve and CBR Curve for Dune Sand, Item 15

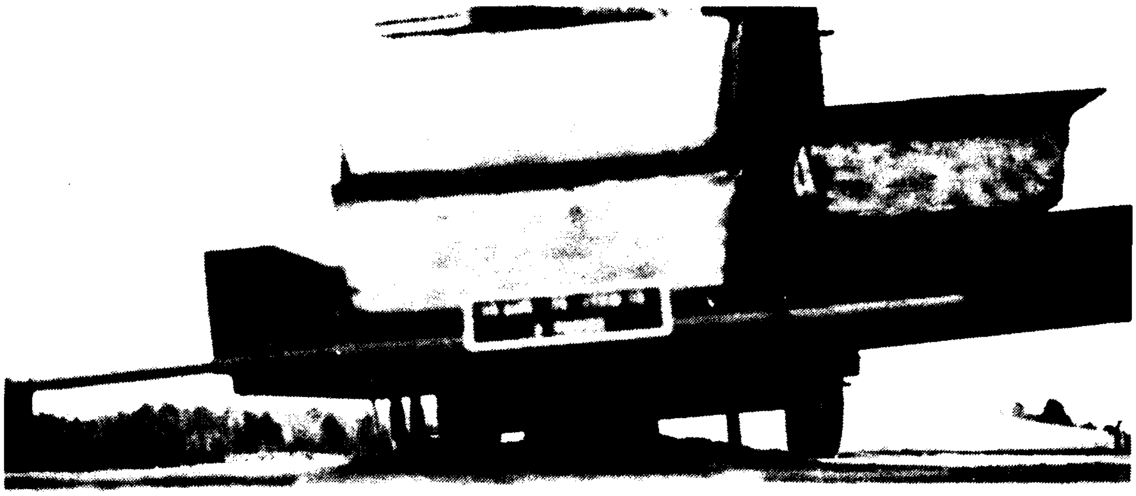


Figure 62. Shear Failure, Item 15

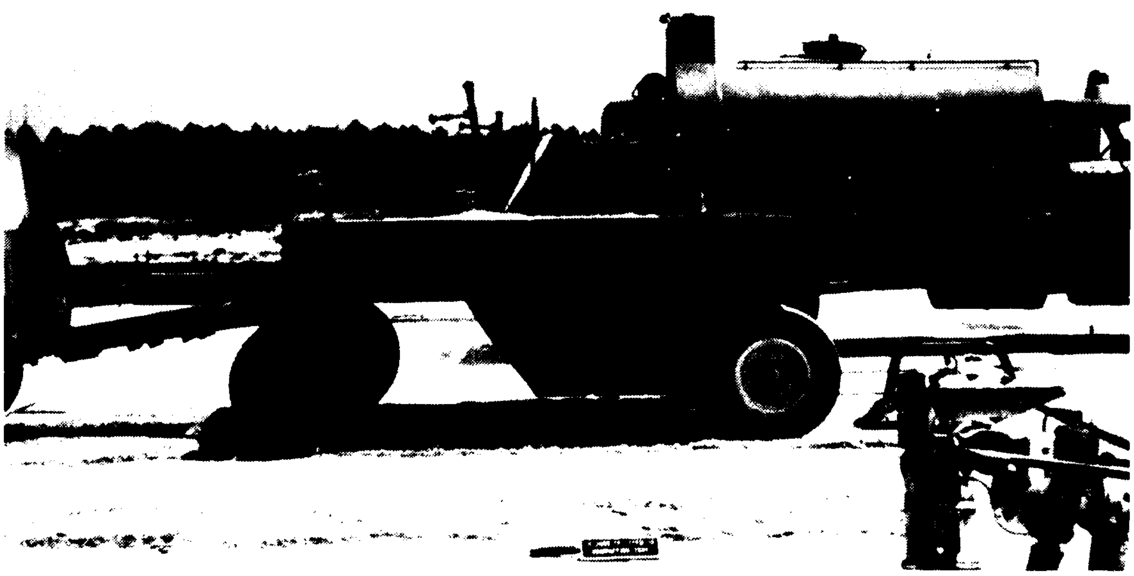


Figure 63. Thirteen Wheel Pneumatic Tired Roller

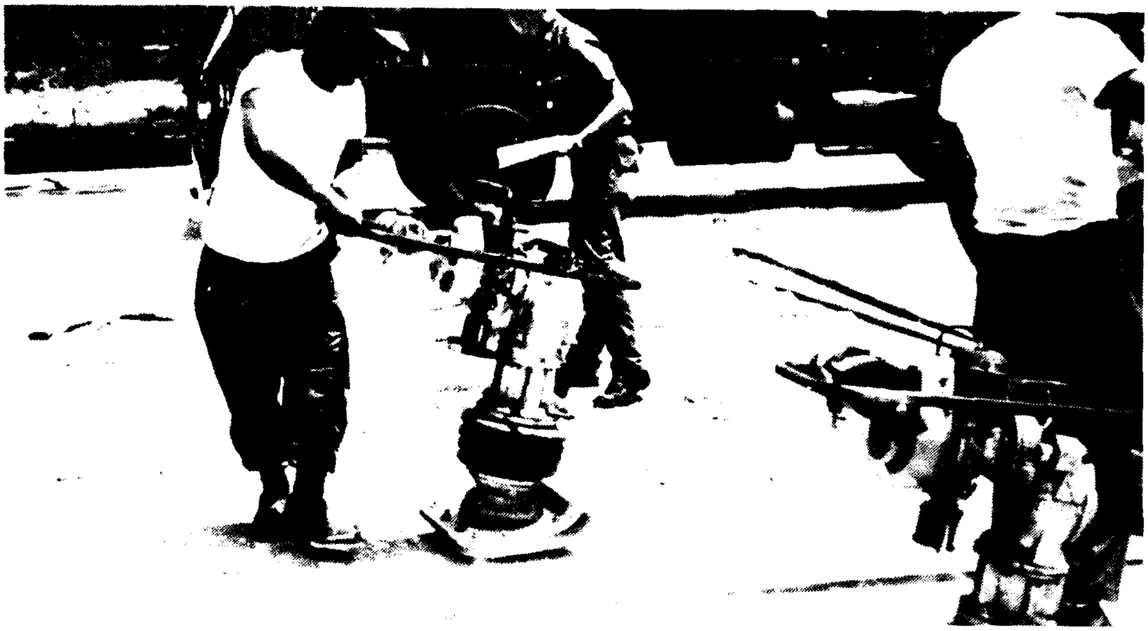


Figure 64. Gasoline Powered, Hand Operated Impact Compactor Model GVR 220 Y

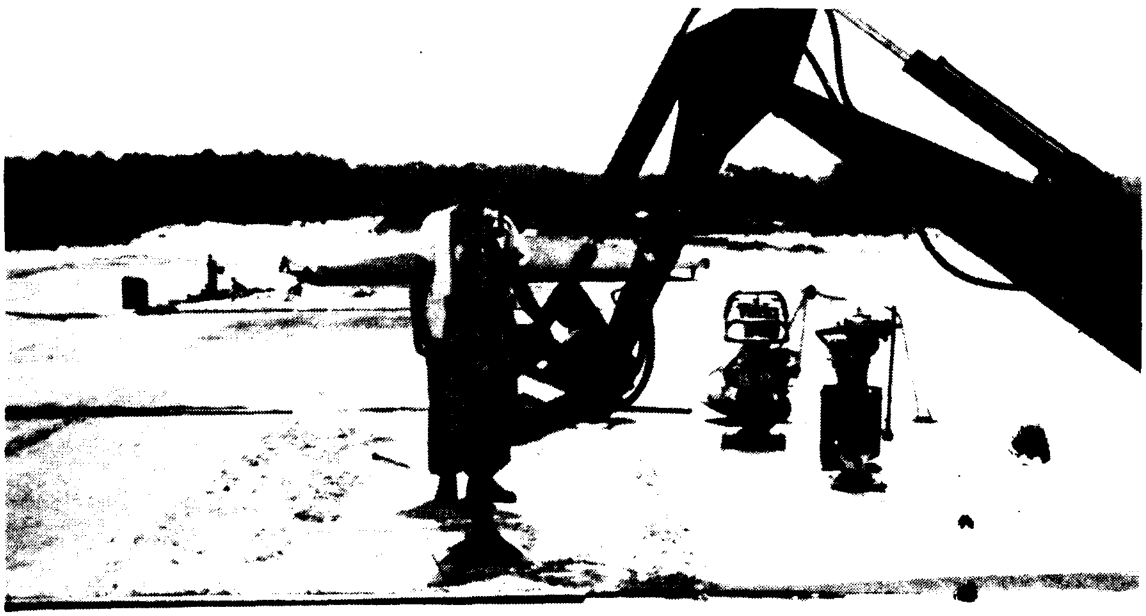


Figure 65. Hydraulic Operated Impact Compactor on a Backhoe

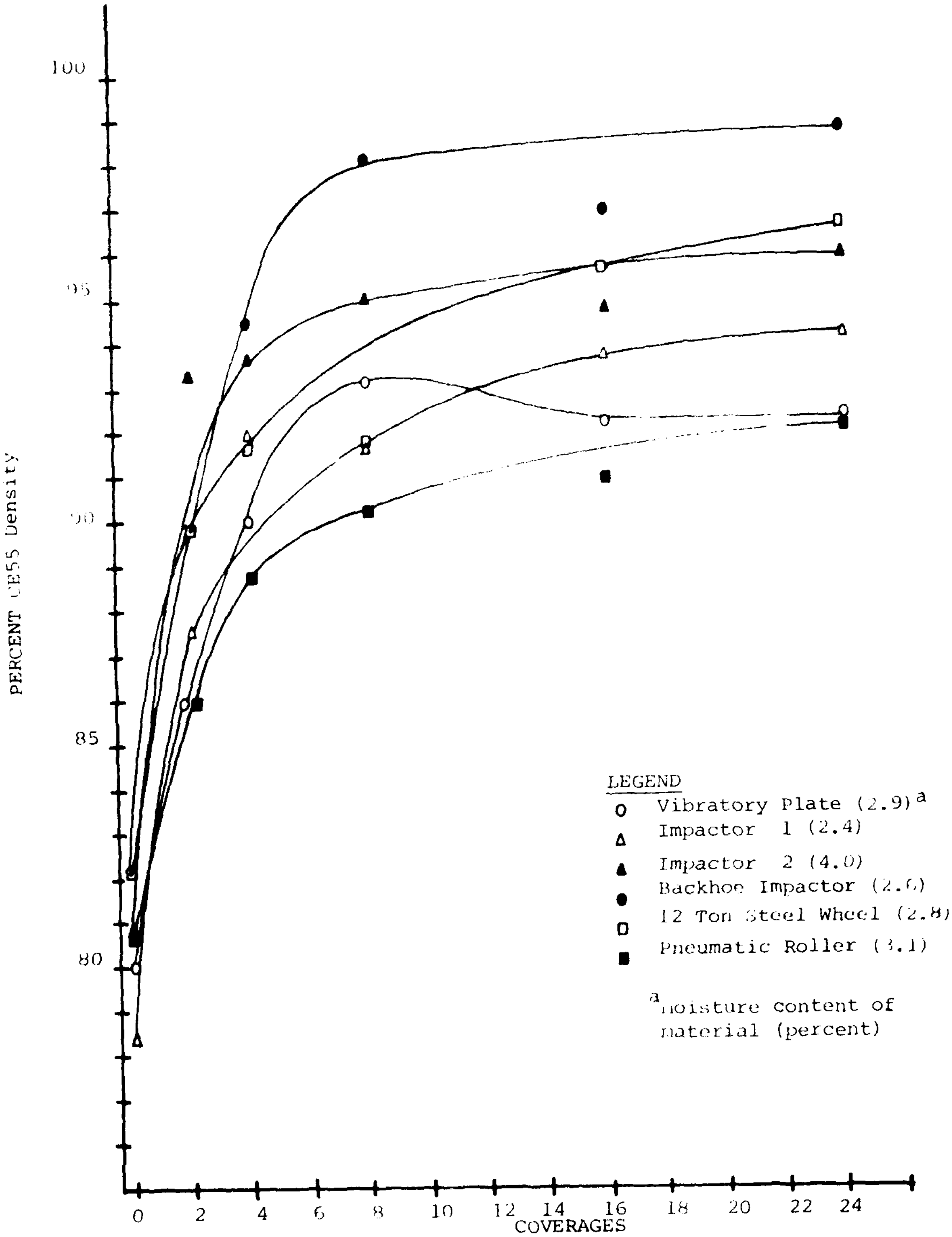


Figure 66. Compaction Results of Various Compactors

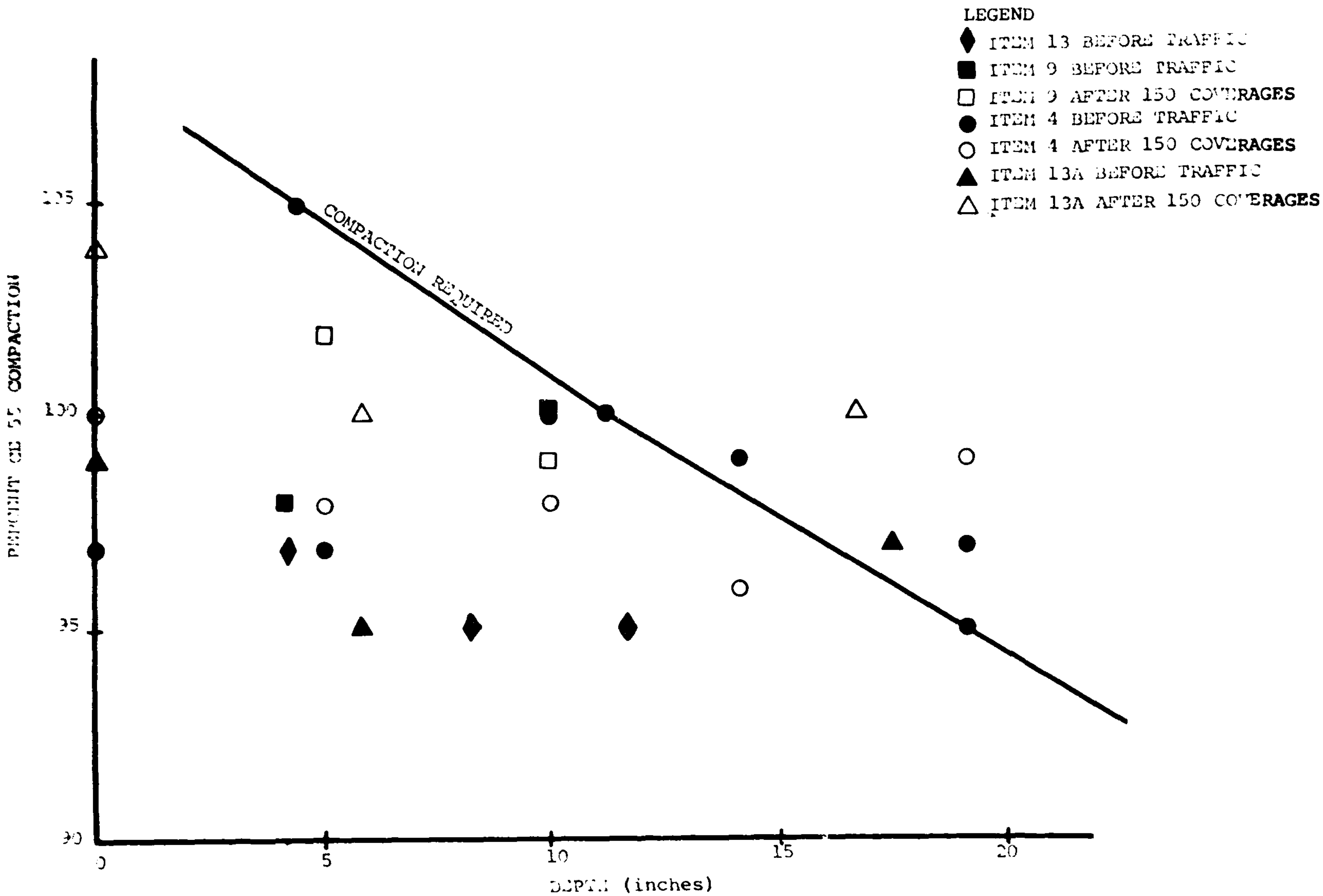


Figure 67. Compaction Requirements

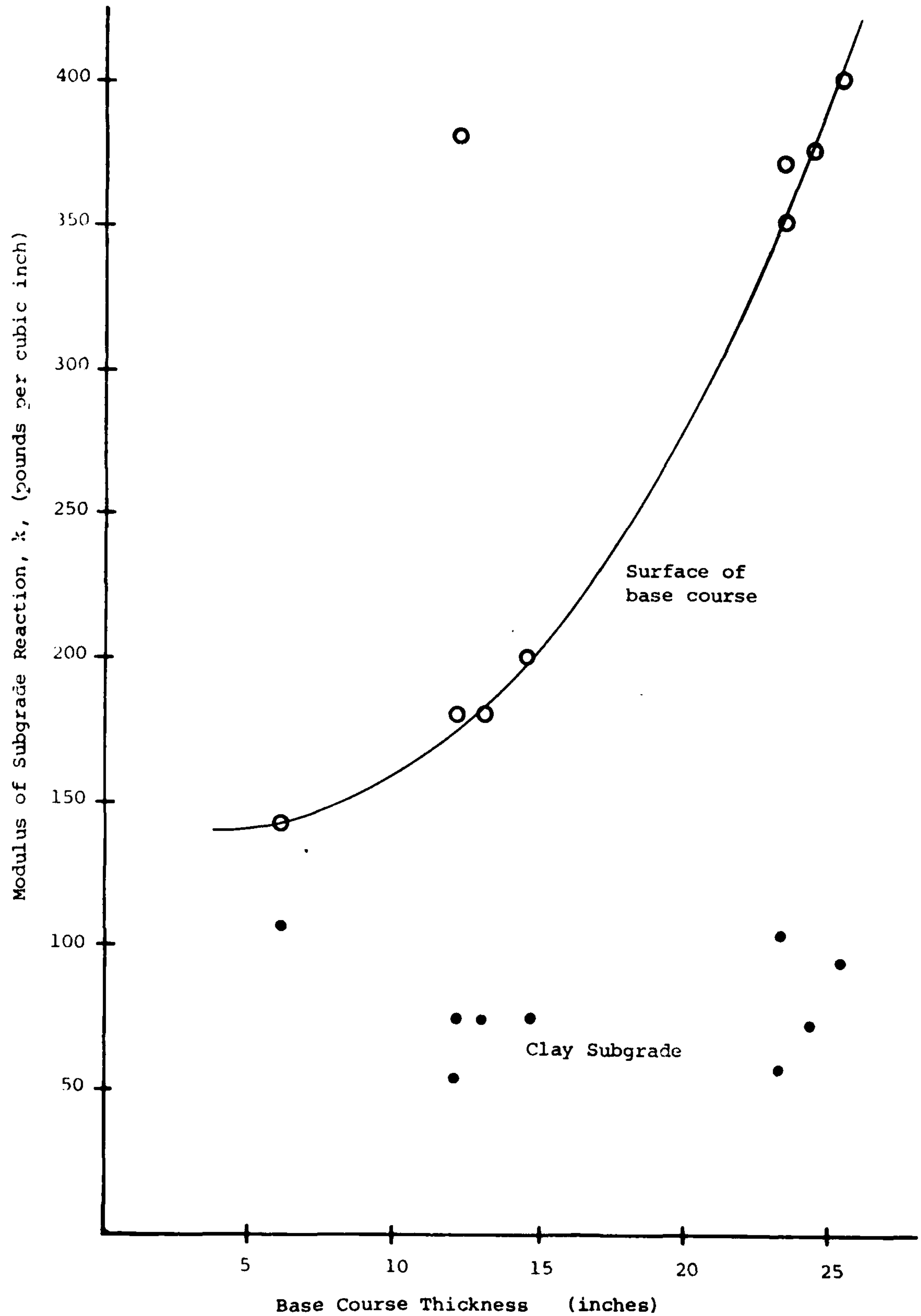


Figure 68. Effect of Base Course Thickness on Modulus of Subgrade Reaction (K)

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APPENDIX A

DENSITY MEASUREMENTS

From the beginning of this test considerable difficulty was encountered in determining the sand cone density of the base course material. Measured densities in the base course aggregate were consistently higher than what was thought to be reasonable. Consistency was generally within 2 to 3 pounds for the wet density but the dry density was too high considering method of compaction and CBR values obtained. Sand cone density tests were conducted by five different technicians of various experience, but results were all unsatisfactory.

The primary error in the sand cone density test lies in the determination of the volume of the hole (Reference A-1). Digging in cohesionless base course materials results in unavoidable volume change of surrounding material due to shear. Controlled tests have found the sand cone method to overestimate density by as much as 32 percent and underestimate it by as much as 16 percent (Reference A-2). The direction and magnitude of error depends on the material density and its moisture content.

A Troxler model 3411B nuclear density moisture gage was obtained part way through this testing program. Seventy sand cone density tests and nuclear density tests were run side by side on the base course of various test items to try to develop correlations (Figure A-1). The nuclear gage wet density was determined with the radioactive source at a 4-inch depth. The nuclear dry density was calculated using the moisture content of oven dried samples. A linear regression analysis provided the following correlation:

(Nuclear Dry Density) = 49.2 + 0.64 x (Sand Cone Dry Density).

The correlation coefficient is a poor 0.67.

The nuclear gage is believed to provide more reliable density measurements in the base course. The nuclear gage densities were used for all base course measurements for items 11 through 15 and the compaction tests. Sand cone densities on all previous items were reduced using the above correlation.

Nuclear gage densities were used only on cohesionless materials. Clay densities were all determined by the balloon density method.

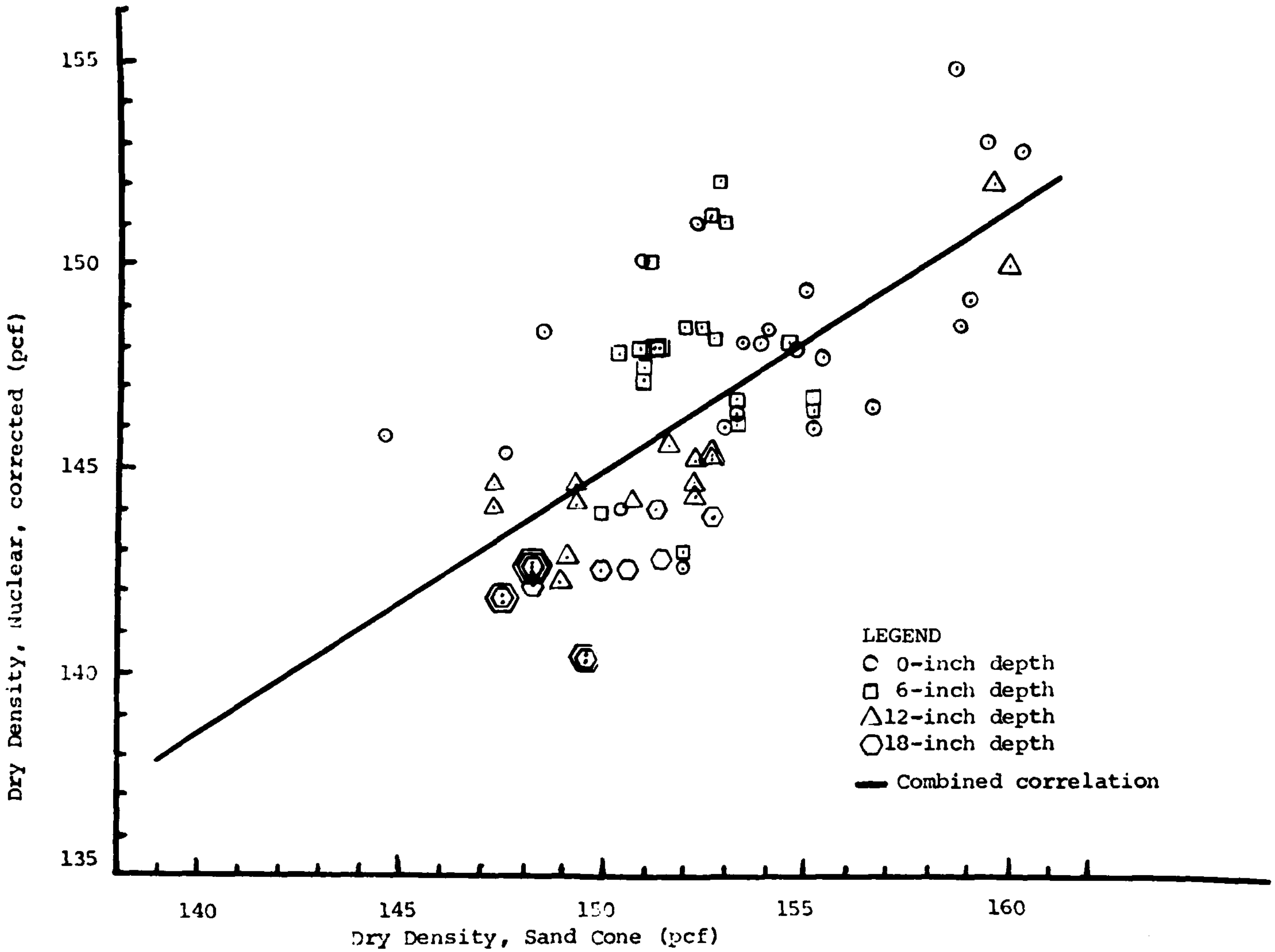

Figure A-1. Nuclear Gage and Sand Cone Density Correlations

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APPENDIX B

MANUFACTURERS' DATA ON IMPACT COMPACTORS

	Impactor 1	Impactor 2	Backhoe
Manufacturer	Whacker	Whacker	Hughes
Model	GVR 220Y	GVR 151Y	Impactor
Weight (pounds)	210	117	233
Shoe Size (inches)	15 3/4 x 15 3/4	11 x 13	14 1/8 x 20
Foot-pounds/second	912	495	2083[a]
Blows/minute	440 - 540	580 - 620	1000
Pounds/blow	2020	1430	[b]

[a]Based on manufacturers' data showing 125 foot-pound per blow at 1000 blows per minute.

[b]Not available.

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