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RAPID RUNWAY REPAIR (RRR) IN-HOUSE TEST AND EVALUATION

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The U.S. Air Force has conducted research and development work since the early 1960s to improve the capability to repair bomb-damaged airfields. As part of the in-house testing for the Rapid Runway Repair (RRR) Program, the Air Force Engineering and Services Center (AFESC) has conducted Development, Test and Evaluation on interim systems for crater and spall repairs.

The two interim crater repair methods, precast slab and fiberglass mat over crushed stone, were tested. The precast slab tests were conducted in two phases, using two generations of the slab technology. The fiberglass mat over crushed stone tests compared two different polyurethane resins for use in rainy or high water table conditions. In addition to these tests of the repair methods, a comparative test of compaction equipment performance was conducted.

The final test series evaluated the proposed polymer concrete formulations for the interim spall repair system, including water-tolerant polyurethane, furfuryl alcohol, and magnesium polyphosphate.

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18. Polymer Concrete/Precast Slab Repair/Rapid Runway Repair (RRR)/Spall Repair

PREFACE

This technical report was prepared by the BDM Corporation, 7915 Jones Branch Drive, McLean, Virginia 22102 under contract F08635-84-C-0185, for the Air Force Engineering and Services Center (AFESC), Engineering and Services Laboratory, Tyndall Air Force Base, Florida 32403.

This report summarizes work done between January 1981 and December 1983. The field testing was part of the Rapid Runway Repair In-House Test and Evaluation Program. Captain G. Beyer, Captain J. Rosenberg, Captain D. Pierre, Captain R. Pearson, Captain M. Oelrich, and Mr. P. Dukes were the AFESC Project Officers. Engineering technicians who conducted the tests included Ssgt. S. Poole, Ssgt. R. Wilkins, Ssgt. F. Doerle, and Msgt. R. Murphy.

This report documents the field-testing of two interim crater repair methods, precast slab and fiberglass mat over crushed stone, and advanced material spall repairs. A comparative test of compaction equipment was also conducted.

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 technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

A. OBJECTIVE

This report documents developmental test and evaluation (DT&E) conducted on expedient methods for repairing craters and spalls on a bomb-damaged airfield. The DT&E was conducted as part of the Air Force Engineering and Services Center (AFESC) In-House Testing Program at Tyndall Air Force Base, Florida.

B. BACKGROUND

Military aircraft must take off and land on high-quality airfield surfaces strong enough to support frequent aircraft passes and smooth and clean (i.e., free of foreign object debris) enough to prevent structural damage to sensitive aircraft components. Because these aircraft must operate on high-quality surfaces, an enemy can thwart U.S. and allied airpower by attacking and damaging the runways. The aircraft are grounded, leaving air forces with no means of counterattack. To counter offensive attacks to airfields, U.S. and allied air forces must identify and repair Minimum Operating Strips (MOS) on which aircraft launch and recovery operations can be restored. They must also continuously evaluate and update their ability to repair bomb-damaged runways exposed to changing enemy air threats.

The U.S. Air Force (USAF) has conducted research and development work since the early 1960s to improve its bomb damage repair (BDR) techniques. USAF has used the AM-2 aluminum landing mat for BDR work since 1965. This repair method uses a debris-backfilled crater topped with a base course of select fill, over which preassembled AM-2 mats are dragged and anchored to the undamaged pavement. However, this technique has proved to be time-consuming, labor-intensive, and ineffective in meeting surface roughness criteria.

Classified airbase vulnerability studies completed in the mid-1970s indicated that the AM-2 repair method no longer met BDR needs. Intelligence analysts estimated that the enemy air threat had increased: U.S. and allied airbases would sustain greater damage, and work done to repair this damage would be more complex. These airbase vulnerability studies also showed that USAF BDR methods had stagnated.

In response to the analyses, the USAF has allocated more funds for research and development in airbase recovery and survivability.

1. Spall Repair Methods

Runway repair goals are to reduce the time and effort needed to repair spalls and craters. The current spall repair technique uses

Silikal®, a methyl methacrylate polymer mortar. Workers first remove loose debris, unsound pavement, and water from the spall. They next hand-mix the Silikal® components and pour the repair mixture into the spall. Finally, they tamp and level the Silikal®. However, the Silikal® spall repair method is a slow, labor-intensive process, and requires extra effort in inclement weather. It is also flammable and can cause respiratory problems.

Because of these problems, three alternative material systems have been investigated to yield a more efficient spall repair system. These three alternative systems are respectively based on polyurethane, furfuryl alcohol, and magnesium polyphosphate as a binder for an advanced material concrete. The advanced material concrete develops adequate strength for aircraft operations within 30 minutes. When placed with specialized equipment under development, it would also require less manpower for deployment.

2. Crater Repair Methods

Alternative crater repair techniques are also being evaluated to strengthen BDR capabilities and correct AM-2 mat repair deficiencies. These techniques include a precast slab system, a polymer impregnated fiberglass mat repair, and a polymer structural cap.

The U.S. Air Forces in Europe (USAFE) developed a precast slab repair system to replace the AM-2 mat with a "flush" crater repair, using precast concrete slabs and standard industrial equipment. Backfill and ballast rock are placed in the crater and covered with a level course of uniform-sized gravel, and the concrete slabs are placed over this foundation.

The USAF also studied crushed stone as a possible base material for crater repairs. Although it is a suitable fill material, the crushed stone must be covered to alleviate ingestion of loose stones into aircraft engines. These covers must be thin enough to provide a nearly "flush" repair to minimize surface roughness.

Efforts were made to find a suitable cover with a thinner profile and lower cost that could be deployed quicker than AM-2 matting. A plastic mat repair concept was adapted from the advanced multipurpose surfacing system (AMSS), a research and development effort conducted by the Naval Civil Engineering Laboratory (NCEL). AFESC began efforts in 1980 to identify improved mats. Technical literature and research showed potential for a polyurethane-impregnated fiberglass mat to be used with the crushed stone crater repair.

C. SCOPE

AFESC conducted in-house testing on the interim systems for crater and spall repairs. These tests, summarized in Table 1, are documented in this report.

The two interim crater repair methods, precast slab and fiberglass mat over crushed stone, were tested. The precast slab tests were conducted in two phases, using two generations of the slab technology. The fiberglass-mat-over-crushed stone tests compared two different polyurethane resins for fabricating the mats and also demonstrated the repair technique for use in rainy or high water table conditions. A comparative test of compaction equipment performance was conducted in conjunction with these tests.

The final test series evaluated the proposed polymer concrete formulations for the interim spall repair system, including water-tolerant polyurethane, furfuryl alcohol, and magnesium polyphosphate.

TABLE 1. TESTS FOR INTERIM CRATER REPAIR AND SPALL REPAIR SYSTEMS.

- PRECAST SLABS
  - INITIAL TESTS
    - JAN 31 PRELIMINARY TEST
    - MAY 83 TEST 2: 2-METER SLABS (NO COMPACTION)
    - JULY 83 TEST 3: 2-METER SLABS (NO COMPACTION, ALTERNATE LEVELING COURSE)
    - JUNE 83 TEST 4: 2-METER SLABS (COMPACTION, ALTERNATE LEVELING COURSE)
    - AUG 83 TEST 5: 2-METER SLABS (FILLED JOINTS)
    - MAY 83 TEST 6: 3-METER SLABS
    - JUNE 83 TEST 7: F-4 DYNAMIC TEST
  - USAFE SLABS TESTS
    - NOV 83 SETTLED SLABS (NORMAL STRENGTH)
    - DEC 83 NORMAL/HIGH STRENGTH SLABS-BRICKWORK PLACEMENT
- COMPACTION EQUIPMENT EVALUATION
  - NOV 83 ROLLER/COMPACTOR PLATE COMPARISON
  - DEC 83 COMPACTOR PLATE EVALUATION
- FIBERGLASS MATS/CRUSHED STONE REPAIR
  - OCT 83 ALTERNATE POLYURETHANE MAT COMPARISON
  - FEB 84 WET CRATER REPAIR (EXPLODED CRATER)
- SPALL REPAIRS
  - AUG 83 POLYMER CONCRETE COMPARISON
  - SEP 83 MULTIPLE SPALL REPAIR

SECTION II

TEST FACILITIES, MATERIALS, AND EQUIPMENT

A. TEST FACILITIES

The test program described in this report was conducted at two Tyndall Air Force Base facilities - the Exploded-Crater Test Facility (referred to as "SKY TEN") and the Small-Crater Test Facility (SCTF).

1. Exploded-Crater Test Facility (SKY TEN)

This test site, located in a remote area in the southeast portion of Tyndall Air Force Base, consists of a test pad constructed to simulate a typical USAFE runway. The test pad has been reconstructed several times, and two different constructions were used for these tests.

At the time of the preliminary precast slab repair test in 1981 (Section III), the 135- by 195-foot test pad consisted of a 12-inch thick base course of well-graded crushed limestone and a 12-inch thick portland cement concrete (PCC) pavement. Half of the test pad was topped with a 4-inch thick asphalt concrete (AC) overlay. Fifteen-foot-square slabs of 5000 pounds per square inch (psi) concrete were placed in a rectangular pattern 9 slabs wide and 13 slabs long (Figure 1). Six clay cores to simulate weak subgrades were located under the test pad area, and the preliminary precast slab test was conducted in a previously repaired crater at Core Location 4.

SKY TEN was reconstructed in February 1982, enlarging the test area to 150 by 210 feet. The test pad consisted of a 12-inch thick base course of crushed limestone, an 8-inch thick pavement of 5000 psi PCC with a 6-inch AC overlay. The 15-foot-square PCC slabs were placed in a pattern 10 slabs wide by 14 slabs long (Figure 2). Cold-poured, keyed construction joints run north and south with contraction joints sawed east to west. Nine 20-foot-square clay core subgrades were constructed under the test pad, three (A-1, B-1, C-1) in a common trench and six in separate excavated pits. The cores at the north edge (A-3, B-3, C-3) were centered over slabs, while the remaining cores were centered over joints.

2. Small-Crater Test Facility (SCTF)

The SCTF is a permanent facility constructed at Tyndall Air Force Base to accommodate testing of various pavement materials and designs. The local water table fluctuates and approaches the surface of the natural sand subgrade during wet seasons. The 6-foot deep soft clay subgrade core was placed and compacted at a high water content to achieve a California Bearing Ratio (CBR) of 3 to 7, representing the worst-case situation that might be expected in an actual crater. The local sand dune was stabilized with oyster shells to construct a sand fill around the test site, topped by

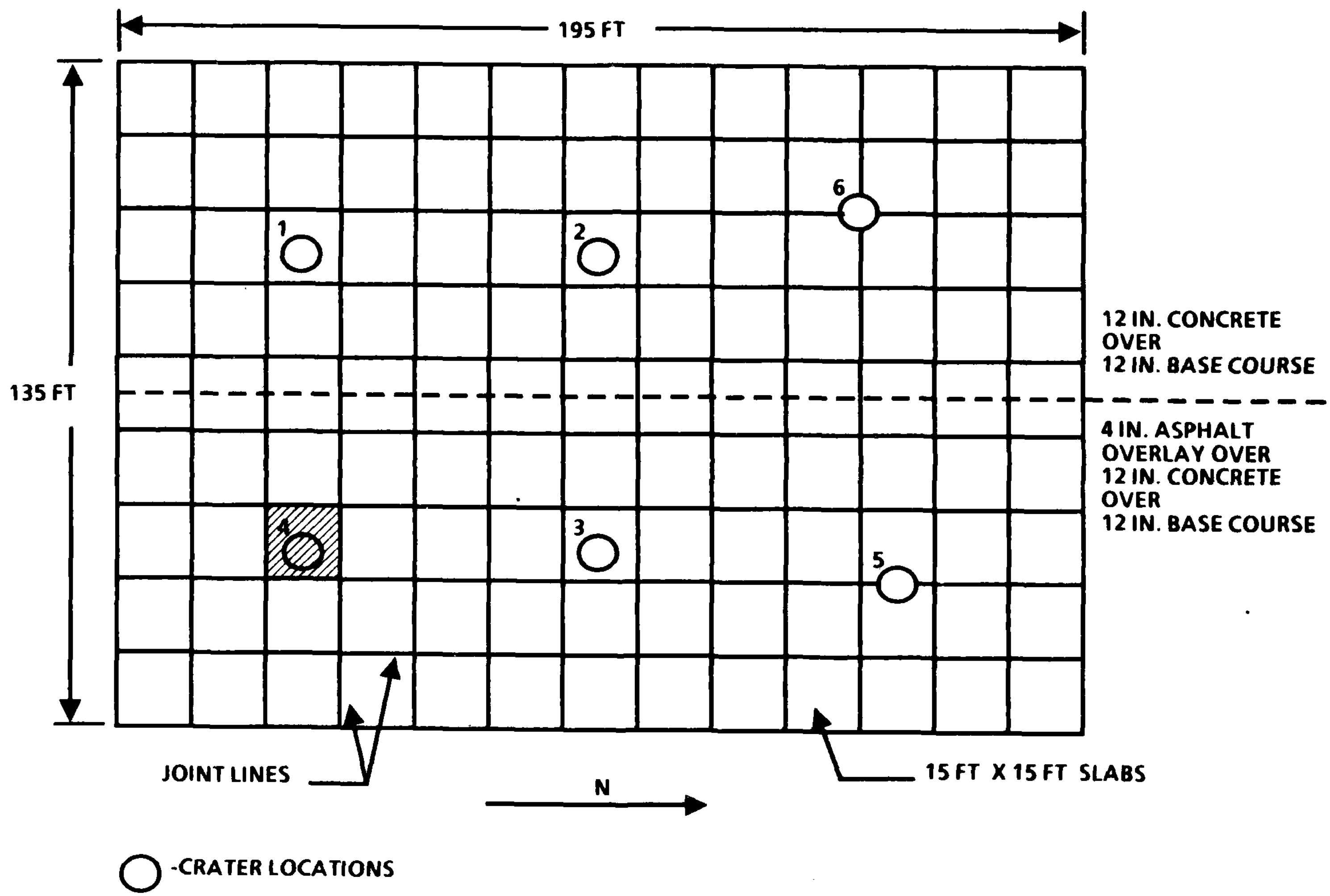

Figure 1. Plan View of SKY TEN (1981 Construction).

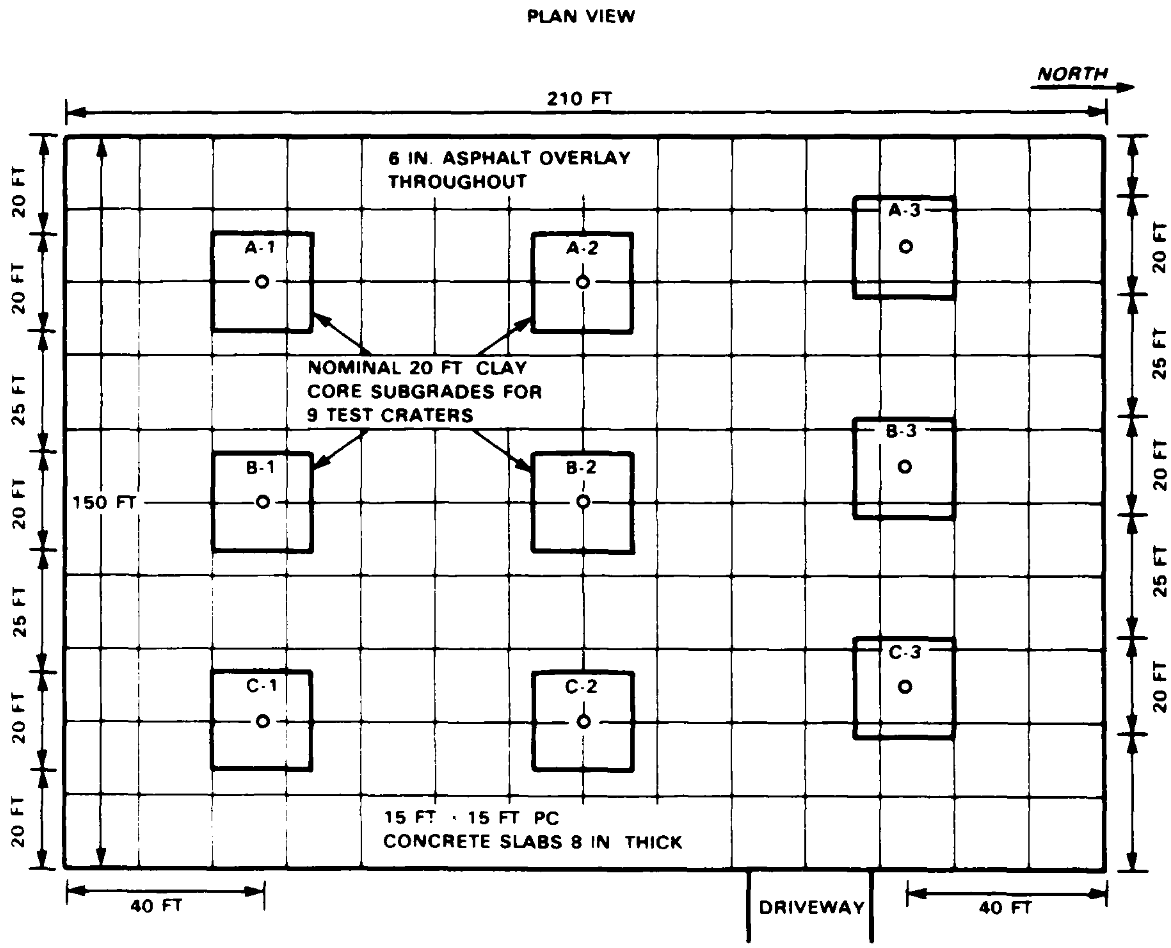

Figure 2. Plan View of SKY TEN (1982 Reconstruction).

a 10-foot wide asphalt berm surrounding the test site. A 12-inch thick PCC pavement was placed over a 12-inch crushed limestone base course. Three 20-foot-square sections were formed in the PCC slab to serve as test pits. Figures 3 and 4 illustrate plan and cross-section views of the test facility.

B. MATERIALS

1. Subgrade and Aggegrate Layers

a. Subgrade

The subgrade for the crater repair tests was either actual debris or a weak clay simulating the strength of debris backfill. The local Wewahitchka clay (classified as CH by the Unified Soil Classification System) is processed to the appropriate water content to yield a field CBR of 3 to 7 when compacted in the SCTF test pits.

b. Base and Leveling Courses

Several aggregate materials were used in these tests as base and leveling course layers. Typical gradations of these materials are shown in Figures 5 and 6.

Ballast rock (Figure 5) was used as the base course for most of the precast slab repairs and for wet crater repairs with fiberglass mats. The gradation of the ballast rock is according to size Number 24 ASTM D 448.

Number 57 stone is an uniformly graded aggregate, nominally 1 inch to sieve Number 4 in size. It is suitable as an aggregate for the polymer concrete placed by percolation for spall repairs. It was also used as a leveling course for some of the initial precast slab repair tests.

Number 7 stone is an uniformly graded aggregate with particle sizes from 1/2 inch to sieve Number 4 (0.187 inch) in diameter. This stone was used as a leveling course for some of the initial precast slab repair tests and for the tests with the USAFE slabs.

Number 10 stone had particles sizes smaller than 3/8 inch. This size was used as a joint filler material for some precast slab tests.

A well-graded crushed stone (gradation shown in Figure 6) was used as the base course for the preliminary precast slab test and for one of the fiberglass mat tests. It was also used to choke the ballast rock for the base course of the wet crater fiberglass mat test to reduce rutting under traffic loads. The crushed stone fills in void spaces of the top several inches of the ballast rock, providing confinement of the layer.

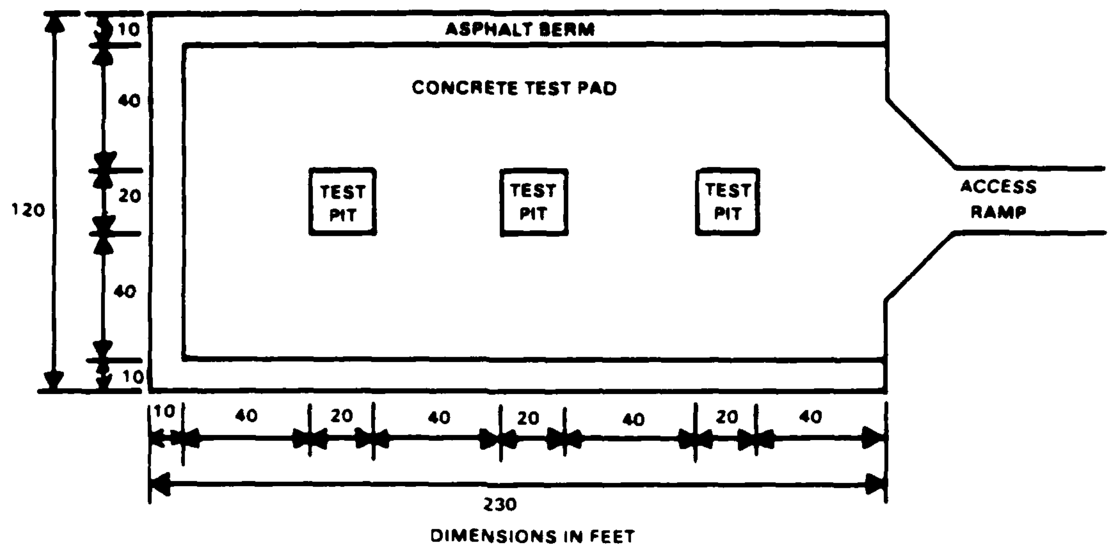

Figure 3. Plan View of Small-Crater Test Facility (SCTF).

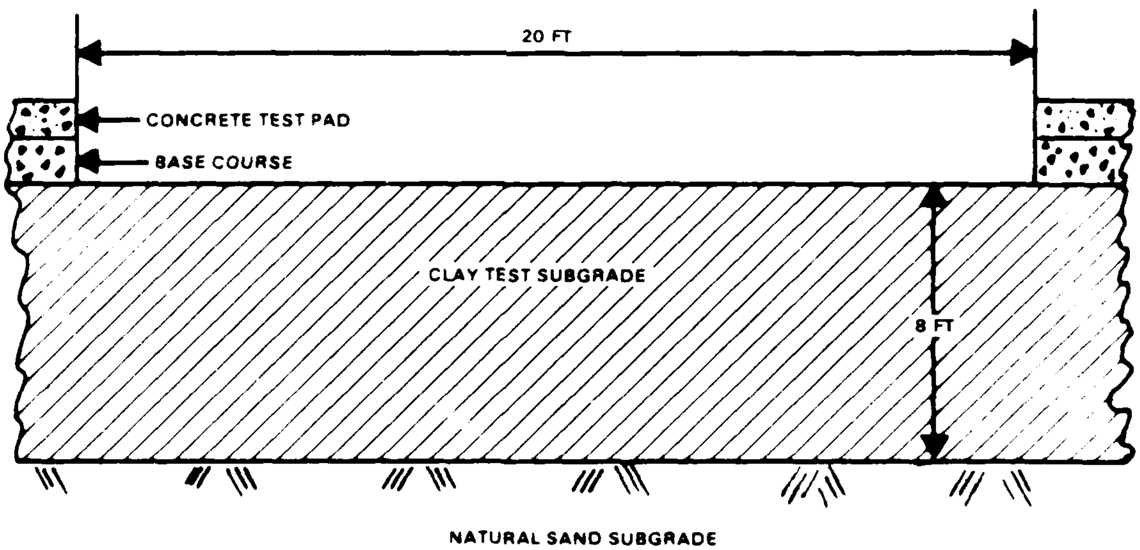

Figure 4. Test Pit Cross Section (SCTF).

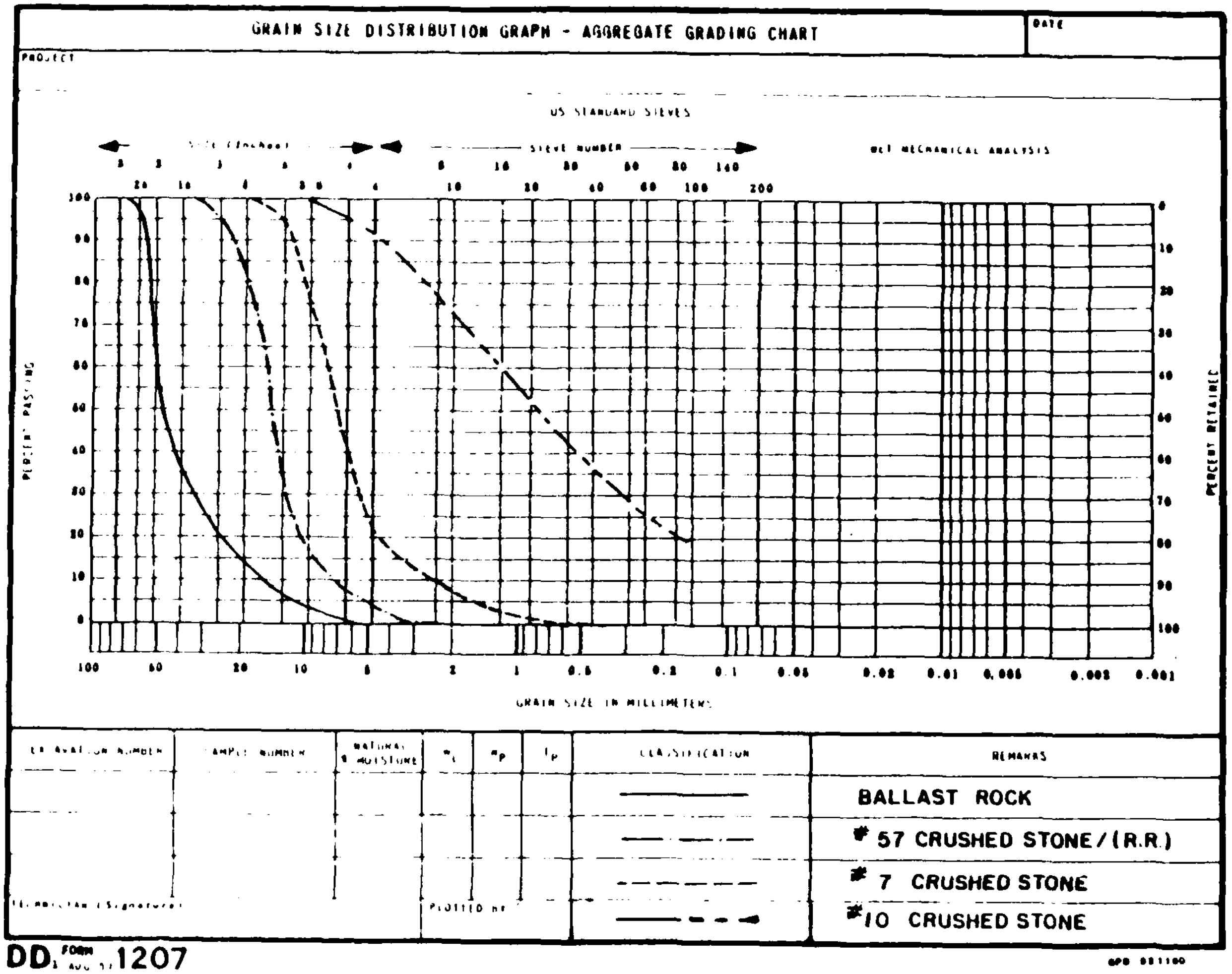

Figure 5. Typical Sieve Analysis of Base Course and Leveling Course Materials.

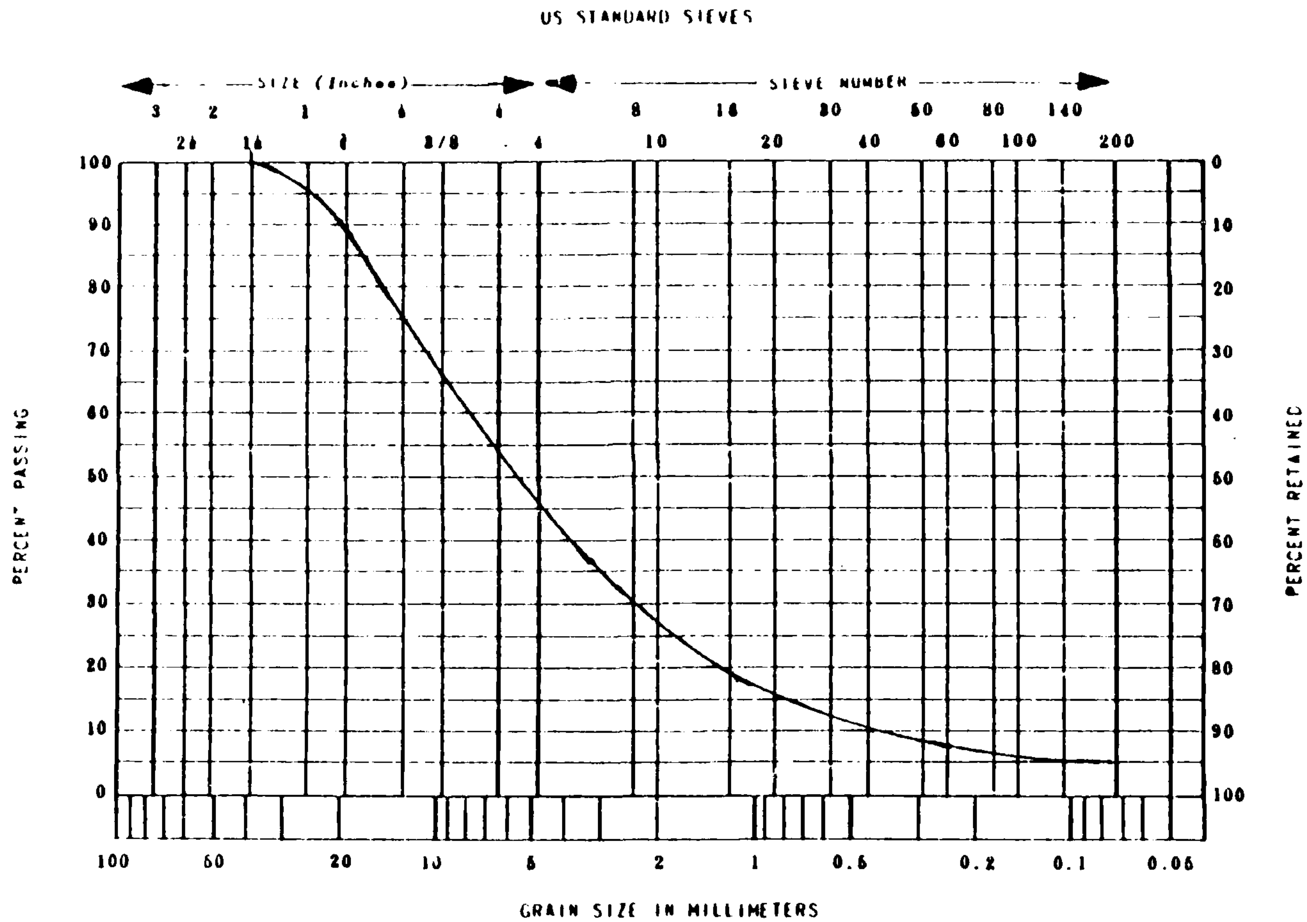

Figure 6. Typical Sieve Analysis of Well-Graded Crushed Stone.

2. Precast Slabs

a. Local Slabs

The initial tests (Section III) used precast PCC slabs which approximated those built by USAFE for early slab concept testing. Three variations of the slabs, constructed locally, were tested.

The nine slabs used in the preliminary (1981) test were constructed at Tyndall Air Force Base by engineering support (AFESC/RDCF) personnel. These slabs were 6 feet 6 inches square by 6 inches thick. The slabs were constructed with 5000 psi PCC and were reinforced in both directions with Number 4 steel reinforcing bars. No details on rebar spacing were provided.

The slabs for the SCTF initial tests were fabricated locally according to AFESC specifications and drawings. Most of these tests, designated as the 2-meter slab tests, used slabs which were 6 feet 6 inches square by 6 inches thick. The slabs used in the 3-meter slab tests were 8 feet 8 inches square and 8 inches thick. Both of these variations had similar construction, with Number 3 deformed reinforcing bars placed top and bottom in both directions as shown in Figures 7 and 8. These slabs also had tapered edges and angle iron corner nosings, which are features of the USAFE slabs. The local slabs differed from the USAFE slabs slightly, having four pickup points (instead of two) and larger size reinforcing bars (Number 3 versus Number 2).

b. USAFE Slabs

The slabs used for the later precast slab repair tests (Section IV) were procured from the Stelcon Company and are comparable to those used in earlier development testing by USAFE. The slabs were 6 feet 6 inches square and 6 inches thick. Slabs of normal and high-strength concrete were tested; however, no data on slab strengths or details of reinforcing steel were available.

3. Fiberglass Mats

The fiberglass mats were fabricated on location by AFESC personnel to various dimensions, as dictated by test conditions. The mats, nominally 3/8-inch thick, are constructed of two layers of fiberglass impregnated with 0.75 pounds per square foot of polyurethane resin per layer.

Commercially available materials were used in fabricating the mats. The fiberglass was Type 4020, consisting of 40 ounces per square yard of woven roving chemically bonded to 2.0 ounces per square foot of chopped strand (Figure 9). The mats consisted of two layers of staggered fiberglass strips. A third layer was sandwiched between the two plies, along the sides, to permit recessing of anchoring hardware. The fiberglass

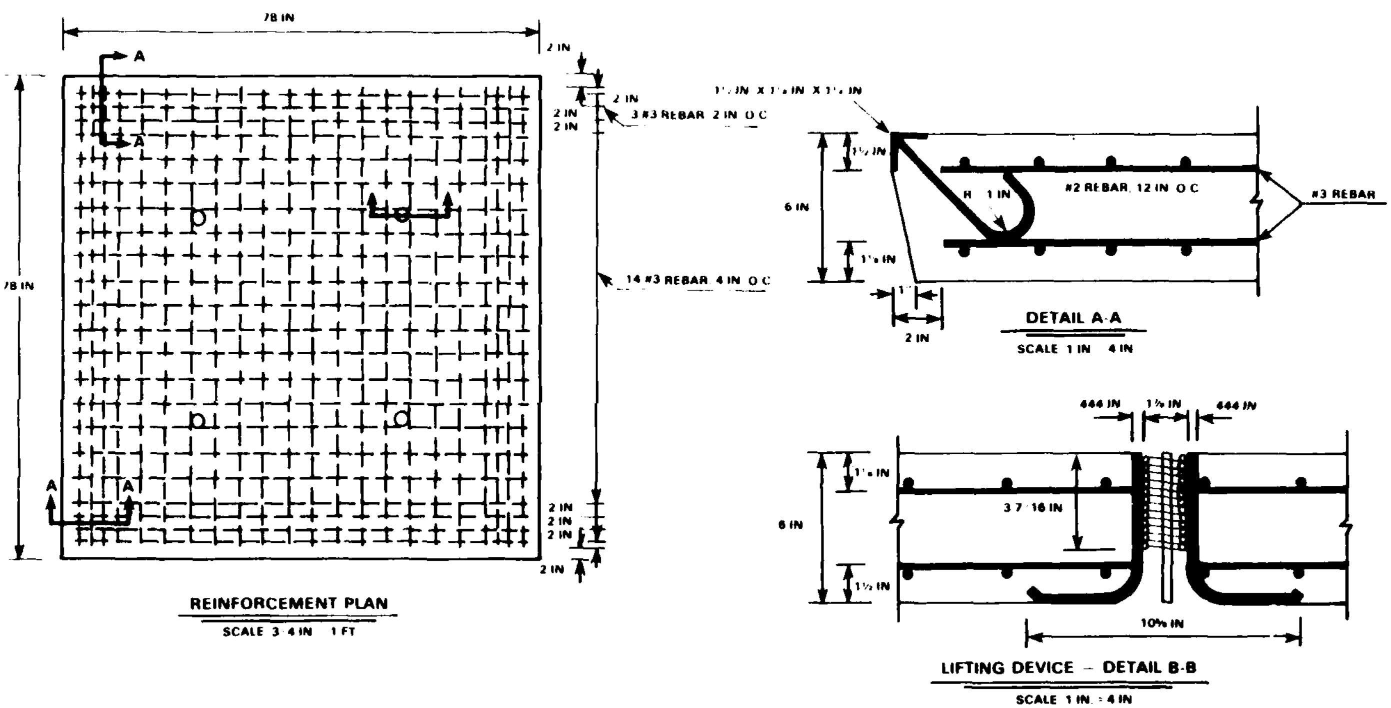

Figure 7. Plan and Cross Sections of 2-Meter Precast Concrete Slab.

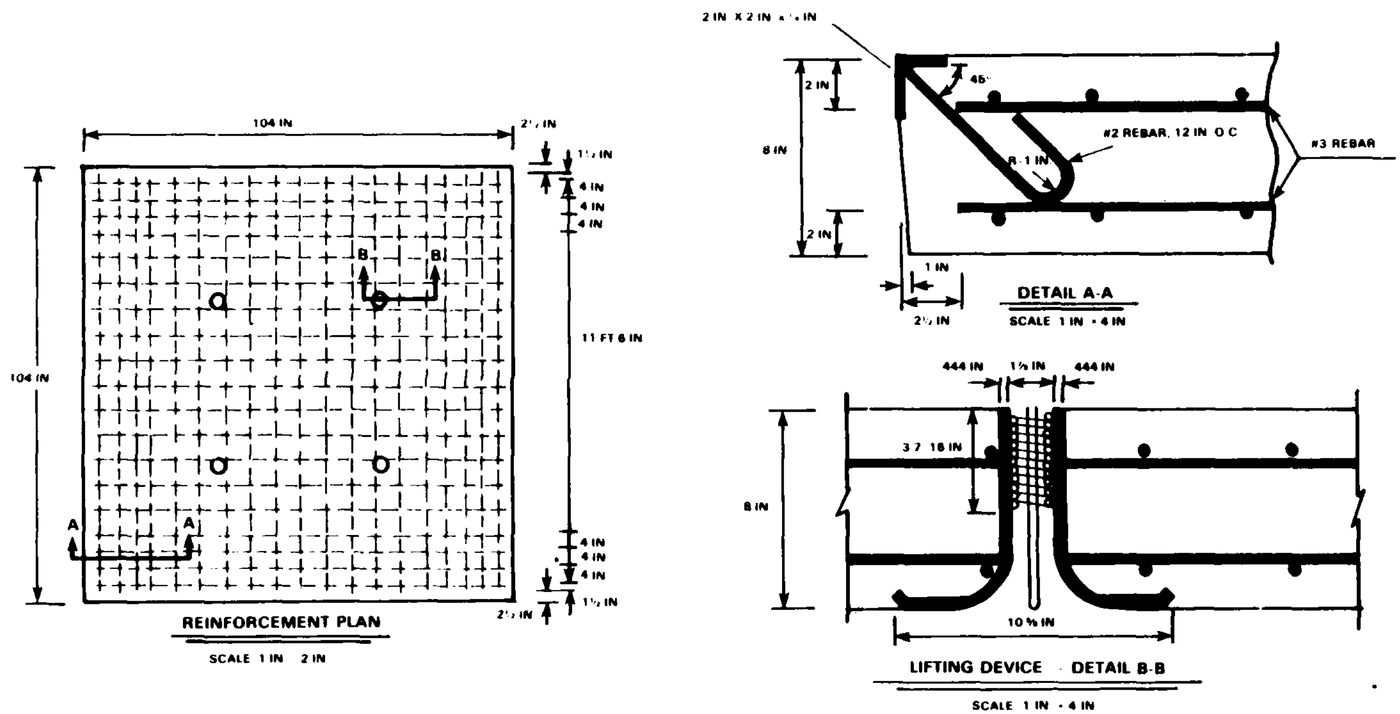

Figure 8. Plan and Cross Sections of 3-Meter Precast Concrete Slab.

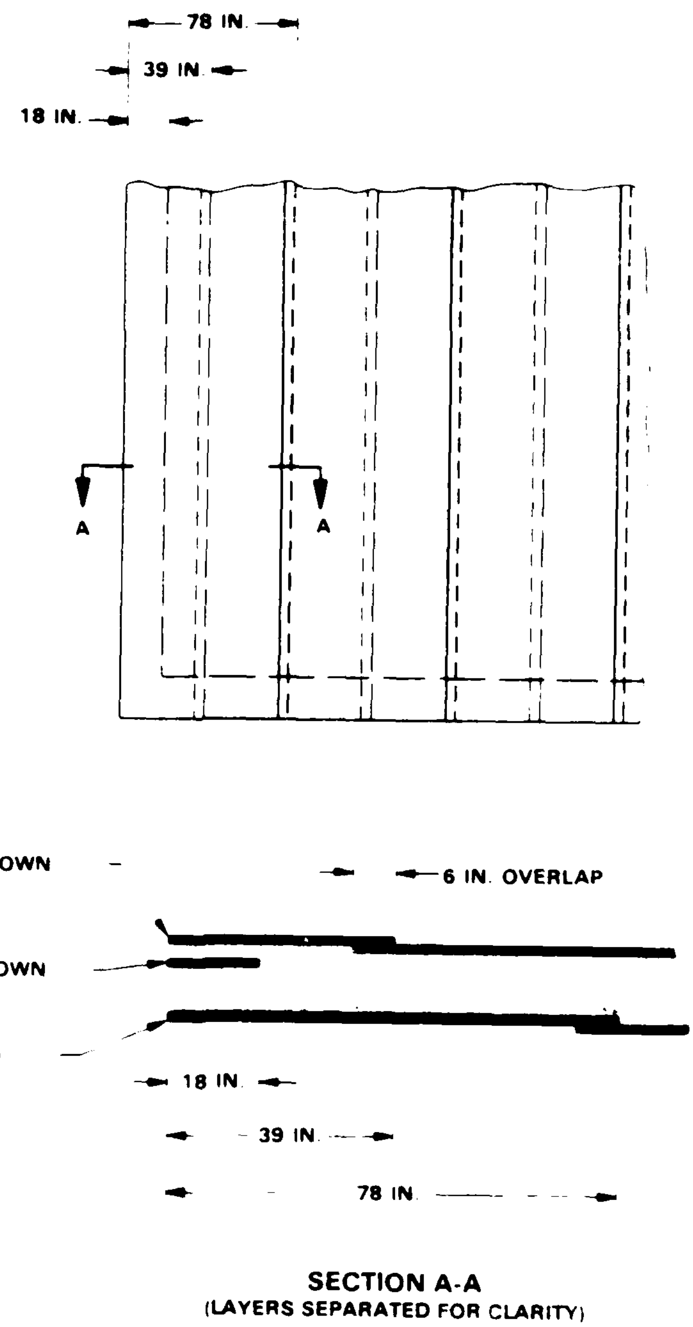

Figure 9. Diagram of Fiberglass Mat Layout.

was impregnated with a two-component polyurethane resin. Resin formulated by two vendors were used for these tests. One polyurethane resin system, known as PepSet, was manufactured by Ashland Chemical Company. The other resin system, designated PERCOL, was developed by ARNCO and is a modified water-tolerant polyurethane. The polyurethane resin was manually mixed and worked into the fiberglass using squeegees. The impregnated mat was trimmed to the finished size and transported to the crater repair. It was anchored using rock bolts and low-profile bushings (Figure 10) to the pavement surrounding a crushed stone crater repair.

An alternate mat construction, which permits air and overland transportation, was also fabricated and tested. This concept utilizes phased construction to fill specific narrow hinge strips with elastomeric polyurethane to allow folding and packaging of mat units (Figure 11). The hinges were impregnated before the semirigid polyurethane was poured onto the bare fiberglass panels.

4. Polymer Concrete

Three polymer concrete formulations were investigated - modified polyurethane, furfuryl alcohol, and magnesium polyphosphate. The first material was the same PERCOL polyurethane system used for fiberglass mat fabrication. The PERCOL was percolated into a bed of screeded uniformly graded aggregate. The other two material systems, furfuryl alcohol and magnesium polyphosphate, were premixed with aggregate and then placed.

The polyurethane (PU) system consisted of an isocyanate component mixed in equal volumes with a polyol component. The material set within minutes of mixing, depending on material temperature and the amount of additional catalyst. At 77°F, the set-time is estimated at 100 seconds, while 13 minutes is estimated at 0°F. The set-time could be shortened to approximately 15 seconds by adding appropriate amounts of catalyst.

The furfuryl alcohol polymer concrete (FA-PC) consisted of a furfuryl alcohol monomer (which is made from agricultural waste), an initiator (1,1,1-trichlorotoluene), a promoter (zinc chloride), a retarder (pyridine), coupling agents (silane), and fine and coarse silica aggregate. The coarse aggregate were first mixed with the dry components (fine silica aggregate and zinc chloride), placed into the spall, and then impregnated with a mixture of the liquid components (FA monomer, TCT initiator, pyridine retarder, and silane coupler).

The magnesium polyphosphate (MPP) cement concrete consisted of a cation-leachable powder (magnesium oxide - MgO), a cement-forming liquid (ammonium polyphosphate - Poly N), an activator (monoammonium phosphate - MAmP), a retarder (disodium octaborate tetrahydrate - POLY BOR), and silica aggregate. The workable time for this formulation was typically 10 minutes.

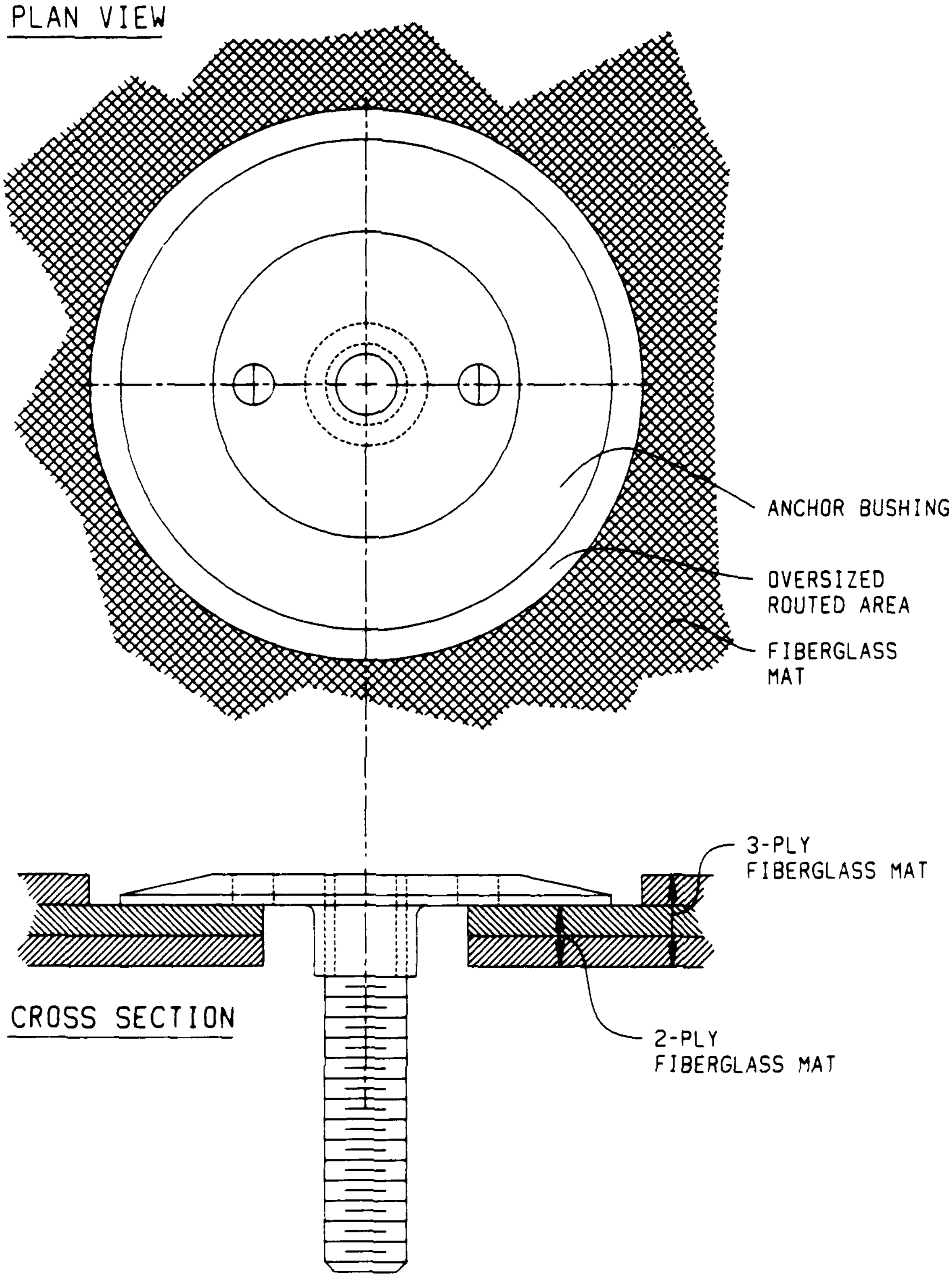

Figure 10. Low-Profile Anchor Bushing and Bolt for Fiberglass Mat.

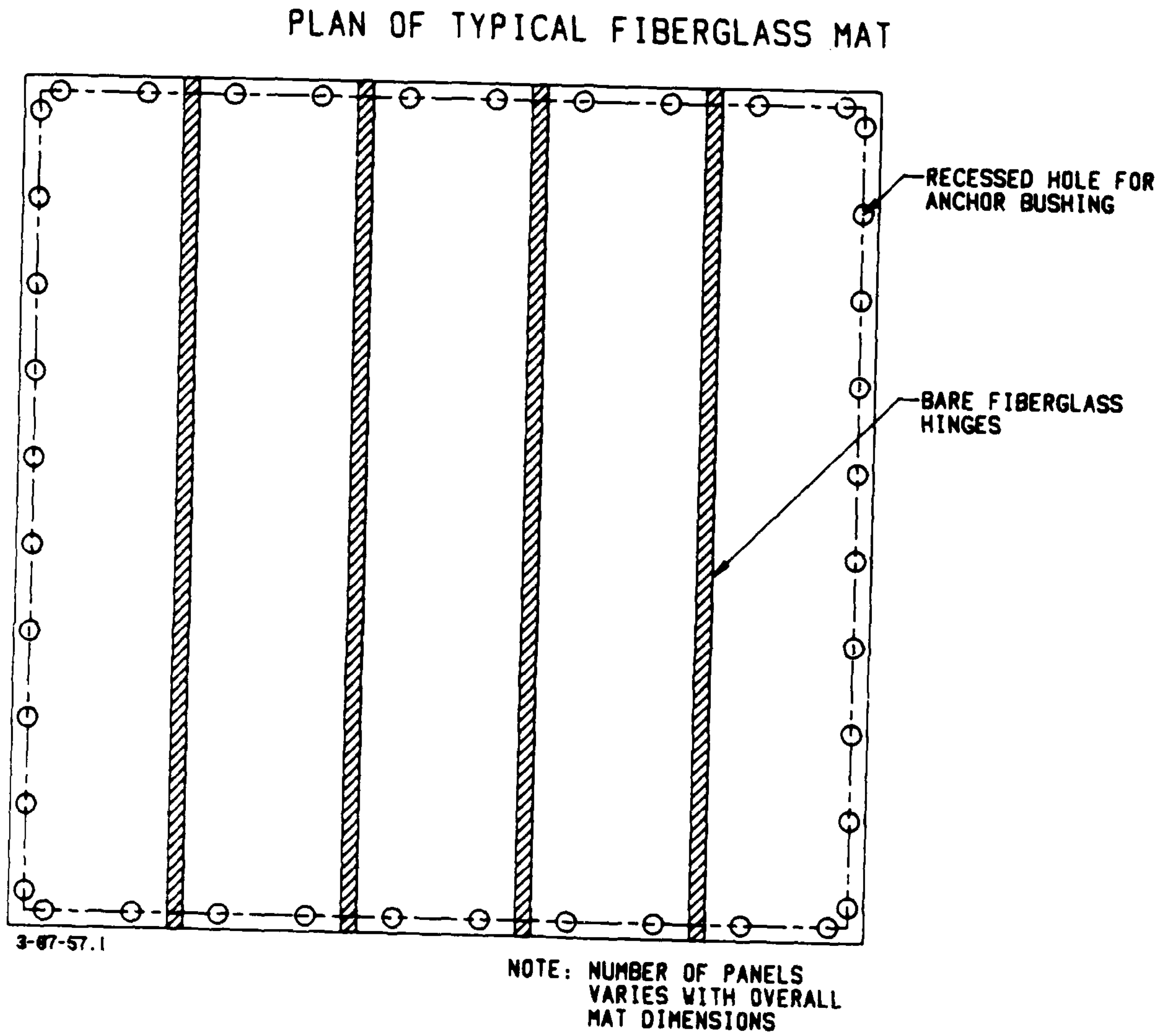

Figure 11. Plan of Typical Folded Fiberglass Mat.

C. EQUIPMENT

1. Loadcarts

Loadcarts were used to simulate F-4, F-15, and C-141 aircraft traffic. All of the repaired sections were tested with either the F-4 or F-15 loadcart. Selected tests also used the C-141 loadcart.

The F-4 loadcart consists of a modified truck with a rolled steel frame behind the cab (Figure 12). The frame supports lead weights, an F-4 aircraft tire inflated to 265 psi, and an outrigger wheel for stability. The F-4 loadcart is loaded to provide a dead weight of 27,000 pounds on the aircraft tire. The wheel pattern used to apply F-4 loadcart traffic is shown in Figure 13 and represents a typical normal distribution.

Following a mission change, the F-15 aircraft was selected as the design load for RRR systems. The modified truck for the F-4 loadcart was adapted for use as an F-15 loadcart by using a 355 psi tire and increasing the lead weights to provide a wheel load of 30,600 pounds. The F-15 traffic distribution pattern is shown in Figure 14.

The C-141 aircraft has a twin-tandem main gear with four wheels. To simulate this load, the C-141 loadcart (Figure 15) applies a 141,000-pound main gear load with 185 psi tires. The tires are mounted within a steel frame which has two external outrigger tires. The traffic distribution is shown in Figure 16. The multiple wheels of the C-141 gear overlap so that 34 passes of the gear over a seven-lane zone is equivalent to 10 coverages (in one coverage, each point in the traffic zone is loaded by one wheel pass).

2. Compaction Equipment

A comparative study of compaction performance was conducted as part of the development of the crushed stone/fiberglass mat repair system. This test series, documented in Section V, evaluated the capability of a vibratory roller and a multifunction excavator with compaction plate to compact various depths of base aggregate.

a. Vibratory Roller

The RayGo® 410A single smooth drum vibratory roller was used with the crushed stone/fiberglass mat and precast slab repair concepts. The roller has a 59-inch diameter, 84-inch wide drum, and can travel at speeds up to 9 mph. The operating weight of the unit is 22,510 pounds, and the dynamic force is 27,000 pounds for a total force applied at the drum of 39,550 pounds (471 psi).

Figure 12. F-4/F-15 Loadcart (Partially Loaded with Weights).

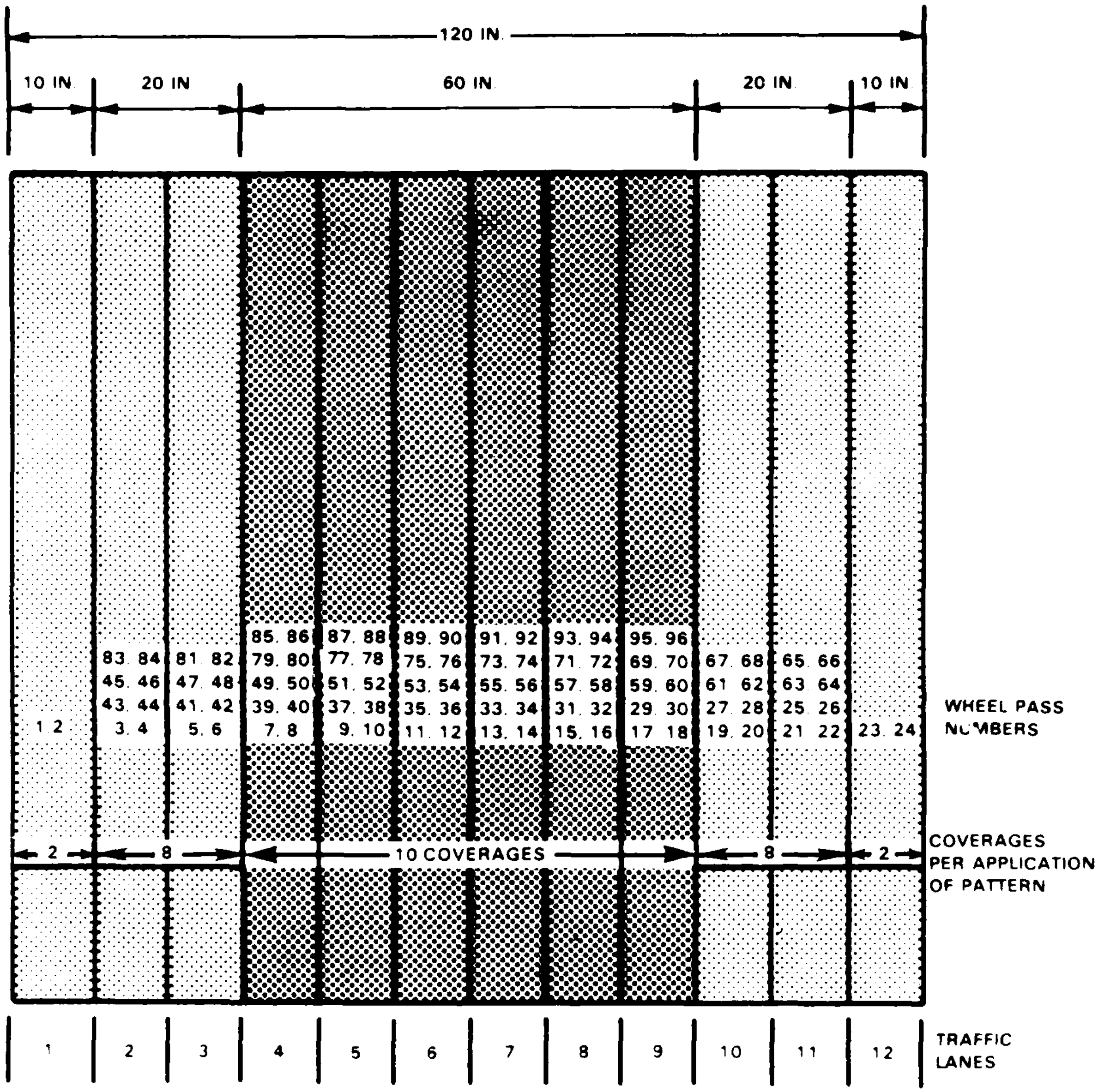

Figure 13. Traffic Distribution Pattern for the F-4 Loadcart.

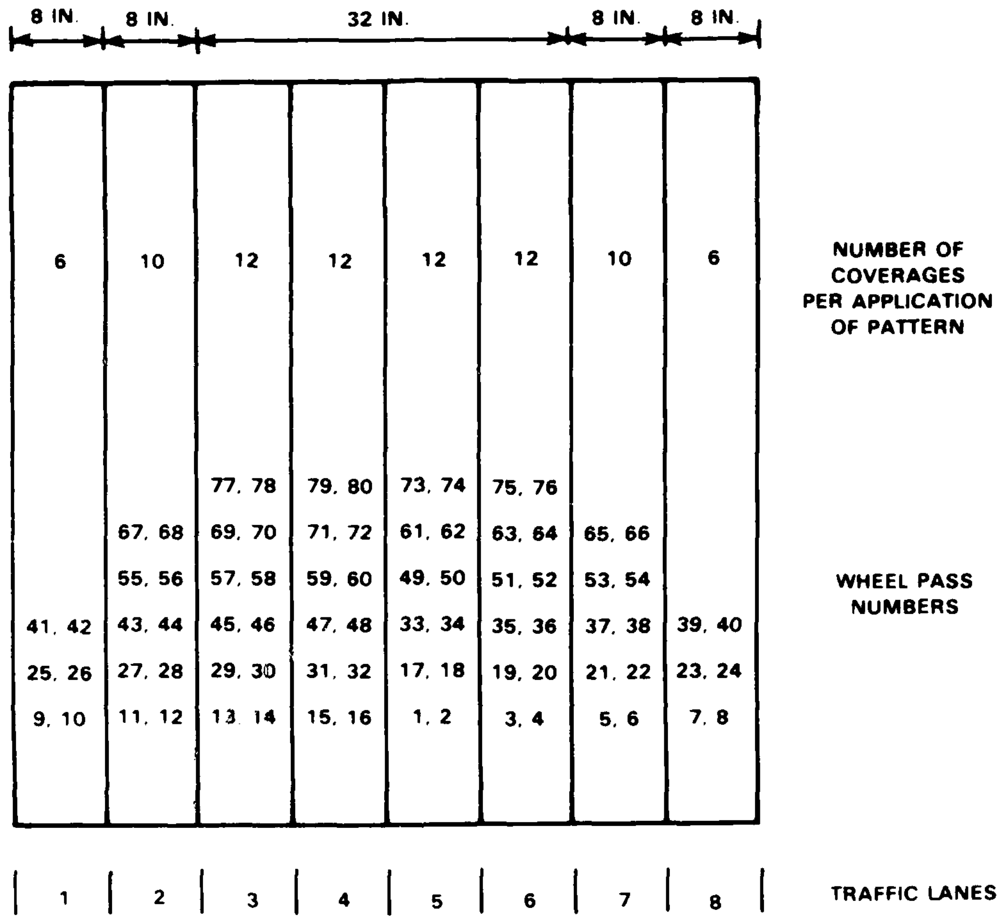

Figure 14. Traffic Distribution Pattern for the F-15 Loadcart.

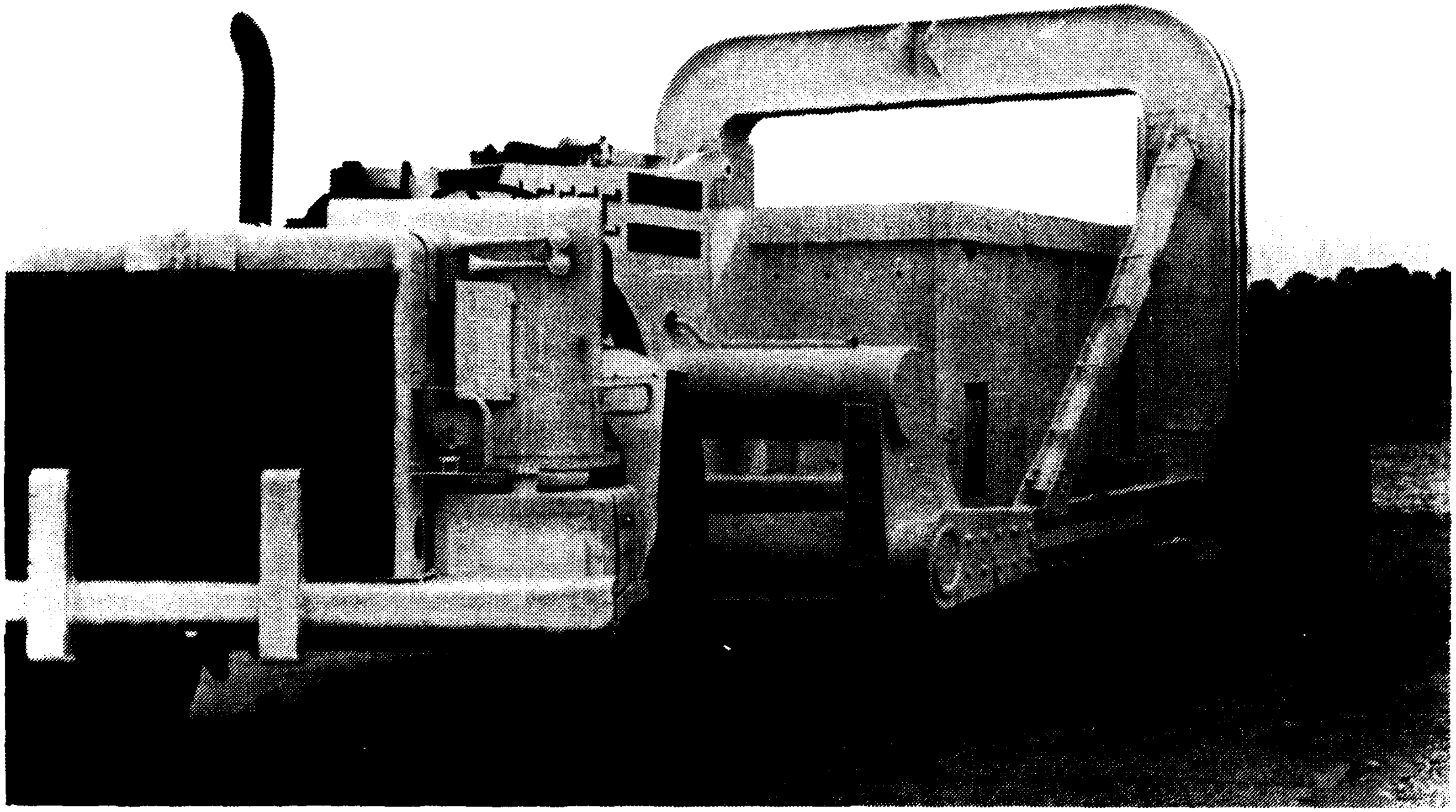

Figure 15. C-141 Loadcart.

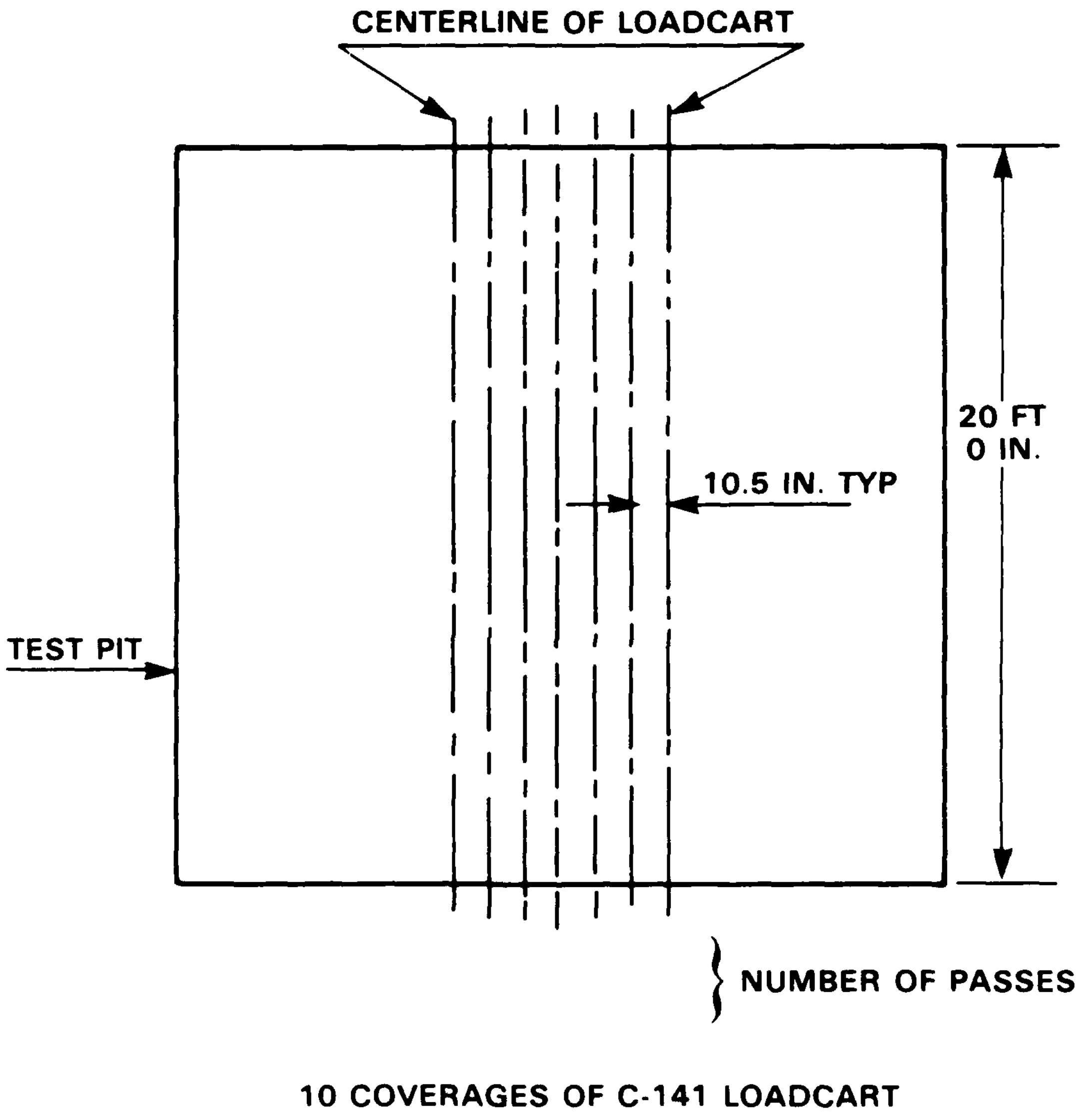

Figure 16. Traffic Distribution Pattern for the C-141 Loadcart.

b. Compaction Plate

The alternate compaction equipment used with the crushed stone/fiberglass mat repair system was the vibratory compaction plate mounted on a John Deere 690B multifunction excavator (Figure 17). The excavator is equipped with an all-terrain undercarriage (designed by Standard Manufacturing Company) for increased maneuverability. A 34- by 42-inch compaction plate attaches to the excavator's boom. The plate has an effective compaction width of 28 inches and has been operated at rates in excess of 0.5 feet per second.

D. CRATER REPAIR DEFINITIONS

The various repair methods were required to support at least 150 fighter aircraft coverages. The F-4 loadcart was used for tests prior to late 1983. Tests conducted from late 1983 on were trafficked with the F-15 loadcart. Selected tests were also trafficked with 60 C-141 coverages after the F-4/F-15 traffic. During loadcart traffic application, the repair sections were evaluated for surface roughness to determine acceptability of the system to support the design loads.

Evaluation criteria for the crater and spall repair systems were established based on RRR Interim Planning Guidance (December 1981) and are consistent with requirements for aircraft safety. The interim repair systems were required to meet these criteria through 150 fighter aircraft coverages with no more than one maintenance action. Examples of the F-4 aircraft requirements for various zones within the MOS are listed in Table 2. Following are the definitions for the terms used in describing surface roughness, as illustrated in Figure 18.

- Change in slope: The net change in slope, expressed as a percent, experienced traversing any point on the repair surface.

- Imaginary repair surface: A line established by stretching a string across the repair, suspended over the repair peaks, and contacting undamaged pavement on either side of the repair.

- Length of crater: The length of damaged pavement parallel to the MOS centerline. This includes length of all materials which are significantly above the original elevation of undamaged pavement, such as upheaved crater lip or AM-2 matting.

- Repair Peaks: The two highest points on the actual repair surface. The stringline which stretches across the repair to determine the "imaginary repair surface" is supported by the repair peaks.

- Repair Quality: Levels of repair quality designated "A", "B", "C/D", and "E", indicating progressively less restrictive specifications. A higher quality repair can be used in place of a lower repair quality. For example, "B" meets or exceeds the requirements for a "C" level repair

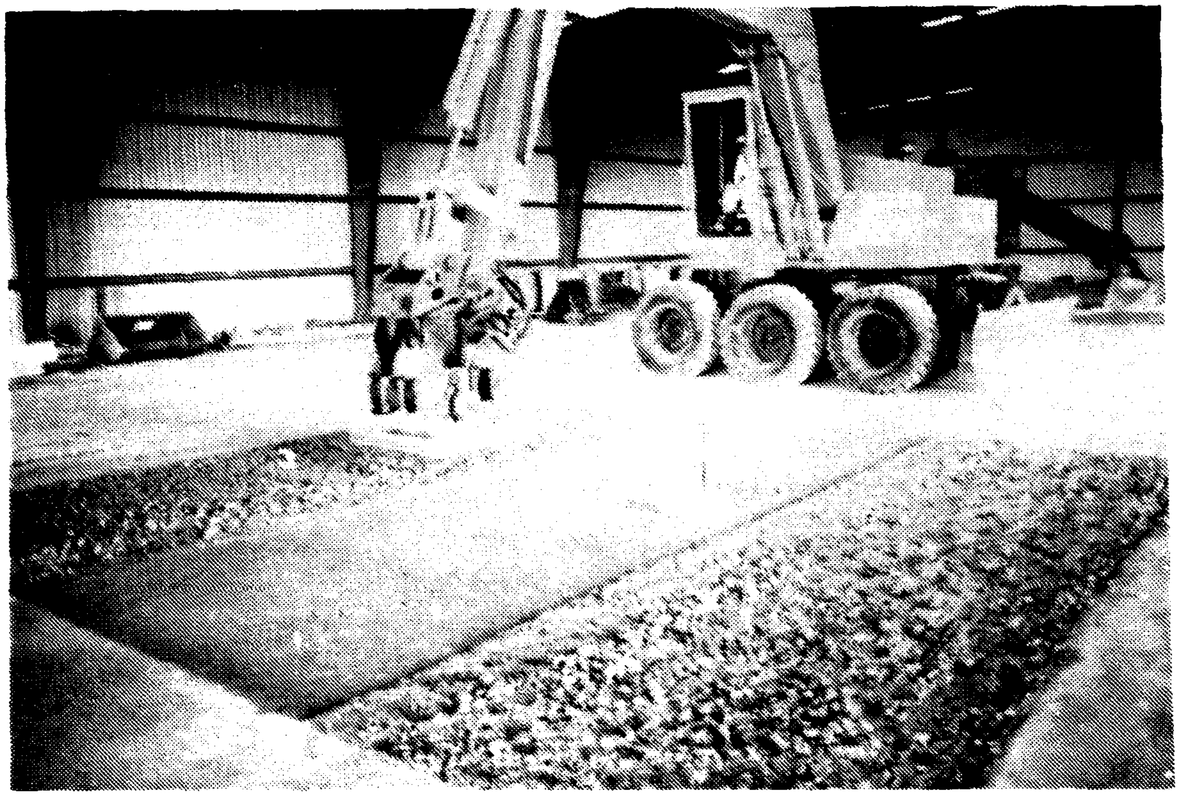

Figure 17. Multifunction Excavator with Compaction Plate.

TABLE 2. SUMMARY OF F-4 SURFACE ROUGHNESS CRITERIA.

	TYPE REPAIR QUALITY			
	A	B	C/D	E
PEAK ALLOWABLE SAG, INCHES	1.0	1.0	2.5	4.0
MAXIMUM REPAIR UPHEAVAL, INCHES	1.5	3.0	3.0	4.5
NOMINAL SAG, INCHES	0.5	0.5	2.0	3.5
MAXIMUM ALLOWABLE SPAN OF SAG BELOW NOMINAL SAG, FEET	5	5	10	20
MAXIMUM LENGTH OF CRATER, FEET	N/A	N/A	70	N/A
MAXIMUM ALLOWABLE CHANGE IN SLOPE (PERCENT)	5	5	5	5

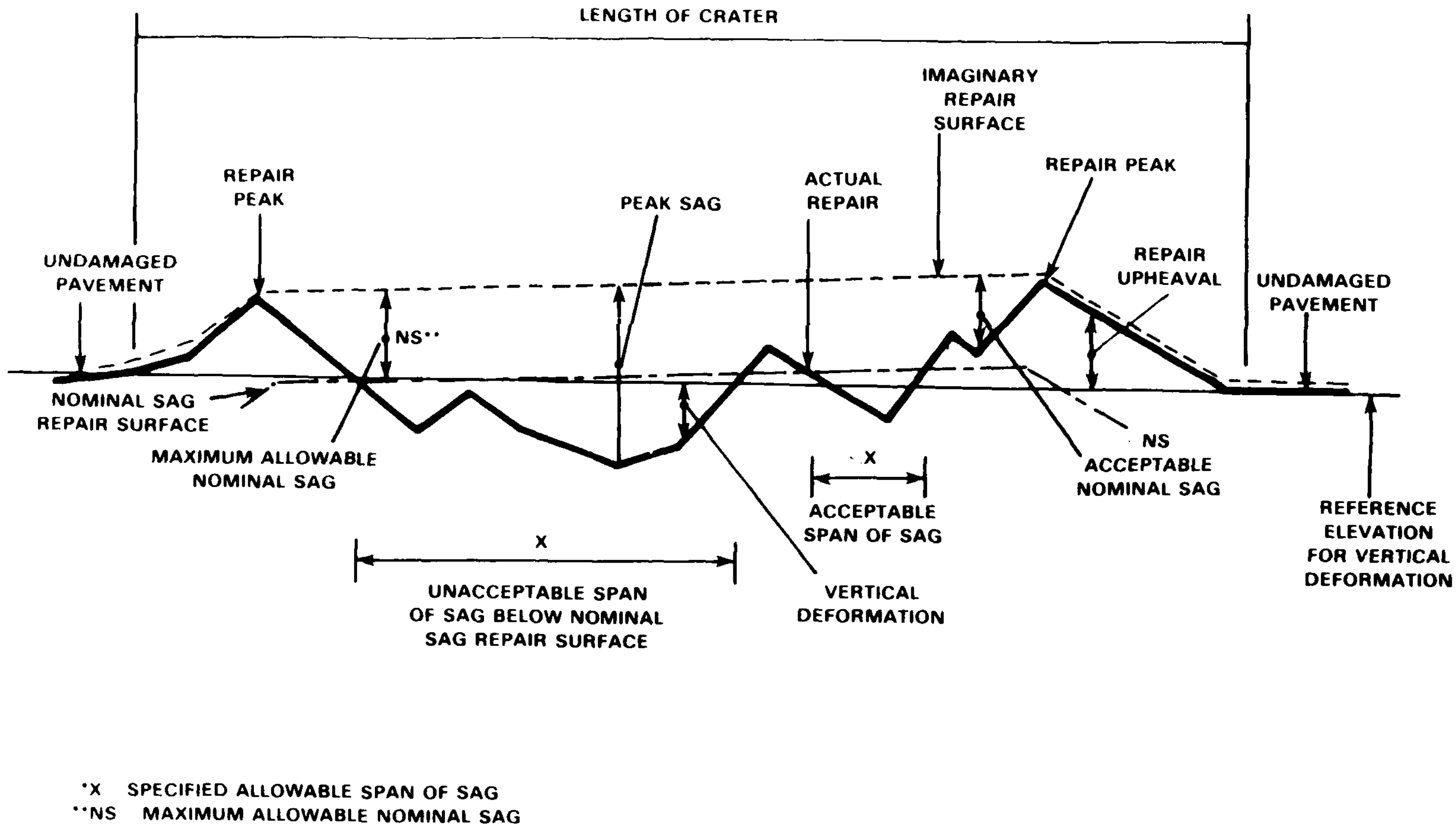

Figure 18. Elements of Crater Repair Surface.

and can be used in its place, but does not meet the "A" quality and cannot be used in place of an "A" level repair.

- Repair Upheaval: Repair surface that is above the elevation of adjacent undamaged pavement. Repair upheaval is measured relative to a line connecting the first and last elevations of undamaged pavement on either side of the repair along the longitudinal centerline.

- Sag: The vertical distance between the low points of the actual repair surface and an "imaginary repair surface" established by stretching a string across the repair to contact the pavement beyond the start of upheaval. "Nominal sag" is the maximum allowable sag which is acceptable without consideration of a sag span length. "Peak sag" refers to the peak distance below the string and must be associated with a "maximum span below nominal sag," a parameter defining how far down the MOS that the sag can exceed the nominal sag toward the peak sag limit. The repair surface must return to a point above the nominal sag at least once in each maximum span. The maximum span parameter allows the sag to approach the allowable peak sag as long as the effective frequency of the repair surface does not stimulate reinforcement of dynamic aircraft loads as the aircraft traverses the repair.

- Vertical deformation: The permanent vertical displacement of the repair surface resulting from traffic loads. Maximum vertical deformation at a point is measured relative to the elevation before application of loading. Average vertical deformation is calculated by dividing the area between the before and after traffic longitudinal profiles (determined using the trapezoidal rule for calculating areas) by the length of the test pit.

Some of these criteria are not easily measured in the field. For this reason, determination of the span of sag and change in slope were not used in the analysis of these tests.

The precast slabs presented a special case for surface roughness analysis, since this repair method consists of rigid surfaces of finite length responding independently to loads. The key parameters considered for these tests were tipping of loaded slabs and differential settlement of slab corners with respect to adjacent slabs or pavement.

SECTION III

INITIAL PRECAST SLAB REPAIR TESTS

A. INTRODUCTION

ESC test personnel conducted a series of seven full-scale tests to determine the feasibility of using precast concrete slabs to repair bomb-damaged pavements within the RRR program. The tests consisted of trafficking precast slab-repaired craters with F-4 and C-141 loadcarts to observe their performance under simulated loading conditions.

The first test, referred to as the preliminary test, was conducted at SKY TEN at Tyndall Air Force Base, Florida, in January 1981. The remaining six tests were conducted at SCTF at Tyndall Air Force Base from March 1983 to August 1983.

1. Background

Although the use of square precast slabs is a promising bomb damage repair concept, it requires the rapid accomplishment of two tasks which are not normally done quickly. These tasks, sawing through concrete to create a rectangular repair section and screeding the leveling course at a specific subsurface height to provide a flush repair, are the primary obstacles to making the precast concrete slab concept viable for RRR.

To overcome these obstacles, Air Force researchers suggested an alternate precast slab approach which uses panels submerged in a polymer concrete or other fast-setting cement such as magnesium phosphate. This concept eliminates the need for a rectangular repair section and for a level base course, but complicates matters by introducing the need for a fast-setting material and the additional equipment to rapidly mix and place it. In 1980, University of Texas researchers performed two crater repair tests using this approach. The tests involved several types of polymer concretes which proved to be highly successful structurally but were unacceptable because the polymer concrete essentially made the repairs permanent. The details of the tests are reported in the AFESC Report ESL-TR-82-04, "Methyl Methacrylate Polymer Concrete for Bomb Damage Repair." Following these tests, AFESC initiated a design study with the U.S. Army Waterways Experiment Station (WES) to assess the advantages and disadvantages of different precast slab methods by comparing estimates of resource requirements, time of repair, and associated costs. The study recommended using submerged slabs (slabs recessed 2 inches and covered with a fast-setting polymer concrete) and cited faster placing and greater structural capacity as justification (ESL-TR-83-42).

Concurrent to the WES study, USAFE conducted independent investigations in an effort to expedite precast slab system research and develop near-term capabilities. USAFE/DEX concentrated their studies on the original, nongrouted, precast slab concept. The favorable reports that resulted from the USAFE tests, along with a feeling of urgency for a near-term fieldable system, resulted in initial AFESC testing being performed on the original, nongrouted slab concept. This section presents the description, results, and conclusions of these initial tests on the non-grouted slabs.

The seven initial tests consisted of repairing craters with precast slabs and trafficking the repairs with simulated aircraft traffic. F-4 and C-141 loadcarts simulated aircraft traffic.

2. Test Objectives

The general objective of the tests was to assess the feasibility of the original precast slab system. Each test, however, had a specific objective which, when considered with the results of the other tests, provided a basis for determining the system's feasibility. The specific objective of each test follows:

a. Test 1: Preliminary Test

Determine if settlement of adjacent slab corners relative to each other due to variability of backfill material would be severe enough to prohibit trafficking the repaired section.

b. Test 2: 2-Meter Slab Test (Uncompacted Ballast Rock Fill with Number 57 Leveling Course)

Determine the performance of a precast slab repair under simulated aircraft traffic. The repaired section was not compacted. By conducting additional tests on compacted sections, the sensitivity of performance to compaction will be assessed.

c. Test 3: 2-Meter Slab Test (Uncompacted Ballast Rock Fill with Number 7 Leveling Course)

Identify the sensitivity of repair performance to the grain size of the leveling course material. This will be accomplished by comparing results of Tests 2 and 3. Test 3 will also provide uncompacted repair data to be used in the comparison of compacted to uncompacted repair performances.

d. Test 4: 2-Meter Slab Test (Compacted Ballast Rock Fill with Number 7 Leveling Course)

Provide performance data for a compacted repair section. Those data will be used in the comparison of compacted to uncompacted repair performances (Tests 3 and 4) to assess the sensitivity of performance to compaction.

e. Test 5: 2-Meter Slab Test (Compaction, Joint Filler Testing)

Determine the effects on performance of using sand to fill joints between slabs and to fill voids between slabs and the edge of craters.

f. Test 6: 3-Meter Slab Test (Uncompacted Ballast Rock Fill with Number 7 Leveling Course)

Determine the sensitivity of repair performance to slab size. This will be accomplished by comparing results of Tests 4 and 6.

g. Test 7: 2- and 3-Meter Slab Dynamic Loading Test

Evaluate the structural adequacy of repaired sections when subjected to dynamic loads simulating aircraft touchdowns and high-speed taxiing.

3. Test Sections

Two basic test section configurations were used: one for the preliminary test of SKY TEN and one for the remaining tests at SCTF. AFESC test personnel conducted the preliminary test on a previously repaired bomb crater excavated to a depth of 6 feet and partially refilled with debris from the original cratering to approximately 2 feet below grade. Figure 19 presents a diagram of the repair cross section that resulted from adding a leveling course and precast slabs to the excavated and partially refilled section. As shown in the diagram, test personnel placed the leveling course over the debris in various thicknesses to a depth of 6 inches below grade. This enabled the placement of 6-inch thick precast slabs to complete the repair.

Test personnel used the same basic repair cross section for each of the six tests conducted at the SCTF. As illustrated in Figure 20, the basic section consisted of a ballast rock base course placed over the subgrade, a crushed stone leveling course over the ballast rock, and the precast slabs. However, variations in the thickness of the slabs and leveling course, the type of stone used for the leveling course, compaction effort, joint filler, and slab size resulted in six unique repair sections. Table 3 summarizes the respective materials and layer thicknesses for each repair section.

B. TEST 1: PRELIMINARY TEST

1. Introduction

This test determined the settlement of corners of adjacent concrete slabs used in crater repair when trafficked with an F-4 loadcart as well as the differential settlement or rocking of an individual slab

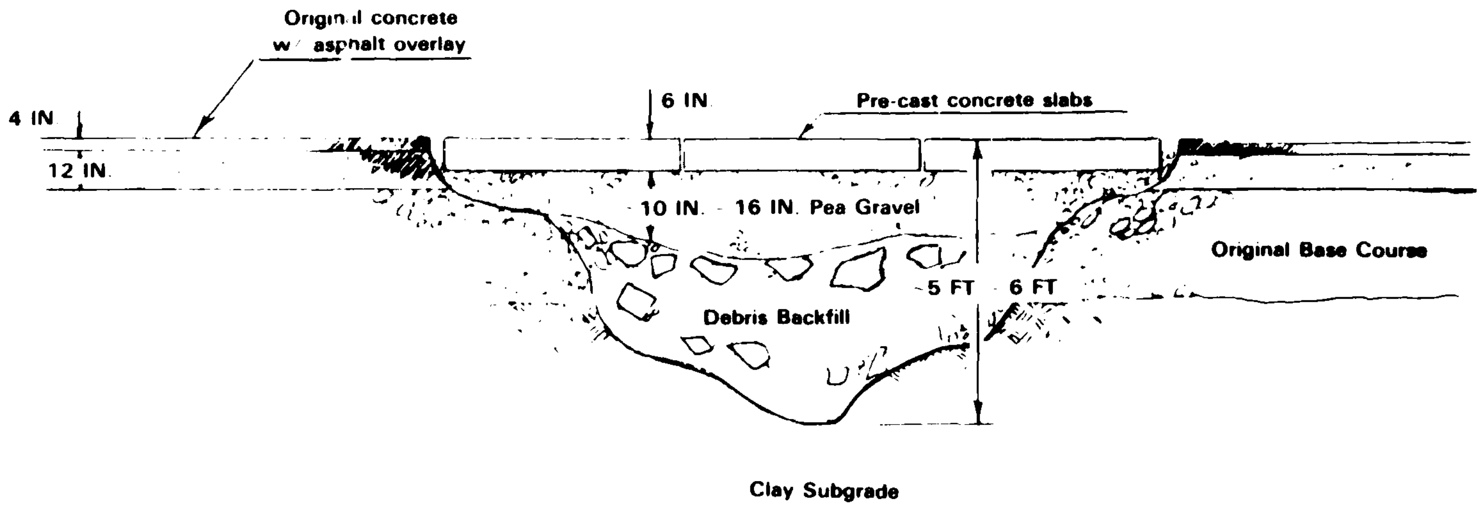

Figure 19. Cross Section of Preliminary Precast Slab Test (SKY TEN).

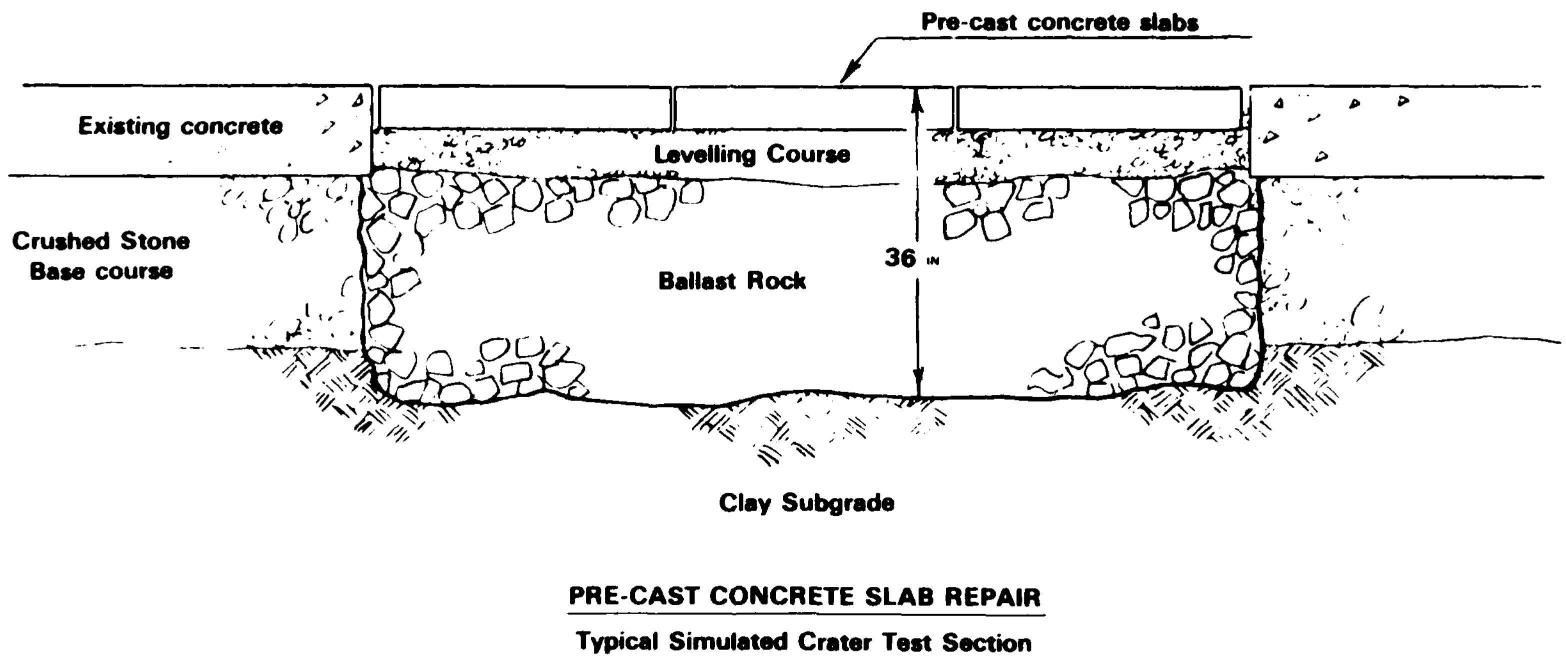

Figure 20. Cross Section of Simulated Crater Precast Slab Test (SCTF).

TABLE 3. SUMMARY OF INITIAL PRECAST SLAB TEST SECTIONS.

TEST NO.	TEST SITE	BASE COURSE MATERIAL TYPE	BASE COURSE THICKNESS (IN.)	LEVELING COURSE MATERIAL TYPE	LEVELING COURSE THICKNESS (IN.)	COMPACTION (COVERAGES)	SLAB SIZE
1	ECTF	PEA GRAVEL	18	NONE	0	4	2 METER
2	SCTF	BALLAST ROCK	24	NO. 57 STONE	4-6	0	2 METER
3	SCTF	BALLAST ROCK	24	NO. 7 STONE	4-6	0	2 METER
4	SCTF	BALLAST ROCK	24	NO. 7 STONE	4-6	1	2 METER
5	SCTF	BALLAST ROCK	24	NO. 7 STONE	2-3	1/2/6[a]	2 METER[b]
6	SCTF	BALLAST ROCK	24	NO. 57 STONE	2-4	0	3 METER
7	SCTF	SAME AS TEST 6[c]		SAME AS TEST 6		0	3 METER
		SAME AS TEST 4[c]		SAME AS TEST 4		0[d]	2 METER

NOTES:

[a]COMPACTION PLATE USED TO SETTLE SLABS 1, 4, 7; TWO PASSES OF ROLLER TO SETTLE SLABS 3, 6, 9; AND SIX PASSES OF ROLLER TO SETTLE SLABS 2, 5, 8.

[b]SAND USED TO FILL JOINTS BETWEEN SLABS ON ONE HALF OF PIT.

[c]PREVIOUSLY TESTED SECTIONS WERE USED FOR DYNAMIC TEST.

[d]NO ADDITIONAL COMPACTION APPLIED.

under loadcart traffic. From this test, the suitability of precast slabs as a means of crater repair will be evaluated.

2. Test Description

The test was conducted in a previously repaired crater located at SKY TEN. Test personnel excavated the crater to a depth of 5 feet, exposing clay subgrade.

Personnel then filled the crater with debris to approximately 22 inches below the crater edge and added pea gravel to create a ramp for the large roller. The RayGo® 410 vibratory roller operator compacted the crater with four coverages (two forward, two backward) in each of two lanes. After compaction, personnel added more pea gravel to an elevation of 6 inches below ground surface. Before the slabs were lowered into place, laborers hand-leveled the gravel and placed string lines and upheaval marker posts to measure slab elevations. Figure 21 indicates the notation for identifying slabs, corners, and joints during the test.

Following slab placement, the F-4 loadcart trafficked the repair. Data collectors recorded slab corner elevations prior to traffic and after 10, 20, 30, 40, 60, 100, and 150 coverages. Positive elevations are above pavement level, negative elevations are below pavement level, and a reading of zero implies that the slab is level with the pavement surface at the edge of the test pit.

3. Results

Test observations cite pavement upheaval around the crater lip of up to 2 1/2 inches along the south edge of the repair (Figure 21) and approximately 1 inch along the north edge. When test personnel placed the concrete slabs on the pea gravel, the corners were flush with the upheaved pavement. Elevations of slab corners taken before leveling ranged from 0.5 to 1.625 inches on the north edge and from 1 to 3 inches along the south edge. Test personnel judged corners A-6 and F-6 to be too high prior to testing, so they removed Slabs 7 and 9, and releveled the slabs.

Data collectors planned to measure the elevations from a line stretched over the upheaval portions of the adjacent pavement. However, personnel actually measured from a line stretched from points on the existing undisturbed pavement grade, lowering the reference elevation, and resulting in undermeasurement of the perceived sag of the slabs prior to trafficking equal to the height of the upheaval. Therefore, the sag prior to trafficking actually exceeded the allowable 2 inches in many corners. Test personnel did not realize this error until 30 F-4 coverages had been applied to the repair. Test personnel removed the slabs at this point, added and leveled pea gravel, and replaced the slabs. Slab corner elevations after this action are listed in Table 4. After the repair, the F-4 loadcart operator applied 120 additional coverages, and data collectors

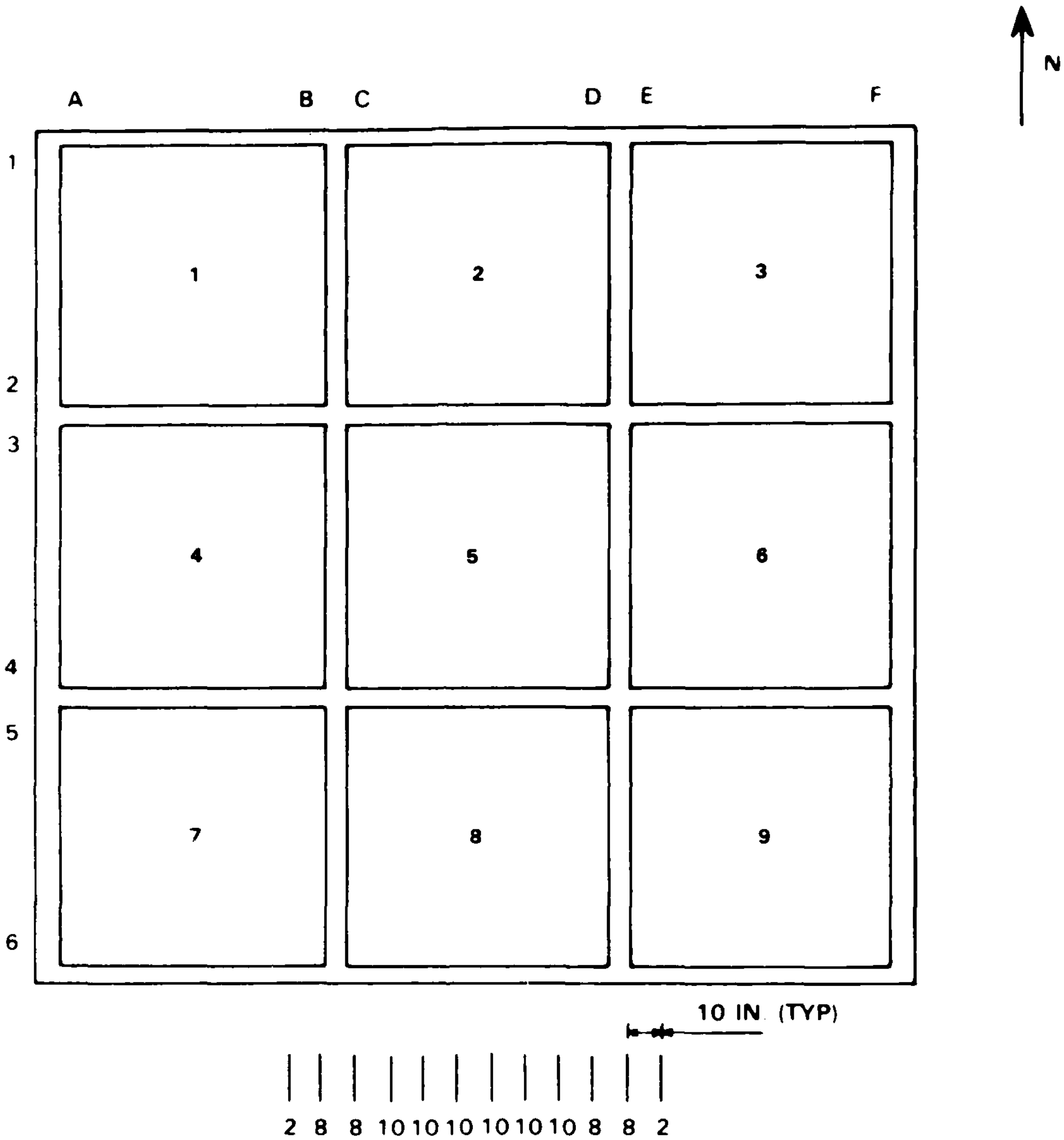

Figure 21. Traffic Pattern and Profile Lines for Preliminary Precast Slab Test.

TABLE 4. SLAB CORNER ELEVATIONS PRELIMINARY TEST.

ELEVATIONS PRIOR TO F-4 TRAFFIC

	A	B	C	D	E	F
1	1 5/8	1/2	1	1	3/4	1 3/8
2	1 5/8	3/4	0	-3/8	-1/4	3/4
3	1 7/8	-3/8	1/4	-1/8	0	1
4	2 1/4	1/8	1/4	-1/8	-3/4	3/8
5	1 3/4	3/4	1/4	-1/2	-1 1/4	2
6	2	1 1/4	1 7/8	1 1/4	3/8	2

ELEVATIONS AFTER 10 COVERAGES

1	2 1/8	-1/8	1/4	3/4	0	1 1/4
2	1 1/2	-1 1/8	-1 3/8	-1 1/8	-1/2	5/8
3	1 3/4	-1 7/8	-1 3/8	-1 1/4	-5/8	1
4	2 5/8	-1	-7/8	-1	-1 3/8	3/8
5	2	-1/8	-5/8	-1 3/8	-2	0
6	2 3/4	1/2	1 1/4	1/2	1/2	2 1/2

ELEVATIONS AFTER 20 COVERAGES

1	2	-1/4	0	1/2	-1/4	1 1/2
2	1 1/4	-1 1/4	-1 3/4	-1 3/8	-5/8	1/2
3	1 3/4	-2	-1 3/8	-1 1/2	-7/8	1
4	2 1/2	-1 1/4	-1 1/4	-1 1/2	-1 1/2	1/2
5	1 7/8	-1/2	-1	-1 3/4	-2 1/8	1/8
6	2 1/2	1/8	7/8	1/4	1/4	1/2

ELEVATIONS AFTER 30 COVERAGES BEFORE RELEVELLING

1	2	-3/8	0	1/4	-1/4	1 1/8
2	1	-1 3/8	-2	-1 3/4	-1	3/8
3	1 1/2	-2 3/8	-1 5/8	-1 5/8	-1	3/4
4	2 3/8	-1 3/8	-1 3/8	-1 3/4	-1 5/8	1/4
5	1 3/4	-5/8	-1 1/2	-1 7/8	-2 3/8	-1/8
6	2 3/8	0	5/8	0	1/4	2 1/2

TABLE 4. SLAB CORNER ELEVATIONS PRELIMINARY TEST (CONTINUED).

ELEVATIONS AFTER 30 COVERAGES AFTER RELEVELLING

	A	B	C	D	E	F
1	7/8	1/2	0	5/8	-1/8	1 1/2
2	1 1/8	3/4	-1/4	1/8	-5/8	3/4
3	1 1/2	1/4	-1/8	-3/8	0	1
4	1 1/2	1/2	-1/8	-3/8	1/4	1 1/2
5	1 5/8	1 1/8	1 1/4	-1/4	1/4	1 3/8
6	2 1/8	1 1/2	1 3/4	3/8	1/4	1 1/4

ELEVATIONS AFTER 40 COVERAGES

	A	B	C	D	E	F
1	3/4	1/8	-1/8	1/8	-1/8	1 3/8
2	3/4	0	-7/8	-3/4	-3/4	5/8
3	1 3/8	-1/2	-7/8	-7/8	-1/2	5/8
4	1 1/4	-3/8	-7/8	-5/8	-1/8	1 1/4
5	1 3/8	1/2	0	-3/8	-1/8	1 1/8
6	1 3/8	1/2	1/4	0	-1/8	1

ELEVATIONS AFTER 60 COVERAGES

	A	B	C	D	E	F
1	7/8	1/8	-1/4	0	0	1
2	1	0	-1	-1	-5/8	1/4
3	1 1/2	-1	-1	-1	-1/2	1/4
4	1 1/2	-1/2	-1	-7/8	-1/8	5/8
5	1 3/4	1/8	-1/4	-5/8	-1/4	1/2
6	1 3/4	1/4	-1/8	-1/4	-1/2	1/4

ELEVATIONS AFTER 100 COVERAGES

	A	B	C	D	E	F
1	1/2	-1/4	-3/8	-1/8	-3/4	1
2	3/4	-3/4	-1 1/8	-1 1/2	-1	3/4
3	5/8	-1 1/4	-1	-1 1/8	-1	1/2
4	1 1/4	-3/4	-1 1/8	-1 1/8	-1/2	1
5	1 1/4	-1/2	-1/4	-3/4	-1/2	1
6	1 1/8	1/8	-3/8	-1/2	-5/8	1

TABLE 4. SLAB CORNER ELEVATIONS PRELIMINARY TEST (CONCLUDED).

ELEVATIONS AFTER 150 COVERAGES

	A	B	C	D	E	F
1	1/2	-1/2	-3/4	-1/2	-1 5/8	1
2	1/2	-3/4	-1 1/4	-1 3/4	-1 1/4	3/8
3	1	-1 1/2	-1	-1 1/2	-1 1/4	1/2
4	1	-5/8	-1	-1	-5/8	1
5	1 1/2	-1/2	-1/8	-1	-5/8	1
6	1 1/8	1/8	-1/4	-1/4	-1/2	1

recorded elevations as scheduled. The slab corner elevations after 40, 60, 100, and 150 coverages are listed in Table 4.

Figures 22 through 27 profile slab corners along longitudinal edges before traffic, after 30 coverages, after releveling, and after 150 coverages. The differential settlement that resulted is evident by the diverging plots of Slab 1 (Edge 1-2), as shown in Figures 22 and 23, and Slab 2, as shown in Figure 24 and 25. Except for the settlement during the first 30 passes, the two corners of Slab 4 (Edge 3-4) settled almost the same amount, as shown in Figures 22 and 23, both being in the center of the crater. However, Corner B 2 of Slab 1 toward the crater center settled 2 1/8 inches, while corners supported by the denser original base course near the crater edge settled only 7/8 inch. The edge along Line 6 of the current test section is near the middle of an earlier crater repair, which probably had more consistent debris backfill subgrade. Some of this earlier backfill was still in place for this test; therefore, Slab 7 and other slabs along the south side of the crater did not exhibit severe differential settlement.

Test 1 tested precast slabs placed on 22 inches of pea gravel over 4 feet of compacted debris backfill to determine the severity of differential settlement of individual slabs in the repair center and of slabs near the edge under F-4 loadcart traffic. The differential settlement problem was confirmed and is shown in Figure 29, which plots settlement (average of the four slab corners settlement) versus traffic for Slab 4 along the crater edge and Slab 5 at the crater center.

At the conclusion of traffic, the precast slabs were marginally serviceable. Every slab corner within the traffic lane was cracked, a number of longitudinal and transverse cracks had developed along the full length of the slabs, and the edges of slabs which had contacted adjacent slabs were spalled severely. The edge spalling was ignored because the use of an appropriate spacer or joint material would presumably resolve that problem by preventing the slabs from striking each other. The slabs did not have angle iron corner nosing which would probably reduce spalling and the resulting FOD hazard. Figure 29 shows representative edge spalling after 10 coverages.

4. Conclusions

Differential settlement of slabs near the crater edge is a problem for precast slab repairs. The problem of differential settlement, or rocking of an individual slab, may be reduced by using a more stable aggregate under the slab, such as a well-graded crushed material with angular particles, that will provide granular interlock and increased density. This will not shift so readily under load, and with the addition of filler material between the slabs should control rocking.

The test resulted in early settlement under traffic loads. This may be reduced by using more and better material on top of the debris back-

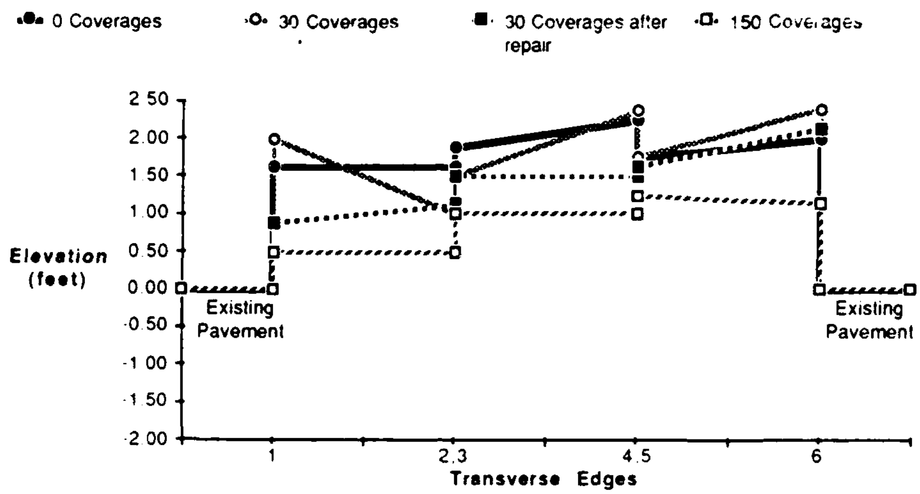

Figure 22. Slab Elevation Profiles Along Longitudinal Edge A, Preliminary Test.

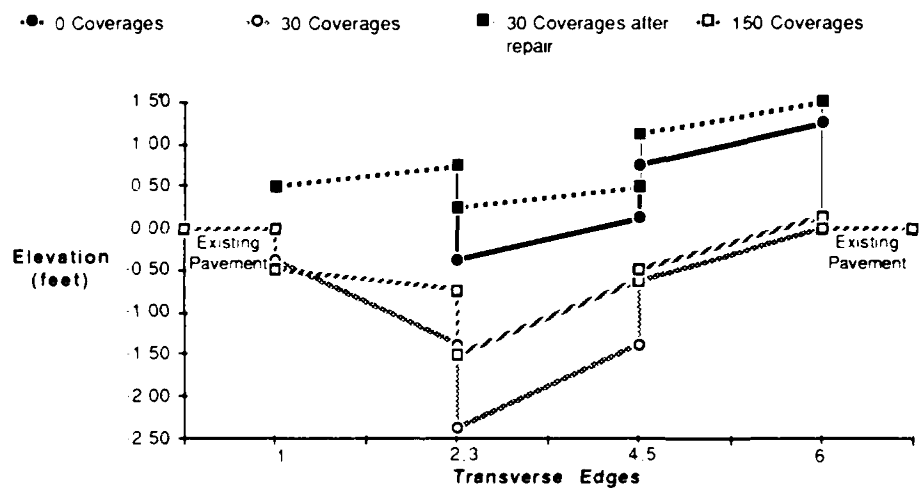

Figure 23. Slab Elevation Profiles Along Longitudinal Edge B, Preliminary Test.

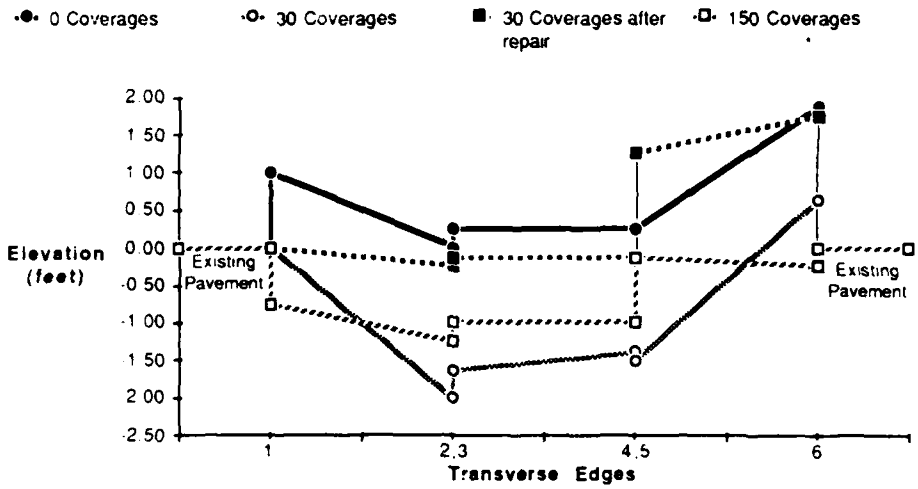

Figure 24. Slab Elevation Profiles Along Longitudinal Edge C, Preliminary Test.

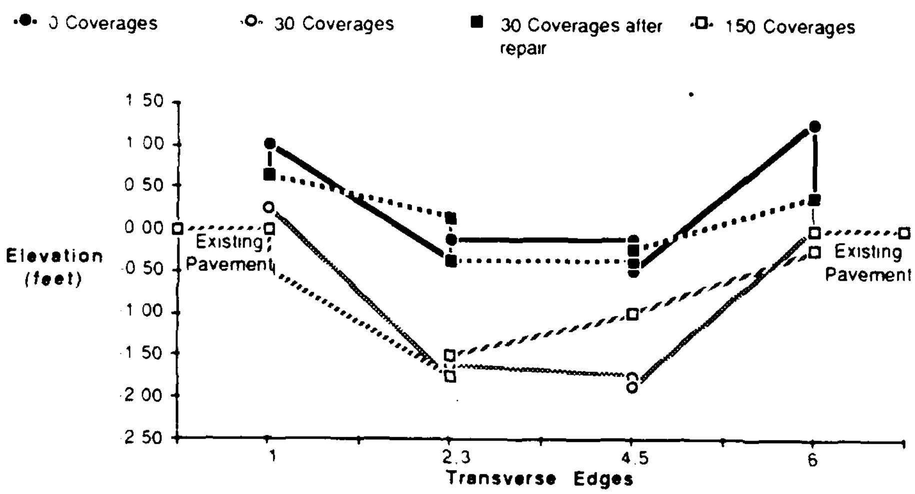

Figure 25. Slab Elevation Profiles Along Longitudinal Edge D, Preliminary Test.

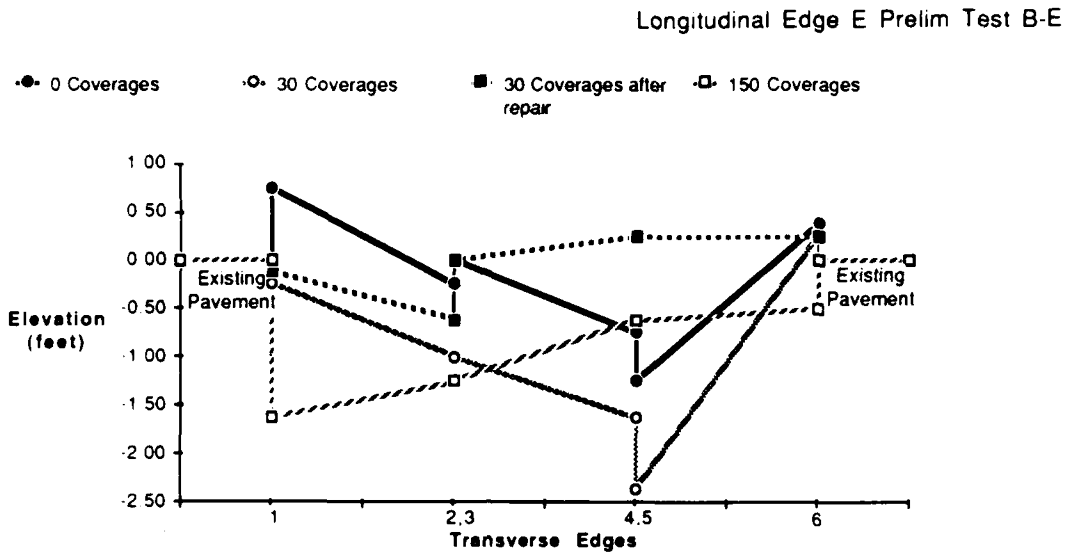

Figure 26. Slab Elevation Profiles Along Longitudinal Edge E, Preliminary Test.

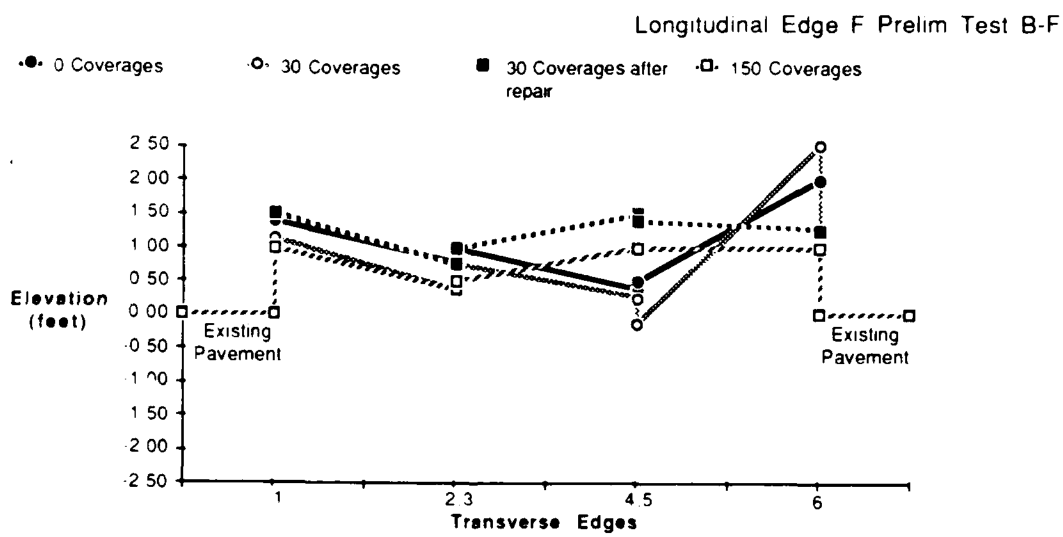

Figure 27. Slab Elevation Profiles Along Longitudinal Edge F, Preliminary Test.

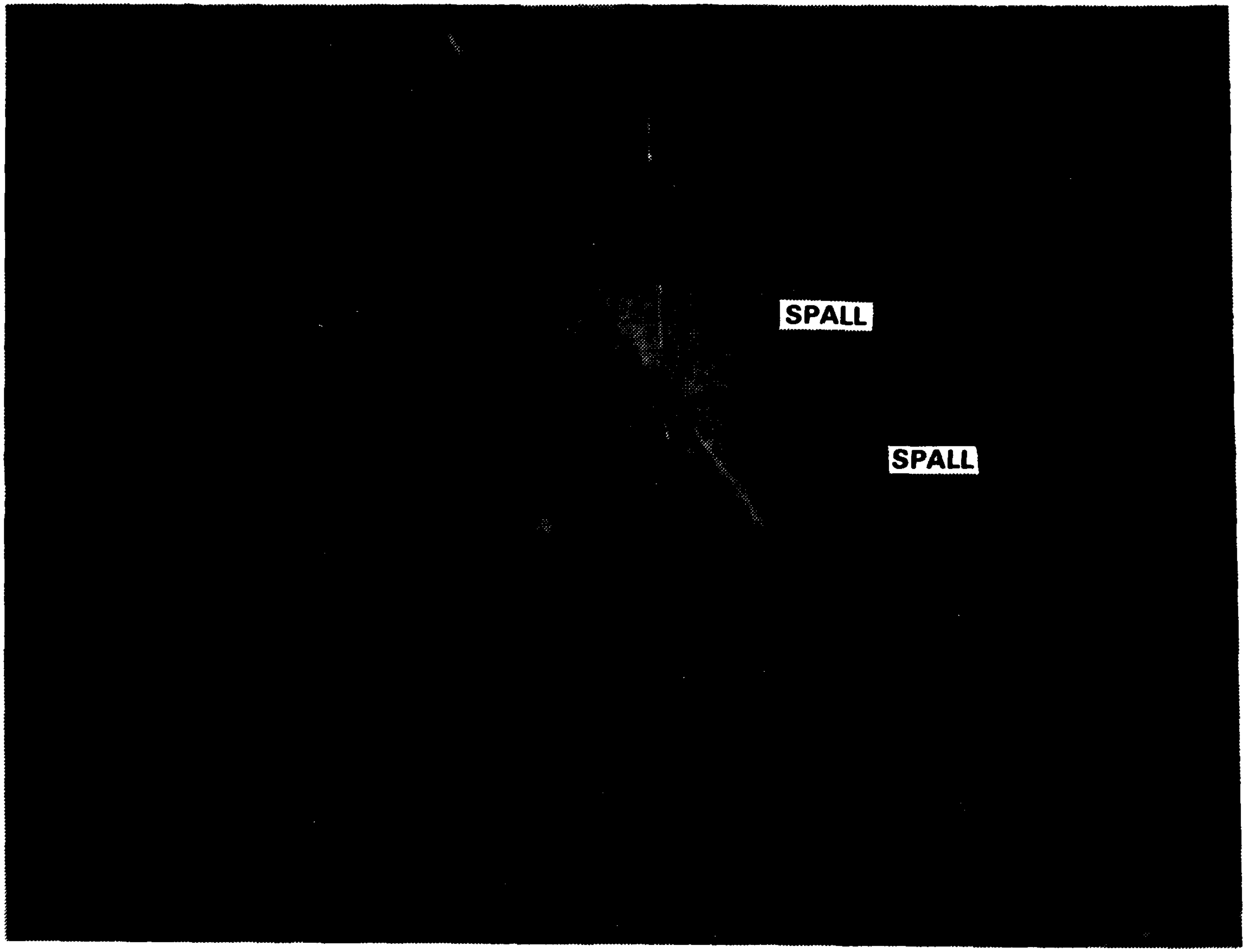

Figure 28. Representative Edge Spalling, Preliminary Test.

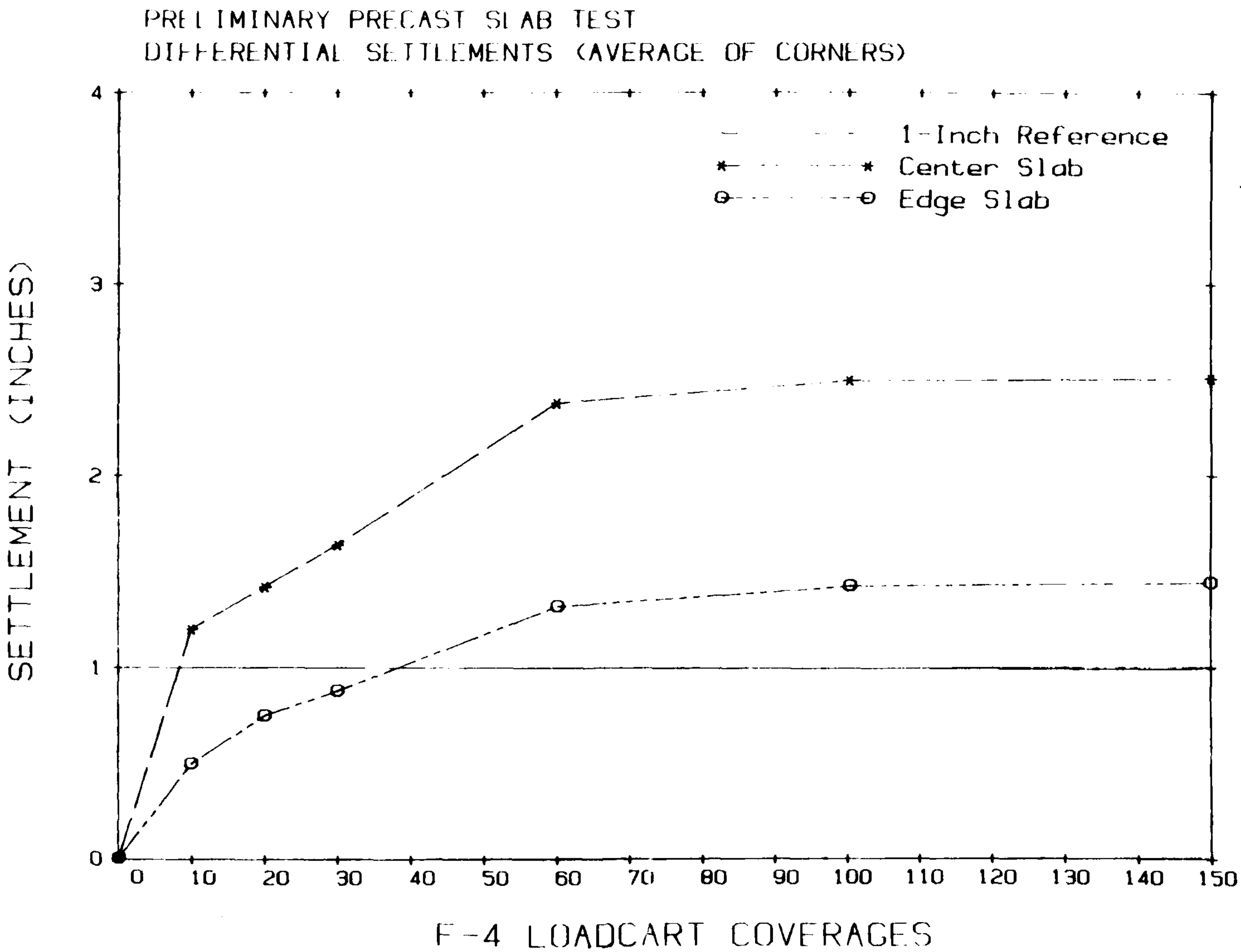

Figure 29. Settlement Versus F-4 Loadcart F-4 Loadcart Coverages, Preliminary Test.

fill, compacting more prior to traffic, and avoiding the use of large debris so as not to create subsurface voids. One method is to use ballast rock beginning at a minimum depth of 36 inches from the surface. Ballast rock may not require compaction to achieve dense condition, and will exhibit less particle-to-particle motion than pea gravel thereby also reducing differential settlement.

C. TEST 2: 2-METER SLAB TEST-UNCOMPACTED, BALLAST ROCK FILL WITH CRUSHED STONE LEVELING COURSE

1. Introduction

This test evaluated the performance of precast slabs over an uncompacted base course under F-4 loadcart traffic.

2. Test Description

The test was conducted in SCTF Test Pit 3. Test personnel constructed the test section by placing a polyethylene sheet over the clay subgrade (to prevent intrusion of the subgrade into the aggregate layers which would weaken the test section) and then adding 24 inches of ballast rock. They did not compact the ballast rock before adding a 4- to 6-inch layer of Number 57 crushed stone over the ballast rock, raising the level of the test section to approximately 6 inches below the level of the existing pavement. Test technicians again did not compact the crushed stone, but leveled this layer with a hand screed. A front-end loader with a special attachment placed nine precast reinforced concrete slabs over the crushed stone layer, leaving spaces of approximately 1/2 to 1 inch between slabs. Personnel did not roll or compact the slabs after placement. They filled the spaces between adjacent slabs with blasting sand to reduce slab movement during trafficking. Following construction of the repair, the F-4 loadcart trafficked the test section using a normal traffic distribution patterns, as shown in Figure 30. Each distribution consisted of seven traffic lanes that were each 10 1/2 inches wide. During trafficking, technicians measured the elevations of slab corners in an unloaded condition after 0, 12, 24, 48, 72, 84, 96, 120, 144, and 156 loadcart coverages.

The maximum allowable settlement of adjacent slab corners was 1 1/2 inches, and the allowable peak sag and peak upheaval were limited to 3 inches and 1 1/2 inches, respectively. When any of these limits were exceeded, loadcart traffic was discontinued until the test section had been repaired to within allowable limits. Following maintenance of the repair, Number 10 aggregate (ASTM D448) was used to fill joints between precast slabs, slab edge elevations were remeasured, and loadcart traffic resumed.

The performance of the test section was documented by recording the slab corner elevations and observing the performance of the slabs and the joint filler material under loadcart traffic.

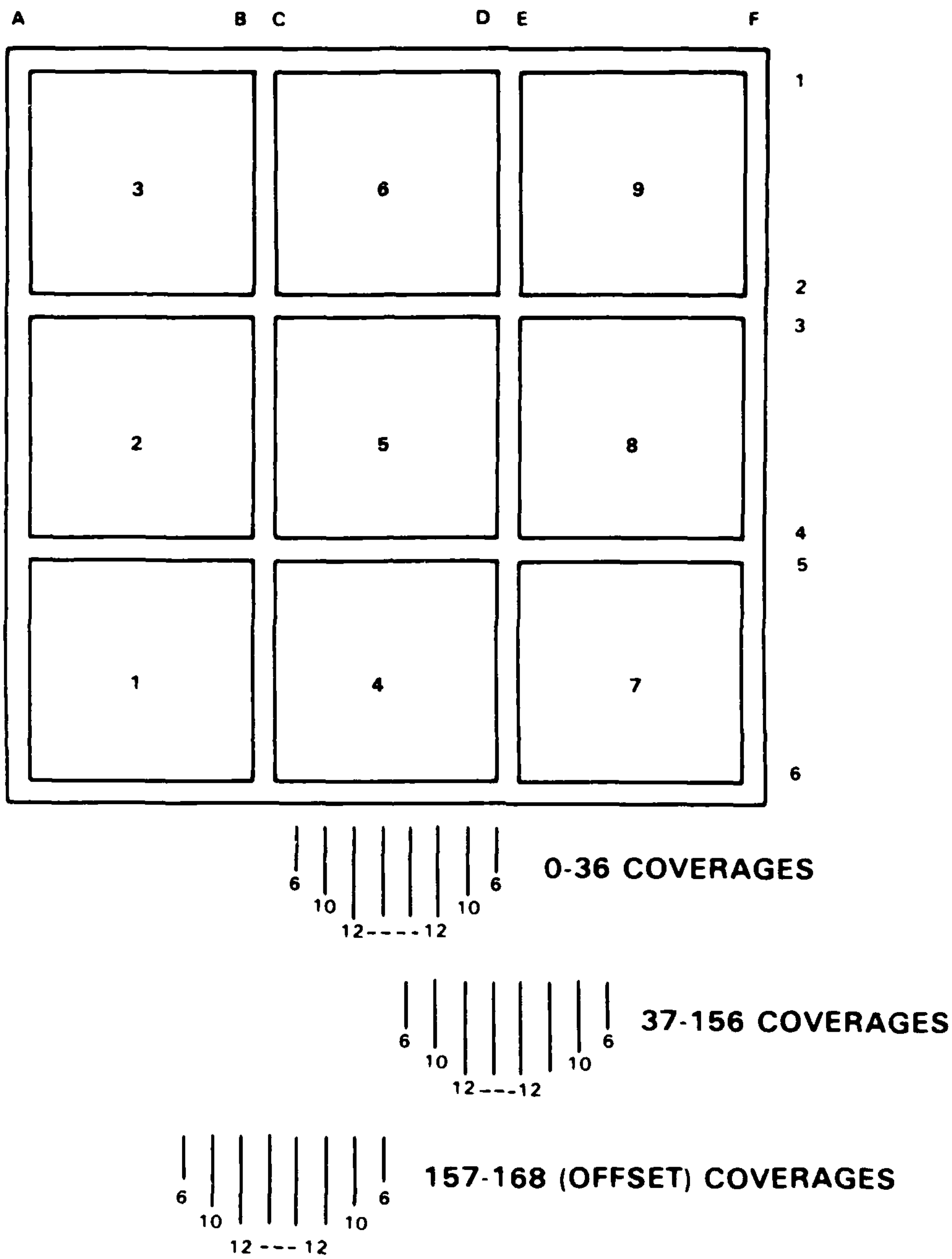

Figure 30. Plan View for Test 2: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course.

3. Results

Construction of the test section, F-4 loadcart trafficking, and measurement of slab corner elevations went as planned. Although this was not a timed exercise, times for some of the repair activities were recorded and are included in Appendix A.

Figures 31 through 38 present elevation profiles of slabs along Edge B, C, D, and E during F-4 loadcart traffic. Only vertical measurements were taken during the surveys.

After 12 loadcart coverages, test personnel noted horizontal displacement of the slabs. Slab 6 had shifted to approximately 3 inches from the east edge (Line 1 in Figure 30) of the test pit. With the exception of the untrafficked north edge (Line A) of the section, the blasting sand used to fill the original joint between the slab and the edge had settled into the underlying leveling course.

After 24 coverages, personnel noted significant displacement in two places along the perimeter of the section due to settlement of Corner 1-E of Slab 9 and Corner 6-E of Slab 7. Although the displacement did not exceed the allowable settlement of 1 1/2 inches between adjacent slab edges, the test personnel discontinued traffic and performed a maintenance action. Technicians repaired the section in 80 minutes by removing the slabs, adding additional Number 57 aggregate to the leveling course, screeding the leveling course, replacing the slabs, and filling the joints with Number 10 crushed aggregate instead of blasting sand. Technicians measured the slab corner elevations after the repair, and loadcart trafficking resumed.

Traffic continued to 36 coverages with the normal distribution pattern centered over the test section and from 37 to 156 coverages with traffic centered over the joint between slab Edges D and E. No further maintenance of the test section was necessary. Data collectors measured no relative settlement of adjacent slabs exceeding the 1 1/2-inch criterion at all slab corners. The maximum relative settlement between adjacent slabs was approximately 1 inch, and located between Edges D and E. As shown in Figure 30, this area received more traffic than any other.

Throughout trafficking, the slabs shifted towards the center of the section and consistently rocked toward the traffic lane. As previously mentioned, filler sand settled below the slabs by the time 12 loadcart coverages were applied due to the rocking and shifting of the slabs.

The loadcart applied an additional 12 coverages (shown as 157-168 coverages on Figure 30) which were applied to the section over Slabs 7, 8, and 9. Figures 39 to 42 present elevation profiles before and after the additional 12 passes. Relative settlement of adjacent slabs from the additional traffic was less than 1 inch in all locations.

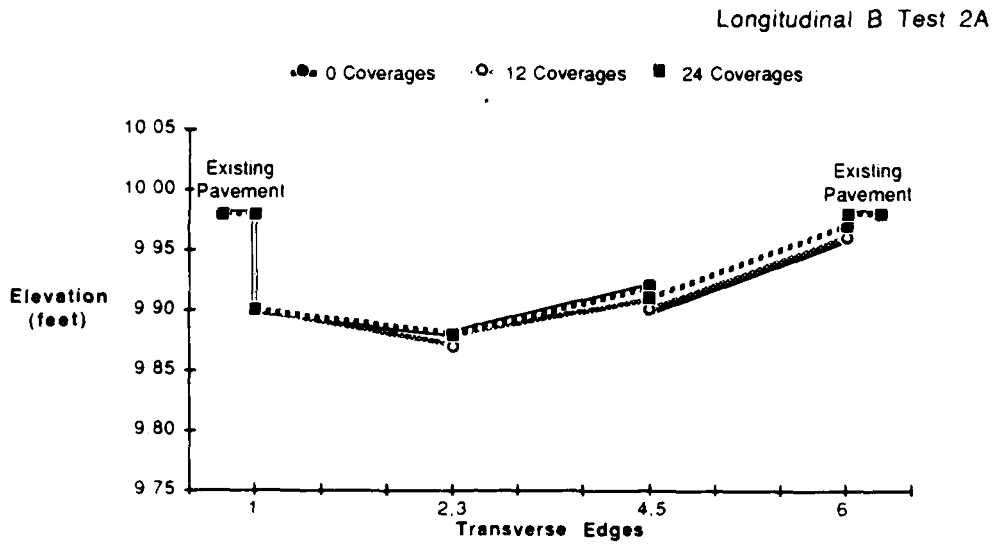

Figure 31. Slab Elevation Profiles Along Longitudinal Edge B, Test 2: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (Before Traffic, 0 F-4 Loadcart Coverages (Repositioned Slabs), 12 F-4 Loadcart Coverages, 24 F-4 Loadcart Coverages).

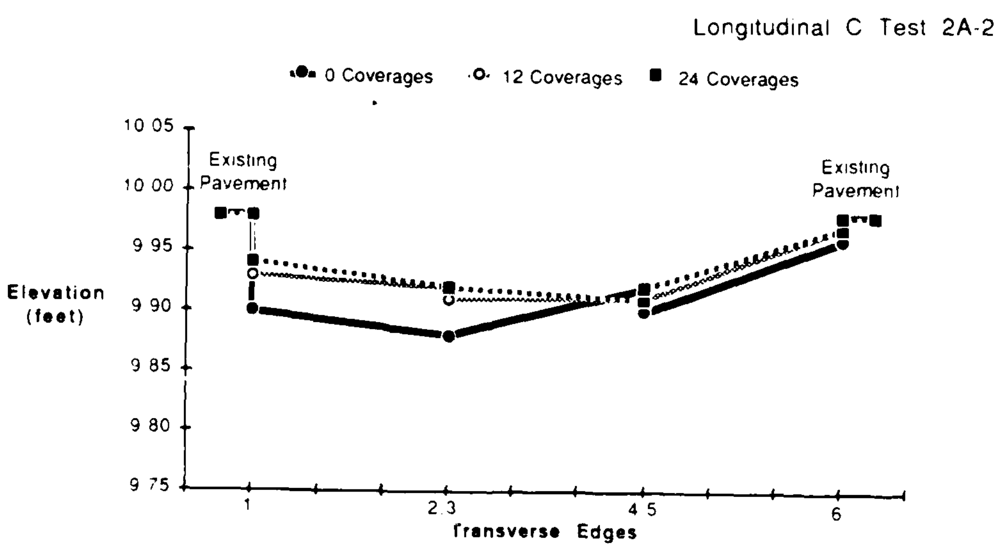

Figure 32. Slab Elevation Profiles Along Longitudinal Edge C, Test 2: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (Before Traffic, 0 F-4 Loadcart Coverages (Repositioned Slabs), 12 F-4 Loadcart Coverages, 24 F-4 Loadcart Coverages).

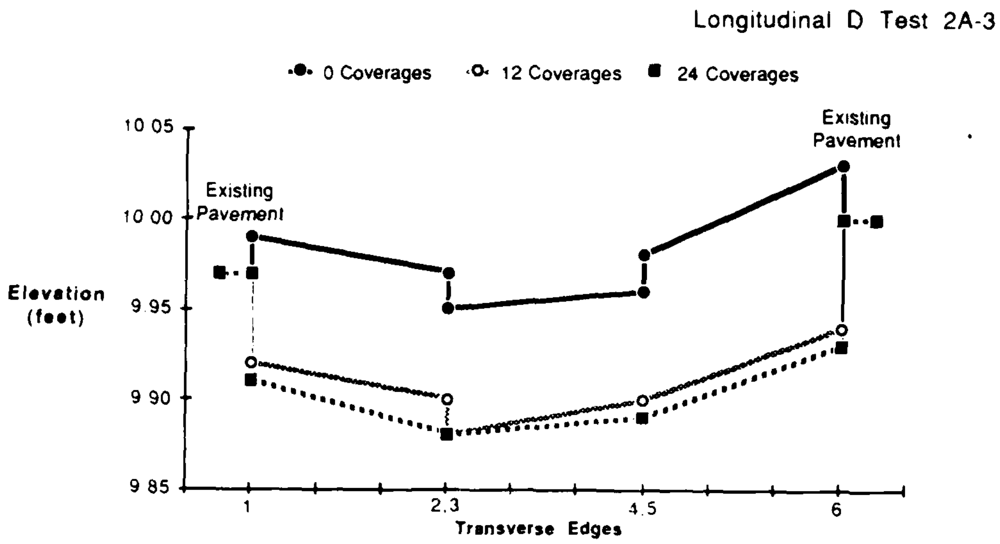

Figure 33. Slab Elevation Profiles Along Longitudinal Edge D, Test 2: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (Before Traffic, 0 F-4 Loadcart Coverages (Repositioned Slabs), 12 F-4 Loadcart Coverages, 24 F-4 Loadcart Coverages).

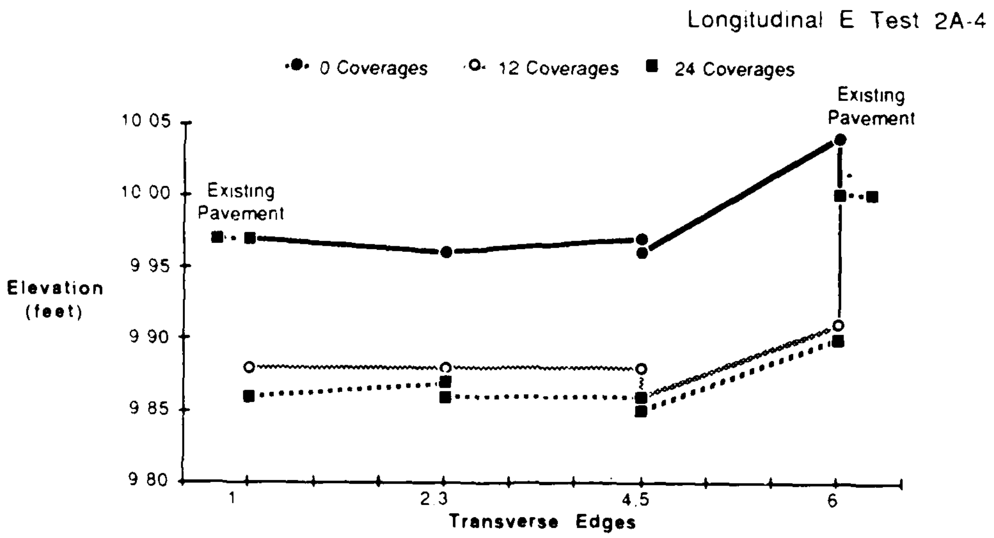

Figure 34. Slab Elevation Profiles Along longitudinal Edge E, Test 2: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (Before Traffic, 0 F-4 Loadcart Coverages (Repositioned Slabs), 12 F-4 Loadcart Coverages, 156 F-4 Loadcart Coverages).

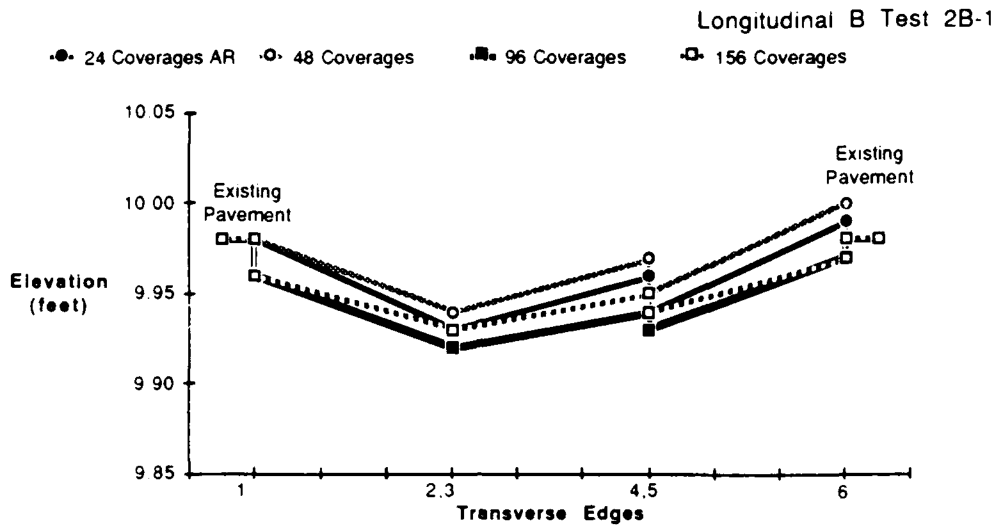

Figure 35. Slab Elevation Profiles Along Longitudinal Edge B, Test 2: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (24 F-4 Loadcart Coverages after Repair, 48 F-4 Loadcart Coverages, 96 F-4 Loadcart Coverages, 156 F-4 Loadcart Coverages.

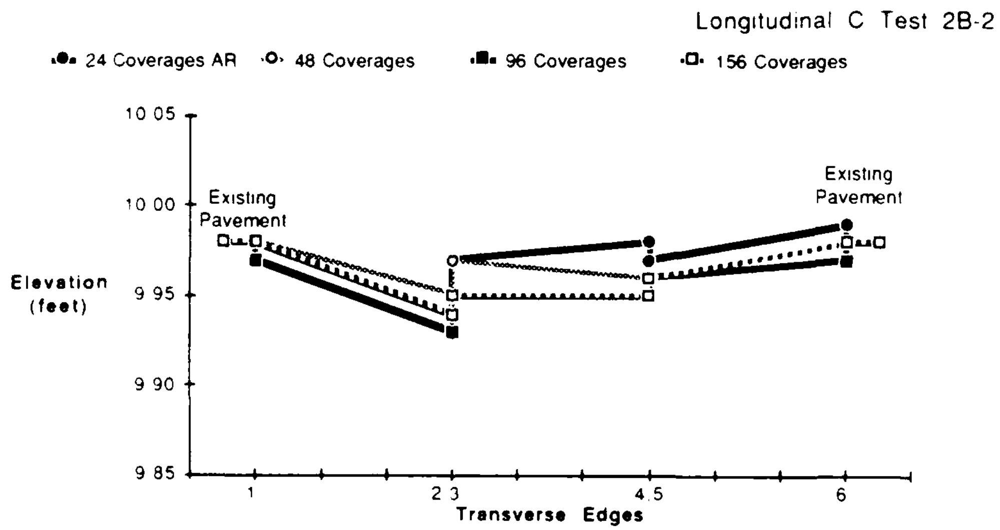

Figure 36. Slab Elevation Profiles Along Longitudinal Edge C, Test 2: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (24 F-4 Loadcart Coverages after Repair, 48 F-4 Loadcart Coverages, 96 F-4 Loadcart Coverages, 156 F-4 Loadcart Coverages).

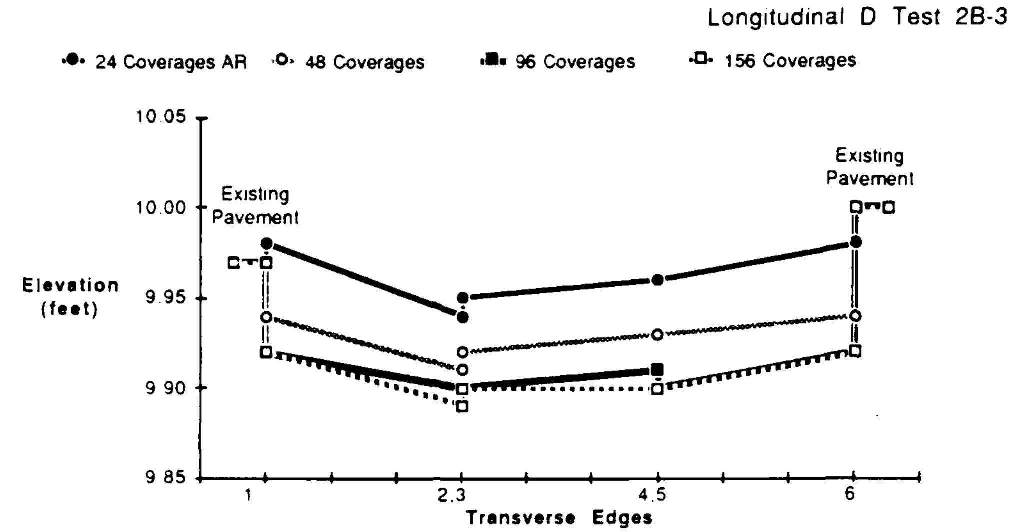

Figure 37. Slab Elevation Profiles Along Longitudinal Edge D, Test 2: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (24 F-4 Loadcart Coverages after Repair, 48 F-4 Loadcart Coverages, 96 F-4 Loadcart Coverages, 156 F-4 Loadcart Coverages).

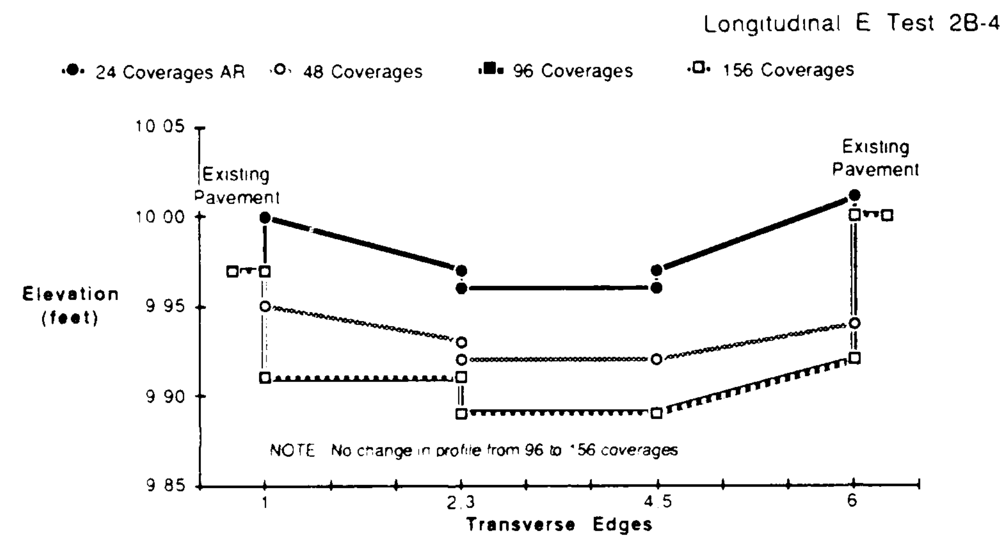

Figure 38. Slab Elevation Profiles Along Longitudinal Edge E, Test 2: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (24 F-4 Loadcart Coverages after Repair, 48 F-4 Loadcart Coverages, 96 F-4 Loadcart Coverages, 156 F-4 Loadcart Coverages).

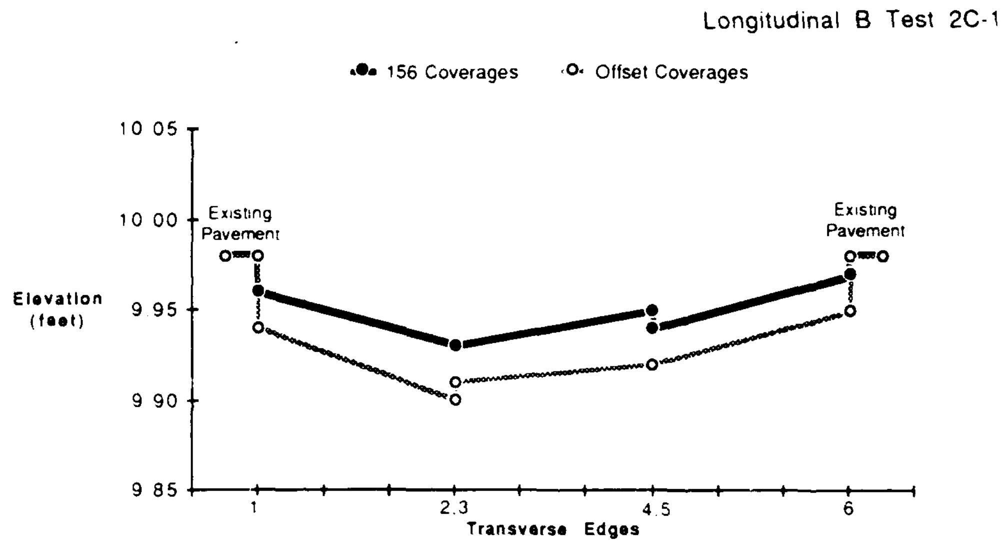

Figure 39. Slab Elevation Profiles Along Longitudinal Edge B, Test 2: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (Before and after 12 Offset F-4 Loadcart Coverages).

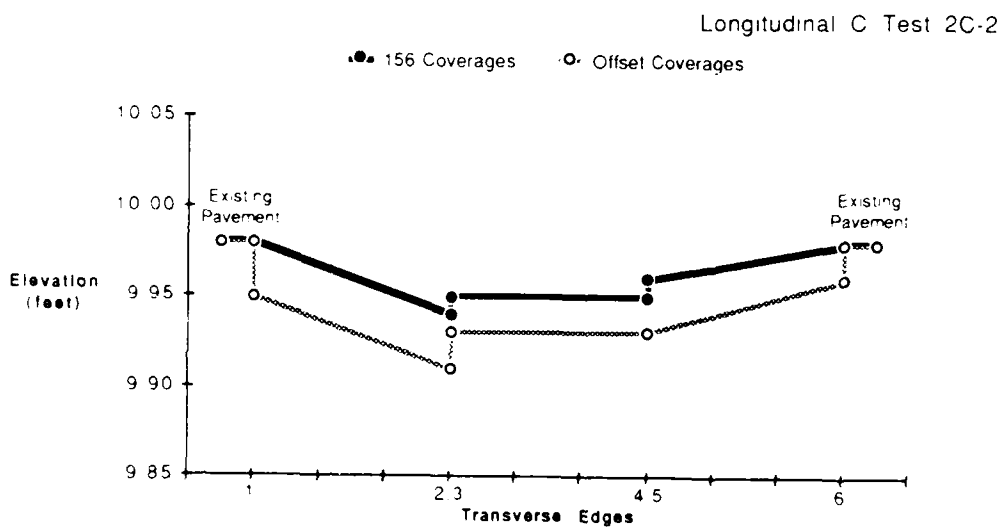

Figure 40. Slab Elevation Profiles Along Longitudinal Edge C, Test 2: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (Before and after 12 Offset F-4 Loadcart Coverages.

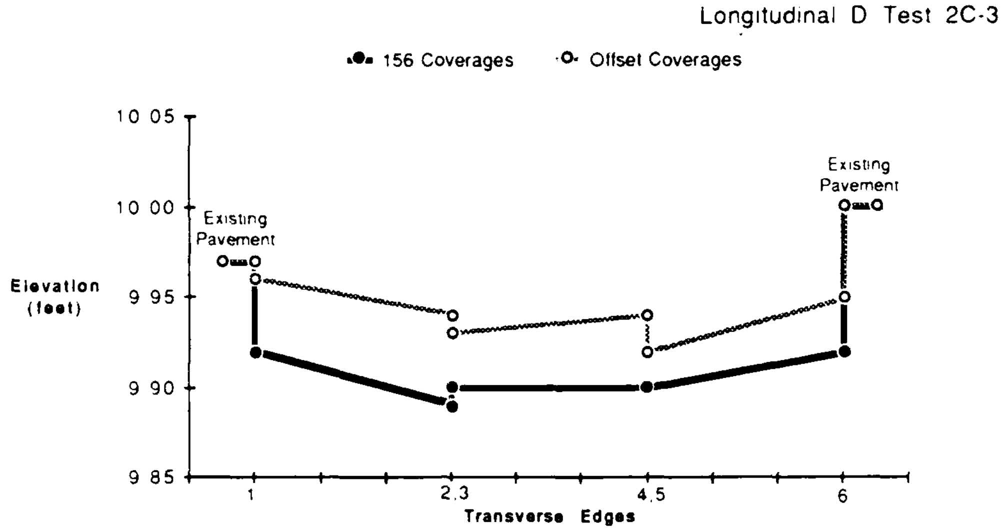

Figure 41. Slab Elevation Profiles Along Longitudinal Edge D, Test 2: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (Before and after 12 Offset F-4 Loadcart Coverages).

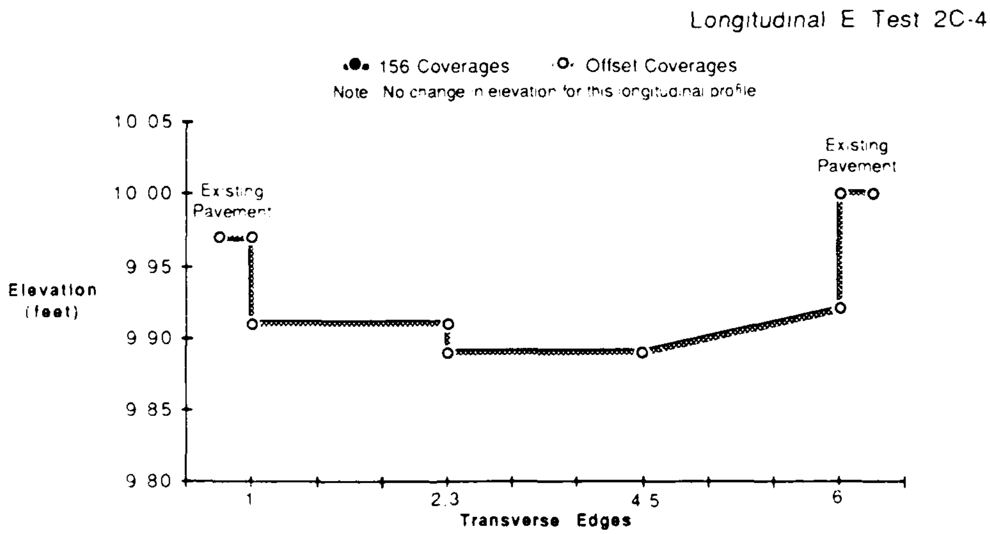

Figure 42. Slab Elevation Profiles Along Longitudinal Edge E, Test 2: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (Before and after 12 Offset F-4 Loadcart Coverages).

In addition to slab corner elevations, the elevations at the centers of Slabs 4, 5, and 6 were measured before and after the additional traffic, while the slabs were both unloaded and loaded by parking the loadcart on the them. Figure 43 illustrates the static load measurement procedure. The comparison of these measurements are presented in Figure 44. Loaded slab displacement relative to adjacent slabs ranged from 0.38 inches for Slab Number 4 to 0.88 inches for Slab 6.

4. Conclusions

Test 2 evaluated precast slabs placed on 4 to 6 inches of uncompacted Number 57 crushed stone, over 24 inches of uncompacted ballast rock, on covering to determine the performance of uncompacted base under F-4 loadcart traffic. Dry blasting sand was used as filler material between the slabs. The precast slabs settled a maximum of 1.44 inches and an average of 0.90 inches in the area receiving the heaviest traffic which, although not exceeding surface roughness tolerance, is significant. Only one maintenance was accomplished, but it was not required by surface roughness criteria. However a decrease of early settlement and especially rocking is desirable.

The early settlement is believed to be due to compaction or migration into the ballast rock of the Number 57 material by the initial loadcart passes. The Number 57 leveling base course over ballast rock performed well after initial settlement, requiring no further corrective maintenance to support requisite traffic applications. Once densified, the graded Number 57 crushed aggregate did not migrate into the ballast rock layer and provided better resistance to displacement than the pea gravel in Test 1, thereby, reducing rocking. This is evidenced by a reduction in settlement from an average of 1.95 inches after 30 coverages in Test 1 to 1.15 inches after coverages in Test 2, measured along the joint receiving the heaviest traffic for each test.

Blasting sand did not perform well as a joint filler, given the slab movement due to the loose base material. It was quickly lost into the base course and under the slabs. The Number 10 material appeared to perform better as a joint filler, although it was also eventually lost to the base, and therefore the improved slab stability is attributed to previous densification of the base material. It is recommended that smaller joint spacing be used when using fine joint filler material.

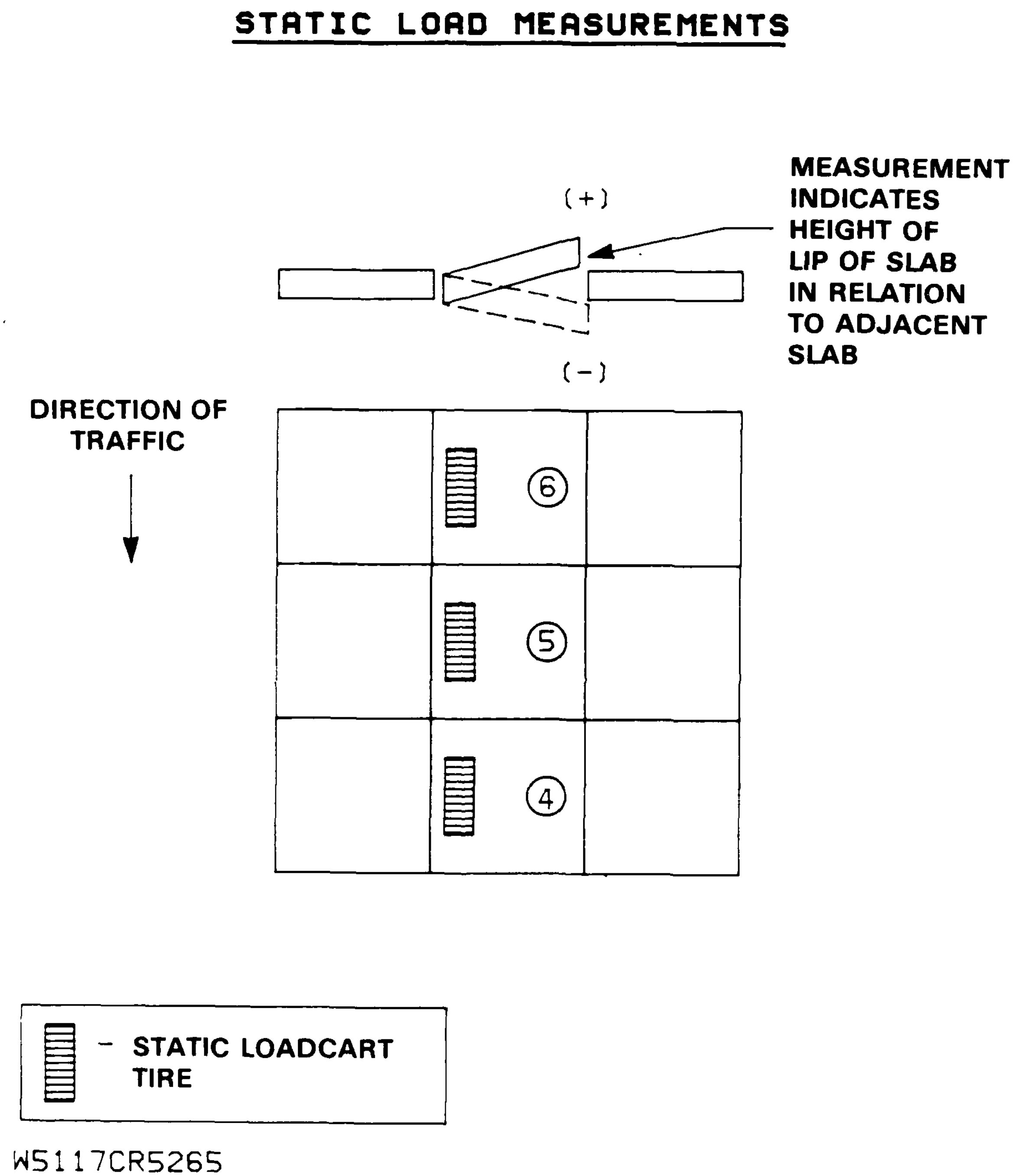

Figure 43. Static Load Measurement for Precast Slab Tests.

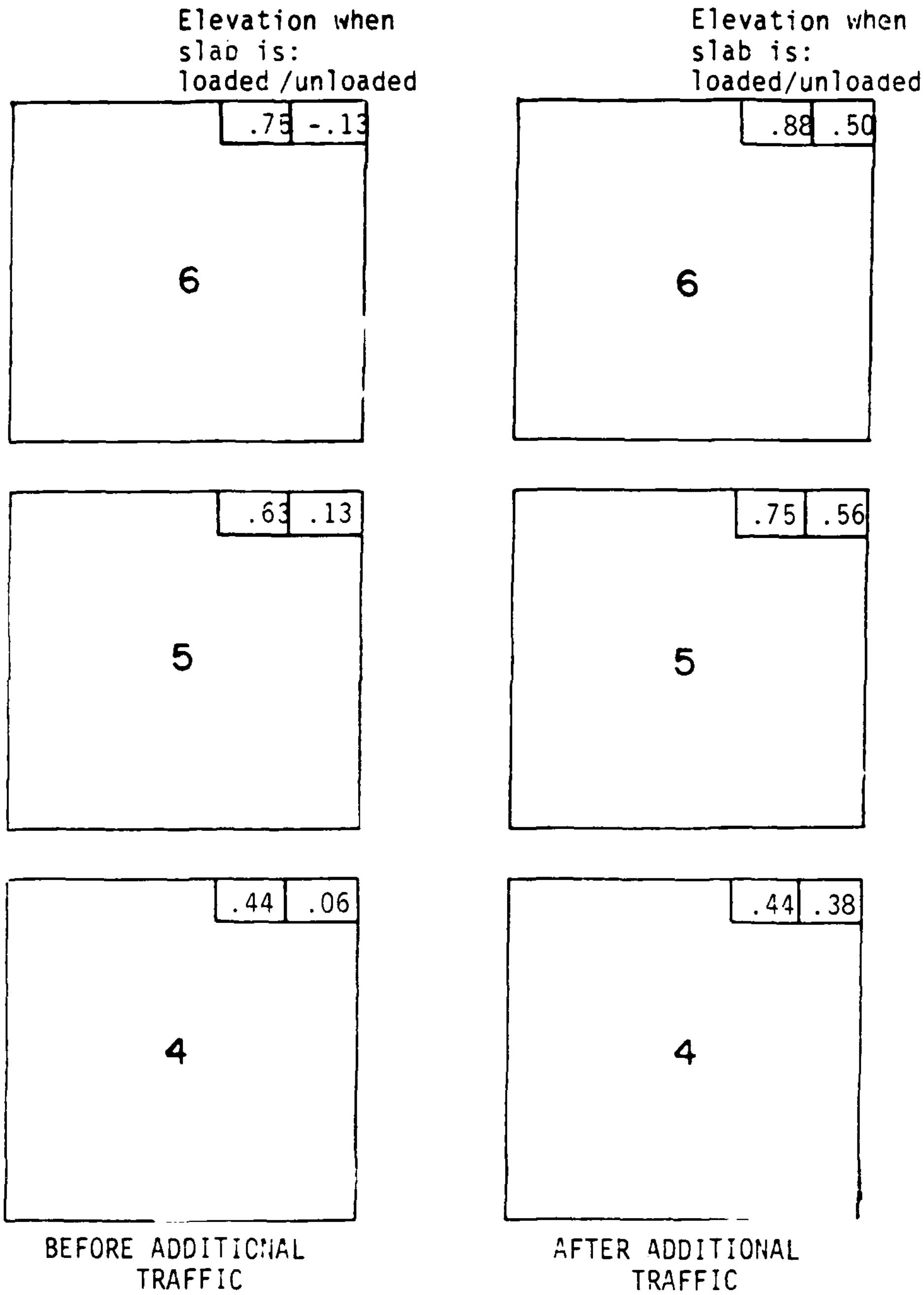

Figure 44. Slab Corner Elevation Measurements Before and After Static Loadcart Placement, Test 2: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course.

D. TEST 3: 2-METER SLAB TEST: UNCOMPACTED, BALLAST ROCK FILL WITH NUMBER 7 CRUSHED STONE LEVELING COURSE

1. Introduction

Test Number 3 evaluated the performance of precast slabs under F-4 loadcart traffic when the test section was not compacted. Test 3 varied from Test 2 in two ways:

- Number 7 crushed stone was used as leveling course over the ballast rock rather than Number 57 crushed stone. The use of this smaller size aggregate was intended to determine if leveling course gradation affects precast slab performance.

- The blasting sand used to fill joints was wetted down after placement, to determine if wet sand performs better as a joint filler than the dry sand used in Test 2.

2. Test Description

The test used SCTF Test Pit 3. Personnel followed a test procedure identical to the Test 2 plan except for the following modifications to the leveling course gradation and the joint-fill sand.

- Personnel placed Number 7 crushed stone for the leveling course instead of Number 57 crushed stone.

- After placing blasting sand in joints, test personnel used a hose to wet down the sand to almost full saturation.

3. Results

After the test section was constructed and prior to loadcart traffic, test technicians measured initial slab corner elevations. Technicians also measured elevations at several other key points in the test, and these elevations are shown in Figures 45 to 56 present the resulting elevation profiles of longitudinal edges.

After 12 loadcart coverages, significant settlement had occurred along Edge D and Edge E. The maximum settlement was 2 7/8 inches occurring at Corner E-4 of Slab 8. Personnel measured settlement greater than the allowable 1 1/2 inches for nine of the 12 slab corners along the joint bounded by Edges D and E. Test technicians repaired the section by removing all slabs, adding and hand screeding Number 7 aggregate to remove the rut which had formed, replacing the slabs, and filling the joints with wet sand as before. Personnel measured slab corner elevations after the repair and trafficking continued.

Traffic continued until after 96 loadcart coverages had been applied. Personnel halted traffic to measure the deformation of the slabs

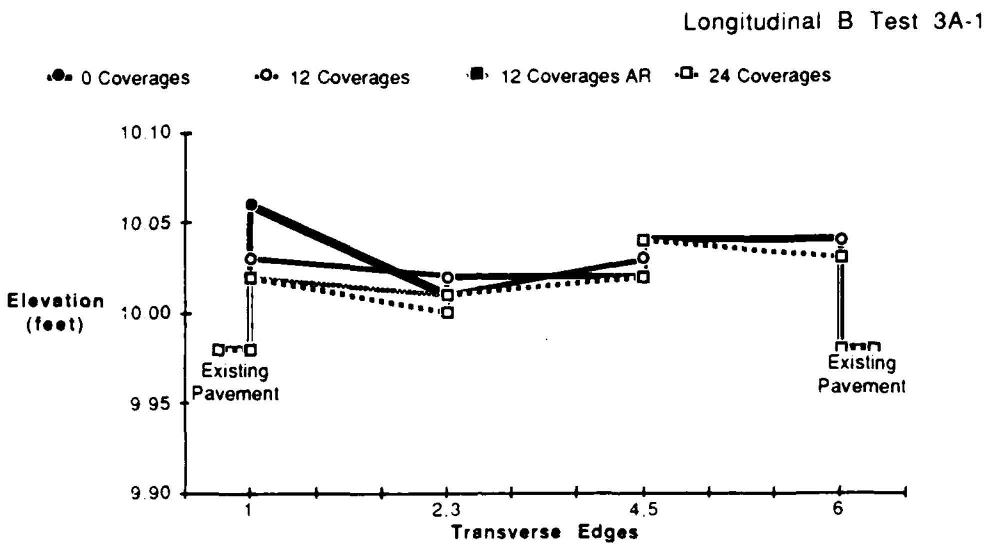

Figure 45. Slab Elevation Profiles Along Longitudinal Edge B, Test 3: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 7 Leveling Course (0, 12, 12 After Repair, and 24 F-4 Load-cart Coverages).

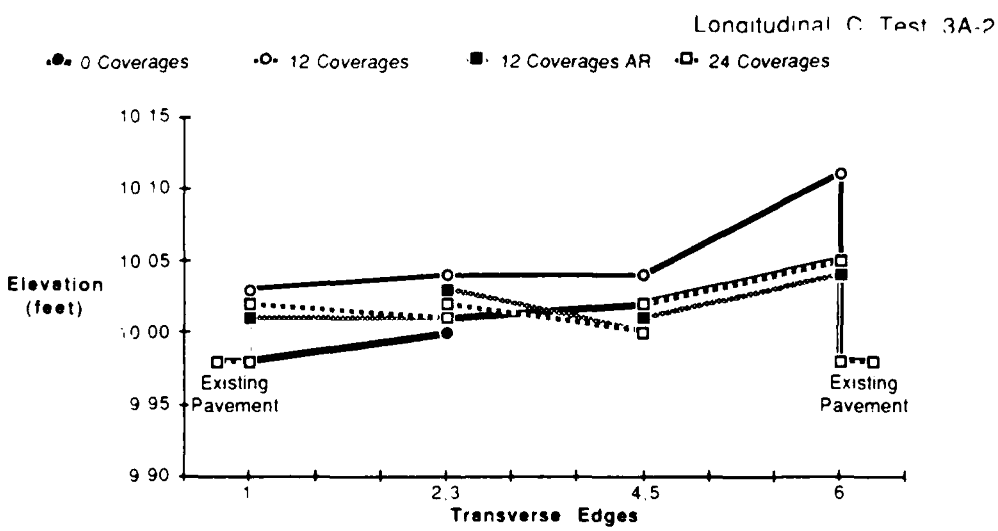

Figure 46. Slab Elevation Profiles Along Longitudinal Edge C, Test 3: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 7 Leveling Course (0, 12, 12 After Repair, and 24 F-4 Load-cart Coverages).

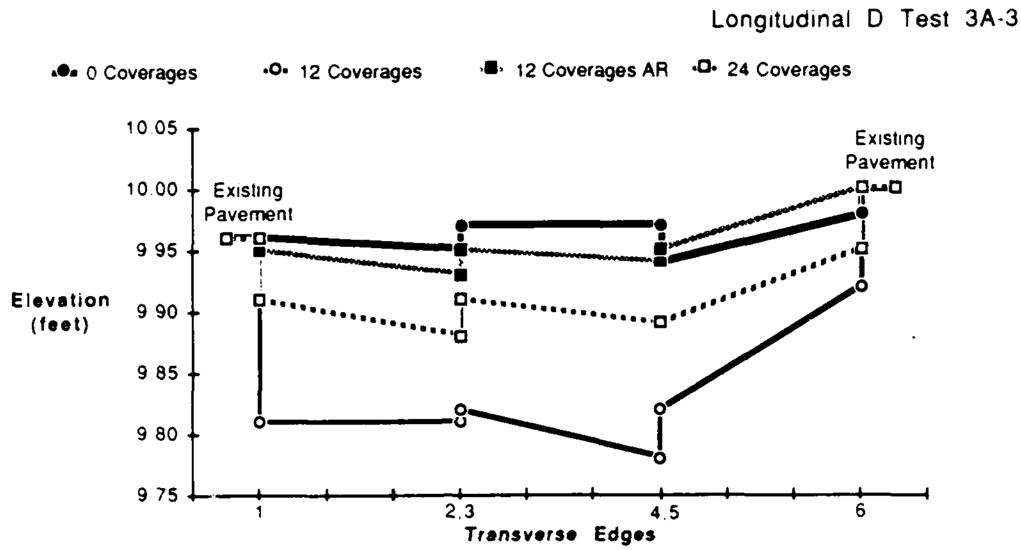

Figure 47. Slab Elevation Profiles Along Longitudinal Edge D, Test 3: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 7 Leveling Course (0, 12, 12 After Repair, and 24 F-4 Load-cart Coverages).

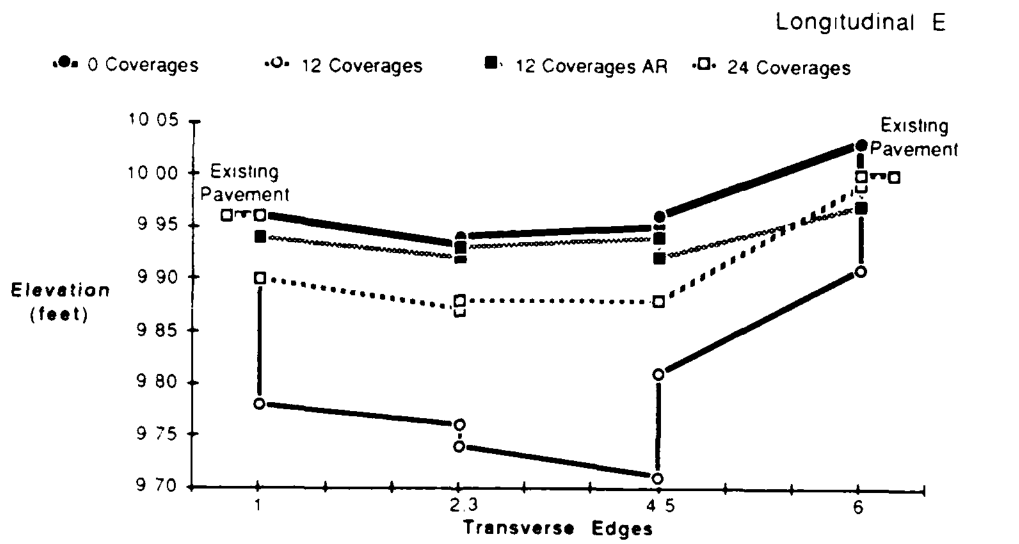

Figure 48. Slab Elevation Profiles Along Longitudinal Edge E, Test 3: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 7 Leveling Course (0, 12, 12 After Repair, and 24 F-4 Load-cart Coverages).

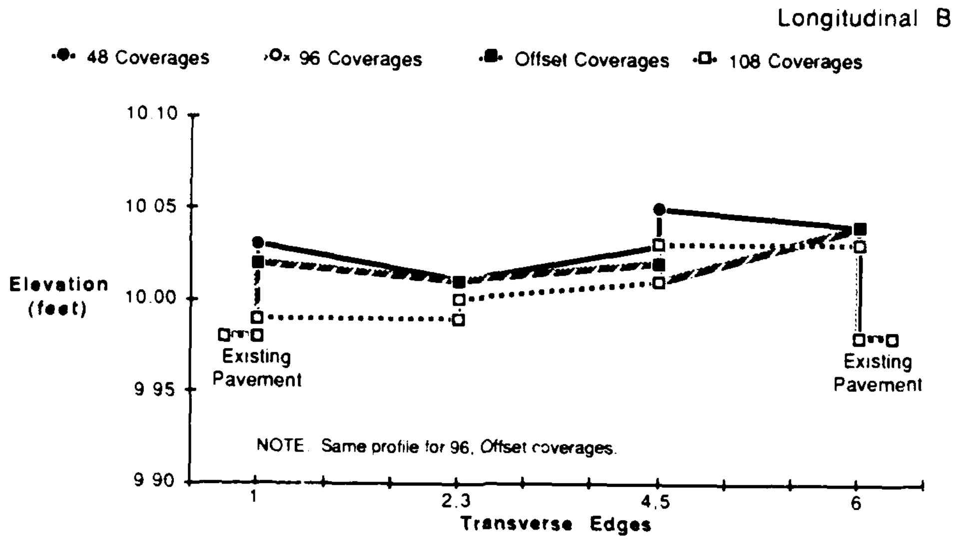

Figure 49. Slab Elevation Profiles Along Longitudinal Edge B, Test 3: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 7 Leveling Course (48, 96, Offset, and 108 F-4 Loadcart Coverages).

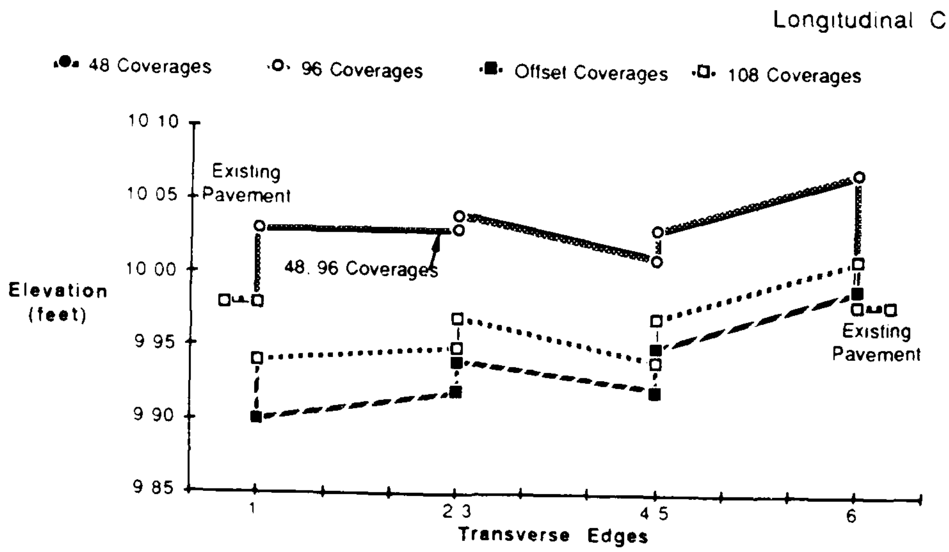

Figure 50. Slab Elevation Profiles Along Longitudinal Edge C, Test 3: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 7 Leveling Course (48, 96, Offset, and 108 F-4 Loadcart Coverages).

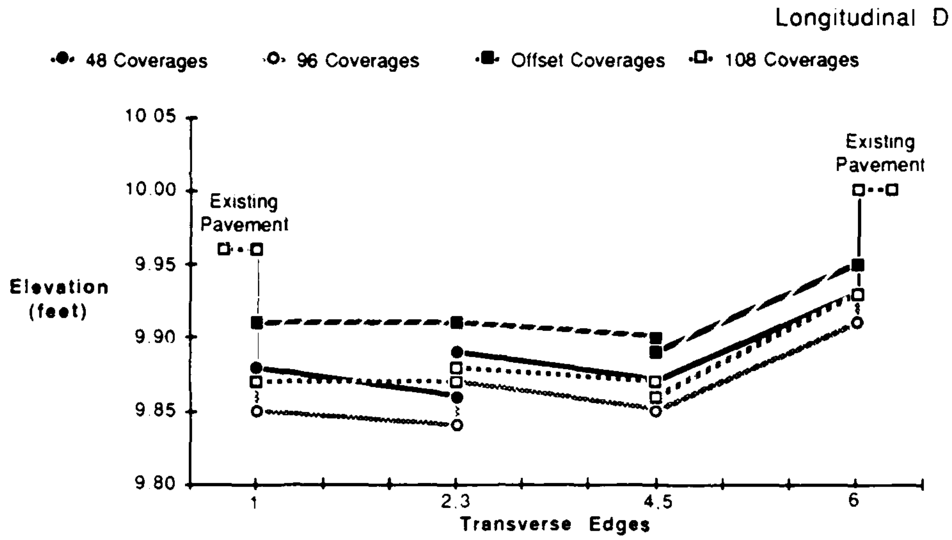

Figure 51. Slab Elevation Profiles Along Longitudinal Edge D, Test 3: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 7 Leveling Course (48, 96, Offset, and 108 F-4 Loadcart Coverages).

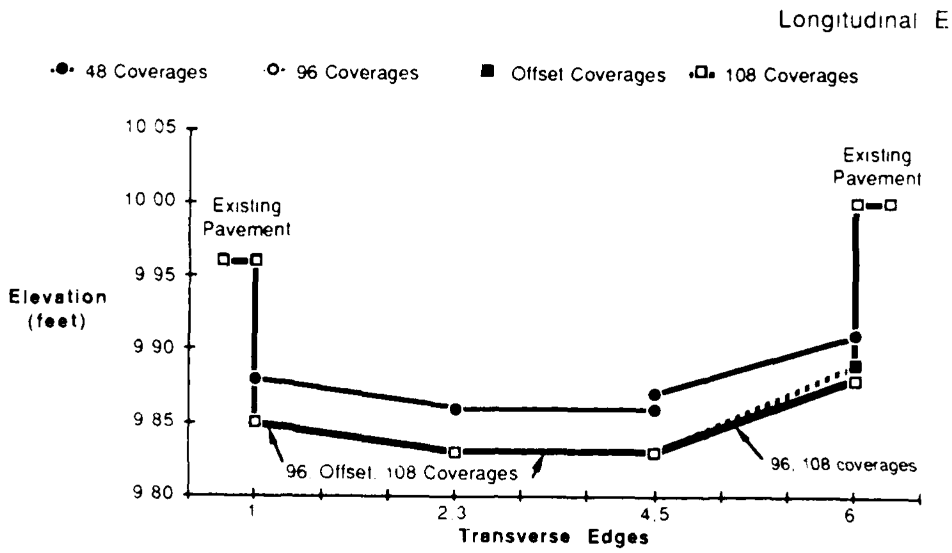

Figure 52. Slab Elevation Profiles Along Longitudinal Edge E, Test 3: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 7 Leveling Course (48, 96, Offset, and 108 F-4 Loadcart Coverages).

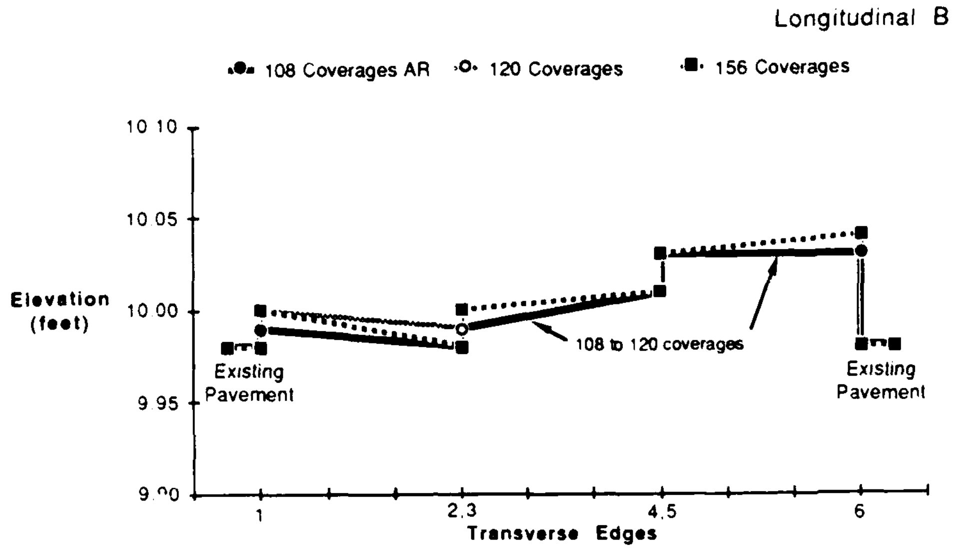

Figure 53. Slab Elevation Profiles Along Longitudinal Edge B, Test 3: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 7 Leveling Course (108, 120, 144, and 156 F-4 Loadcart Coverages).

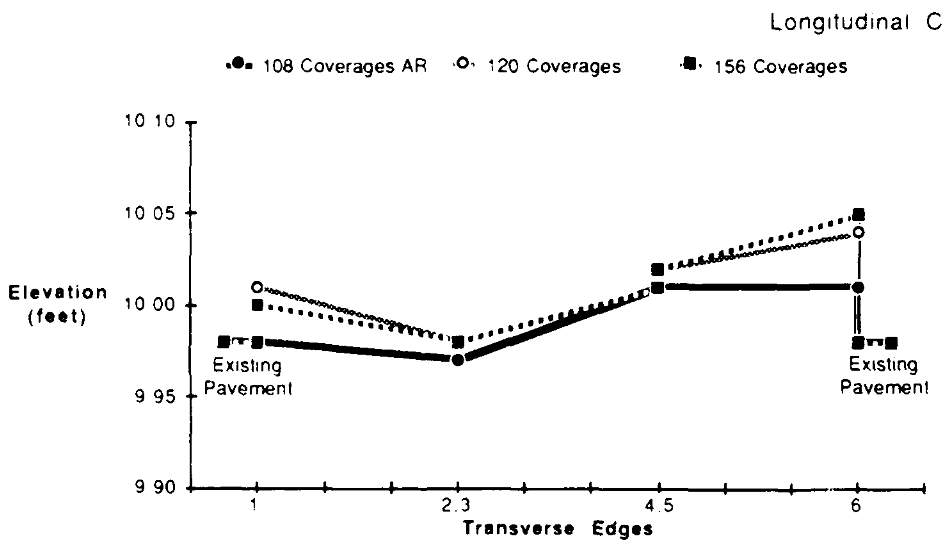

Figure 54. Slab Elevation Profiles Along Longitudinal Edge C, Test 3: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 7 Leveling Course (108, 120, 144, and 156 F-4 Loadcart Coverages).

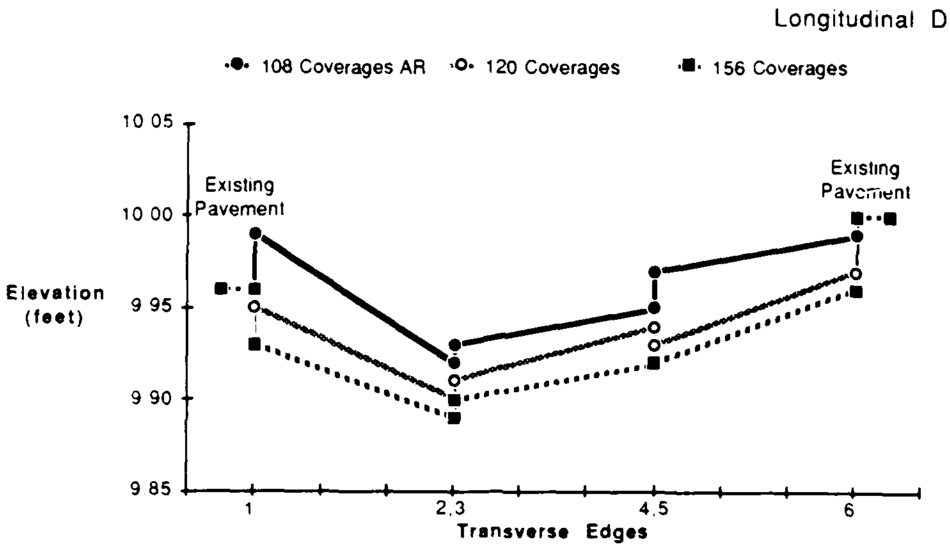

Figure 55. Slab Elevation Profiles Along Longitudinal Edge D, Test 3: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 7 Leveling Course (108, 120, 144, and 156 F-4 Loadcart Coverages).

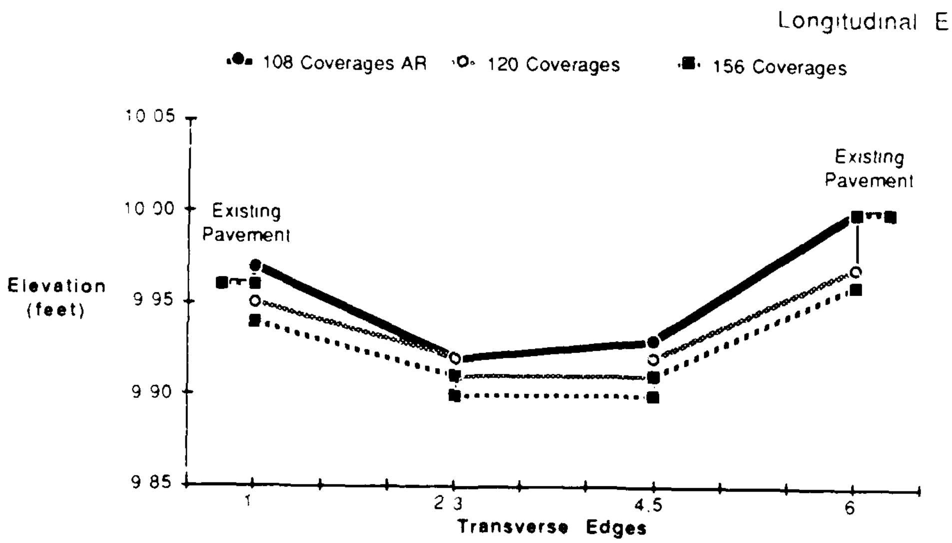

Figure 56. Slab Elevation Profiles Along Longitudinal Edge E, Test 3: 2-Meter Slabs - Uncompacted Ballast Rock Fill with Number 7 Leveling Course (108, 120, 144, and 156 F-4 Loadcart Coverages).

under static loading. Data collectors took these measurements because the slabs were rocking in the direction of traffic from the loadcart, and measuring slab corner elevations while the loadcart was parked on the slabs would more accurately measure the actual response of the slabs to traffic. The procedure for measuring response to static load consisted of parking the loadcart at the northwest corner of a slab and measuring the elevation at the southwest corner, and then parking the loadcart at the northeast corner of the slab and measuring the elevation at the southeast corner. Data collectors measured static load elevations at the corners of Slabs 4, 5, and 6 using this procedure.

After 96 loadcart coverages and the static load measurements, a noticeable rut had developed between Edges D and E. Rather than performing maintenance on the repair, traffic continued with a modified pattern centered over Slabs 4, 5, and 6. Test personnel modified the pattern to reduce the rutting of Edge D by lowering the north edge and to possibly decrease the slab-to-slab settlement to allowable limits. The offset pattern concentrates the loadcart traffic over Edge C. Sixty additional coverages were applied using the modified pattern but are not included in the total number of coverages because they were offset over a different part of the test section. Following application of the 60 coverages, slab corner elevations and static load elevations at Slabs 4, 5, and 6 were measured. The modified traffic pattern succeeded in raising the south edge and lowering Edge C and reduced the relative settlement of adjacent slabs to within the allowable 1 1/2-inch maximum. The modified traffic pattern did not reduce the rocking of the slabs.

Following the static load measurements, personnel resumed application of loadcart traffic using the original traffic distribution. After 12 more coverages (total 108), the rut along Edge D redeveloped and resulted in differential settlement of 1 3/8 inches between northeast and southeast corners of Slab 4. Maintenance was performed on the test section in the same manner as after the first 12 coverages. The rut was eliminated and traffic resumed, continuing until the scheduled 156 coverages. No further maintenance was required.

After completion of the loadcart trafficking, the precast slabs were intact with no visible cracks, and the wedges of wet sand used to fill joints had disappeared only in areas where the sand had been inadequately wet down. Little sand was lost to the underlying aggregate layers. When personnel removed the slabs from the test pit and examined the leveling course, they observed that the Number 7 crushed stone had penetrated the full depth of the ballast rock layer. This indicated that Number 7 aggregate was too fine to use with ballast rock.

4. Conclusions

Test 3 tested precast slabs placed on 4 to 6 inches of uncompacted Number 7 crushed stone on 24 inches of uncompacted ballast rock, with a polyethylene sheet between the clay subgrade and ballast rock, to determine the performance of uncompacted base under F-4 loadcart traffic. Wet blasting sand filled the material spaces between the slabs. The precast slabs settled significantly during initial trafficking, which is attributed mostly to densification of the aggregate layer as occurred in Test 2. Settlement and slab rocking continued after maintenance, indicating that the Number 7 aggregate over ballast rock did not provide sufficient support for the slabs even after densification.

Investigation of the aggregate layers after trafficking showed the Number 7 aggregate had penetrated to the lower portion of the ballast rock layer. The loss of this fine-grained leveling material, which apparently does not provide aggregate interlock, is thought to be the cause of continued settlement and rocking. It is therefore concluded that Number 7 is not suitable as a leveling course over ballast rock for precast slab repairs.

The wet sand did not settle under the slabs and or into the lower layers as had occurred with dry sand in Test 2. However, the wet sand did not reduce the slab rocking; although, it may prevent lateral shifting if it can be kept in place during trafficking. Reducing the rocking by other means such as compacting the base layers slows the loss of filler material. Filler material that provides some load transfer may help reduce the rocking.

E. TEST 4: 2-METER SLAB TEST (COMPACTED BALLAST ROCK FILL WITH NUMBER 7, LEVELING COURSE)

1. Introduction

Test 4 evaluated the performance of precast slabs under F-4 and C-141 loadcart traffic after seating the slabs and compacting the repair using a roller. The seating and compaction were intended to reduce the excessive slab settlement exhibited during the initial loadcart coverages of Tests 2 and 3.

The test section included a polyethylene sheet between the leveling course and the precast slabs to improve the stability of the joint filler sand by preventing infiltration of the sand into the leveling course.

2. Test Description

AFESC personnel conducted Test 4 in SCTF Test Pit 3. They placed a polyethylene sheet over the existing clay subgrade to prevent intrusion of the subgrade into the ballast rock base course and added 24 inches of ballast rock. Personnel placed a 4- to 5-inch layer of Number 7 crushed stone over the ballast rock to raise the test section level to approximately 6 inches below existing pavement. Test personnel leveled the crushed stone by hand with a screed beam before covering it with a polyethylene sheet. A dozer rigged with lifting hooks to fit the slab pickup points lifted each of the nine slabs and placed them on the test section, leaving spaces of approximately 1 1/2 inches between slabs. A RayGo® 410 vibratory roller applied one pass to seat each slab, traveling in the direction of loadcart traffic. Personnel shoveled blasting sand into the spaces between adjacent slabs and between slabs and test pit edges and then moistened the sand until near saturation. Data collectors measured and recorded the elevation of each slab corner and the elevation of the test pit edge at points where joints between slabs intersected. The F-4 loadcart applied 156 coverages to the test section using the distribution pattern shown in Figure 13. Data collectors measured the elevations of unloaded slab corners after 12, 24, 36, 48, 60, 72, 96, 132, and 156 loadcart coverages. The requirements for maintaining the repair were relative settlement of adjacent slab edges in excess of 1 1/2 inches, peak sag in excess of 3 inches, or peak upheaval greater than 1 1/2 inches. The test personnel maintained the repair by removing the slabs and the top polyethylene sheet, regrading the leveling course (adding material as necessary), replacing the slabs and the sheet, and refilling the joints with wet sand. Data collectors measured slab corner elevations prior to continuing traffic. The C-141 loadcart traffic applied to coverages after F-4 loadcart traffic using the same traffic distribution. Data collectors measured slab corner elevations after 10, 40, and 70 C-141 coverages.

3. Results

Personnel constructed the test section according to the test description, with each slab compacted with one pass of the RayGo® vibratory roller as scheduled. In addition, the roller applied two passes without vibration to Slabs 2 and 3. Slab 1 received a 15-second static application of the roller.

Slab 1, 4, and 7 settled excessively during compaction. Personnel removed these slabs, regraded the leveling course, replaced the slabs, placed wet sand in all joints, and measured the elevation of each slab corner to start the test. Test personnel did not apply any additional compaction over Slabs 1, 4, and 7.

During F-4 loadcart traffic, data collectors measured slab corner elevations after 12, 24, 36, 48, 60, 72, 96, 132, and 156 coverages to monitor settlement and to determine when repairs were needed. The recorded elevations during F-4 loadcart traffic are presented in Figure 57 to 68.

After 48 coverages, a significant rut had formed along the joint between Edge D and Edge E. Settlement at Edge D and at the north edge of Slab 7 exceeded the allowable slab-to-slab (between edges of adjacent slabs) or slab-to-edge (between a slab edge and the edge of the test pit) settlement of 1 1/2 inches. For this reason, personnel halted traffic, and maintained the repair by removing all slabs and the polyethylene sheet over the leveling course. They added Number 7 crushed stone to the leveling course, graded the leveling course, placed a new polyethylene sheet, replaced the slabs, and resumed traffic.

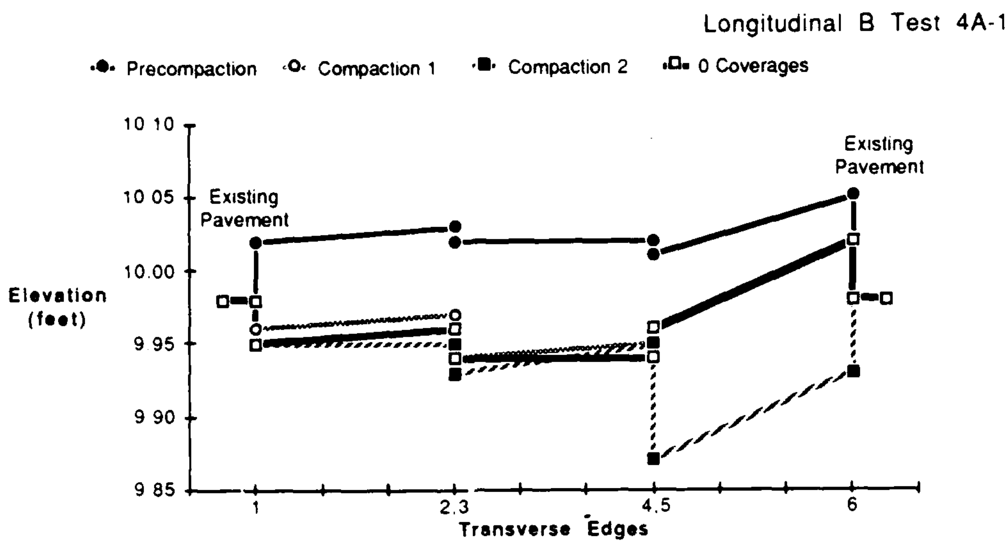

Figure 57. Slab Elevation Profiles Along Longitudinal Edge B, Test 4: 2-Meter Slabs - Compacted Ballast Rock Fill with Number 7 Leveling Course (Precompaction, Compaction Cycle 1, Compaction Cycle 2, and 0 F-4 Loadcart Coverages).

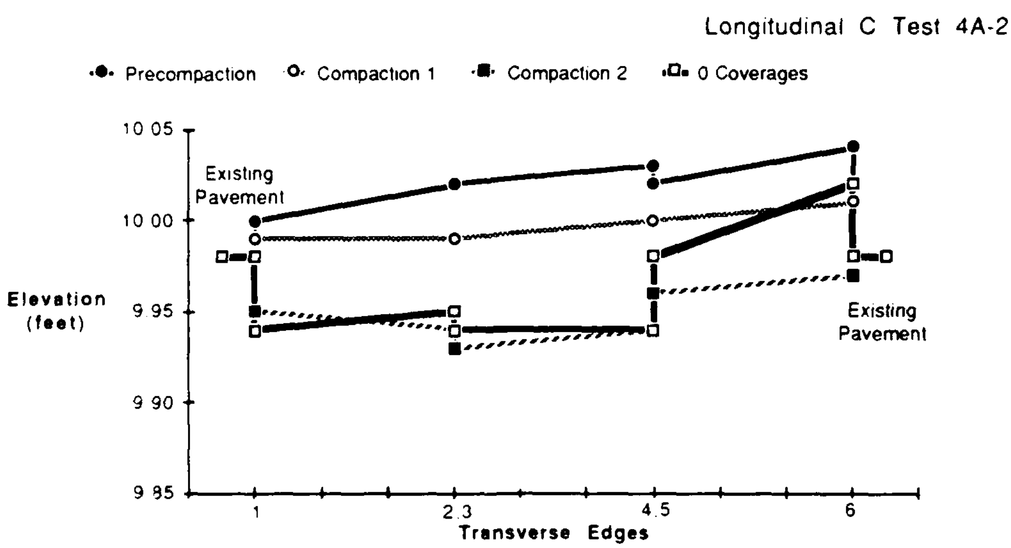

Figure 58. Slab Elevation Profiles Along Longitudinal Edge C, Test 4: 2-Meter Slabs - Compacted Ballast Rock Fill with Number 7 Leveling Course (Precompaction, Compaction Cycle 1, Compaction Cycle 2, and 0 F-4 Loadcart Coverages).

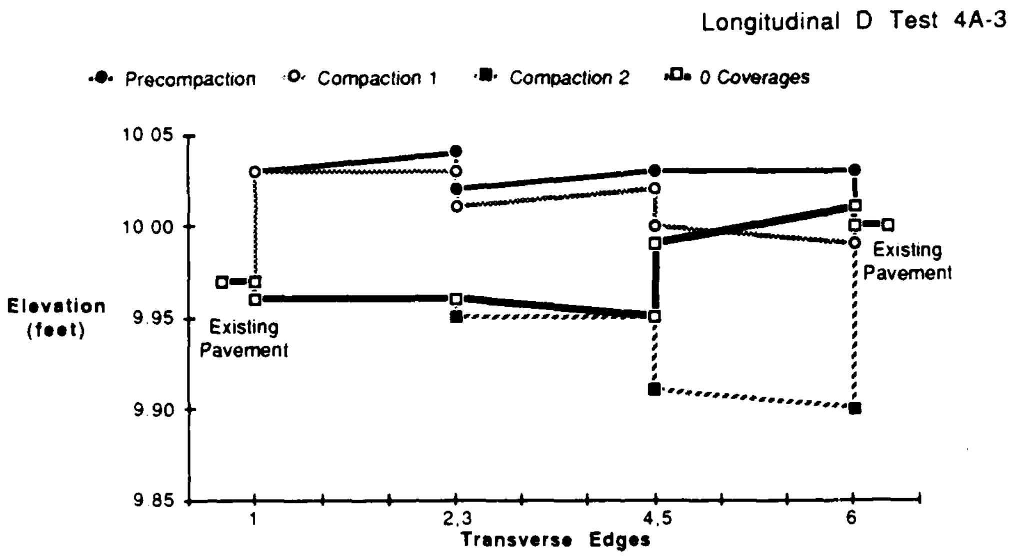

Figure 59. Slab Elevation Profiles Along Longitudinal Edge D, Test 4: 2-Meter Slabs - Compacted Ballast Rock Fill with Number 7 Leveling Course (Precompaction, Compaction Cycle 1, Compaction Cycle 2, and 0 F-4 Loadcart Coverages).

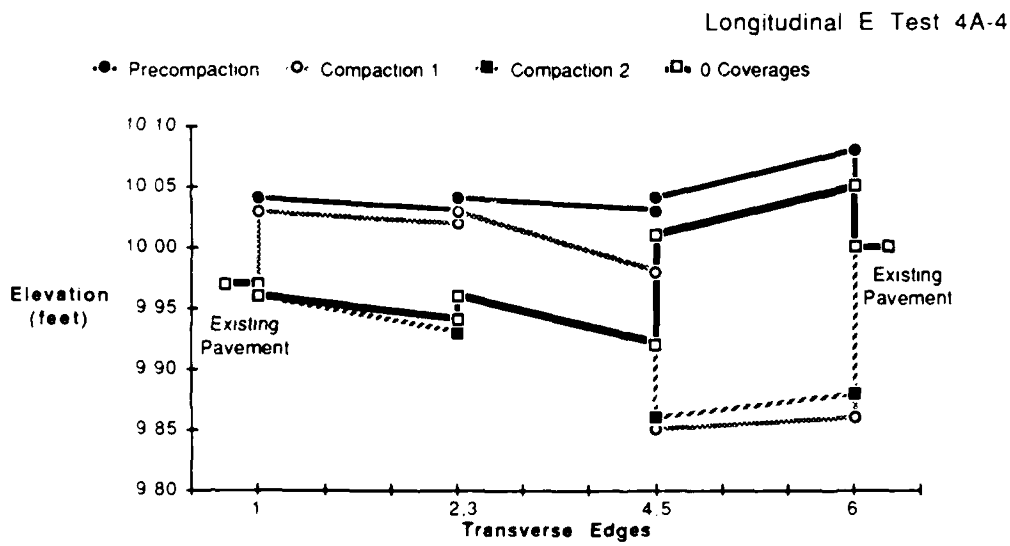

Figure 60. Slab Elevation Profiles Along Longitudinal Edge E, Test 4: 2-Meter Slabs - Compacted Ballast Rock Fill with Number 7 Leveling Course (Precompaction, Compaction Cycle 1, Compaction Cycle 2, and 0 F-4 Loadcart Coverages).

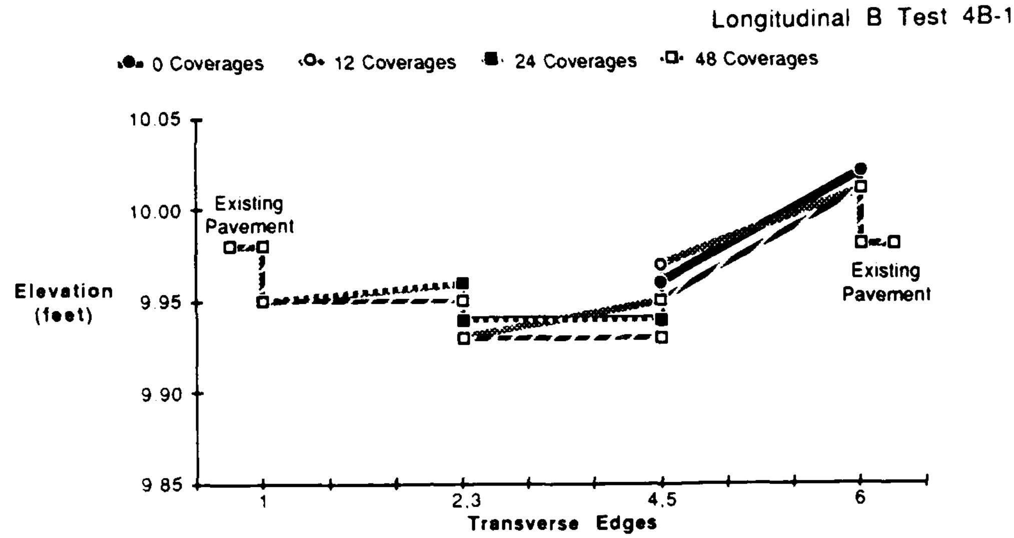

Figure 61. Slab Elevation Profiles Along Longitudinal Edge B, Test 4: 2-Meter Slabs - Compacted Ballast Rock Fill with Number 7 Leveling Course (0, 12, 24, and 48 F-4 Loadcart Coverages).

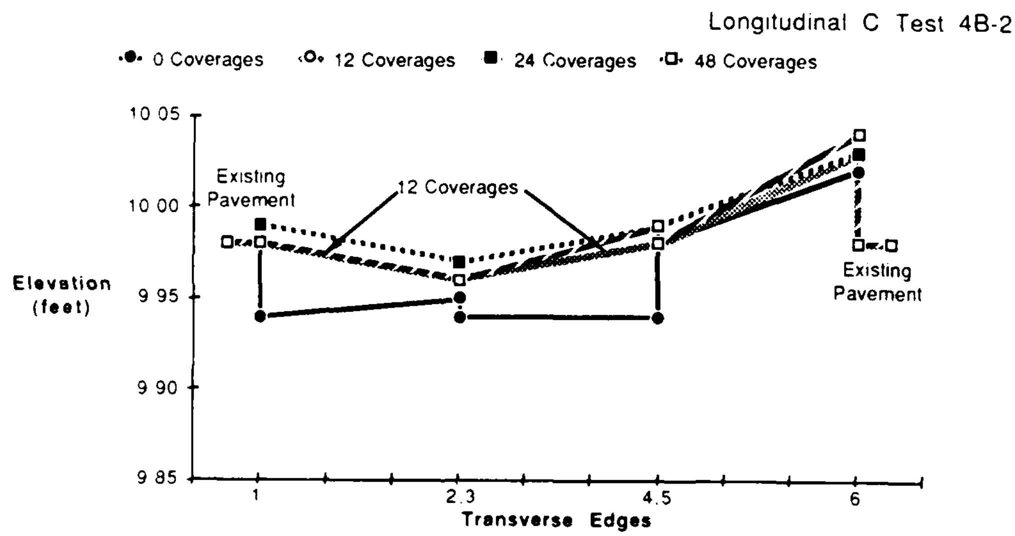

Figure 62. Slab Elevation Profiles Along Longitudinal Edge C, Test 4: 2-Meter Slabs - Compacted Ballast Rock Fill with Number 7 Leveling Course (0, 12, 24, and 48 F-4 Loadcart Coverages).

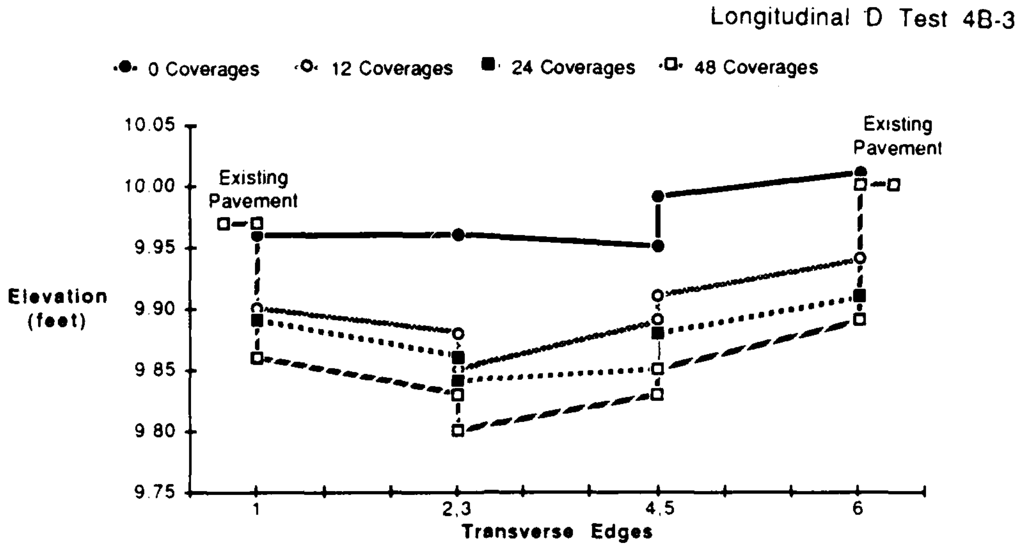

Figure 63. Slab Elevation Profiles Along Longitudinal Edge D, Test 4: 2-Meter Slabs - Compacted Ballast Rock Fill with Number 7 Leveling Course (0, 12, 24, and 48 F-4 Loadcart Coverages).

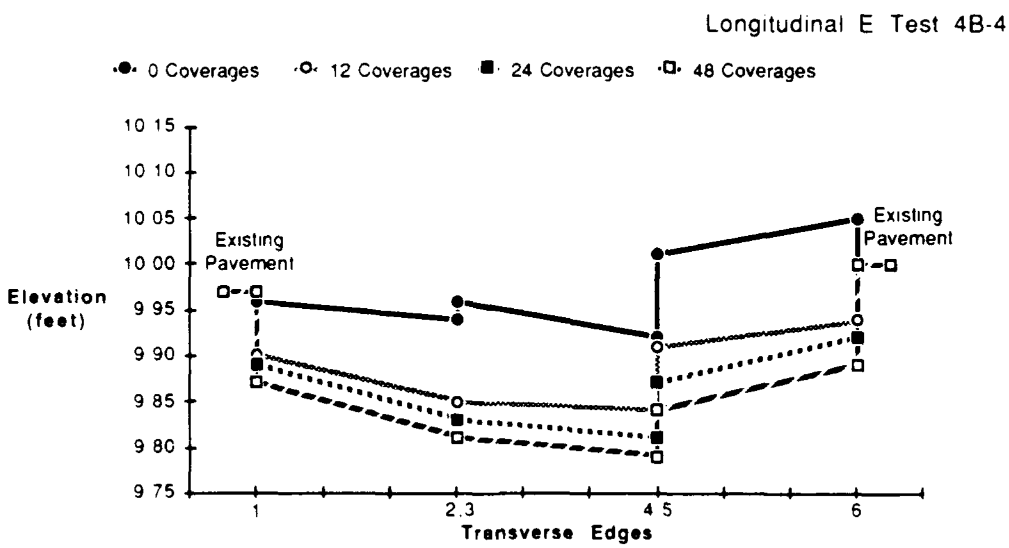

Figure 64. Slab Elevation Profiles Along Longitudinal Edge E, Test 4: 2-Meter Slabs - Compacted Ballast Rock Fill with Number 7 Leveling Course (0, 12, 24, and 48 F-4 Loadcart Coverages).

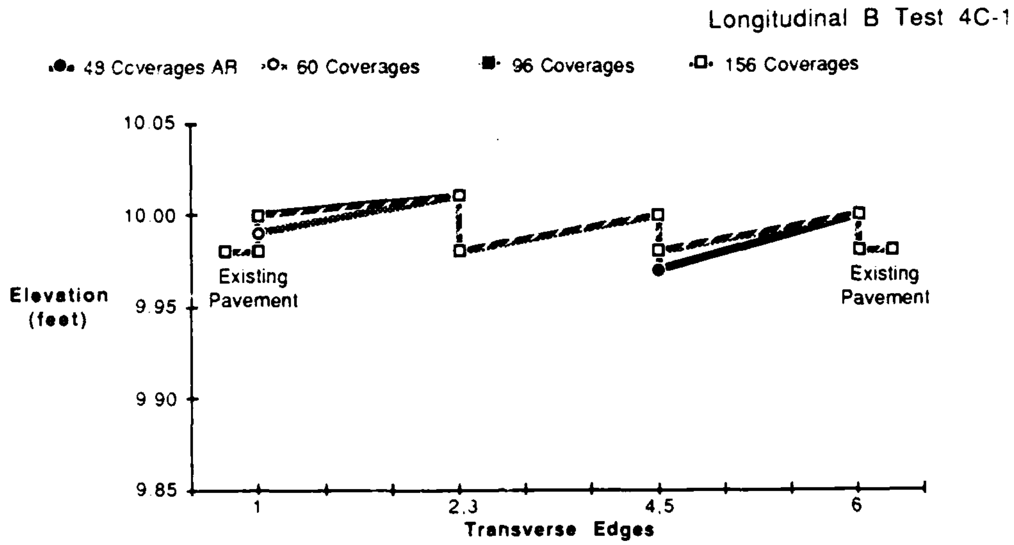

Figure 65. Slab Elevation Profiles Along Longitudinal Edge B, Test 4: 2-Meter Slabs - Compacted Ballast Rock Fill with Number 7 Leveling Course (48 After Repair, 60, 96, and 156 F-4 Loadcart Coverages).

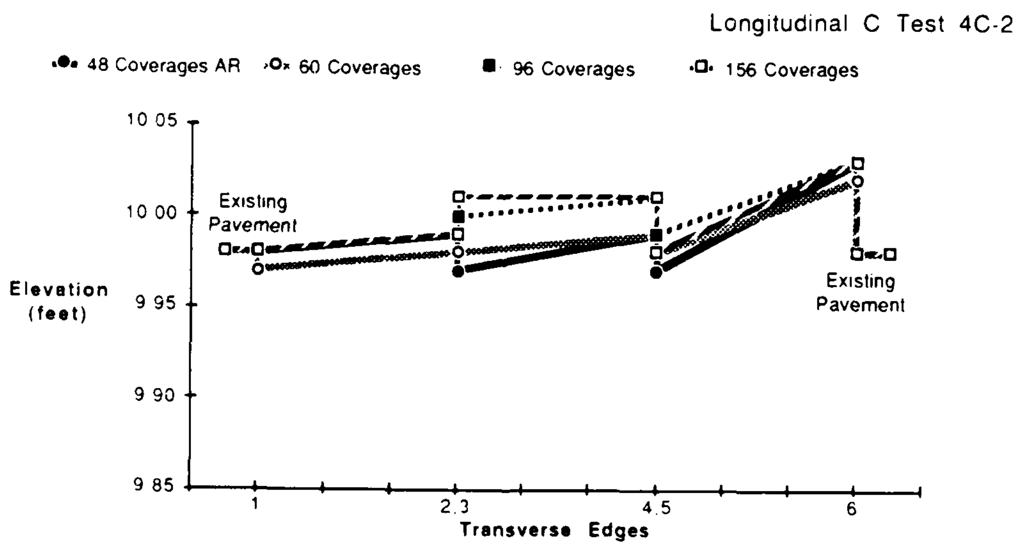

Figure 66. Slab Elevation Profiles Along Longitudinal Edge C, Test 4: 2-Meter Slabs - Compacted Ballast Rock Fill with Number 7 Leveling Course (48 After Repair, 60, 96, and 156 F-4 Loadcart Coverages).

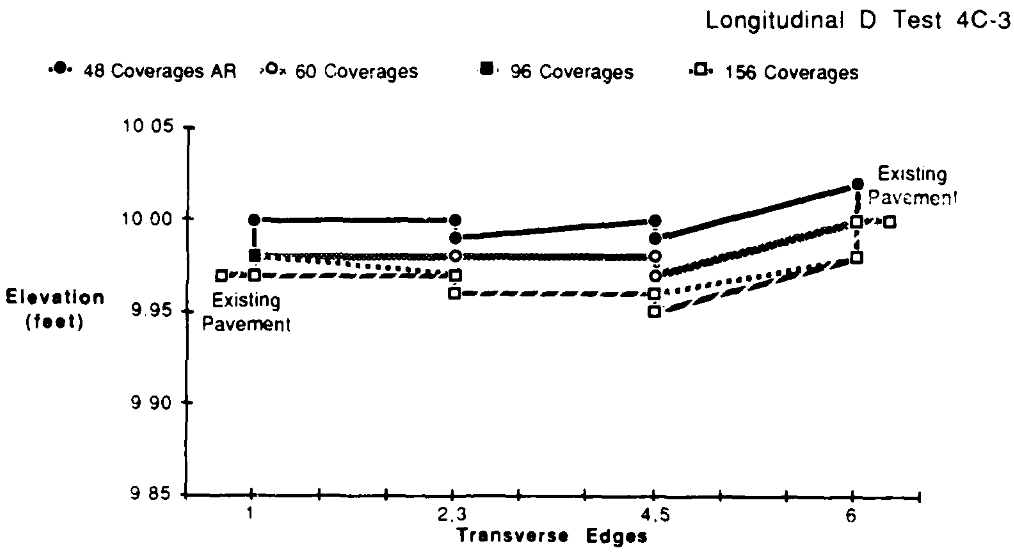

Figure 67. Slab Elevation Profiles Along Longitudinal Edge D, Test 4: 2-Meter Slabs - Compacted Ballast Rock Fill with Number 7 Leveling Course (48 After Repair, 60, 96, and 156 F-4 Loadcart Coverages).

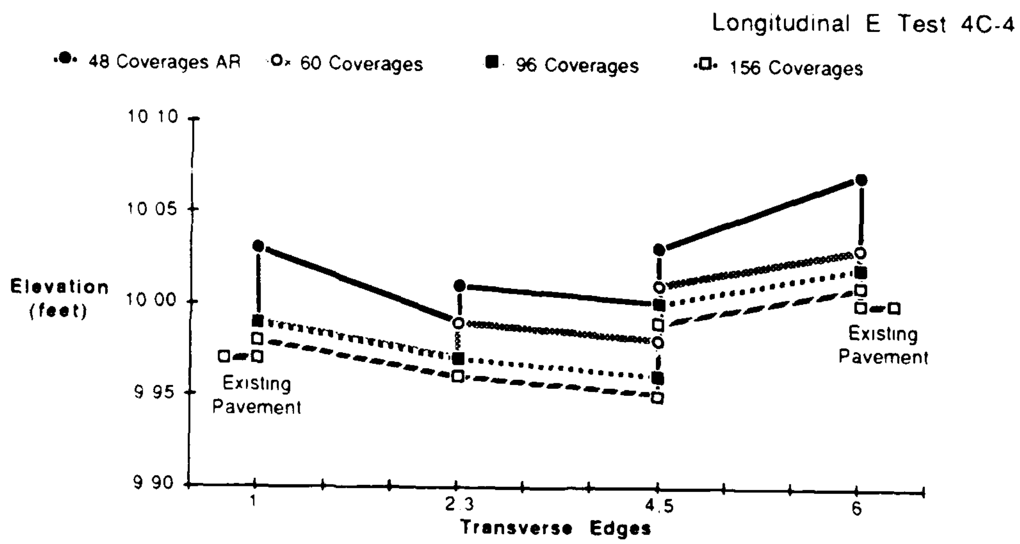

Figure 68. Slab Elevation Profiles Along Longitudinal Edge E, Test 4: 2-Meter Slabs - Compacted Ballast Rock Fill with Number 7 Leveling Course (48 After Repair, 60, 96, and 156 F-4 Loadcart Coverages).

Traffic continued until the scheduled 156 coverages had been applied. The test section required no further maintenance, and differential settlement did not exceed 1/4 inches between adjacent slabs or 1 1/4 inches between slabs and the edge of the test section. The wet sand in the joints settled between all slabs within 12 coverages of resuming traffic.

Personnel applied an additional 24 F-4 loadcart coverages to the test section after the scheduled 156 coverages had been applied. They applied the additional coverages using the normal pattern centered over Edge C in an effort to reduce the significant rocking experienced by Slabs 4, 5, and 6 during previous traffic. Figure 69(a) presents the elevations of the Edge D under two loading conditions before the additional 24 coverages were applied. The first loading condition consisted of parking the F-4 loadcart on a slab in the corner opposite the point of measurement, causing maximum uplift or rocking at the point of measurement. The second condition consisted of no load. As shown, the difference in elevations between loaded and unloaded conditions was 1 3/4 inches on Slab 6 and was greater than 3/4 inches for all points except the northeast corner of Slab 5. Figure 69(b) presents elevations at the same points for loaded and unloaded conditions after the 24 additional coverages were applied. As shown, the difference in elevation between loaded and unloaded conditions was reduced to approximately 1/2 to 3/4 inches.

After the F-4 loadcart coverages, personnel applied 70 coverages using the C-141 loadcart, measuring slab corner elevations after 10, 40, and 70 coverages Figures 70 to 73. All changes in elevation and settlements of adjacent slab edges were within allowable limits, so personnel performed no additional maintenance of the test section.

4. Conclusions

Test 4 tested precast slabs placed on 4 to 6 inches of Number 7 crushed stone on 24 inches of ballast rock, with polyethylene sheets between the clay subgrade and ballast rock and between the Number 7 aggregate and precast slabs. One pass of a vibratory roller settled the slabs prior to filling joints with wet blasting sand, and personnel applied additional nonvibrating roller applications to select slabs to determine if this will improve the performance under F-4 loadcart traffic over the previous uncompacted tests.

The roller application improved the performance of the repair under load by seating the slabs and providing some compaction of the underlying aggregate layers. Previous tests with no compaction required maintenance after 12, 24, and later coverages. This test required maintenance after 48 coverages and then performed adequately through 156 coverages of F-4 and 70 additional coverages of C-141 loadcart traffic. However, some slabs settled excessively during compaction, requiring maintenance before traffic could begin. Therefore, some consideration for initial slab displacement must still be made.

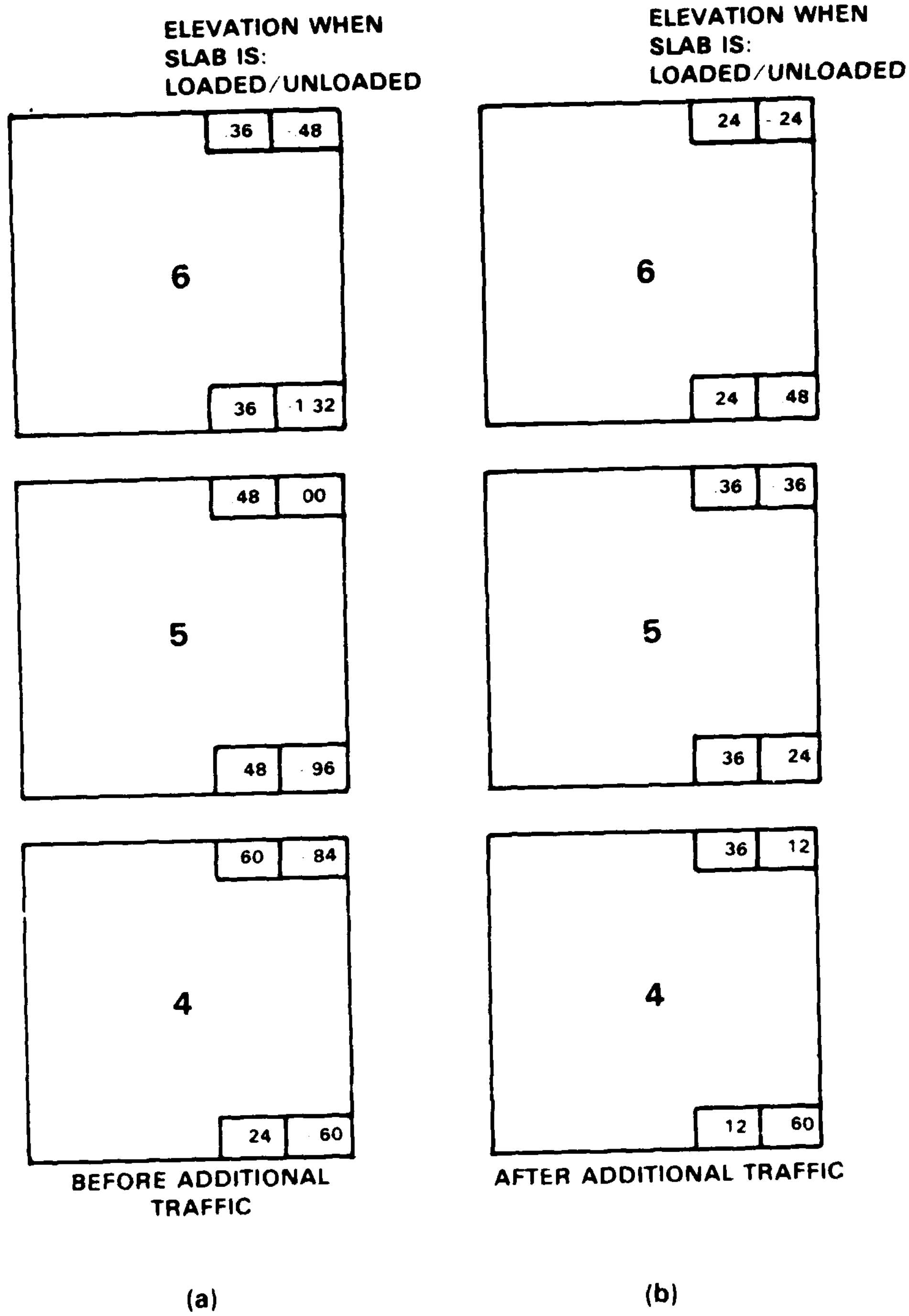

Figure 69. Slab Corner Elevations Under Static Load, Test 4.

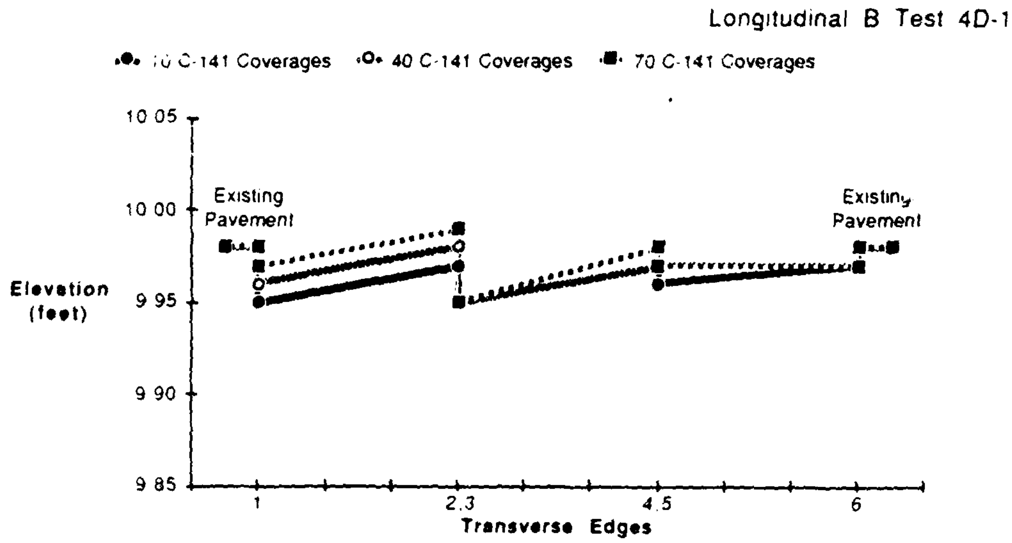

Figure 70. Slab Elevation Profiles Along Longitudinal Edge B, Test 4: 2-Meter Slabs - Compacted Ballast Rock Fill with Number 7 Leveling Course (10, 40, and 70 C-141 Loadcart Coverages).

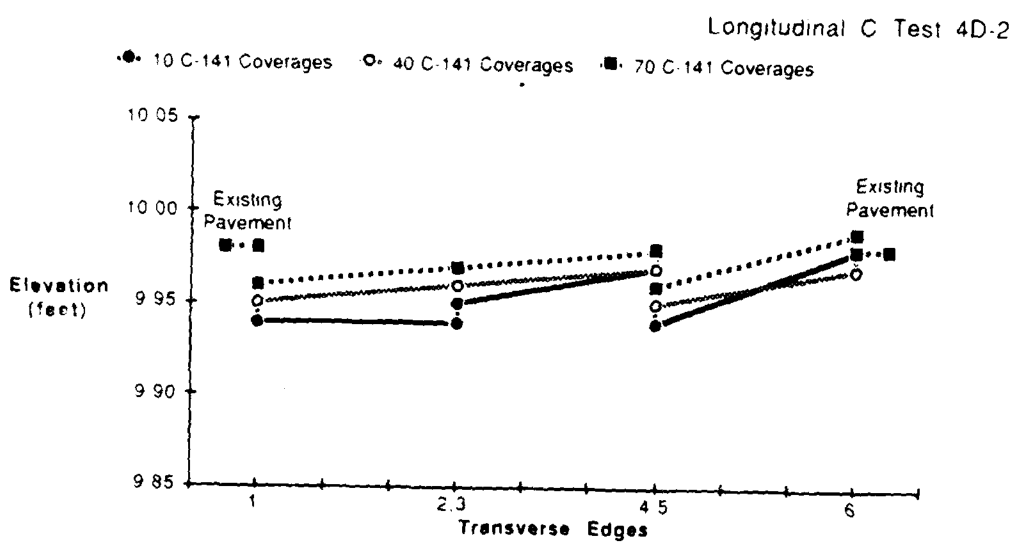

Figure 71. Slab Elevation Profiles Along Longitudinal Edge C, Test 4: 2-Meter Slabs - Compacted Ballast Rock Fill with Number 7 Leveling Course (10, 40, and 70 C-141 Loadcart Coverages).

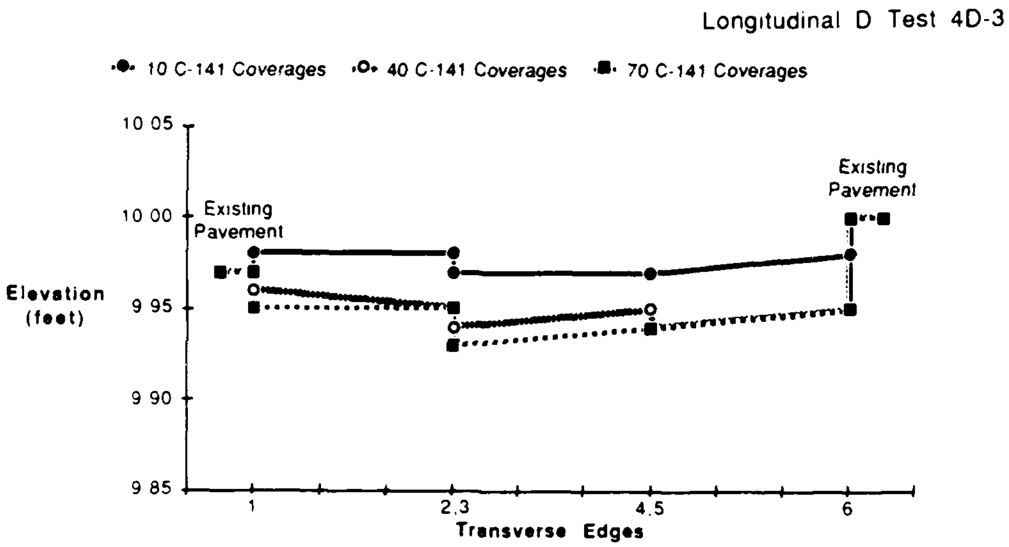

Figure 72. Slab Elevation Profiles Along Longitudinal Edge D, Test 4: 2-Meter Slabs - Compacted Ballast Rock Fill with Number 7 Leveling Course (10, 40, and 70 C-141 Loadcart Coverages).

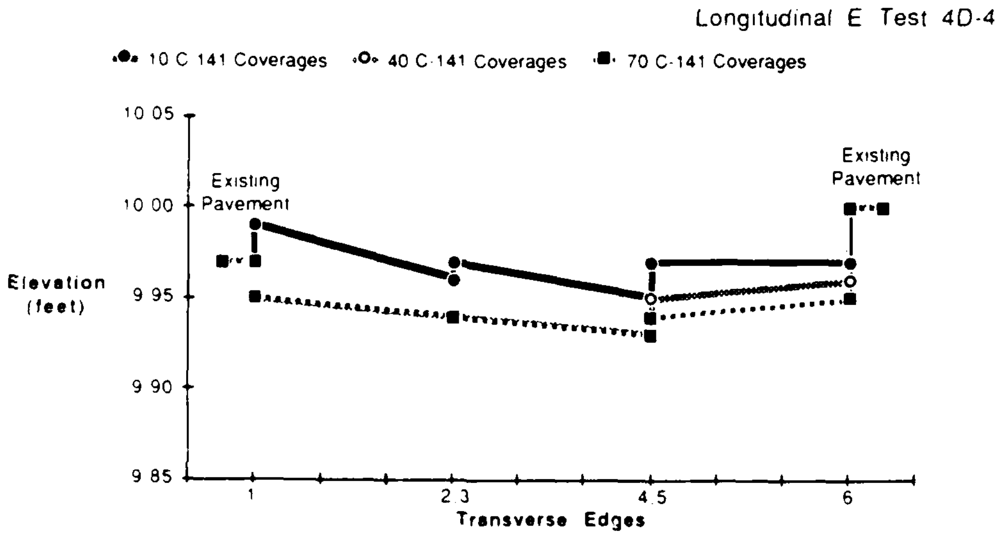

Figure 73. Slab Elevation Profiles Along Longitudinal Edge E, Test 4: 2-Meter Slabs - Compacted Ballast Rock Fill with Number 7 Leveling Course (10, 40, and 70 C-141 Loadcart Coverages).

The wet sand filler continued to migrate under the slabs during load applications; although, it was not lost to the base layer because of the polyethylene sheet. Lateral shifting of the slabs was therefore possible after no more than 12 loadcart coverages, and resistance to rocking was reduced.

Compaction should be performed on top of the leveling aggregate, bringing it to grade prior to placing the slabs. This will reduce the need to remove and replace the slabs prior to trafficking. The space between slabs should be minimized when using fine aggregate filler material.

F. TEST 5: 2-METER SLAB TEST (COMPACTION, JOINT FILLER TESTING)

1. Introduction

This test assessed the ability of sand, used as joint filler, to reduce slab movement during loadcart traffic. The assessment compared the traffic performance of a half test section with sand-filled joints and a half with unfilled open joints.

2. Test Description

AFESC personnel conducted this test in SCTF Test Pit 3 by placing and screeding a 2- to 3-inch layer of Number 7 aggregate (leveling material B) over a ballast rock base course to raise the level of the test section to approximately 4 1/2 inches below the edge of the test pit. Placement of 2- by 6-inch wood boards over the leveling course around the north, south, and west perimeter of the test section reduced the outside dimensions of the test section. Personnel placed nine precast reinforced concrete slabs over the leveling course. The 2-meter square slabs rested approximately 1 1/2 inches above the edge of the test pit after placement. Data collectors recorded slab corner elevations as in previous tests before personnel compacted the test section as necessary to seat the slabs. The compactor plate seated Slabs 1, 4, and 7 while six passes of the vibratory roller seated Slabs 2, 5, and 8, and two passes of the roller seated Slabs 3, 6, and 9. The compactor plate also compacted Slab 8. Following compaction, personnel shifted the slabs using shovels to create 1/4-inch joints slabs. Personnel filled the large spaces between outer slabs and the previously placed 2- by 6-inch boards with 2- by 4-inch boards. Data collectors recorded slab corner elevations after positioning slabs and placing the wood boards. Personnel filled the joints in the south half of the test section (Figure 74) with packed wet sand and left the joints in the north half open.

The F-4 loadcart trafficked the test section with 60 coverages using the standard F-4 traffic distribution. The loadcart operation is centered 30 coverages over the north half and 30 coverages over the south half of the test pit. Data collectors measured and recorded slab corner elevations after 12, 24, 36, 48, and 60 loadcart coverages. Data collectors paid special attention to rocking and general movement of the slabs

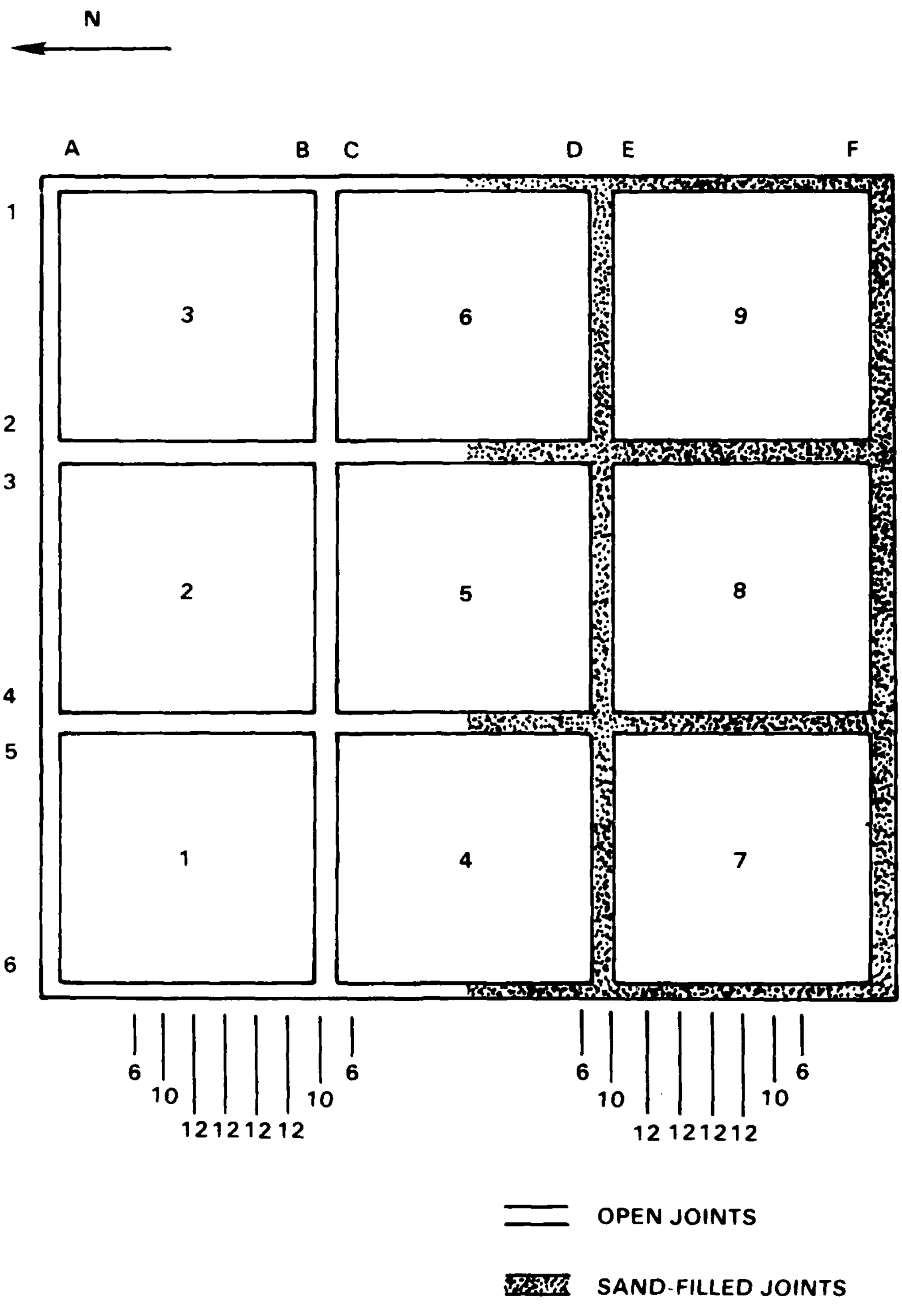

Figure 74. Plan of Test Section, Test 5: 2-Meter Slabs (Compaction, Joint Filler Testing).

during trafficking to allow comparison of performance of the two joint fill conditions.

3. Results

Slab elevations prior to traffic and after 12, 24, 36, 48, and 60 F-4 loadcart coverages are presented in Figures 75 to 82. All settlements were within allowable limits; therefore, no maintenance of the test section was required during the test.

After 48 loadcart coverages, data collectors noted slight shifting of the slabs. The shifting caused complete closing of several joints while others expanded up to 5/8 inch (Figure 83). Personnel observed no significant difference in slab shifting between the sand-filled joint areas and the unfilled joint areas, and the sand filler appeared to have little effect on slab settlement as both halves of the test section settled approximately the same amount. The average slab corner settlement in the joint-filled half of the section was 0.61 inches while the average settlement in the open joint half of the section was 0.70 inches.

4. Conclusions

Test 5 tested slabs placed on 2 to 3 inches of Number 7 aggregate over ballast rock, with 1/4-inch joints half of which were filled with wet sand and the other half unfilled, to assess the ability of sand to reduce slab movement during trafficking. The sand filler provided no significant improvement over unfilled joints with respect to lateral shifting of the slabs or slab settlement.

The closer spacing of the slabs (compared to 1 1/2-inch joints in earlier tests) limited the slab movement, although slabs this close together must be capable of contacting adjacent slabs without incurring damage.

G. TEST 6: 3-METER SLAB TEST (UNCOMPACTED BALLAST ROCK FILL WITH NUMBER 57 LEVELING COURSE)

1. Introduction

This test evaluated the performance of larger precast reinforced concrete slabs under F-4 and C-141 loadcart traffic. Test personnel compared performance of 3-meter square slabs to the 2-meter slabs of previous tests.

2. Test Description

AFESC personnel enlarged the dimensions of SCTF Test Pit 1 to 17.5 by 17.5 feet for this test. The subgrade CBR ranged from 4 to 8. Test personnel constructed the test section with a 2- to 4-inch leveling course of Number 57 crushed stone over a ballast rock base. Personnel

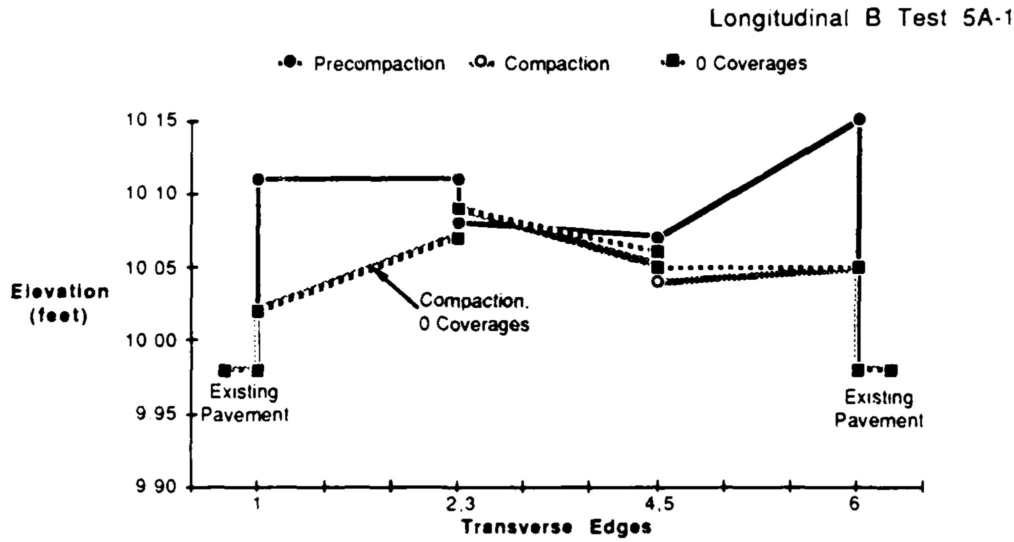

Figure 75. Slab Elevation Profiles Along Longitudinal Edge B, Test 5: 2-Meter Slabs - Compaction, Joint Filler Testing (Pre-compaction, Compaction, and 0 F-4 Loadcart Coverages).

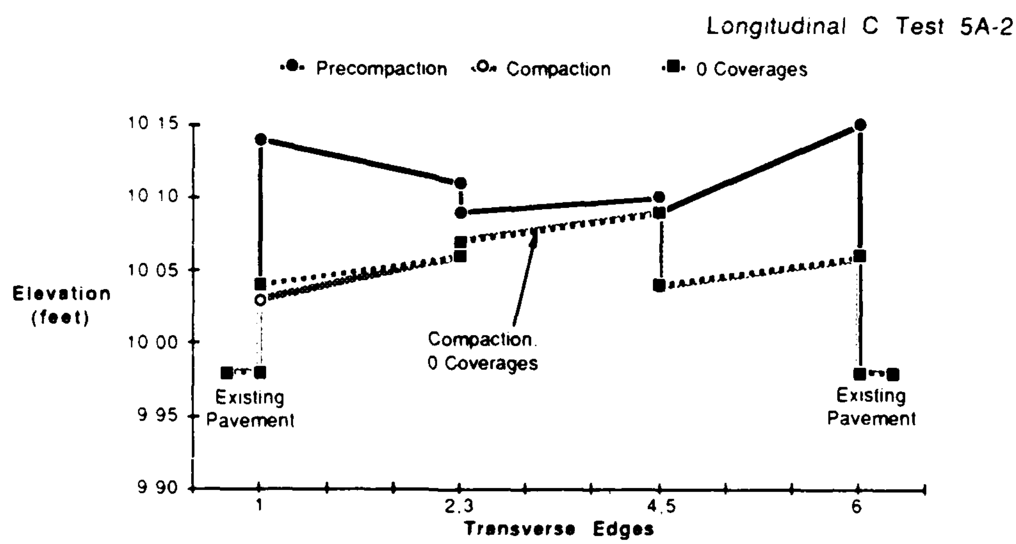

Figure 76. Slab Elevation Profiles Along Longitudinal Edge C, Test 5: 2-Meter Slabs - Compaction, Joint Filler Testing (Pre-compaction, Compaction, and 0 F-4 Loadcart Coverages).

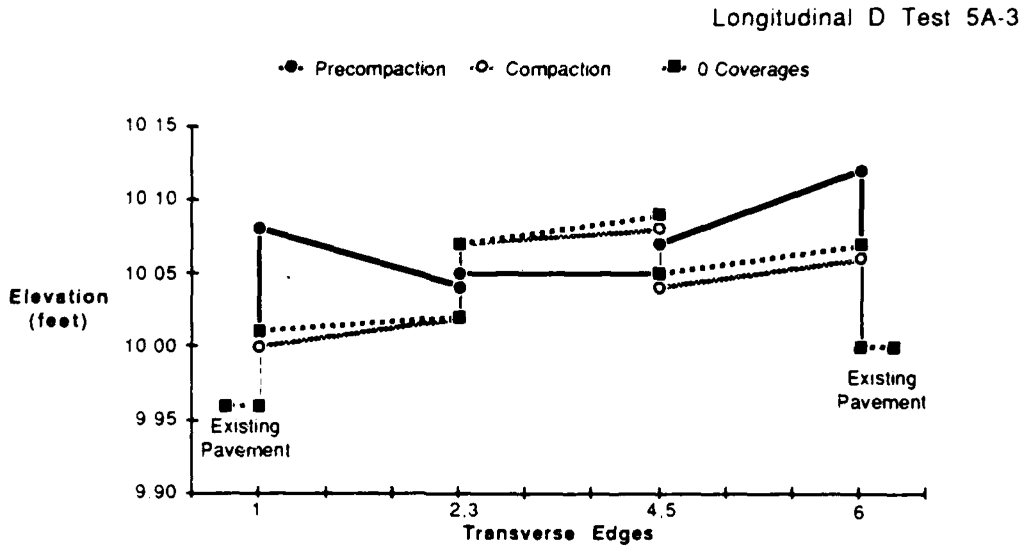

Figure 77. Slab Elevation Profiles Along Longitudinal Edge D, Test 5: 2-Meter Slabs - Compaction, Joint Filler Testing (Precompaction, Compaction, and 0 F-4 Loadcart Coverages).

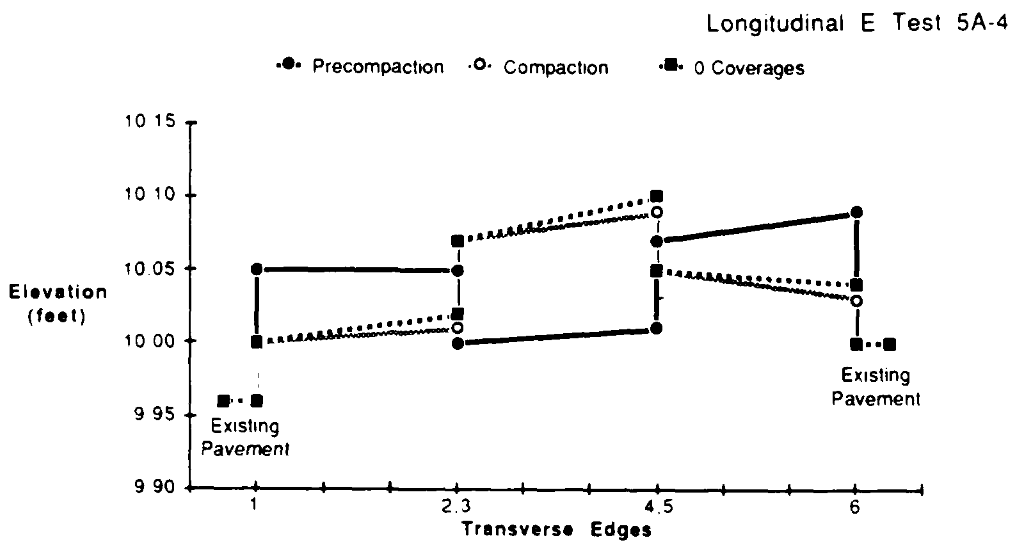

Figure 78. Slab Elevation Profiles Along Longitudinal Edge E, Test 5: 2-Meter Slabs - Compaction, Joint Filler Testing (Precompaction, Compaction, and 0 F-4 Loadcart Coverages).

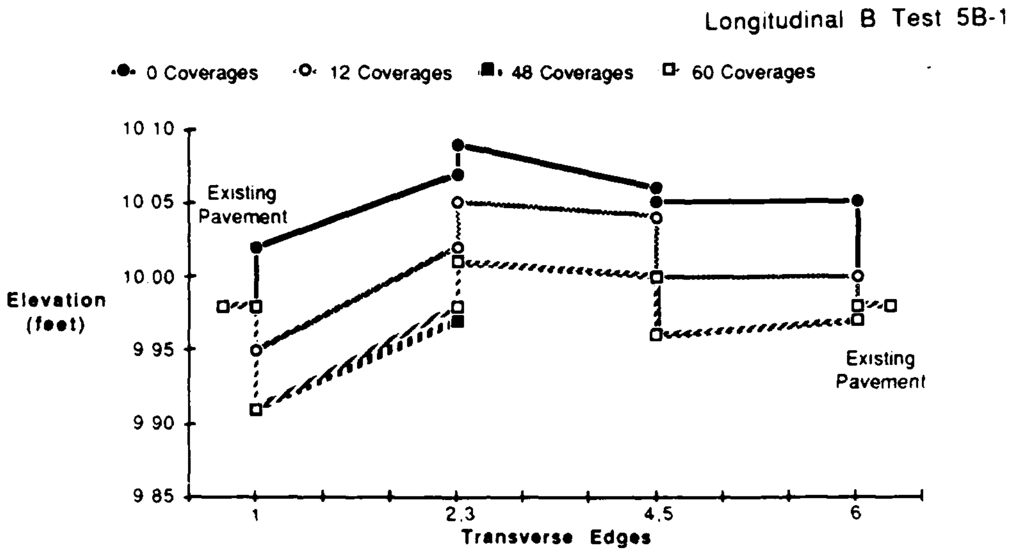

Figure 79. Slab Elevation Profiles Along Longitudinal Edge B, Test 5: 2-Meter Slabs - Compaction, Joint Filler Testing (0, 12, 48, and 60 F-4 Loadcart Coverages).

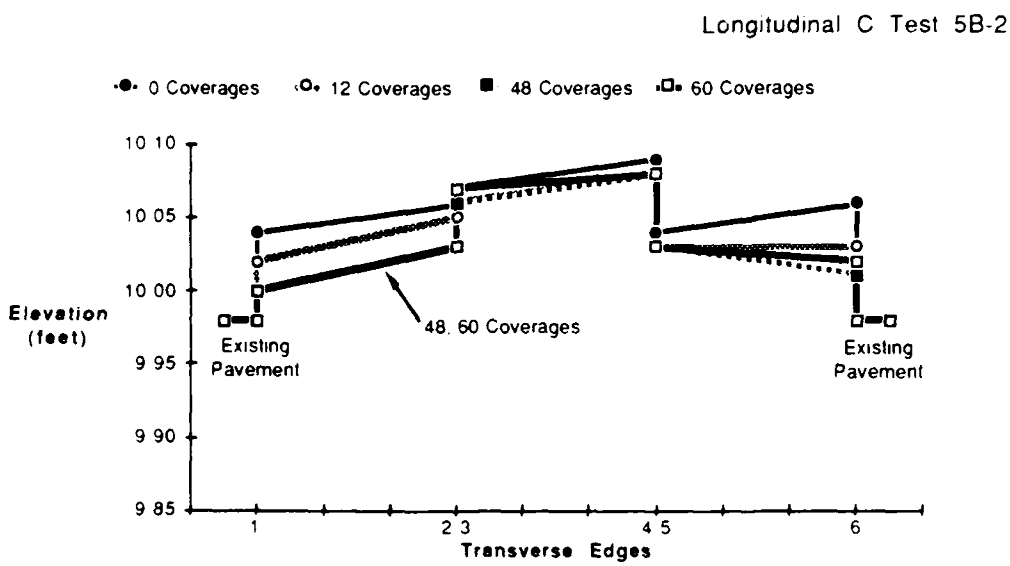

Figure 30. Slab Elevation Profiles Along Longitudinal Edge C, Test 5: 2-Meter Slabs - Compaction, Joint Filler Testing (0, 12, 43, and 60 F-4 Loadcart Coverages).

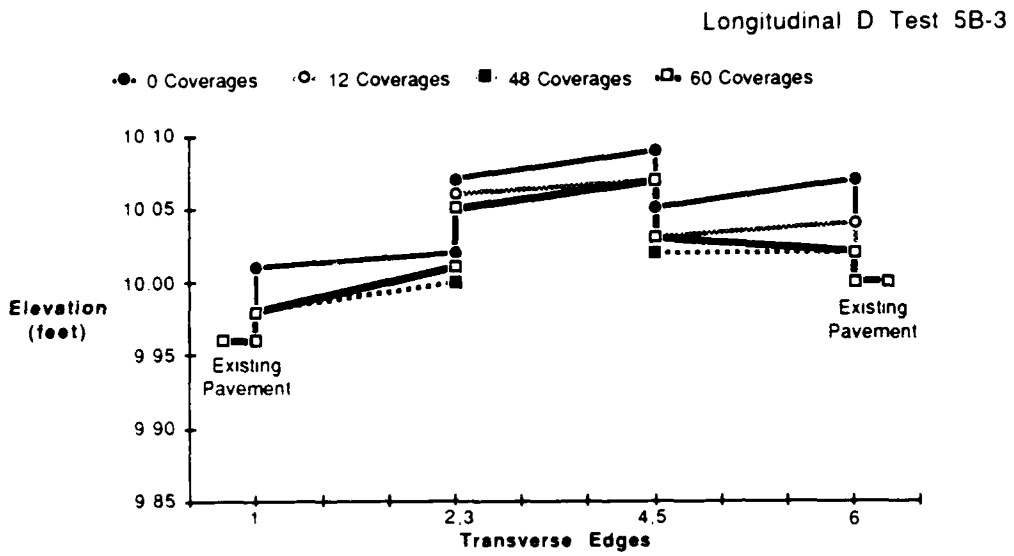

Figure 31. Slab Elevation Profiles Along Longitudinal Edge D, Test 5: 2-Meter Slabs - Compaction, Joint Filler Testing (0, 12, 48, and 60 F-4 Loadcart Coverages).

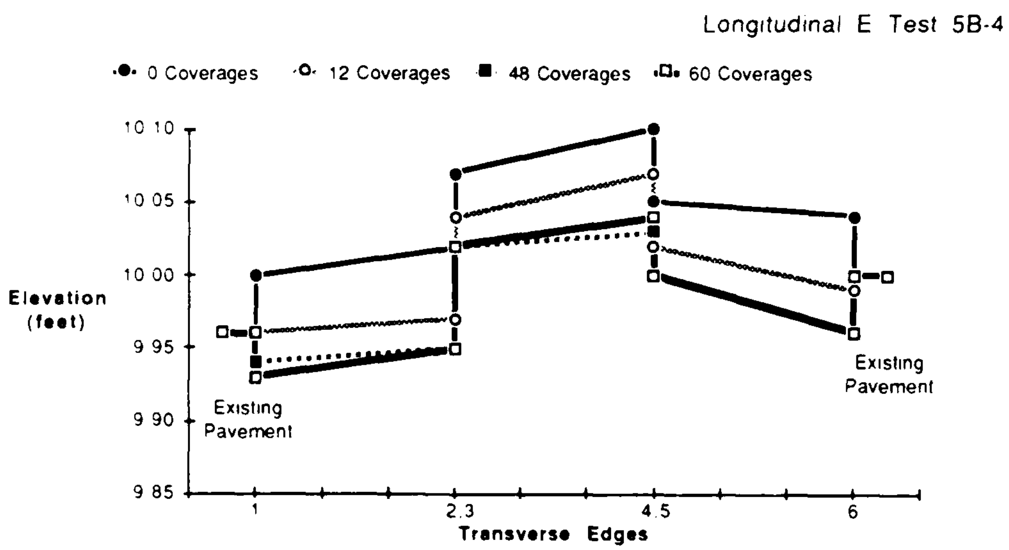

Figure 32. Slab Elevation Profiles Along Longitudinal Edge E, Test 5: 2-Meter Slabs - Compaction, Joint Filler Testing (0, 12, 48, and 60 F-4 Loadcart Coverages).

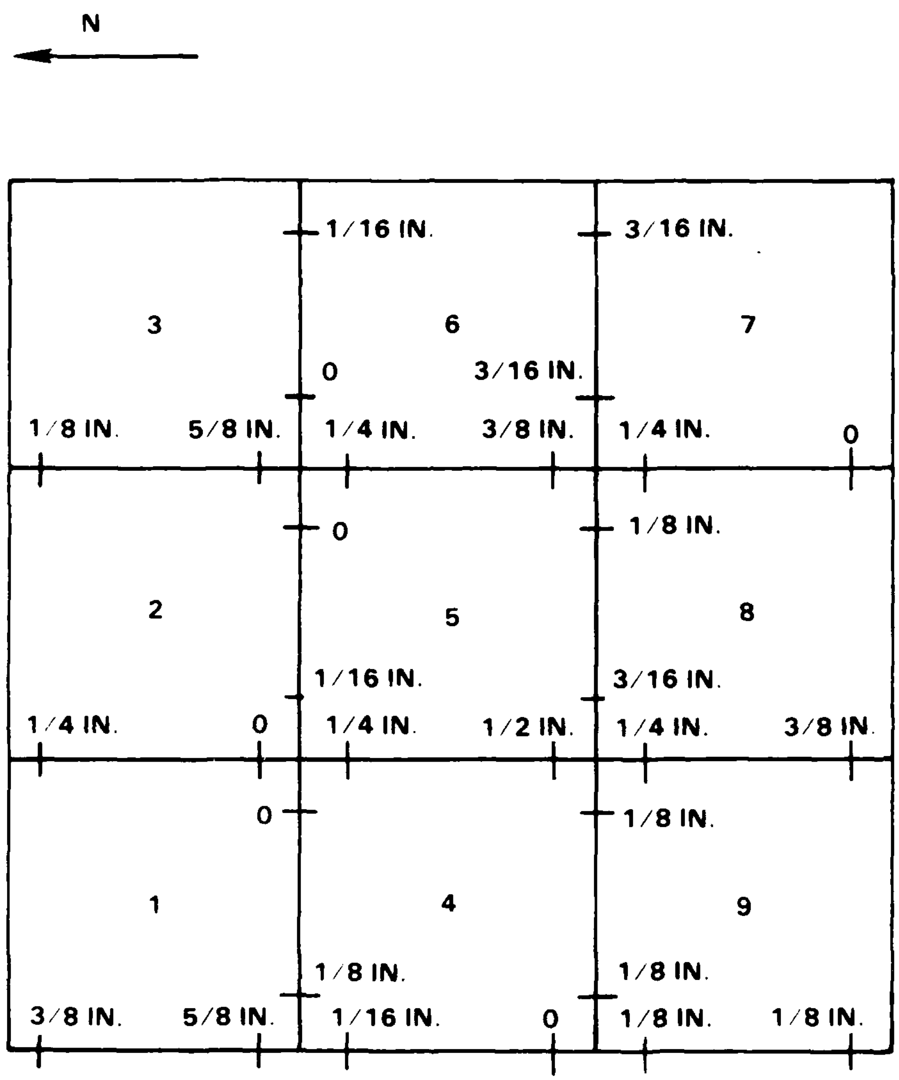

Figure 83. Joint Spacing after 48 F-4 Loadcart F-4 Loadcart Coverages Test 5.

placed four 8-foot 8-inch square by 8-inch thick precast reinforced concrete slabs over the leveling course, leaving joints approximately 1/2 inch wide between the slabs. Test personnel filled the joints with Number 7 crushed stone to reduce slab movement during traffic.

Data collectors recorded slab corner elevations after placement, and the F-4 loadcart applied 156 coverages to the test section according to the traffic distribution pattern in Figure 13 (Section II). Data collectors measured slab corner elevations after 12, 24, 72, 108, 132, and 156 coverages. The settlement failure criteria was as defined in Test 2. Following F-4 traffic, the C-141 loadcart applied 70 coverages according to the pattern in Figure 84.

3. Results

Personnel constructed and trafficked the test section as planned. Initial slab elevations and elevations after 12, 24, 72, 108, 132, and 156 coverages are presented in Figures 85 and 86 for F-4 loadcart traffic.

As shown in the figures, the maximum change in elevation of a slab corner occurred at the southeast corner of Slab 1 and was approximately 1 1/2 inches. After 84 coverages, cracks appeared in the southeast corner (D1) of Slab 1 and the northeast corner (A3) of Slab 3. Cracking continued during the remaining traffic but did not result in complete corner breaks in the slabs. Personnel performed no maintenance during trafficking.

After the scheduled 156 F-4 loadcart coverages were applied, personnel applied an additional 60 coverages to Slabs 1 and 2, according to the distribution pattern in Figure 84, to lower the north half (Line C) of Slab 1 and 2 and reduce the rocking of the individual slabs. Elevation measurements before and after application of the additional coverages show that rocking of both slabs was reduced during the traffic (Figures 87 and 88).

Following the application of the additional F-4 traffic, personnel interrupted the test to conduct the dynamic load testing (Test 7). They applied the C-141 loadcart traffic scheduled for Test 6 after the dynamic load testing. Figures 89 and 90 present slab elevations at the beginning of C-141 traffic and after 10, 40, and 70 coverages. Significant settlement, exceeding 2 inches in Slab 4, occurred along the central longitudinal joint. Despite the excessive settlement, personnel conducted no maintenance but continued traffic until 70 coverages had been applied.

4. Conclusions

Test 6 tested 3-meter precast concrete slabs on 4 to 6 inches of Number 57 crushed stone over ballast rock, with 1/2-inch joints filled with Number 7 aggregate, to assess the performance of larger slabs. Cracking

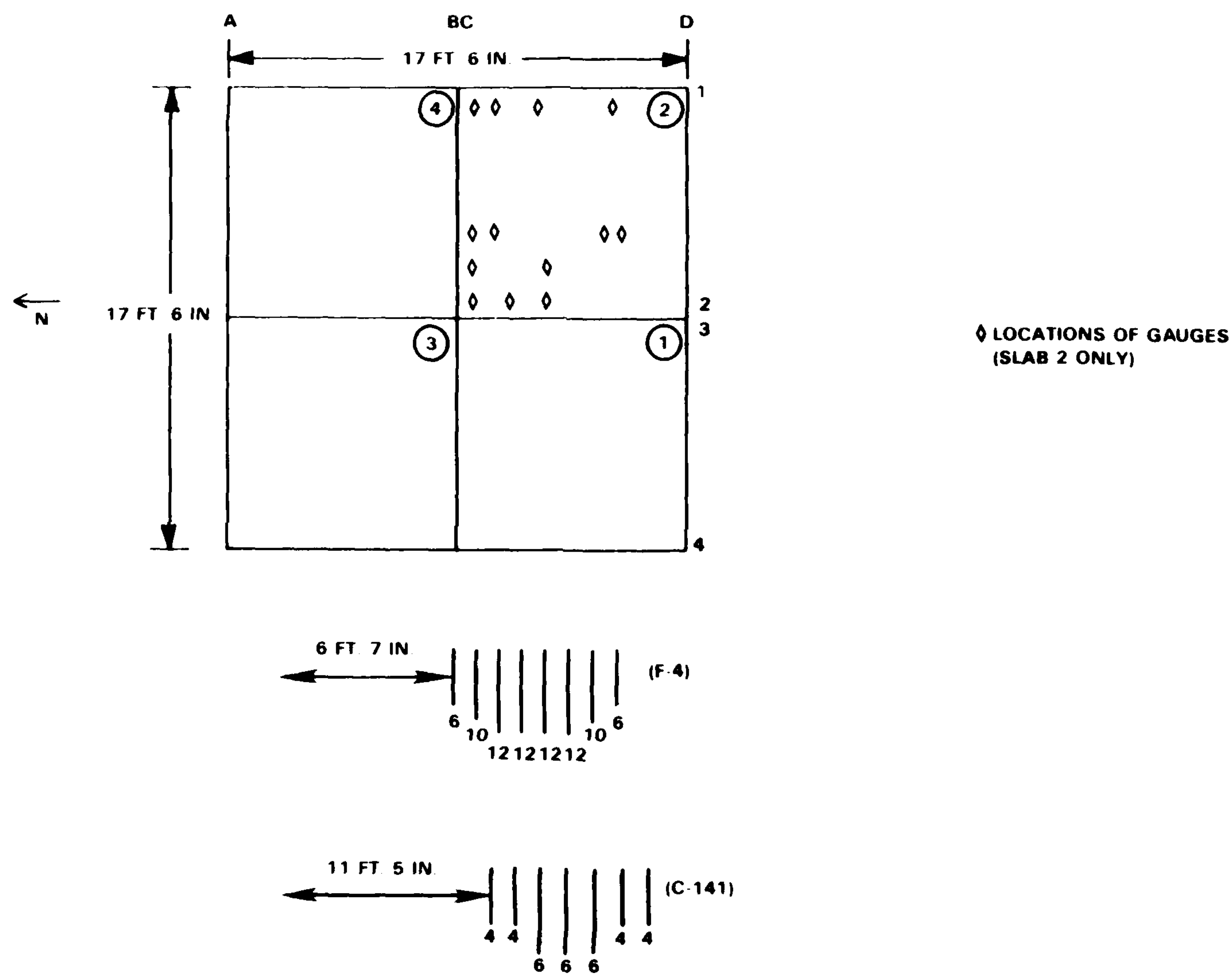

Figure 84. Plan of Test Section, Test 6: 3-Meter Slabs (Uncompacted Ballast Rock Fill over Number 57 Leveling Course).

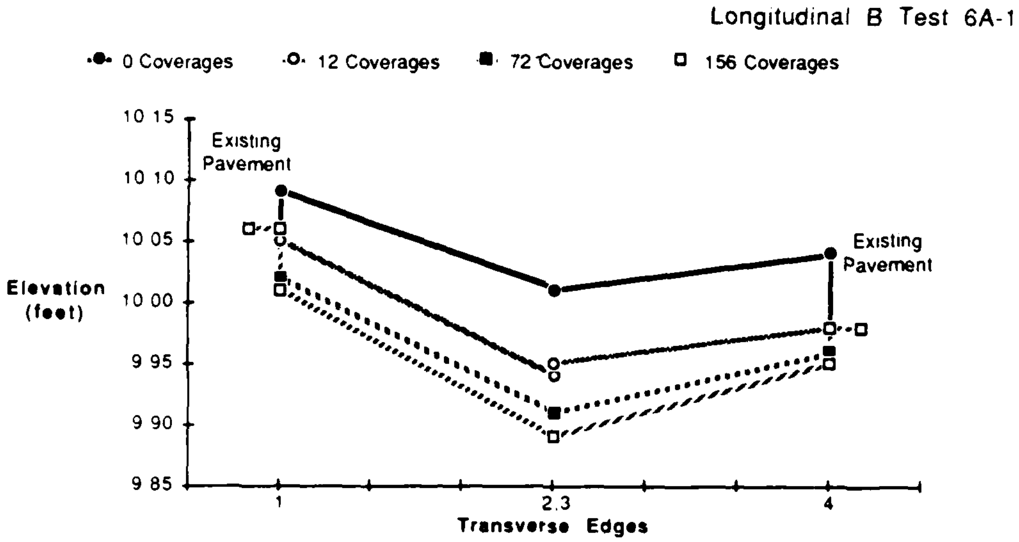

Figure 35. Slab Elevation Profiles Along Longitudinal Edge B, Test 6: 3-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (0, 12, 72, and 156 F-4 Loadcart Coverages).

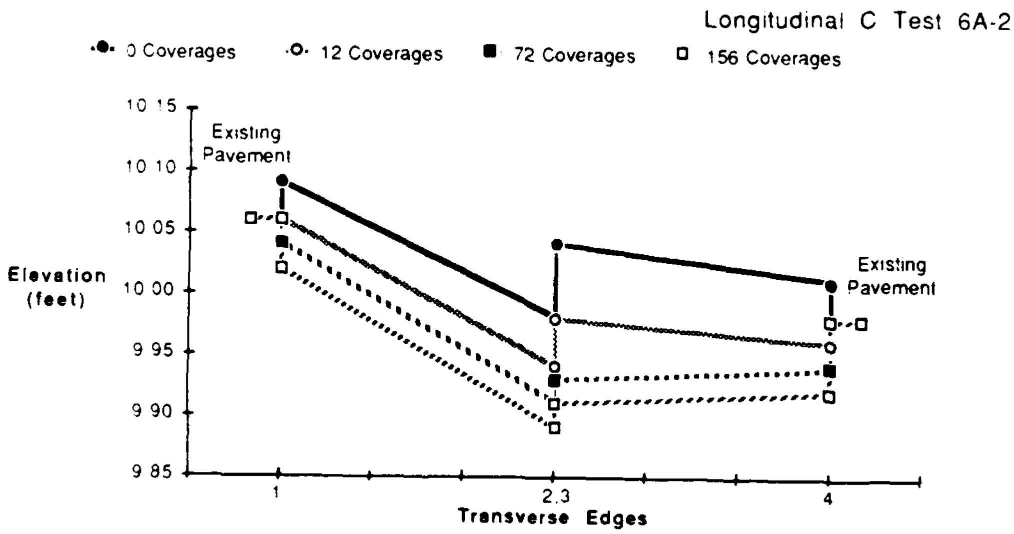

Figure 36. Slab Elevation Profiles Along Longitudinal Edge C, Test 6: 3-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (0, 12, 72, and 156 F-4 Loadcart Coverages).

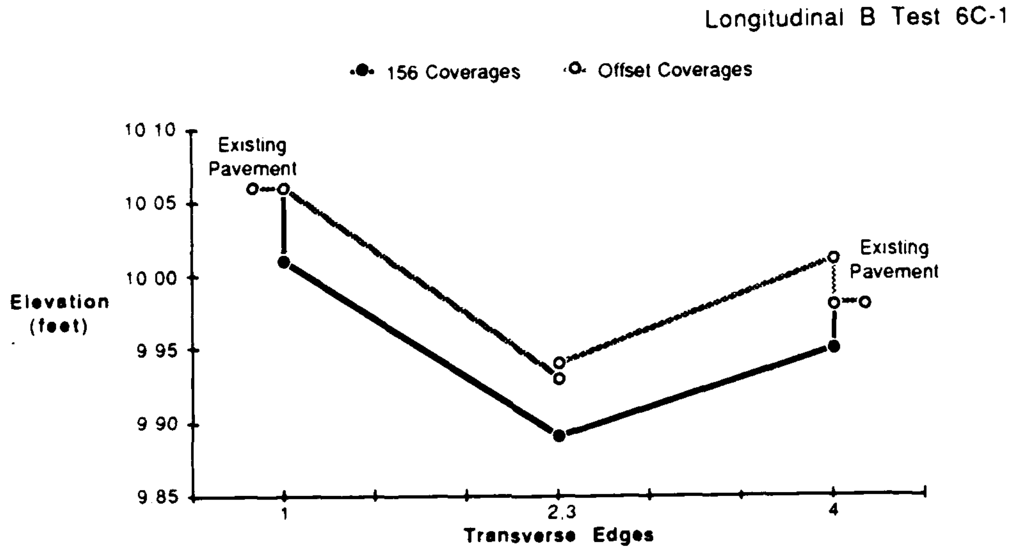

Figure 37. Slab Elevation Profiles Along longitudinal Edge B, Test 6: 3-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (Before and after Offset F-4 Loadcart Coverages).

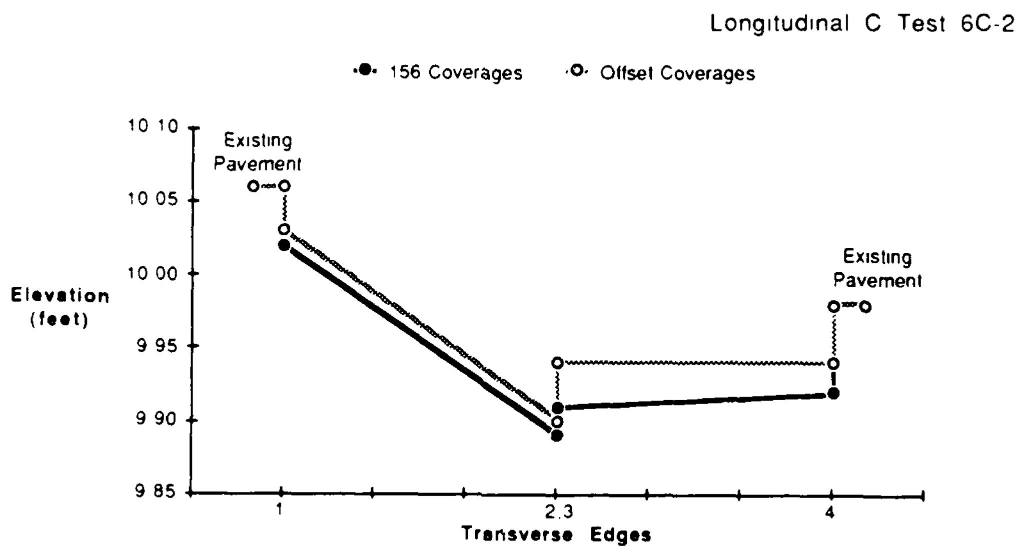

Figure 38. Slab Elevation Profiles Along longitudinal Edge C, Test 6: 3-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (Before and after Offset F-4 Loadcart Coverages).

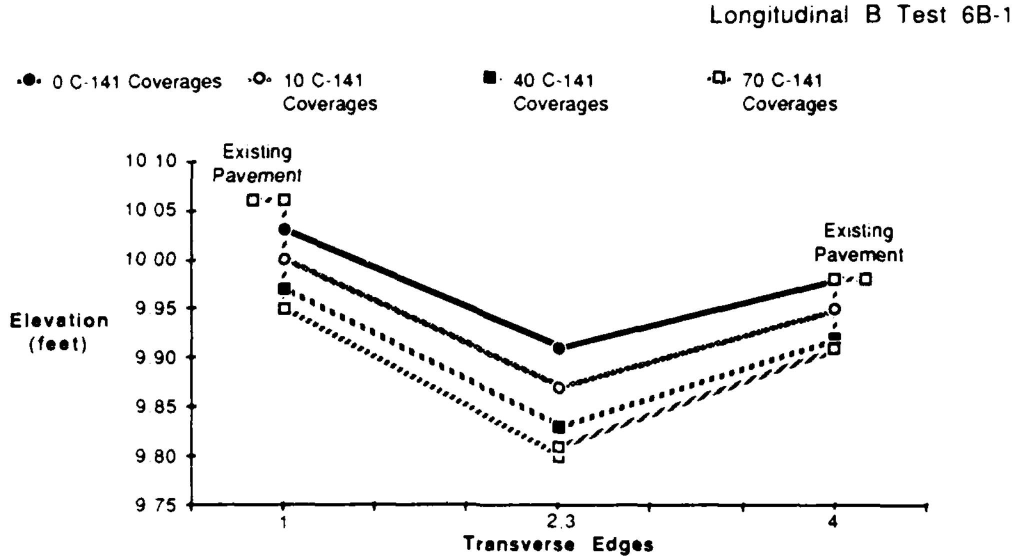

Figure 89. Slab Elevation Profiles Along Longitudinal Edge B, Test 6: 3-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (0, 10, 40, and 70 C-141 Loadcart Coverages).

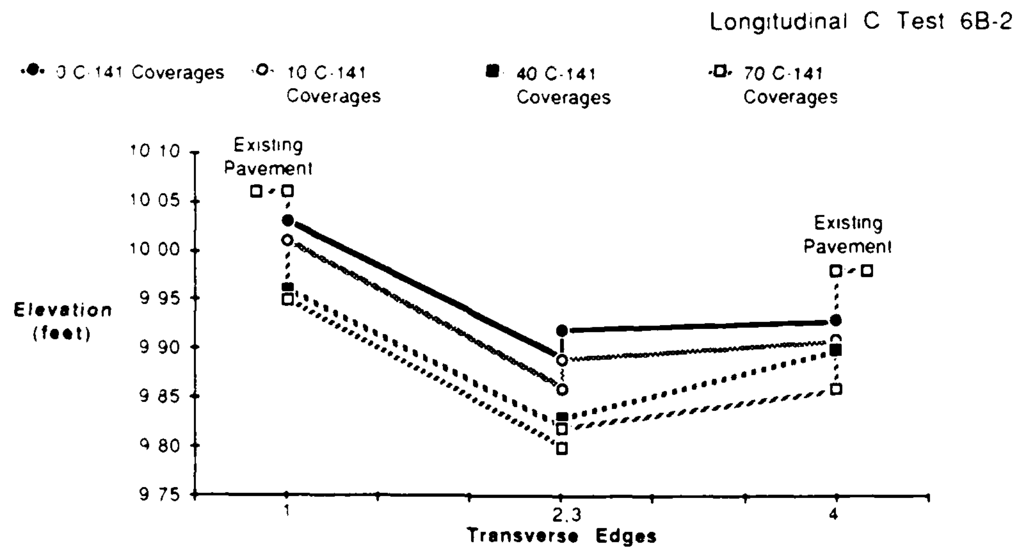

Figure 90. Slab Elevation Profiles Along Longitudinal Edge C, Test 6: 3-Meter Slabs - Uncompacted Ballast Rock Fill with Number 57 Leveling Course (0, 10, 40, and 70 C-141 Loadcart Coverages).

occurred in the corners of some slabs, although there were no complete corner breaks. The settlement of the 3-meter slabs from loading does not appear significantly different from the settlement experienced by 2-meter slabs, although direct comparison is not possible. It is concluded from this test that the 3-meter slabs would not be adequate for the given loading and underlying base conditions.

The slab cracking implies insufficient flexural strength and/or inadequate base support. Performance of the larger slab could be improved by providing a stronger compacted base or by increasing the flexural strength with additional reinforcement or stronger concrete.

Aside from the cracking, the slabs supported the F-4 coverages, and settled beyond criteria during C-141 coverages. However, the effect of interrupting the test to conduct dynamic loading tests (Test 7) before the C-141 trafficking is unknown.

H. TEST 7: 2- AND 3-METER SLAB DYNAMIC LOADING TEST

1. Introduction

This test evaluated the structural adequacy of the precast slab repair concept during touchdown or high speed taxi runs inducing dynamic loads of approximately 2 "g" forces.

2. Test Description

Personnel conducted this test on two previously constructed and trafficked test sections:

- Test Pit 1: 3-meter slabs trafficked in Test 6 with a total of 216 F-4 loadcart coverages and 70 C-141 loadcart coverages, and

- Test Pit 3: 2-meter slabs trafficked in Test 4 with 156 F-4 loadcart coverages.

The test consisted of passing the F-4 loadcart over a specially designed ramp, placed next to the test pits, and onto the test sections. The ramp caused the loadcart to impact the test sections in a manner similar to actual dynamic loads caused by aircraft. Figure 91 shows a diagram of the ramp and its location relative to a test section. Technicians rigged the loadcart specially for this test to determine the magnitude of the induced load. Personnel determined the load indirectly by measuring the compression of the loadcart tire at impact and then correlating the tire compression to dynamic load. Data collectors recorded tire compression measured by a "lazy pointer" mounted on the loadcart. Figure 92 shows a side and top view of the loadcart and shows the location of the lazy pointer. The pointer recorded the peak compression of the tire.

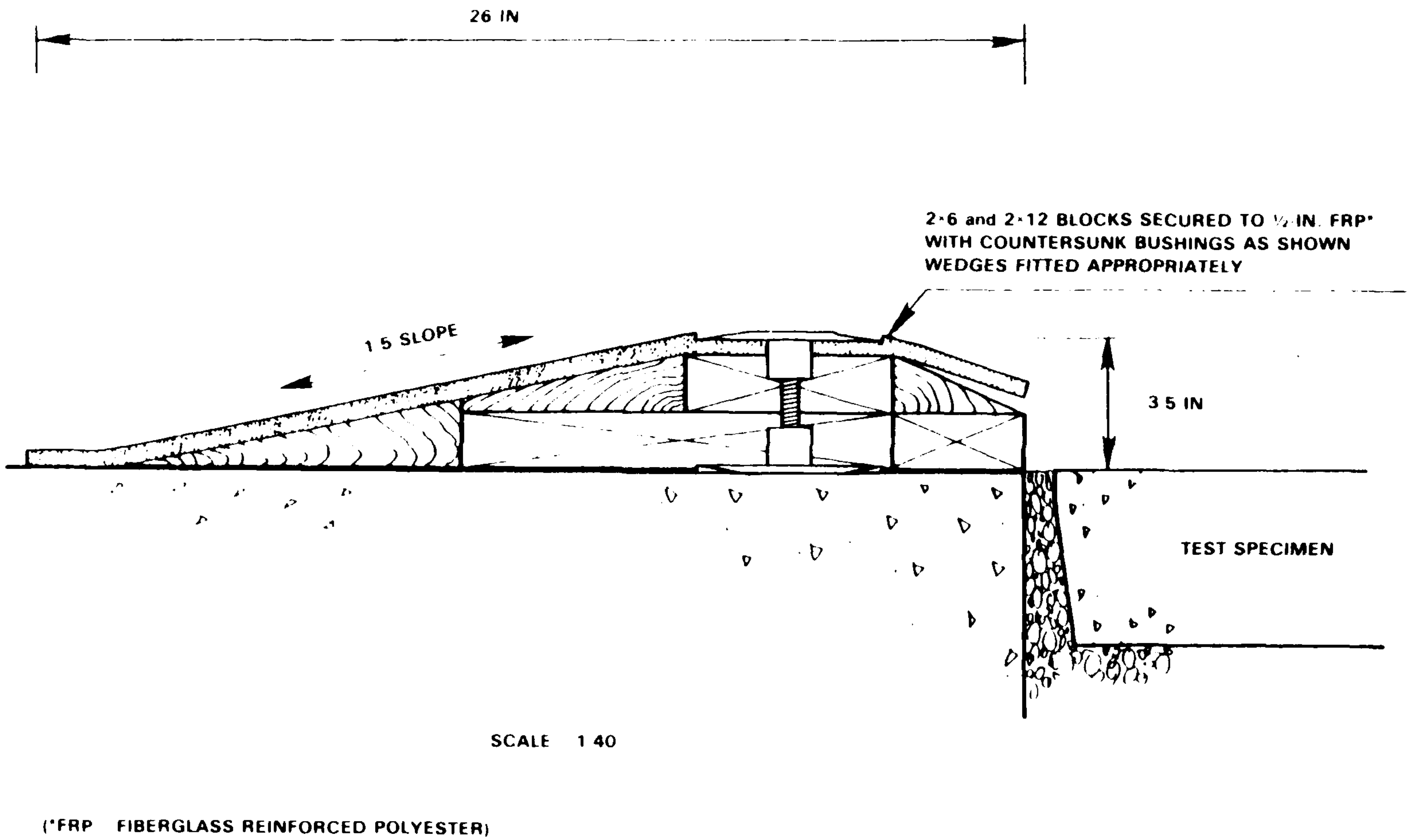

Figure 91. Dynamic Test (Test 7) Ramp Design.

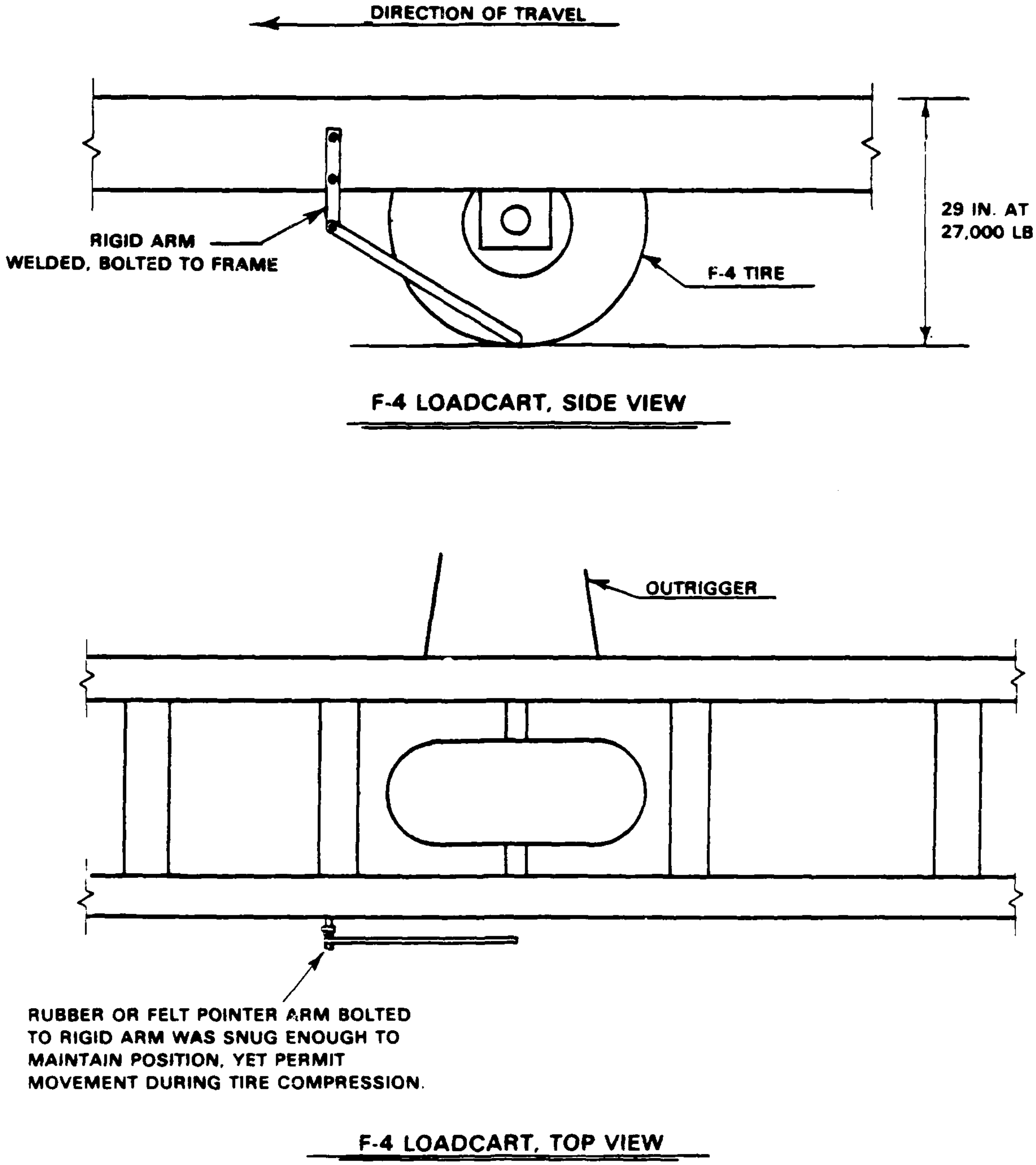

Figure 92. Lazy Pointer Assembly on F-4 Loadcart.

Personnel applied eight passes of the loadcart to the 2-meter slabs in Test Pit 3 and five passes to the 3-meter slabs in Test Pit 1. Data collectors recorded the peak tire compression for each pass to determine the magnitude of the dynamic load.

3. Results

AFESC personnel conducted the test as planned. Table 5 presents the tire compression and the corresponding dynamic load for each test. AFESC personnel determined the relationship between the tire compression and load was linear, as plotted in Figure 93. Data collectors reported no damage for any slab in either test pit.

4. Conclusions

Test 7 tested 2- and 3-meter precast slabs to determine if they could support dynamic loadings resulting from aircraft touchdown or high speed taxiing. Test personnel induced loads of approximately 2 "g" forces using a specially constructed ramp for the F-4 loadcart. As data collectors reported no damage to any slabs, it is assumed that both slab types are capable of supporting dynamic loads without sustaining damage. These results should be verified with additional testing.

I. CONCLUSIONS

The precast slab concept is capable of supporting criteria loads for RRR operations. Table 6 summarizes the performance of each test section. All but one repair configuration supported 156 F-4 coverages, and, in some cases, additional F-4 and C-141 coverages, with no more than one interruption for repair maintenance. It is recognized, however, that precast slabs as well as the repair concept are still being refined.

Specific points relating of this series of tests are discussed below.

1. Repair Construction

The ballast rock performed adequately as a lower layer placed on a weak subgrade or debris but requires aggregate with a wider gradation range on top to provide a stable platform for the slabs and confine the movement of the uniformly graded ballast rock and therefore reduce the rutting under load. Both Number 57 and Number 7 crushed stone were suitable, although because of its smaller particle size, some of the Number 7 aggregate was lost to the ballast rock layer which resulted in continued settlement during traffic applications.

The use of sand between slabs to reduce lateral movement was unsuccessful. The sand quickly settled into the underlying leveling course in all cases, migrating into the Number 57 aggregate more quickly than the Number 7 aggregate. Although wet sand was not lost as fast as dry sand, it had little impact on slab lateral movement or settlement.

TABLE 5. RELATIONSHIP BETWEEN PEAK TIRE COMPRESSION AND DYNAMIC LOAD.

TEST PIT	PASS	PEAK TIRE COMPRESSION (IN.)	DYNAMIC LOAD (LB)
1	1	2 9/16	46,900
	2	2 1/2	45,900
	3	3/8	23,900
	4	2 1/16	41,600
	5	7/8	29,100
2	1	2 15/16	50,800
	2	2 3/16	42,900
	3	1 9/16	36,400
	4	3 1/4	54,100
	5	2 9/16	46,900
	6	2[a]	------
	7	2 3/8	44,900
	8	2 1/4	43,600

[a]THIS DATA WAS NOT CONSIDERED ACCURATE BECAUSE POINTER WAS LOCATED ALONG A JOINT, NOT ON A SLAB.

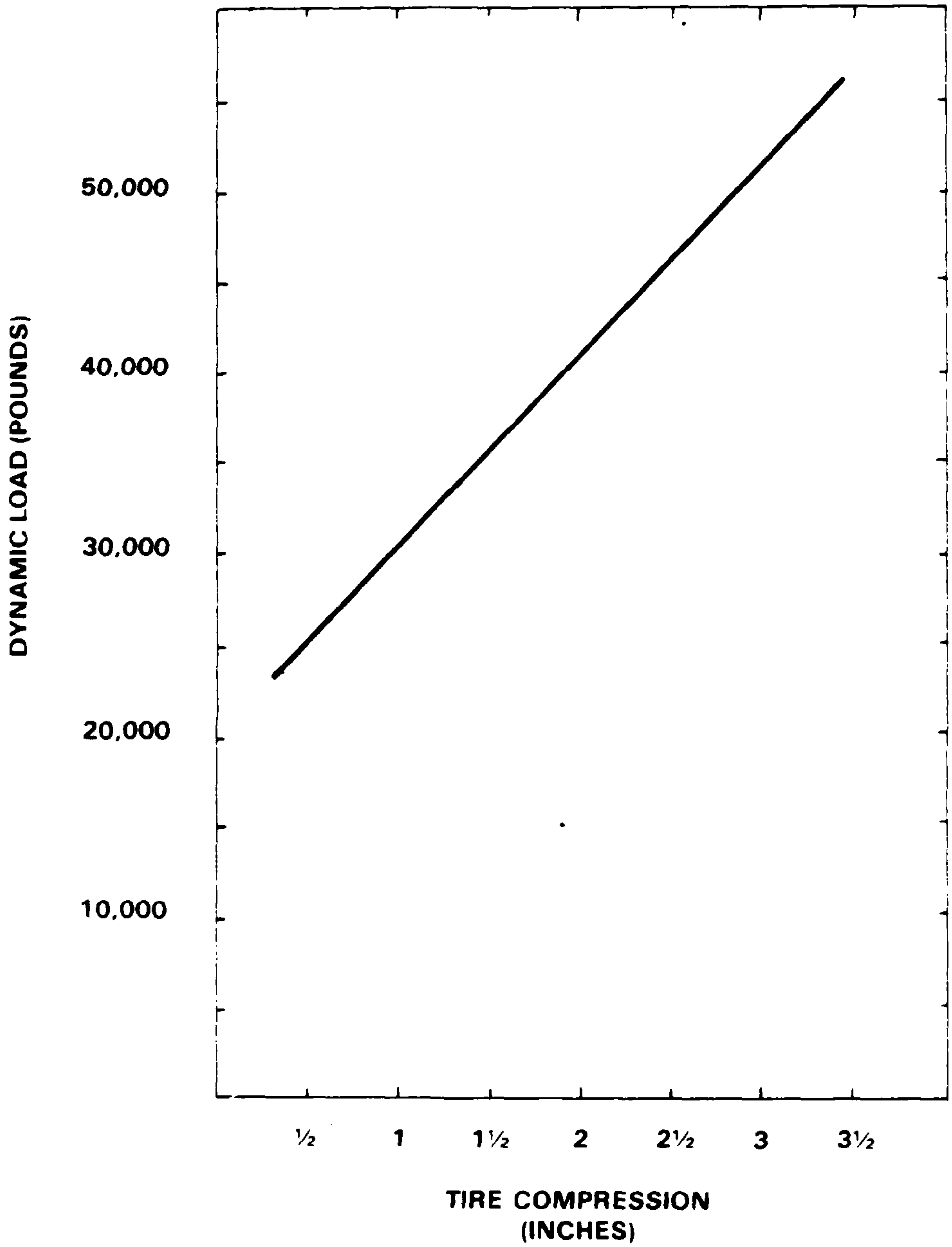

Figure 93. Tire Compression Versus Dynamic Load.

TABLE 6. SUMMARY OF INITIAL PRECAST SLAB TEST RESULTS.

	TRAFFIC COVERAGES		SETTLEMENT (INCHES)			
TEST	F-4	C-141	COMPACTION	TRAFFIC[a]	AFTER MAINTENANCE[b]	COVERAGES AT MAINTENANCE
1. PRELIMINARY TEST	150	-	-	2.88	1.0	30
2. 2-METER SLABS (NO COMPACTION, LEVELING COURSE A)	156	-	-	2.40	1.08	24
3. 2-METER SLABS (NO COMPACTION, LEVELING COURSE B)	156	-	-	4.56	0.60	12 108
4. 2-METER SLABS (COMPACTION, LEVELING COURSE B)	156	70	0.99	2.76	0.72	48
5. 2-METER SLABS (COMPACTION, JOINT FILLER TESTING)	60	-	0.76/0.93[c]	0.61/0.70[c]	N/A	60[d]
6. 3-METER SLABS (NO COMPACTION, LEVELING COURSE B)	156	70	-	2.64	N/A	156 F-4 40 C-141[e]

NOTES:

[a] CUMULATIVE SETTLEMENT OVER ALL TRAFFIC, BEFORE AND AFTER MAINTENANCE ACTIONS.

[b] SETTLEMENT AFTER FINAL MAINTENANCE.

[c] SETTLEMENT OF SLAB CORNERS IN SAND-FILLED JOINT REGION/OPEN JOINT REGION.

[d] NO MAINTENANCE REQUIRED.

[e] MAINTENANCE INDICATED AT 40 C-141 COVERAGES, BUT TRAFFIC CONTINUED TO 70 C-141 COVERAGES WITHOUT MAINTENANCE.

Smaller spaces between slabs reduce rocking and the potential for cracking near the edges of a slab. Slab joint spacing should be minimized although contact between slabs should be prevented. Smaller spacing also will benefit the repair procedure by requiring less filler material.

Some compaction should be applied during the repair to minimize the large early settlement of the slabs. This can be accomplished by compacting on top of the slabs prior to trafficking; although, this may require maintenance to bring the slabs back up to grade if excess displacement occurs, or require that slabs are placed "high" to allow for settlement during compaction. A better way would be to compact the leveling course, adding material if necessary to achieve proper grade, and then placing the slabs.

2. Structural Adequacy

a. Repair Adequacy

Two primary modes of repair distress were noted. First, excessive deformation occurred along the joints receiving the highest concentration of traffic, evidenced by slab settlement, and associated with shear failure of the underlying aggregate layers. Second, the relative settlement between slab edges caused problems, as did the slab rocking under load which is also associated with shear failure in the aggregate layers as well as lack of aggregate stability.

These effects can be reduced by compacting the repair prior to trafficking to presettle the repairs, and by providing well-graded angular aggregate immediately under the slabs. When densified, angular well-graded aggregate will provide some aggregate interlock in the base course to resist shifting (or shearing) under load.

b. Precast Slab Adequacy

Personnel observed cracking on the surface of 2-meter slabs in Test 1 and in the interior corners of the 3-meter slabs in Test 6. Slab cracking is a fatigue failure resulting from inadequate slab flexural strength or underlying base support, both of which must be considered together.

The slab strength is probably adequate if a base platform can be prepared with greater strength and stability. This can be accomplished by using adequate depths of well-graded crushed aggregate and by compacting into a stable layer before placing the slabs. Precast slabs must be strengthened by adding more steel reinforcement if no further consideration is given to the quality of the base layers.

The corners and edges of a slab are areas of high stress concentration during loading and contact with adjacent slabs. Contact with nearby slabs is more likely with smaller joints and with adequate joint filler material, and can result in spalling thereby creating a FOD potential. Protection at the edges such as the angle iron corner nosings reduces the potential for this type of damage.

SECTION IV

USAFE SLABS

A. INTRODUCTION

Following the initial precast slab repair tests, AFESC conducted several tests using a later generation slab developed by USAFE as an interim crater repair system. These USAFE slabs were manufactured by the Stelcon Company.

1. Background

The USAFE slab system resulted from a USAFE testing program conducted between July 1981 and October 1982 to develop an alternative to the AM-2 repair system. USAFE designed these slabs to provide a flush repair which was less manpower intensive and could be readily maintained or repaired. This repair concept uses a clean-crater concept, with all ejecta removed and replaced with ballast rock.

2. Test Objectives

These tests determined the bearing capacity of the USAFE concrete slabs when settled by a vibrator roller over a ballast rock repair. The first test used normal strength slabs to test this objective. The second test used high strength slabs placed in a brickwork pattern to evaluate the advantage, if any, of greater concrete strength and a staggered placement pattern.

B. NORMAL STRENGTH CONCRETE SLABS

1. Purpose

The USAFE normal strength slab test determined the bearing capacity of this slab technology under F-15 and C-141 traffic. Personnel placed the slabs in the typical three-by-three slab pattern (Figure 94) and settled them with the vibratory roller after placement.

2. Test Description

Personnel constructed the test in section SCTF Pit 3 using a ballast rock base course and a thin leveling course of Number 7 crushed stone. The test plan specified a weak clay subgrade to 36 inches below the surface of the concrete test pad and a ballast rock base course to 8 1/2 inches below the pavement, topped by a 4-inch thick leveling course of Number 7 crushed stone. Personnel hand screeded the leveling course to approximately 4 1/2 inches below the test pad so that the 6-inch thick slabs were initially 1 1/2 inches above the pavement elevation. Personnel lowered the slabs into place and adjusted the gaps between slabs. No joint

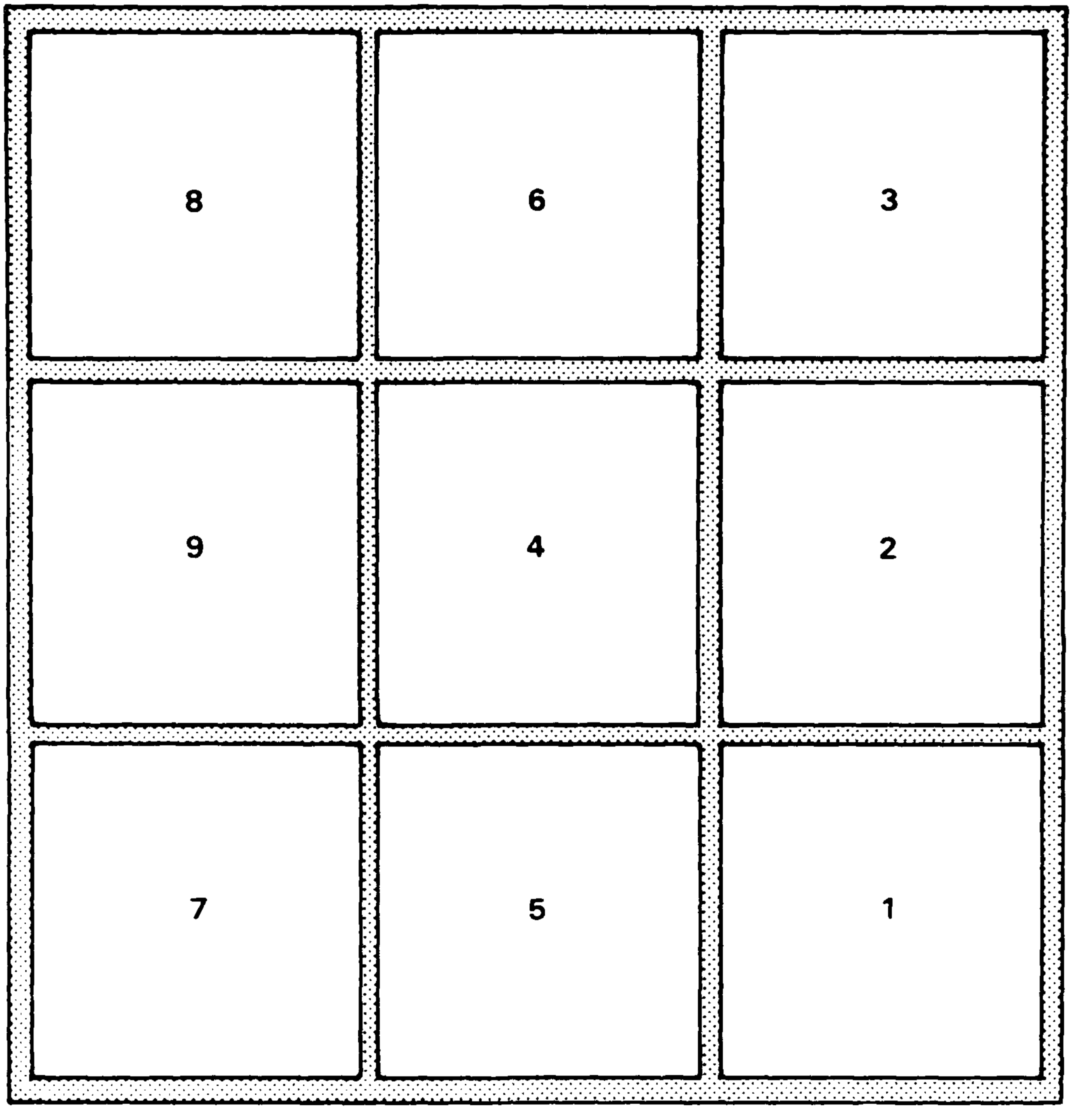

Figure 94. Plan of Test Section, Normal Strength USAFE Slabs.

filler material or spacers were specified for this test, but personnel settled the slabs flush with adjacent pavement using two passes of the RayGo® single-drum vibratory roller.

Personnel prooftested the slab repair with the F-15 loadcart before beginning scheduled traffic with F-15 and C-141 loadcarts. The prooftest consisted of passes forward and backward along the center and longitudinal edges of each row of slabs (Figure 95). Data collectors noted tipping of the slabs during the prooftest for comparison to slab behavior observed at the 1983 North Field exercise.

Following the prooftest, personnel applied 156 F-15 and 60 C-141 loadcart coverages. The specified failure criteria during traffic application included excessive cracking or spalling, punchthrough shear failure, or peak sag in excess of 2 inches. If peak sag failure occurred, personnel could relevel the slabs exceeding the criteria only once, unless safe operation of the loadcart mandated an additional maintenance action. Personnel used Silikal® to patch spots where spalling had occurred to an extent that was unsafe for loadcart operation. Data collectors cored failure areas following the test for subsequent observation.

3. Results

a. Placement

AFESC personnel placed the test section in general accordance with the plan described above. Pretest measurements indicate that the clay subgrade had an average CBR value of 3.6, an average dry density of 96.3 pcf, and average moisture content of 27.2 percent. The surface of the clay subgrade was approximately 39 inches below the pavement elevation.

Personnel placed ballast rock fitting the gradation requirements of ASTM D448 on top of the clay. Typical gradations of the ballast rock and leveling course are shown in Figure 5 (Section II). Personnel then placed and screeded the Number 7 leveling course over the ballast rock. The surface elevation of the leveling course before slab placement was typically 6.3 inches on the north side of the test bed and 5.25 inches on the south side. When personnel positioned the slabs they placed three on the north flush with surrounding pavement and the remaining six approximately 1 1/2 inches above. Personnel settled the slabs with two passes of the vibratory roller and then prooftested them with the F-15 loadcart. Maximum sag after prooftesting was 0.72 inches.

b. Traffic Testing

Personnel trafficked this precast slab repair first with 156 F-15 loadcart coverages, then with 60 C-141 loadcart coverages. Traffic distribution patterns are shown in Figures 14 and 16 (Section II). Data

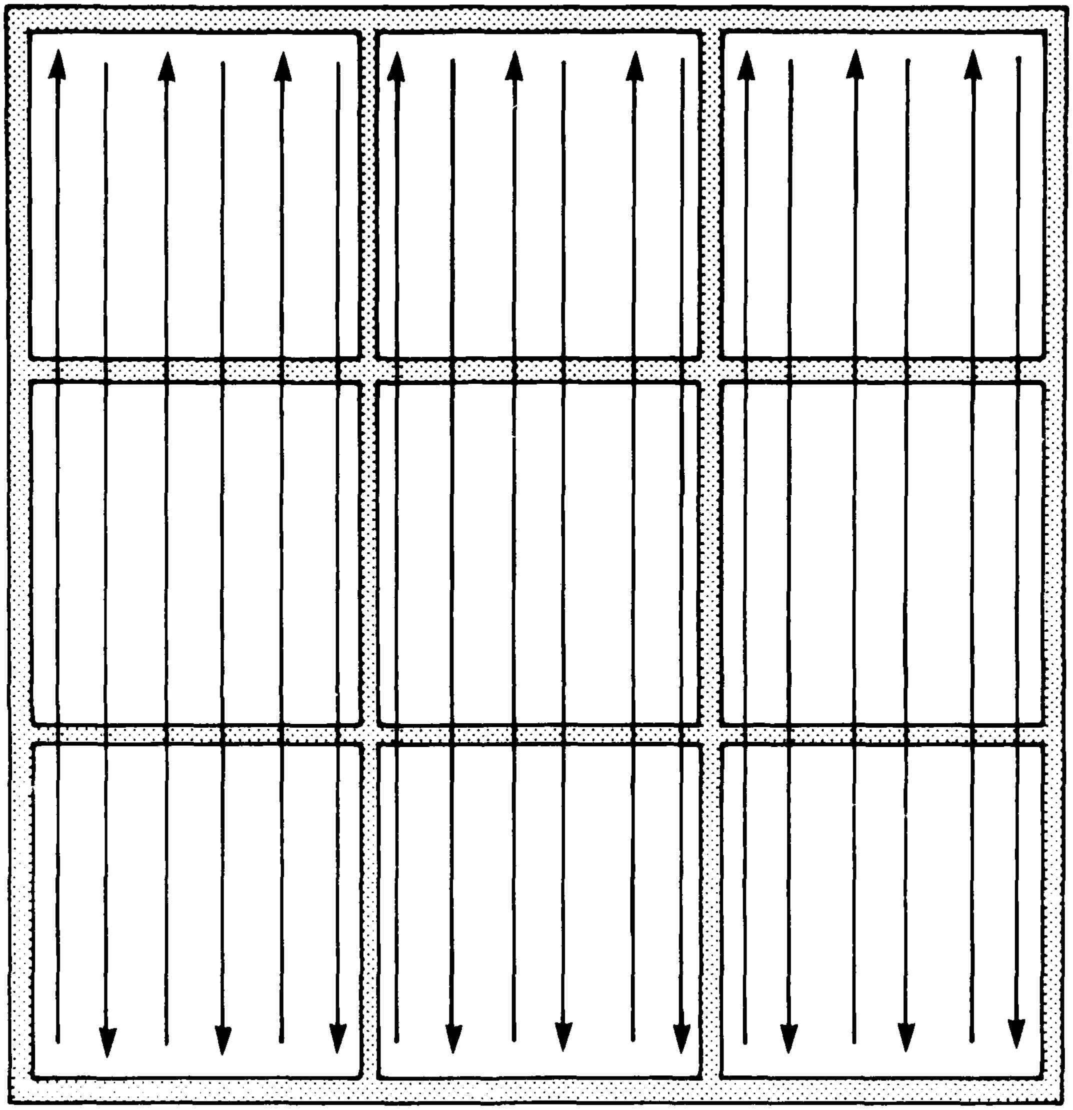

Figure 95. Proof Test Pattern for Normal Strength USAFE Slabs.

collectors recorded static and no-load measurements of slab corner elevations during the traffic applications, at intervals noted in Table 7, generally without the loadcart on the repair section (no-load). Data collectors measured static elevations of slab corners at some intervals with the loadcart parked on the repair. Elevation profiles of the test section before and after compaction and during traffic testing (unload measurements) are shown in Figures 96 to 103.

After 33 passes of the F-15 loadcart, personnel observed distress in the repair section. The metal nosing along the south edge of Slab 9 pulled away from the concrete, and the concrete cracked and spalled in the northwest corner of Slab 5.

Traffic continued until after 160 passes before personnel performed maintenance required to correct relative settlements of 2 inches between the slabs and the north edges of the test bed. Test personnel removed Slabs 4 through 9 and added additional leveling stone to the test pit, without additional compaction or proof rolling before the slabs repositioning onto the leveling course. Test personnel replaced slabs 4, 5, and 8, which were cracked and spalled during the repair.

Personnel completed the remainder of the F-15 traffic without further maintenance repairs. After 156 coverages, data collectors observed maximum relative settlement of 1.80 inches at the corners of Slabs 6 and 8 adjacent to the PCC pavement.

Test personnel observed continued signs of slab distress along the traffic zone as trafficking continued (Figure 104). Slab 6 cracked 14 1/2 inches in from the northeast corner after six applications of the F-15 traffic distribution pattern (480 passes or 72 coverages). After 720 passes (108 coverages), several other slabs had long cracks. Slab 9 had two cracks, approximately 22 and 25 inches from the southeast corner. Slab 5, which had been replaced at the first repair and had been trafficked by 560 passes had cracked approximately 15 1/2 inches in from the corner. Slab 4, also replaced at the first repair, had a 10- by 6-inch spalled area around the steel nosing approximately 14 to 24 inches from the corner.

Data collectors noted additional damage to the slabs at the end of F-15 traffic. Slab 5 had a second crack, 12 inches from the corner. The spalled area on Slab 4 increased to 11 inches by 7 inches, and a crack had formed 18 inches from the corner. A third crack, 23 inches from the corner, formed in Slab 9, along with a spalled area approximately 3 1/2 inches by 4 1/2 inches. Slab 8 (replaced at the first repair), had a 13- by 2 1/2-inch spalled area along the steel nosing.

Data collectors recorded static load measurements of slab corner elevations at intervals during the F-15 traffic. On the first pass, the maximum difference in elevation from the loaded corner to the opposite corner was 3.72 inches. After 153 passes, the maximum difference was 3.48

TABLE 7. SCHEDULE OF STATIC LOAD AND UNLOADED SLAB CORNER ELEVATION MEASUREMENTS, NORMAL STRENGTH USAFE SLABS TEST.

APPLICATIONS[a]	PASSES	COVERAGES	MEASUREMENT[b]
F-15			
-	33	6	S/NL
1	73	12	S/NL
2	153	24	S
3	233	36	S/NL
5	393	60	S
9	713	108	NL
13	1033	156	S/NL
C-141			
1	34	10	NL
2	68	20	NL
4	136	40	NL
6	204	60	NL

NOTES:

[a] NUMBER OF APPLICATIONS OF STANDARD TRAFFIC DISTURIBUTION PATTERN.

[b] MEASUREMENTS: S = STATIC LOAD, (LOADCART PARKED ON SLABS).
NL = NO LOAD (UNLOADED SLABS).

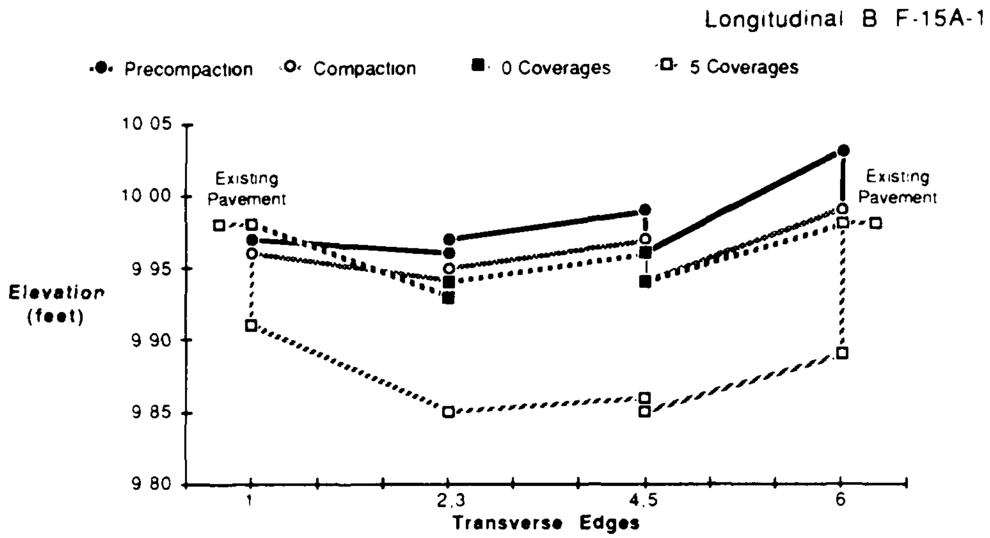

Figure 96. Slab Elevation Profiles Along Longitudinal Edge B, Normal Strength USAFE Slabs Test (Precompaction, Compaction, 0, and 5 F-15 Loadcart Coverages).

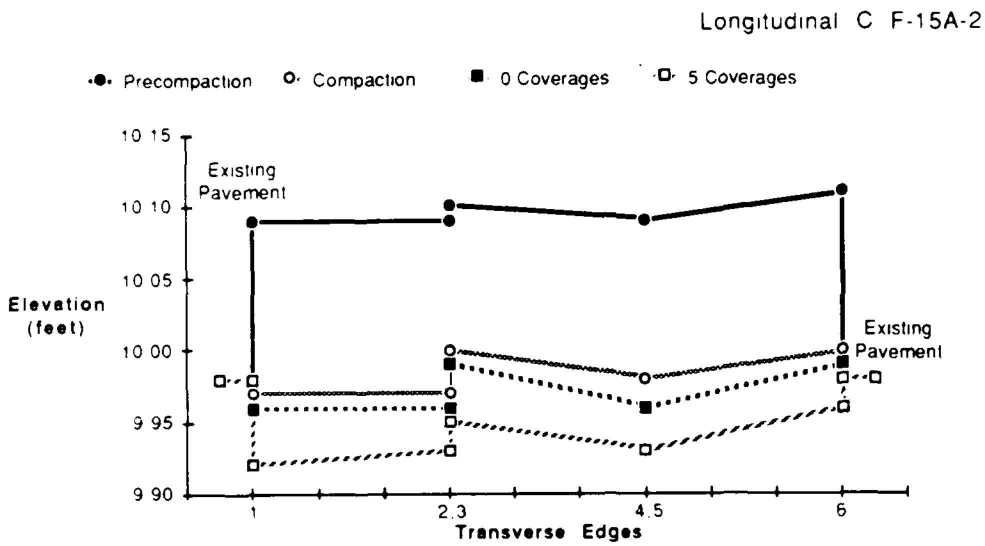

Figure 97. Slab Elevation Profiles Along Longitudinal Edge C, Normal Strength USAFE Slabs Test (Precompaction, Compaction, 0, and 5 F-15 Loadcart Coverages).

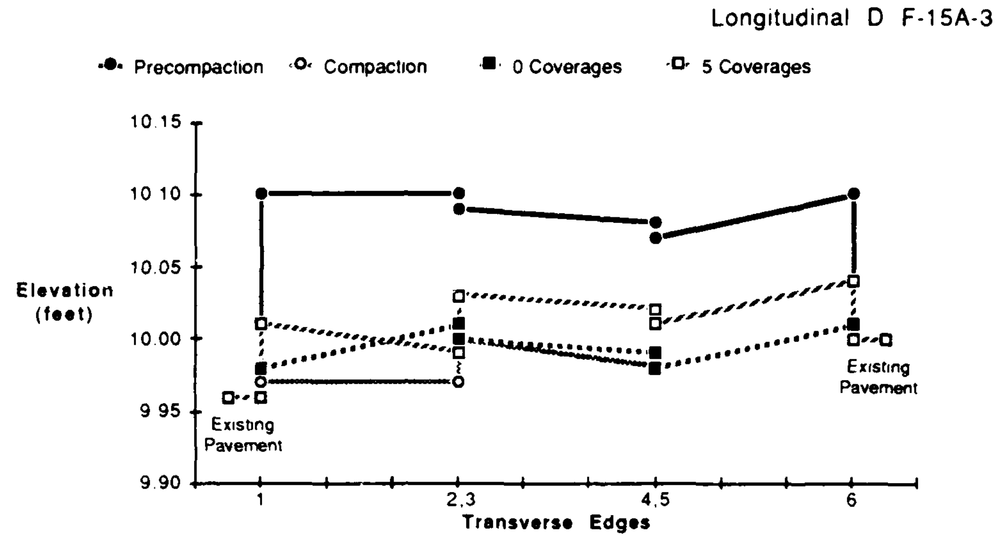

Figure 98. Slab Elevation Profiles Along Longitudinal Edge D, Normal Strength USAFE Slabs Test (Precompaction, Compaction, 0, and 5 F-15 Loadcart Coverages).

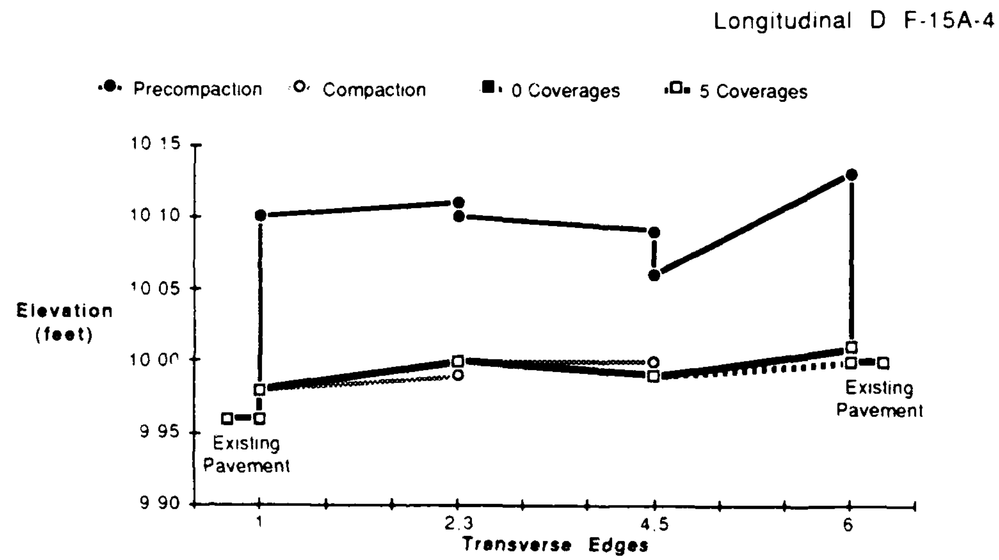

Figure 99. Slab Elevation Profiles Along Longitudinal Edge E, Normal Strength USAFE Slabs Test (Precompaction, Compaction, 0, and 5 F-15 Loadcart Coverages).

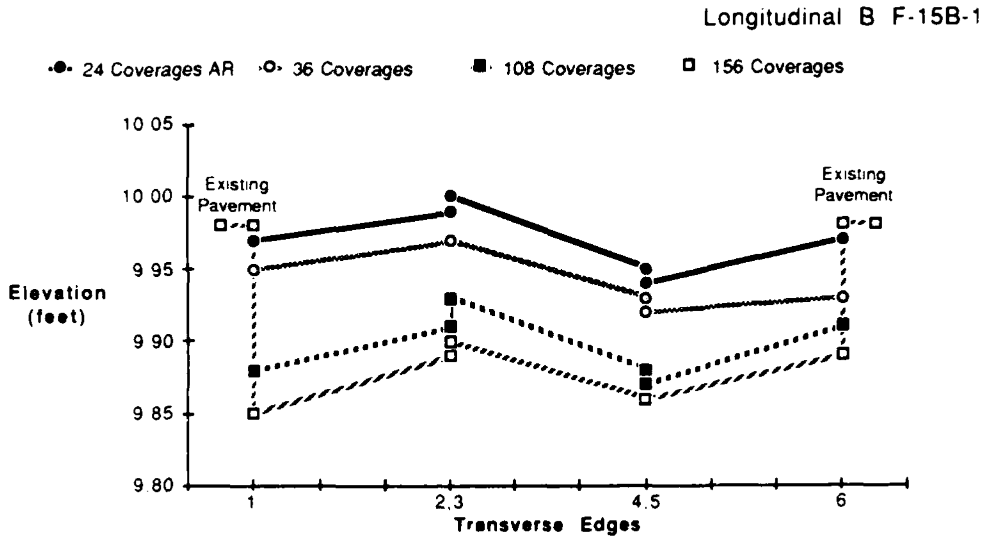

Figure 100. Slab Elevation Profiles Along Longitudinal Edge B, Normal Strength USAFE Slabs Test (24 After Repair, 36, 108, and 156 F-15 Loadcart Coverages).

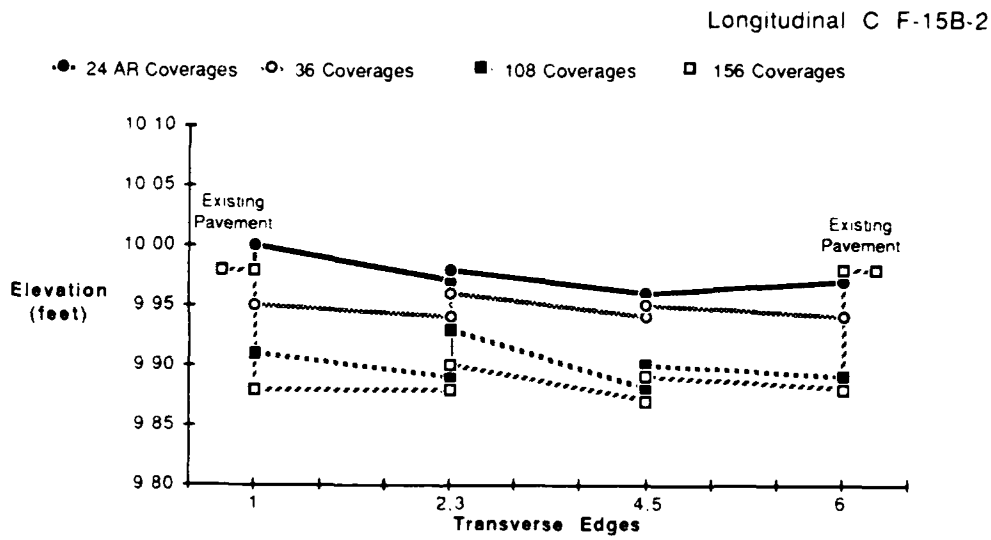

Figure 101. Slab Elevation Profiles Along Longitudinal Edge C, Normal Strength USAFE Slabs Test (24 After Repair, 36, 108, and 156 F-15 Loadcart Coverages).

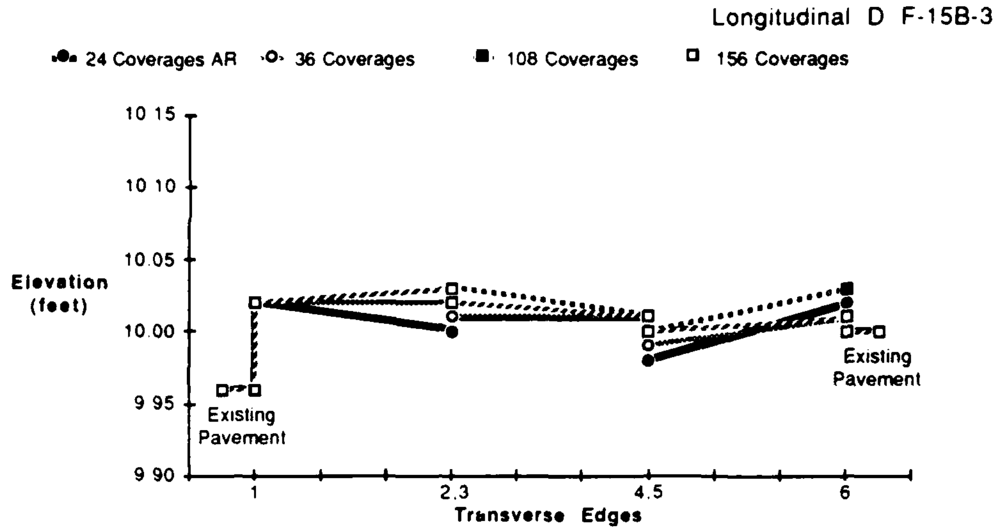

Figure 102. Slab Elevation Profiles Along Longitudinal Edge D, Normal Strength USAFE Slabs Test (24 After Repair, 36, 108, and 156 F-15 Loadcart Coverages).

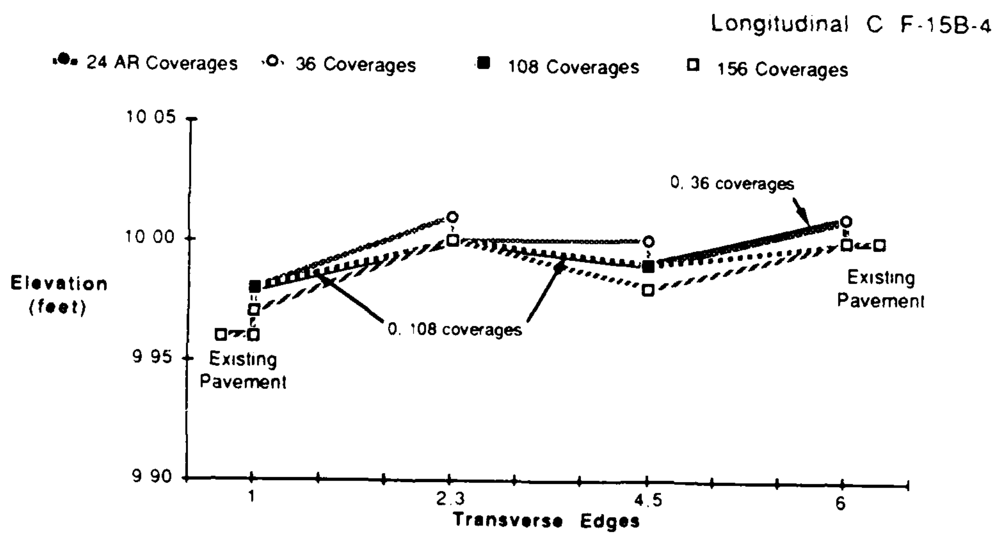

Figure 103. Slab Elevation Profiles Along Longitudinal Edge E, Normal Strength USAFE Slabs Test (24 After Repair, 36, 108, and 156 F-15 Loadcart Coverages).

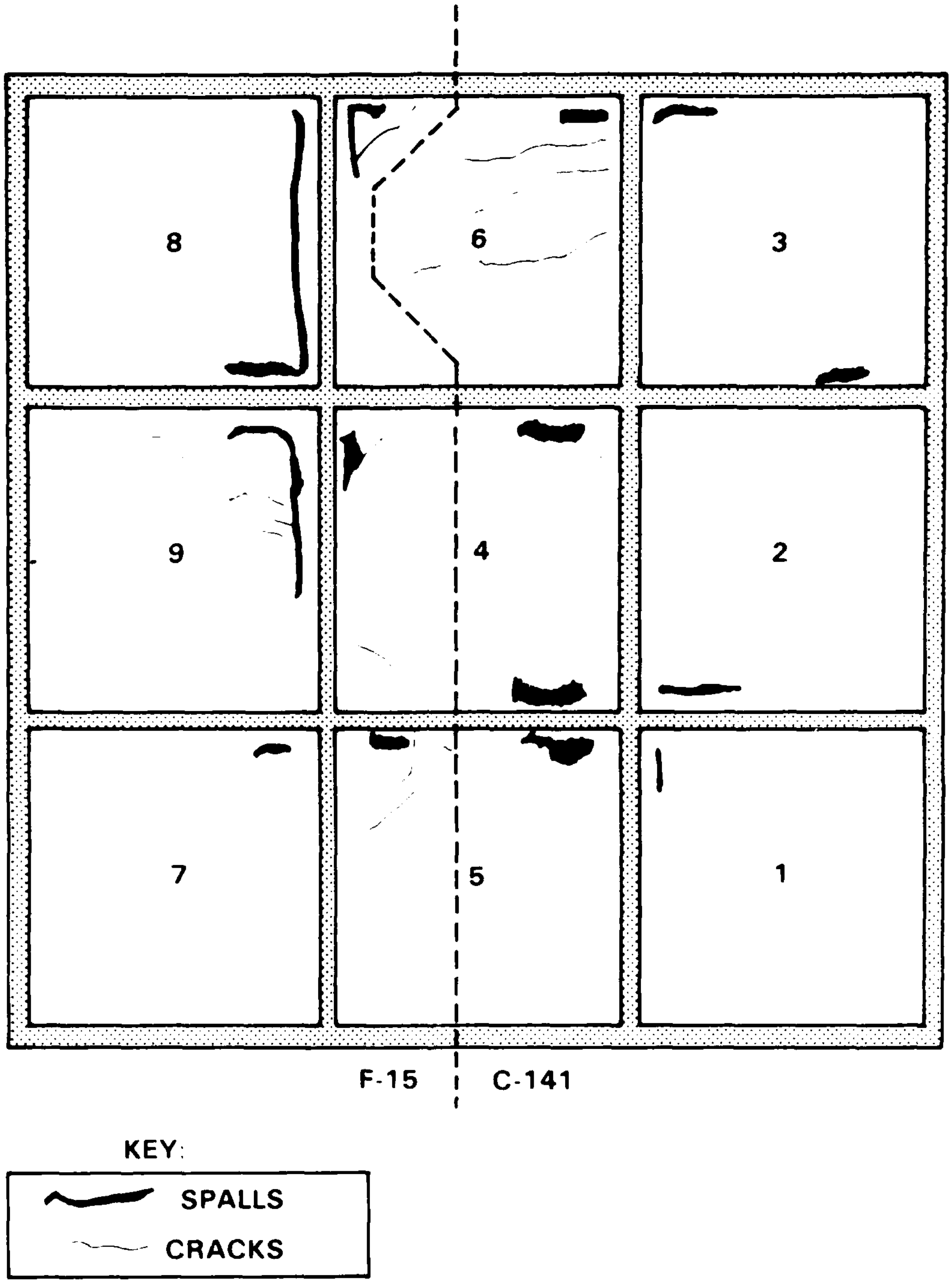

Figure 104. Damage to Slabs from F-15 and C-141 Traffic Loading, Normal Strength USAFE Slabs Test.

inches before repair and 3.36 inches after repair. The value decreased slightly with additional coverages and was 2.88 inches after 1033 passes.

Traffic with the C-141 loadcart followed F-15 loadcart traffic. Elevation profiles are plotted in Figures 105 to 108. Personnel performed no maintenance repairs between F-15 and C-141 traffic. After 10 coverages, data collectors observed no additional damage to the concrete slabs and little tipping (1 inch maximum). They noted spalling in Slabs 2, 4, and 6 after 30 coverages (Figure 104), with the largest damage consisting of 10- by 4-inch spalls on both the east and west edges of Slab 4. These spalled areas enlarged after 60 coverages in Slabs 2, 4, and 6, and personnel noted new spalls in Slabs 1, 3, and 5. Slab 6 also developed three transverse cracks, and Slab 4 had a single crack 18 inches from the northwest corner. No repairs were required during C-141 traffic.

4. Conclusions

The repair section was adequate for providing structural support of the F-15 and C-141 loads, although requiring early maintenance action. Following this repair, no further maintenance was required to complete traffic. The slabs consistently tipped up to 3 inches when loaded with a parked F-15 wheel, without showing much improvement with additional traffic.

The concrete slabs exhibited cracking and spall damage from F-15 and C-141 loads during the test. There was extensive cracking in the slabs, especially at the corners, and significant spalling around the steel reinforcing nosing. This may present a potential foreign object damage or tire hazard in the field.

C. NORMAL/HIGH STRENGTH CONCRETE SLABS

1. Purpose

The severe spalling and cracking observed with the USAFE normal strength slab test led to an addition to the original test plan to evaluate the performance of high strength concrete slabs. The high-strength test also assessed an alternate slab placement pattern.

2. Test Description

Personnel constructed the test section in SCTF Pit 3, after excavating to a depth of 24 inches following completion of the first test. The test plan specified a hand-screeded leveling course approximately 4 1/4 inches below the test pad elevation. Personnel placed full-size and half-size slabs of normal and high-strength concrete, as indicated in Figure 109, and settled the slabs flush with adjacent pavement using the RayGo® single drum vibratory roller applied in a direction transverse to that of loadcart trafficking.

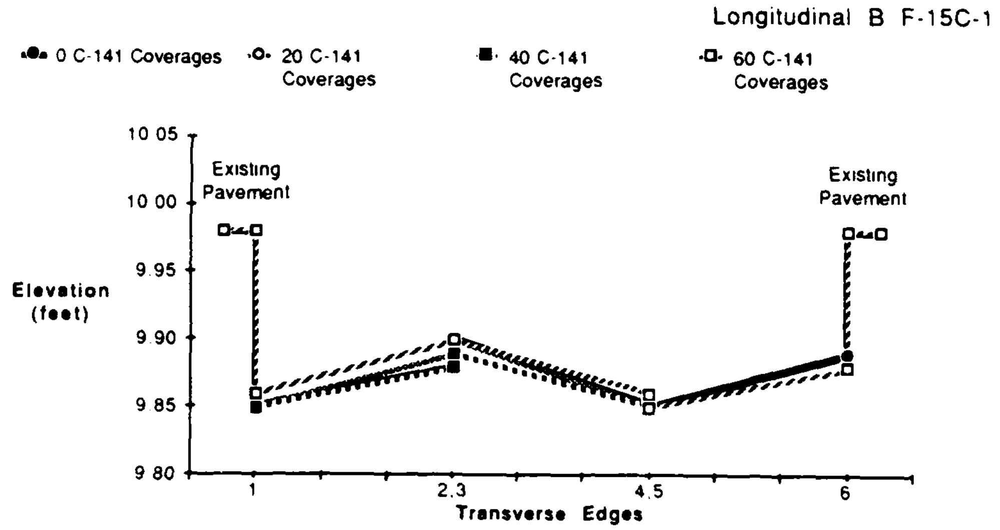

Figure 105. Slab Elevation Profiles Along Longitudinal Edge B, Normal Strength USAFE Slabs Test (0, 10, 40 and 70 C-141 Load-cart Coverages).

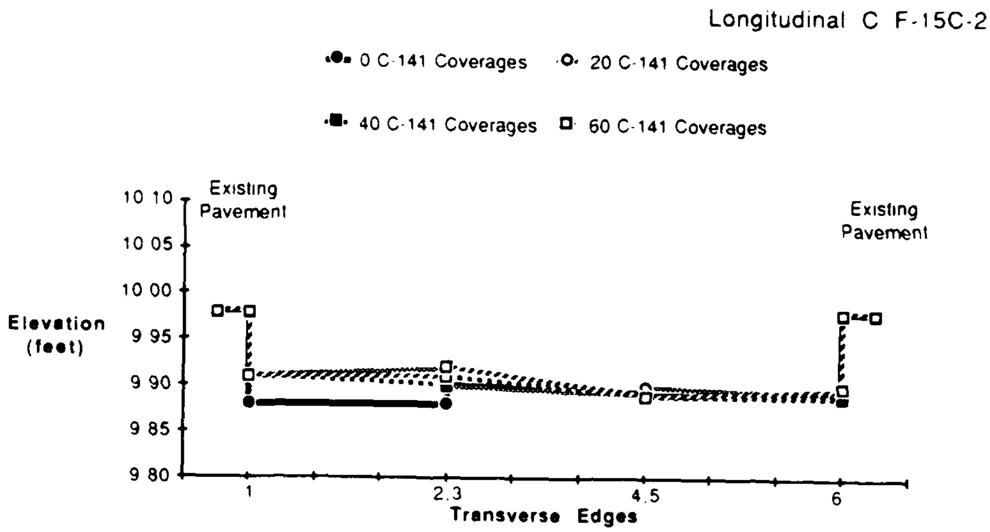

Figure 106. Slab Elevation Profiles Along Longitudinal Edge C, Normal Strength USAFE Slabs Test (0, 10, 40 and 70 C-141 Load-cart Coverages).

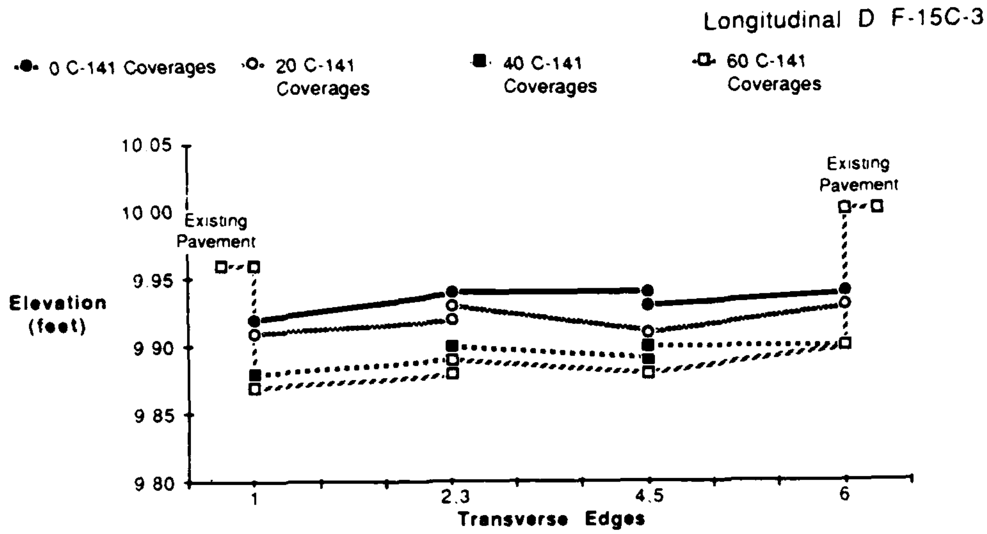

Figure 107. Slab Elevation Profiles Along Longitudinal Edge D, Normal Strength USAFE Slabs Test (0, 10, 40 and 70 C-141 Load-cart Coverages).

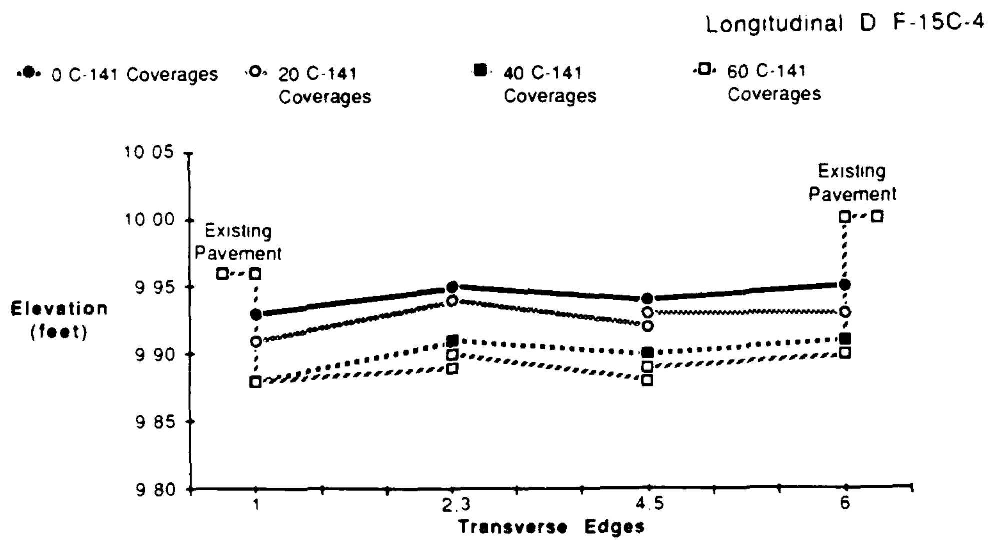

Figure 108. Slab Elevation Profiles Along Longitudinal Edge E, Normal Strength USAFE Slabs Test (0, 10, 40 and 70 C-141 Load-cart Coverages).

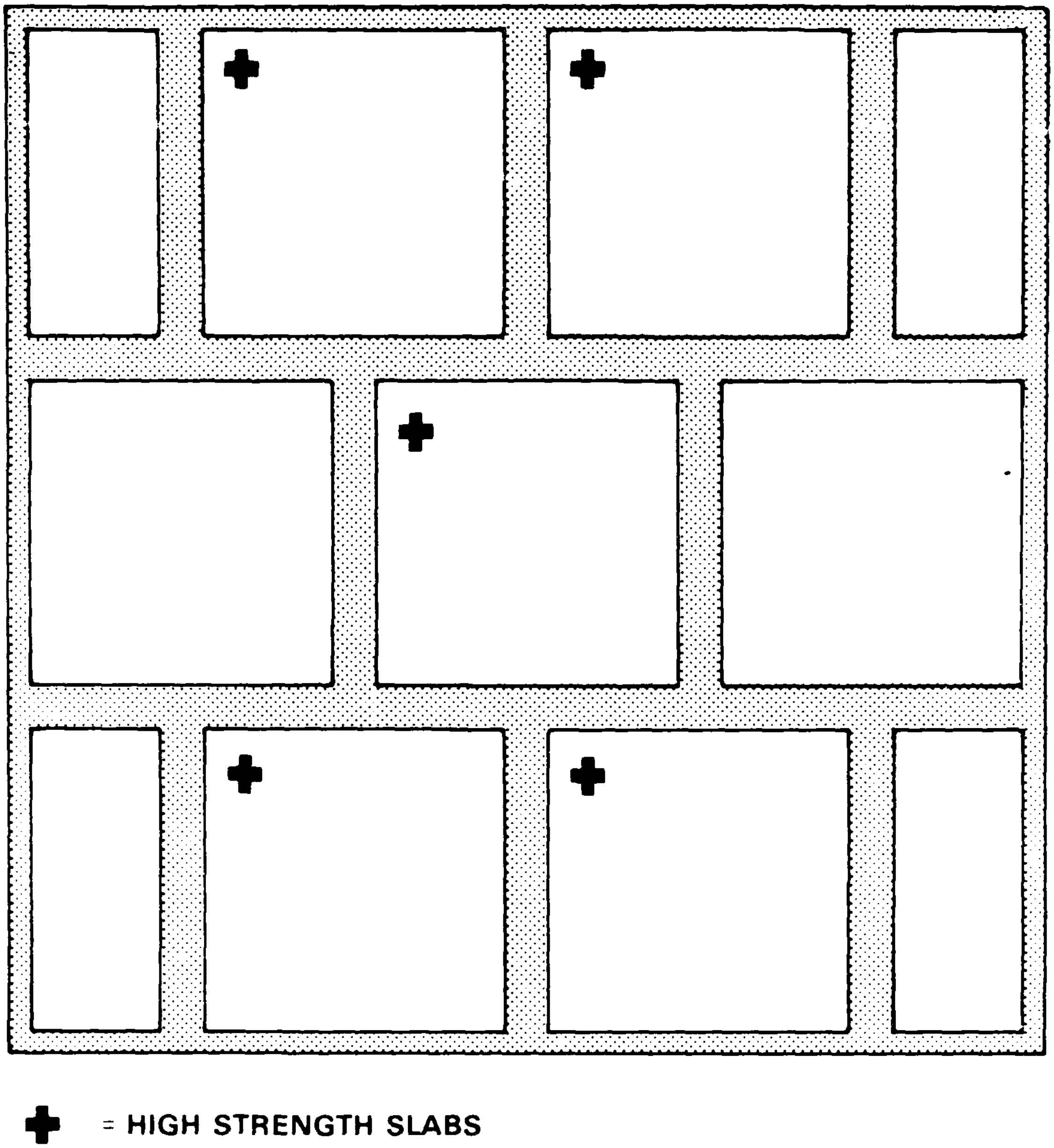

Figure 109. Plan of Test Section, Normal/High-Strength USAFE Slabs Test.

Personnel traffic-tested the slab repair with the F-15 loadcart using two 70-inch wide traffic zones. The failure criteria during traffic application were identical to that of the previous test.

3. Results

a. Placement

Personnel reconstructed the test section as described above. The elevation of the ballast rock base course at the start of this test averaged 8.4 inches below the slab elevation. Test personnel placed and screeded the leveling course that was placed over the ballast. The surface elevation of the leveling course before slab placement was typically 4.1 to 4.9 inches on the edges of the test bed and 5.2 to 5.8 inches in the center. Prior to compaction, data collectors measured the height of the slabs above pavement elevation as typically 1.0 to 1.7 inches on the edges of the test bed and 0.3 to 0.5 inches in the center. Personnel settled the slabs flush with the PCC pavement using the vibratory roller; although, corners of the interior slabs were slightly below existing pavement elevation after compaction, and prooftested the slabs with the F-15 loadcart. Data collectors measured no change in elevations after proof testing, but noted tipping up to 1 1/2 inches.

b. Traffic Testing

Personnel applied 156 F-15 loadcart coverages, equivalent to 13 applications of the distribution pattern of Figure 14 (Section II). Data collectors recorded measurements with static loads and without load according to the schedule in Table 8. Elevation profiles of longitudinal cross sections of the test bed are plotted in Figures 110 through 121. Static load measurements are shown in Figure 122.

Data collectors recorded static load elevation measurements before F-15 loadcart traffic testing and at intervals throughout trafficking. Test personnel accomplished these static load measurements by parking the loadcart wheel on the corner of several slabs and measuring the loaded corner elevations and the transverse and diagonal corners. Data collectors observed maximum tipping of 2.2 inches during the initial static load measurements.

After 33 passes of the loadcart, personnel observed damage in several concrete slabs. Slab 6, the high strength slab in the center of the repair, had three cracks 8 inches from the northeast corner. The half slab in the northwest corner, Slab 11, had a crack from north to south across the entire slab. Slab 9, the half slab in the northeast corner, had lost the nosing at its northwest corner. Slab tipping up to 2 inches at the center of the east edge was noted in static load measurements conducted at this point.

TABLE 8. SCHEDULE OF STATIC LOAD AND UNLOADED SLAB CORNER ELEVATION MEASUREMENTS, NORMAL/HIGH STRENGTH USAFE SLABS TEST.

APPLICATION[a]	PASSES	COVERAGES	MEASUREMENT[b]
<u>F-15</u>			
-	33	6	S/NL
2	153	24	S
3	233	36	S/NL
5	393	60	S
9	713	108	NL
13	1033	156	S/NL

NOTES:

[a] NUMBER OF APPLICATIONS OF STANDARD TRAFFIC DISTRIBUTION PATTERN.

[b] MEASUREMENTS: S = STATIC LOAD (LOADCART PARKED ON SLABS).
NL = NO LOAD (UNLOADED SLABS).

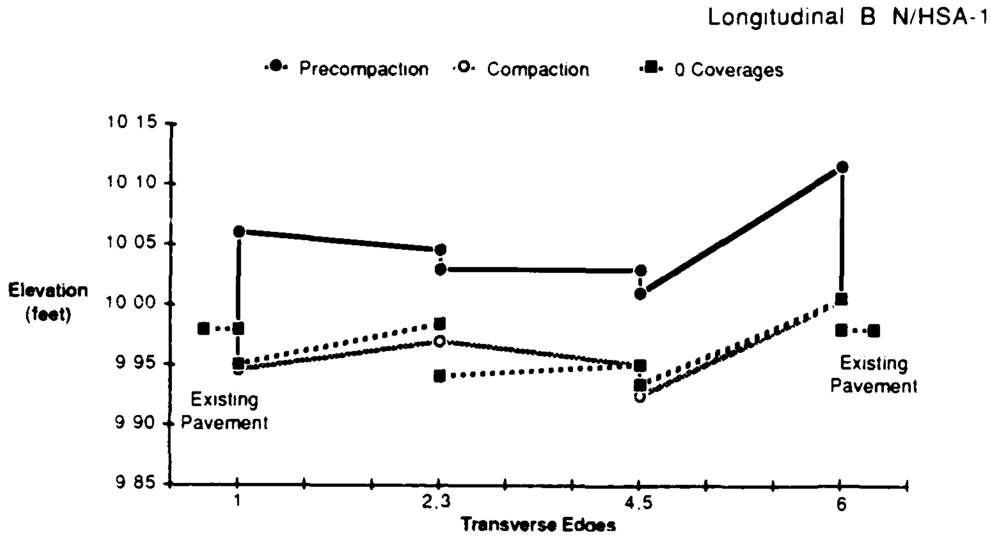

Figure 110. Slab Elevation Profiles Along Longitudinal Edge B, Normal/ High-Strength USAFE Slabs Test (Precompaction, Compaction, and 0 F-15 Loadcart Coverages).

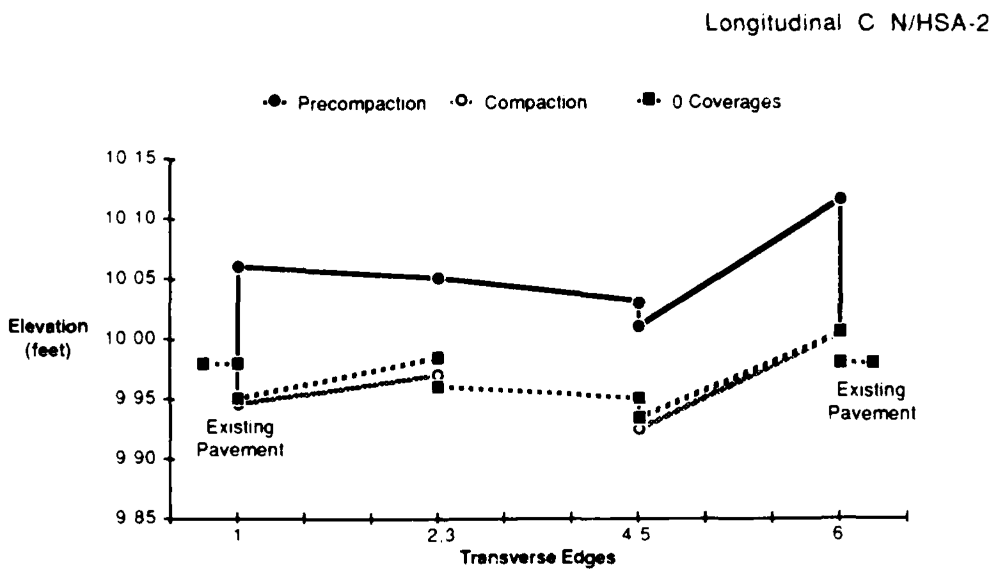

Figure 111. Slab Elevation Profiles Along Longitudinal Edge C, Normal/ High-Strength USAFE Slabs Test (Precompaction, Compaction, and 0 F-15 Loadcart Coverages).

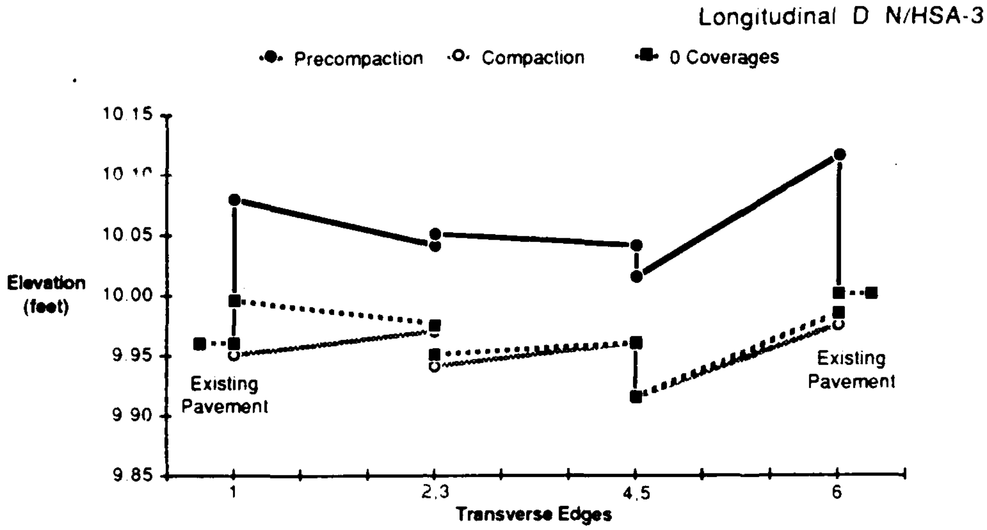

Figure 112. Slab Elevation Profiles Along Longitudinal Edge D, Normal/ High-Strength USAFE Slabs Test (Precompaction, Compaction, and 0 F-15 Loadcart Coverages).

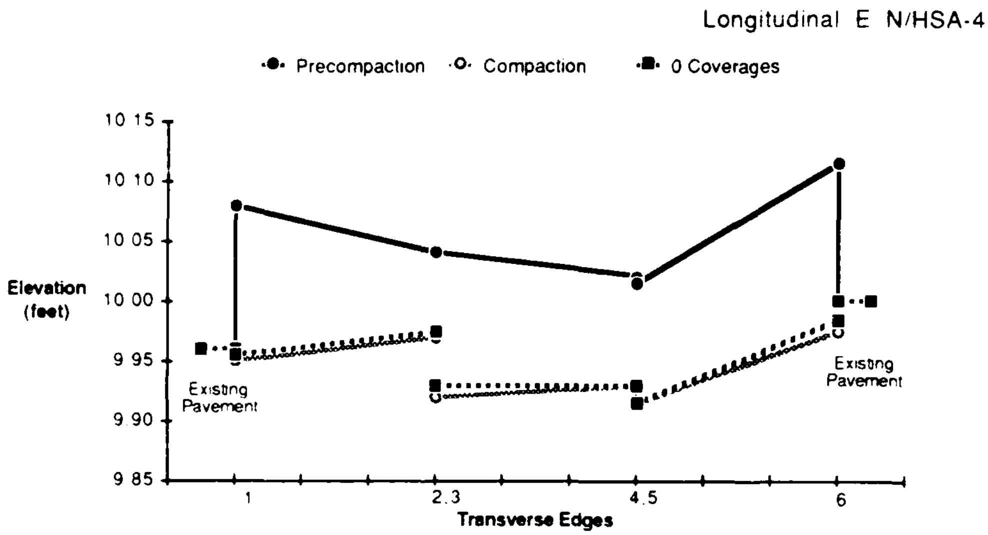

Figure 113. Slab Elevation Profiles Along Longitudinal Edge E, Normal/ High-Strength USAFE Slabs Test (Precompaction, Compaction, and 0 F-15 Loadcart Coverages).

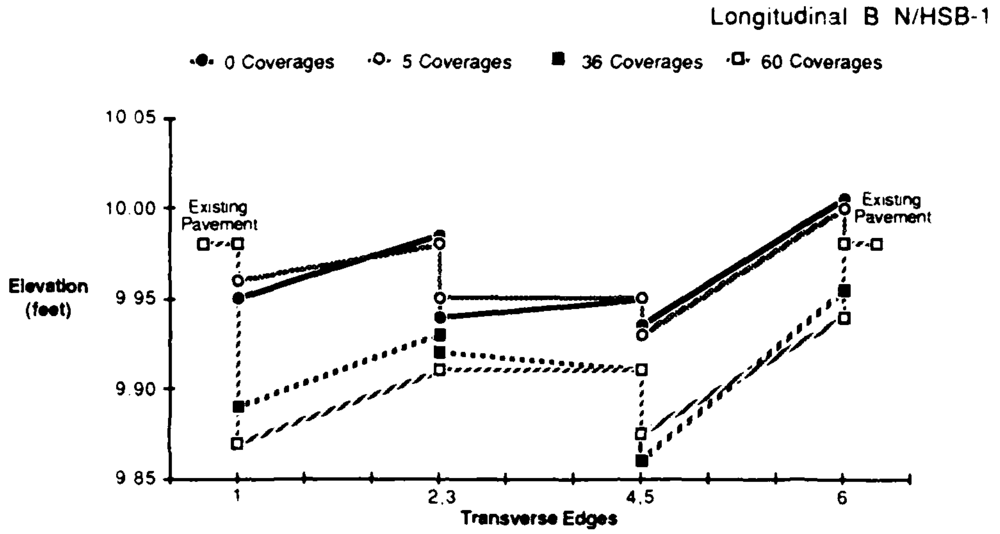

Figure 114. Slab Elevation Profiles Along Longitudinal Edge B, Normal/ High-Strength USAFE Slabs Test (0, 5, 36, and 60 F-15 Loadcart Coverages).

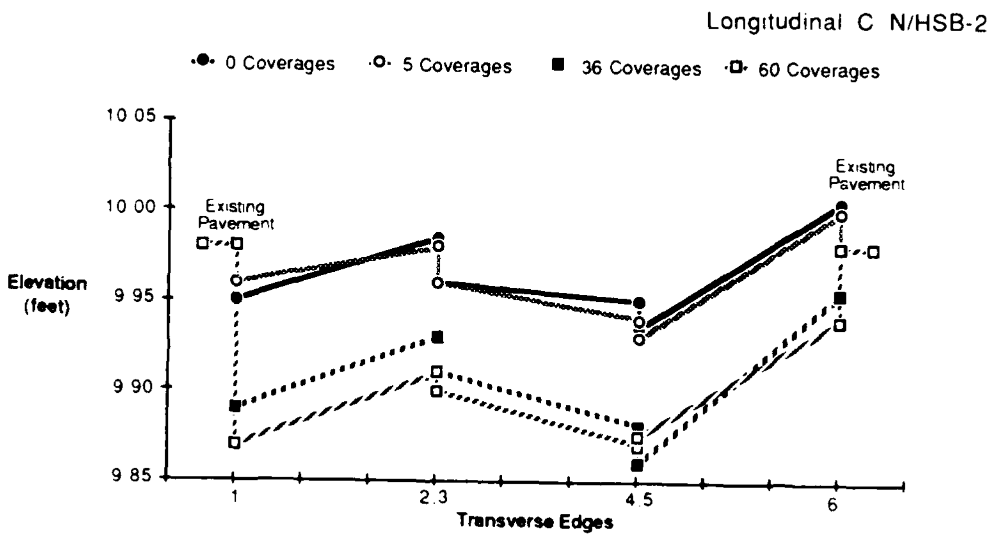

Figure 115. Slab Elevation Profiles Along Longitudinal Edge C, Normal/ High-Strength USAFE Slabs Test (0, 5, 36, and 60 F-15 Loadcart Coverages).

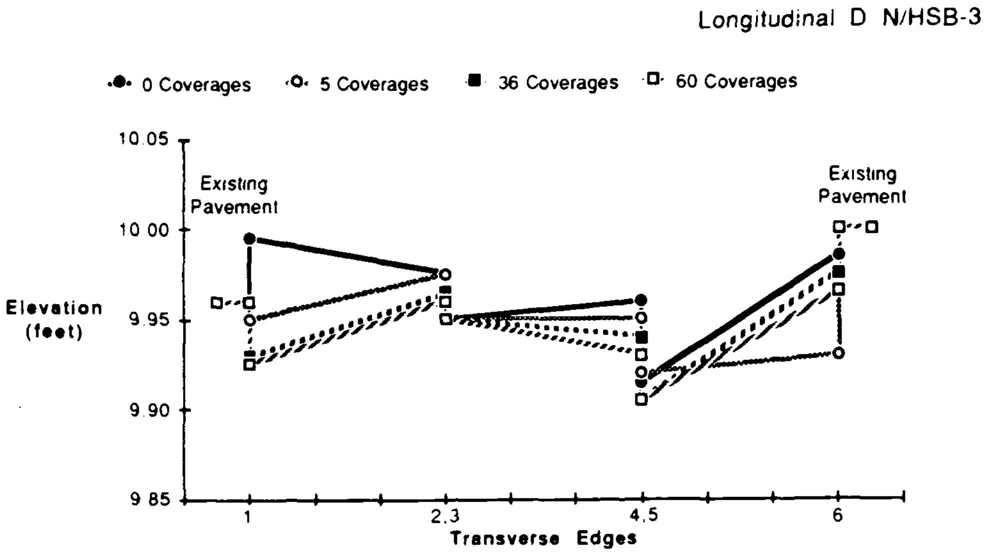

Figure 116. Slab Elevation Profiles Along Longitudinal Edge D, Normal/High-Strength USAFE Slabs Test (0, 5, 36, and 60 F-15 Loadcart Coverages).

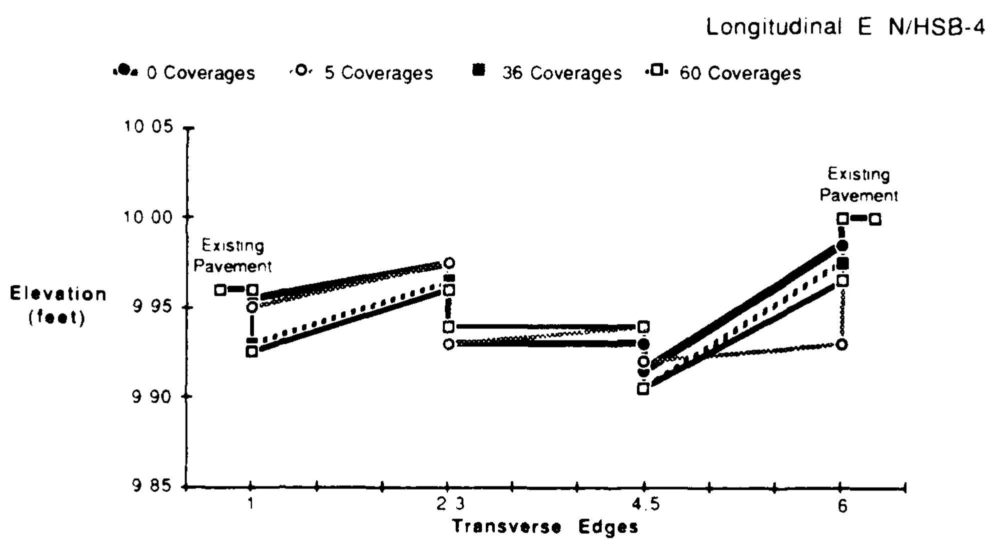

Figure 117. Slab Elevation Profiles Along Longitudinal Edge E, Normal/High-Strength USAFE Slabs Test (0, 5, 36, and 60 F-15 Loadcart Coverages).

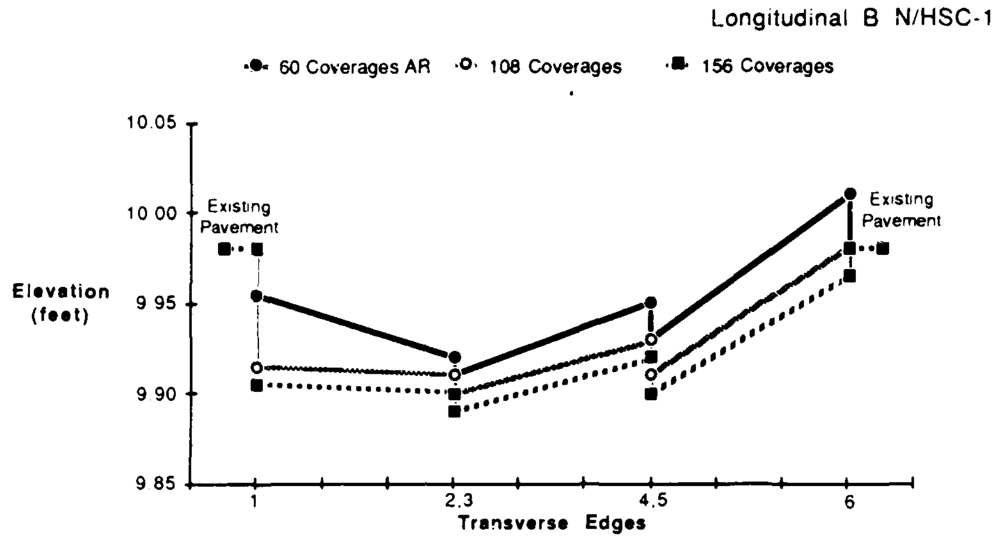

Figure 118. Slab Elevation Profiles Along Longitudinal Edge B, Normal/High-Strength USAFE Slabs Test (60 After Repair, 108, and 156 F-15 Loadcart Coverages).

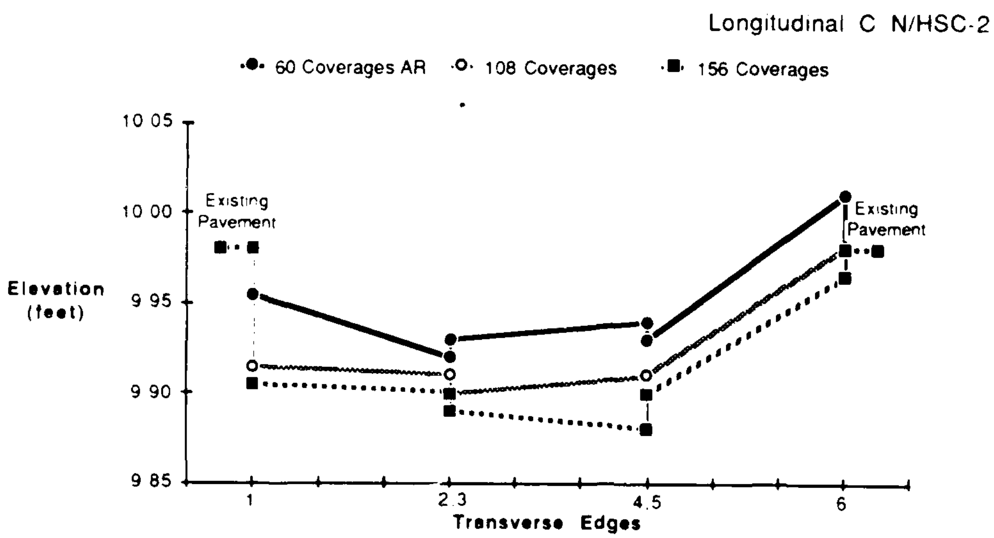

Figure 119. Slab Elevation Profiles Along Longitudinal Edge C, Normal/High-Strength USAFE Slabs Test (60 After Repair, 108, and 156 F-15 Loadcart Coverages).

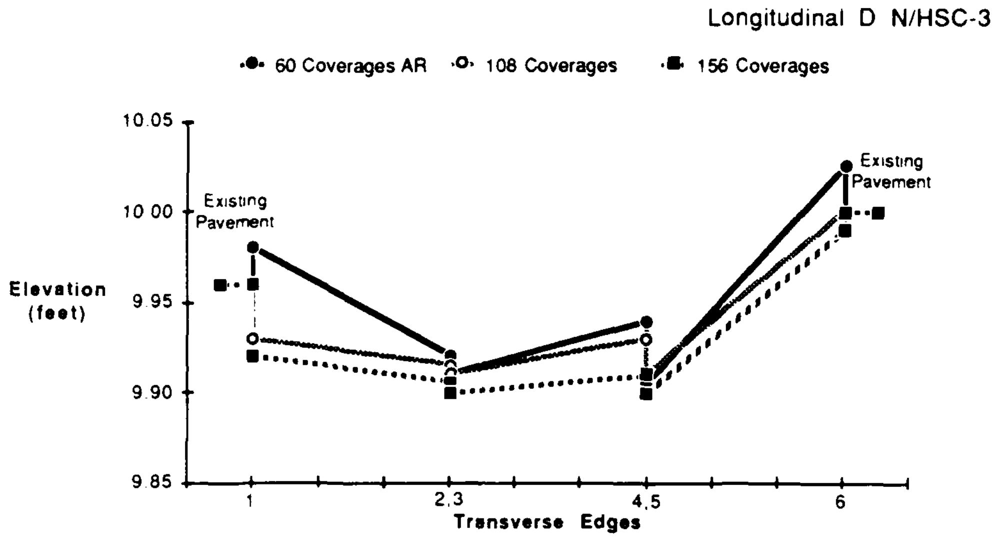

Figure 120. Slab Elevation Profiles Along Longitudinal Edge D, Normal/ High-Strength USAFE Slabs Test (60 After Repair, 108, and 156 F-15 Loadcart Coverages).

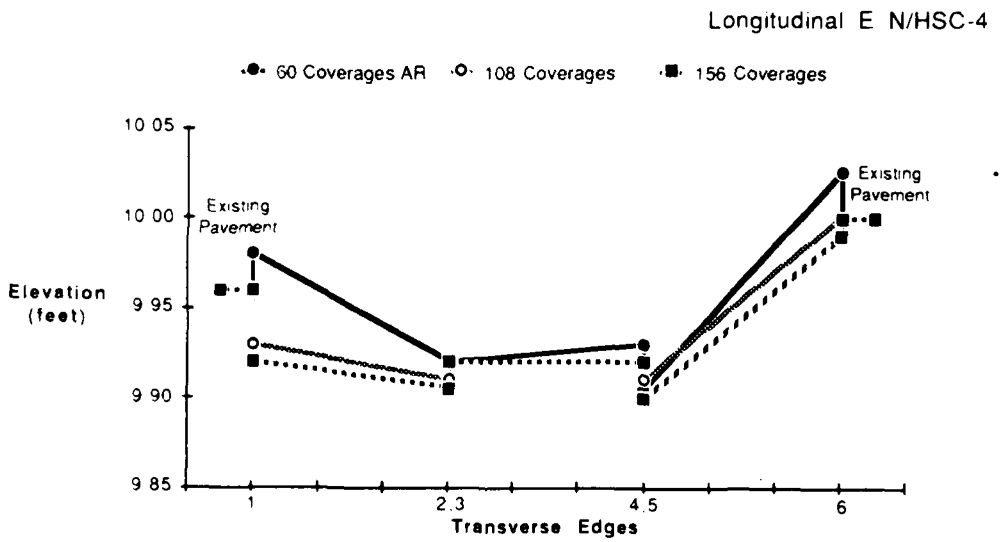

Figure 121. Slab Elevation Profiles Along Longitudinal Edge E, Normal/ High-Strength USAFE Slabs Test (60 After Repair, 108, and 156 F-15 Loadcart Coverages).

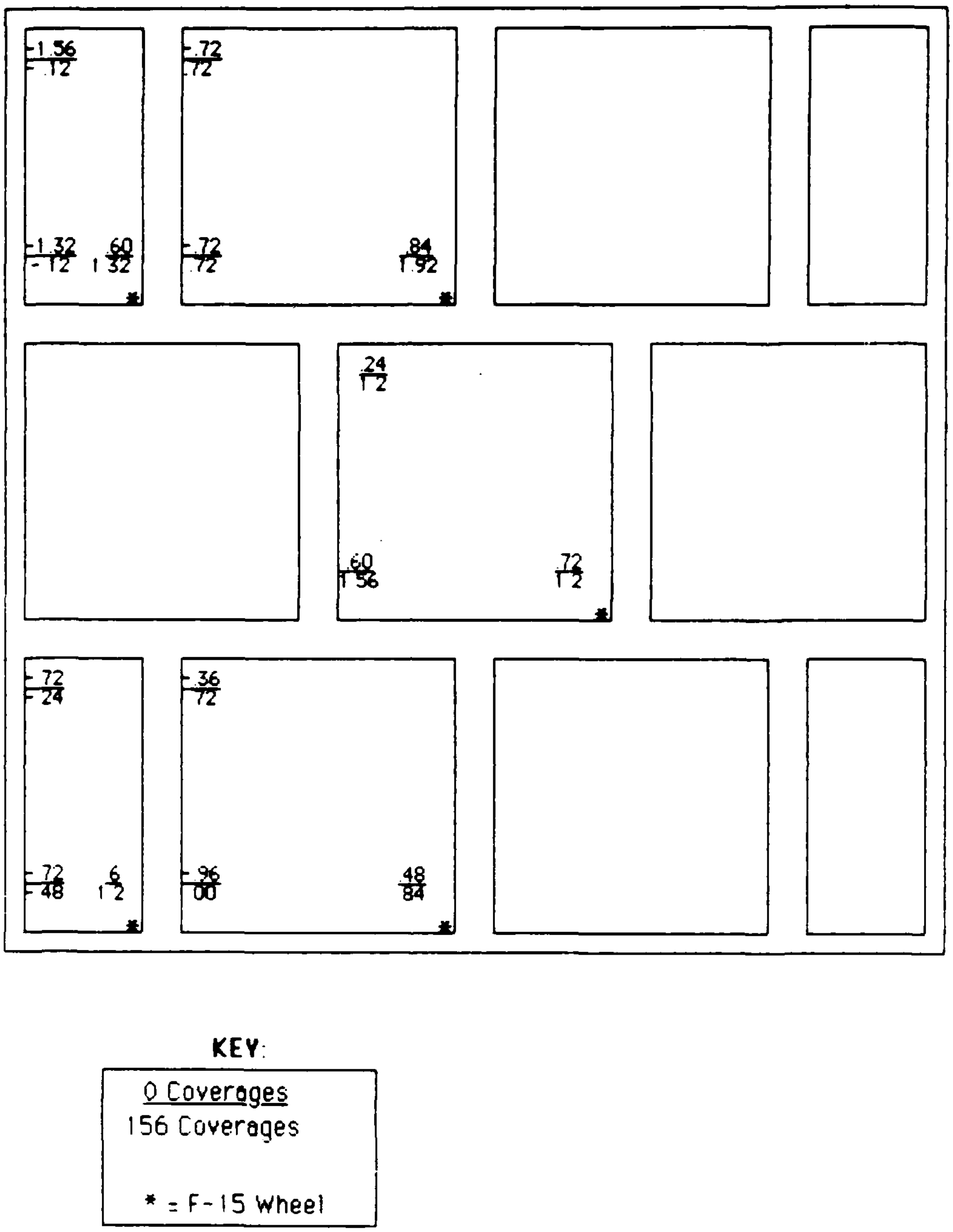

Figure 122. Static Load Measurements (Before and After F-15 Loadcart Traffic), Normal/High-Strength USAFE Slabs Test.

Slab damage increased after 24 coverages. Slab 8 had several cracks across the southeast corner, and Slabs 7 and 11 had small spalled areas.

Data collectors measured unloaded slab elevations after 36 coverages, with maximum settlement between slabs relative to adjacent pavement less than 1 1/2 inches. After 60 coverages, the settlement approached 2 inches along the east edge, and personnel stopped traffic for a maintenance repair. The personnel removed slabs and added additional Number 7 stone to raise the elevation of the leveling course to 6 inches below the adjacent pavement. Personnel replaced the data slabs, and data collectors measured slab surface elevations (static load and unloaded) before traffic resumed. Additional compaction or settlement efforts during the repair were unrecorded.

Personnel noted relative slab-to-slab settlements up to 1 1/2 inches after 48 additional coverages were applied to the repair section (108 coverages total). Personnel continued traffic to 156 coverages without additional maintenance, and the maximum relative settlement after trafficking was 1.56 inches, only slightly greater than the measurement at 108 coverages. All slabs in the traffic zone were spalled or cracked, as shown in Figure 123.

4. Conclusions

The performance of the high strength concrete slabs was somewhat better than the normal strength slabs, in terms of surface damage. None of this test's slab required replacement, although not enough data were available to conclude that the high strength concrete resulted in this improvement. Less spalling resulted around the nosing in this test than in the normal strength test. This section required one maintenance action to support the full 156 F-15 coverages, but supported 60 coverages before having to maintain the repair versus 24 coverages for the previous test.

D. CONCLUSIONS

The USAFE precast slab concept appears adequate for supporting the required fighter and cargo aircraft traffic, although initial settlement of the repair, even with top-of-slab compaction, indicates the need for early maintenance. The results of these tests are summarized below:

- Normal Strength Slabs, F-15 Loadcart Traffic - 160 passes (12 coverages) to first repair maintenance (slab failure).

- High-Strength Slabs, F-15 Loadcart Traffic - 480 passes (40 coverages) to first repair maintenance (excessive sag, no significant damage to slabs).

- Normal Strength Slabs, C-141 Loadcart Traffic - 180 passes (13+ coverages) without repair maintenance.

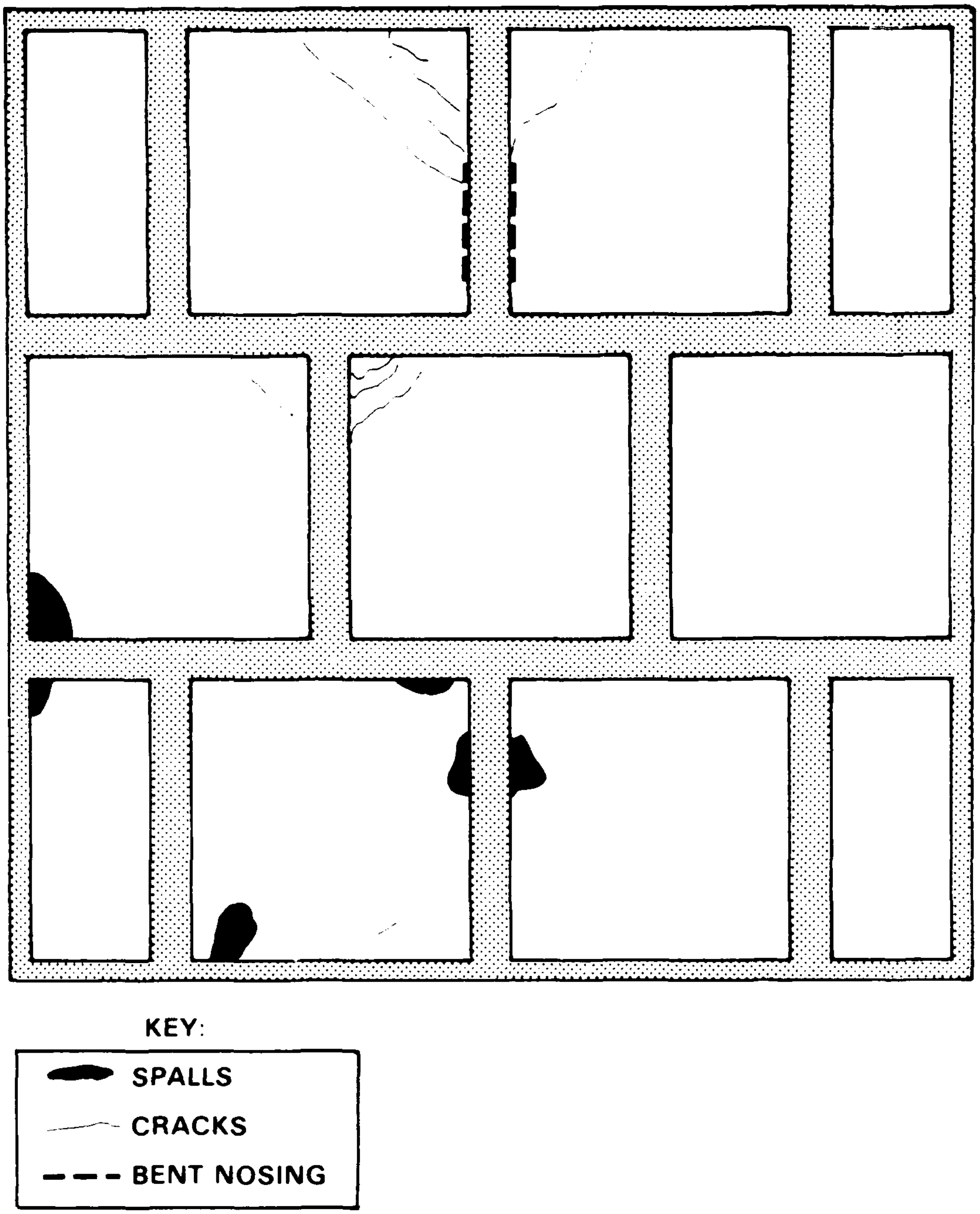

Figure 123. Damage to Slabs after F-15 Traffic, Normal/High-Strength USAFE Slabs Test.

The major problems appear to be early settlement of the slabs relative to edges of surrounding pavement and damage to the nosing area (warping of steel and spalling of concrete). The nosing problem could potentially result in damage to aircraft tires. Personnel observed slab tipping in these tests, which may pose a problem when tailhooks are used.

SECTION V

COMPACTION TESTS

A. INTRODUCTION

In-house test personnel conducted two field tests to determine the performance of two equipment pieces used to compact crushed stone over ballast rock repairs. The RayGo® 410A vibratory roller and the alto-Pac Model 9801 compactor plate, mounted on a John Deere 690B excavator, were tested.

Both tests were conducted at SCTF under dry conditions. The Excavator Compactor Evaluation, conducted in November 1983, compared the two equipment pieces with respect to densities achieved for various layer thicknesses, equipment operating speeds, and number of passes. The Quality Evaluation Procedure, conducted in December 1983, determined what the acceptable field density would be compared to the laboratory value, as a quality control measure for the earlier test results.

1. Background

Vibratory compaction equipment are very efficient for gravel, crushed rock, and other granular soils. The densification obtained depends on the compactor's characteristics such as mass, footprint, and operating frequency; soil characteristics such as aggregate gradation, moisture content, and layer thicknesses; and operating factors such as number of passes and operating speed. In past RRR studies, little attention was given to the influence of all the factors on repair quality. Consequently, some repairs had performance inconsistencies or experienced premature failure during simulated traffic testing. For example, during the Eglin AFB tests in 1983, a crater repaired with at least 6 inches of crushed stone over ballast rock and compacted with the excavator plate rutted badly when subjected to F-4 loadcart traffic (without the FOD cover). A similar section compacted with the vibratory roller successfully withstood approximately 600 passes of the F-4 loadcart. It became apparent that a better relationship was needed between compaction and factors such as compaction equipment, aggregate layer types and thicknesses, and compactive effort.

2. Test Objectives

The general tests objectives were to establish the optimum compactive effort required using the two pieces of equipment to achieve desired densities for various thicknesses of repair aggregate layers. The specific objectives of each test were as follows.

a. Excavator Compactor Evaluation

- Compare the compactor plate's performance with the vibratory roller for various repair layer thicknesses of crushed stone over ballast rock.

- Determine the optimum compactive effort using the two pieces of equipment for various repair layer thicknesses of crushed stone over ballast rock.

- Determine the degree of loosening in a compacted region adjacent to a region being compacted.

b. Quality Evaluation Procedure

Determine the effect of varying the operating speed (travel) of the excavator-mounted compactor plate on the compaction of crushed stone.

B. EXCAVATOR COMPACTOR EVALUATION

1. Purpose

This test was conducted to compare the performance of compaction equipment in attaining a field dry density of 135 pcf, judged by the test director to be adequate for the material, using a minimum effort and a minimum depth of crushed limestone over ballast rock. The compaction qualities of the alto-Pac® Model 9301 compactor plate attached to the John Deere 690B excavator and the RayGo® 410A roller were compared for four test sections having different crushed stone and ballast rock depths. The compaction's speed for the two types of equipment and the effect the speed (varied for the excavator plate) had on the achieved density were compared and evaluated. The test also evaluated the effect that compaction efforts had on nearby compacted areas.

2. Test Description

a. Test Section Descriptions

Test personnel conducted four compaction tests on repair sections constructed as follows:

- Test 1: 3 inches crushed stone over 21 inches ballast rock,

- Test 2: 6 inches crushed stone over 18 inches ballast rock,

- Test 3: 12 inches crushed stone over 12 inches ballast rock, and

- Test 4: 24 inches crushed stone.

Test personnel constructed the sections in Test Pit 2 of SCTF on a clay subgrade which had an average CBR of 3 (measured by cone penetrometer*). Personnel constructed the section for Test 1 first and later prepared the remaining test sections by removing the crushed stone layer and some of the ballast rock used in the previous test and replacing additional ballast rock and a new layer of crushed stone. This loosened the ballast rock remaining in the test pit and increased the crushed stone layer depth for each succeeding test.

b. Compaction

Test personnel graded the crushed stone nearly flush with the pavement surface in each test before compaction began. Compaction of the sections proceeded along the lanes shown in Figure 124 with the vibratory roller and the excavator compactor plate. The RayGo® operator compacted the roller lane first with four roller coverages. The excavator operator then compacted Lanes 1 and 2 with one compactor plate pass, followed by one compactor plate pass on Lanes 3 and 4. The personnel repeated this compaction sequence three times to provide a total of 12 roller coverages for the roller lane and three compactor plate passes for Lanes 1, 2, 3, and 4. The application of 12 roller coverages and three compactor plate passes maintained the ratio of recommended compaction procedures which call for 8 to 10 roller coverages or two compactor plate passes (as later documented in the September 1984 "Rapid Runway Repair Interim Guidance"). The excavator operator used compactor plate speeds of approximately 0.25 ft/sec in Lanes 1 and 3, and 0.50 ft/sec in Lanes 2 and 4, to determine the effect operating speed has on achieved densities.

c. Data Collection

Test technicians measured subgrade moisture-density, taking three readings before crushed stone and ballast rock were added to the test pit. Test personnel used a rod and level to take elevation measurements of the clay surface at the locations shown in Figure 125.

Data collectors recorded compaction times for each lane and base course moisture-density and elevation measurements throughout each of the four tests, as described below.

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*Cone Index versus CBR curve is the standard correlation curve recommended by "Evaluation of Soil Strength of Unsurfaced Forward Area Airfield by Use of Ground Vehicles," G. M. Hammitt, II, WES S-70-17, 1970.

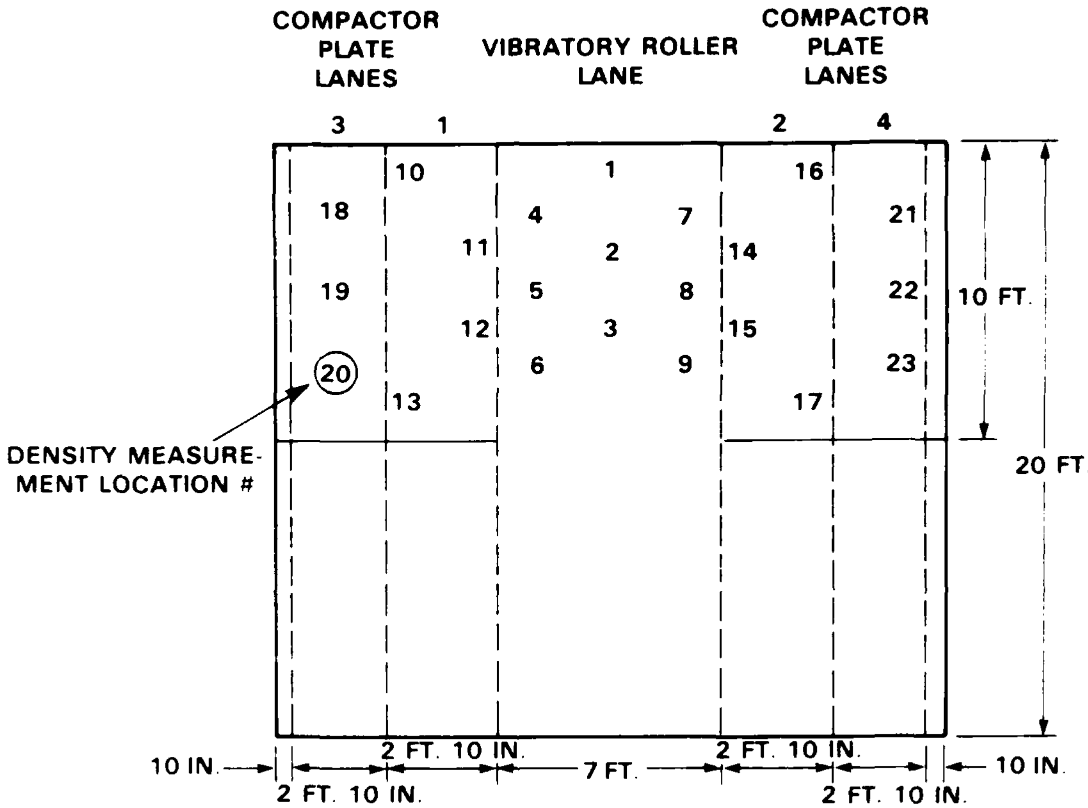


Figure 124. Compaction Lanes and Moisture-Density Measurement Locations, Excavator Compactor Evaluation.

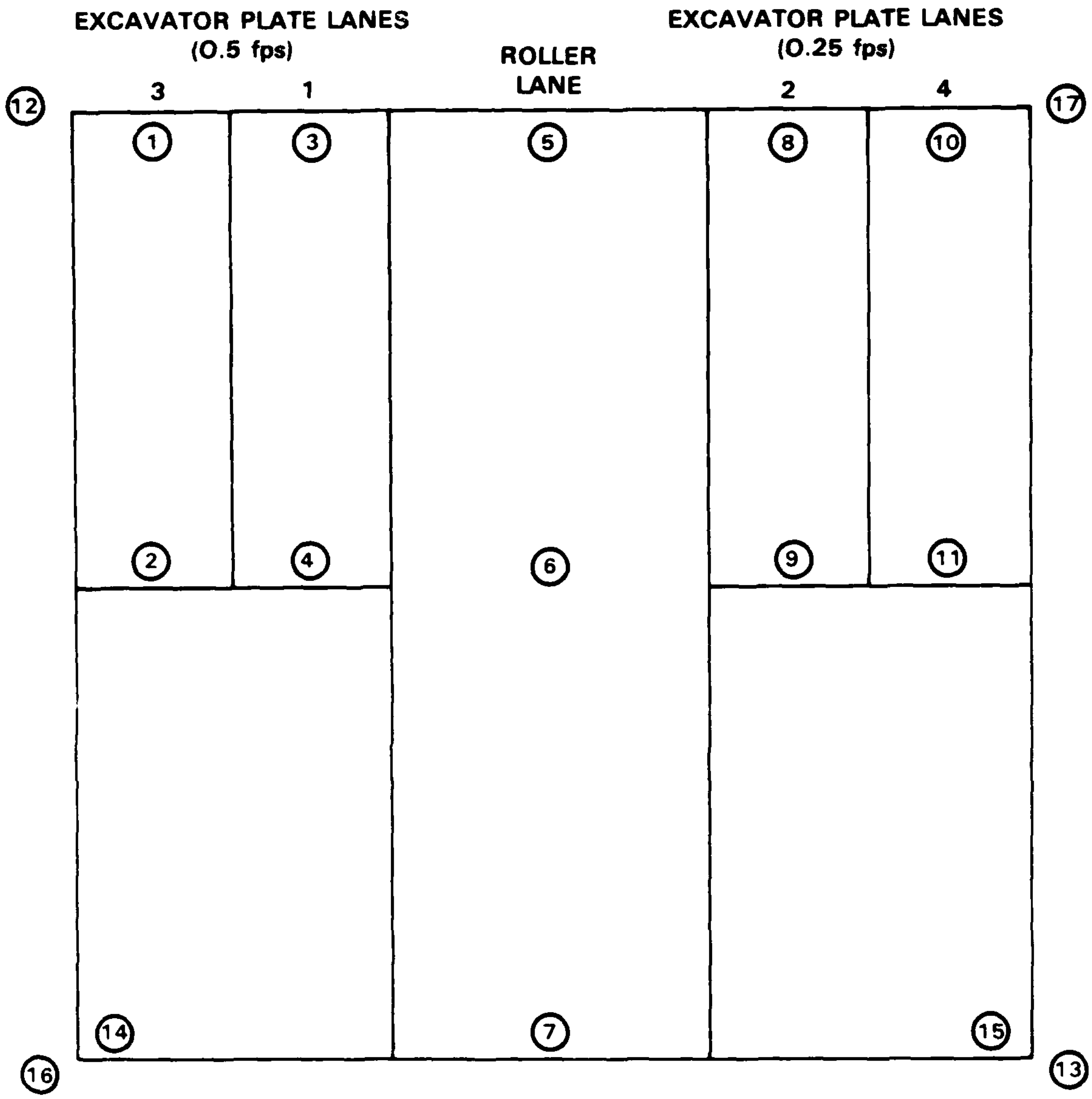


Figure 125. Level Measurement Locations, Excavator Compactor Evaluation.

(1) Moisture-Density Measurements

Test personnel used two nuclear gauges interchangeably to obtain moisture-density readings at the locations shown in Figure 124. The gauges had not been calibrated in accordance with ASTM D2922 before testing but were used equally. Accordingly analysis of one gauge's set of reading would be possible, but comparative analysis of both sets would not be valid due to the variation of readings between the two gauges. Test personnel measured moisture content and densities at 6-inch depths in Tests 1 through 3, and at 6 inches and 12 inches in Test 4, following the sequence outlined below. In test 1, the density probe extended beneath the 3-inch deep layer of crushed stone into the ballast rock. Initially, this might have resulted in low density readings, but later readings could be too high due to gradual migration of crushed stone into ballast rock.

Data collectors recorded moisture-density measurements taken in the center of the roller lane after 2, 4, 6, 8, 10, and 12 roller coverages in all tests, and in Test 4 after 16 roller coverages as well. Test personnel also made moisture-density checks in Lanes 1 and 2 and in Lanes 3 and 4 after one, two, and three compactor plate passes over the respective lanes. This data collection sequence provided layer density versus compaction effort data for the vibratory roller and for the compactor plate operated at two different speeds. In addition, to provide an indication of the degree of loosening in a compacted region adjacent to a region being compacted, personnel measured moisture content and dry density in the roller lane after one, two, and three compactor plate passes over Lanes 1 and 2, and in the roller lane and in Lanes 1 and 2 after one, two, and three compactor plate passes over Lanes 3 and 4.

In Test 4, personnel obtained moisture-density readings at 6-inch and 12-inch depths, as described above, to determine the densities achieved throughout the layer, using both the compactor plate and the vibratory roller. Test personnel increased the number of roller coverages to 16 to determine whether the increase improved the densities obtained at the 12-inch depth.

(2) Elevation Measurements

Test personnel measured surface elevations using a survey rod and level at the locations shown in Figure 125. In Tests 1, 2, and 3 personnel recorded measurements of the ballast rock surface before the crushed stone was placed and of the crushed stone surface before compaction, after four roller coverages and one compactor plate pass, and after 12 roller coverages and three compactor plate passes. In Test 2, personnel also obtained elevation data after eight roller coverages and two compactor plate passes. In Test 4, test personnel measured elevations of the crushed stone surface before compaction, after four roller coverages and one compactor plate pass, after eight roller coverages and two compactor plate passes, and after 16 roller coverages and 3 compactor plate passes.

3. Results

a. Subgrade Data

Data collectors measured subgrade moisture-density, recording an average CBR of 3, dry density of 96.3 lb/ft^3, and moisture content of 35.3 percent.

b. Crushed Stone and Ballast Rock Moisture-Density Data

Thickness of the crushed stone layer for each lane are tabulated in Table 9. Nuclear dry density data for each test are summarized in Table 10. Test personnel recorded data prior to compaction and after compaction in each lane. In Test 1, test personnel did not collect data in Lanes 2 and 4. A more complete set of data is provided in Appendix B.

The locations of the measurements varied from one test to the next, and within each test from one compaction level to the next, because of loosening of crushed stone from the nuclear gauge probe. As a result, and because two uncalibrated gauges were used throughout the tests (an arbitrary check indicated a difference of 1.8 lb/ft^3 in the two gauge readings in the same hole), comparison of the compaction results at each sampling location is not useful. A comparison of average dry densities in each lane can, however, be made since the two gauges were used equally. Thus for all tests, the test director calculated average dry densities for each lane at all compaction levels, and the standard deviation in the measured dry densities, which are included in Appendix B, Tables B-1 through B-12. The data are summarized in Table 10, which presents average dry densities and standard deviations for each test by lane compaction method (i.e., roller lane, compactor plate slow, compactor plate fast) at the various compaction levels.

The data in Table 10 are presented graphically in Figures 126 through 132. The analysis does not consider moisture content because current repair procedures do not include any type of water control, and because the effect of moisture is less important when compacting gravel and rock.

Figures 126 through 129 show dry density versus compaction effort for the four test sections. Typically, dry density increased with compaction effort until a maximum was reached, and then decreased with additional compaction. This behavior is consistent with compaction of soils on the dry side of optimum moisture content, as defined by ASTM D1557. The maximum observed field densities resulted after one to two compactor plate passes in all tests, and after 3 to 10 roller coverages in all tests except in Test 3. In Test 3, the maximum field dry density apparently had not been reached after 12 roller coverages. Figures 126 through 129 also show that at a 5-inch depth compaction with the roller was considerably better than with the compactor plate. Further, the figures show no significant difference in results from using the compactor plate at

TABLE 9. AVERAGE THICKNESS OF CRUSHED STONE AND BALLAST ROCK LAYERS BEFORE COMPACTION, EXCAVATOR COMPACTOR EVALUATION.

TEST NO.	LAYER	LAYER THICKNESS (INCHES) EXCAVATOR (0.5 fps) 1	3	LANES (0.25 fps) 2	4	ROLLER LANE
1	CRUSHED STONE	24.5	24.1	25.2	24.2	24.9
2	CRUSHED STONE	11.5	11.2	11.1	11.5	11.4
	BALLAST ROCK	12.5	12.4	13.0	12.4	13.6
3	CRUSHED STONE	4.4[a]		4.7[a]		5.3
	BALLAST ROCK	19.0[a]		19.1[a]		19.3
4	CRUSHED STONE	4.2[a]		3.9[a]		4.6
	BALLAST ROCK	20.2[a]		20.4[a]		19.8

NOTES:
[a]Average for both lanes, due to limited number of recorded data points.

TABLE 10. DATA SUMMARY - AVERAGE DRY DENSITIES (LB/FT^3) EXCAVATOR COMPACTOR EVALUATION.

TEST NO.	COMP EFFORT	ROLLER LANE MEAN	ROLLER LANE σn	COMPACTOR PLATE LANES 1&3 MEAN	COMPACTOR PLATE LANES 1&3 σn	COMPACTOR PLATE LANES 2&4 MEAN	COMPACTOR PLATE LANES 2&4 σn
1	2	125.4	0.42	—	—	—	—
	4, 1[a]	130.6	4.25	122.2	7.39	—	N/A
	6	134.3	1.11	—	—	—	—
	8, 2	131.1	5.85	119.8	6.08	—	—
	10	136.0	6.69	—	—	—	—
	12, 3	129.1	7.90	118.3	2.24	—	—
2	2	132.8	—				
	4, 1	132.6	4.83	121.7	6.11	120.8	8.43
	6	135.3	2.34				
	8, 2	127	3.48	116.9	10.52	121.2	8.00
	10	136.8	8.76				
	12, 3	138.5	1.29	111.2	6.30	109.7	6.72
3	2	134.6	2.18				
	4, 1	136.2	2.69	132.7	2.86	129.4	1.99
	6	134.2	1.80				
	8, 2	138.3	1.53	130.2	2.35	133.0	3.80
	10	137.8	3.41				
	12, 3	137.5	4.53	130.9	3.25	131.9	2.52
4	2	129.4	2.62				
	4, 1	134.1	4.11	131.3	3.33	131.7	3.28
	6	138.3	2.72				
	8, 2	138.7	2.48	135.4	2.11	134.4	2.71
	10	131.8	0.75				
	12, 3	138.3	1.87	133.2	2.84	129.2	3.09

[a]ROLLER COVERAGES, EXCAVATOR PLATE PASSES

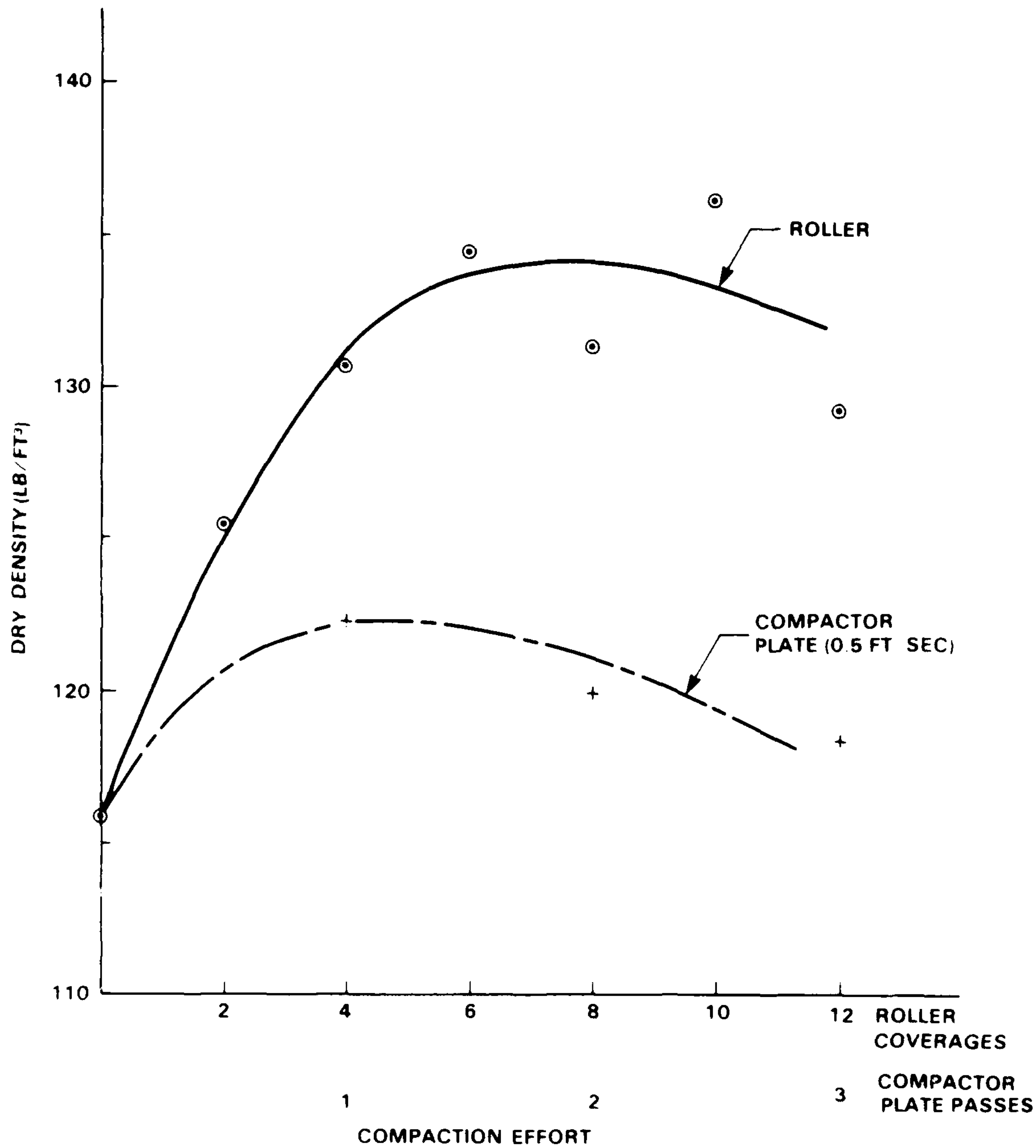


Figure 126. 6-Inch Dry Density Versus Compaction Effort - Test 1, Excavator Compactor Evaluation.

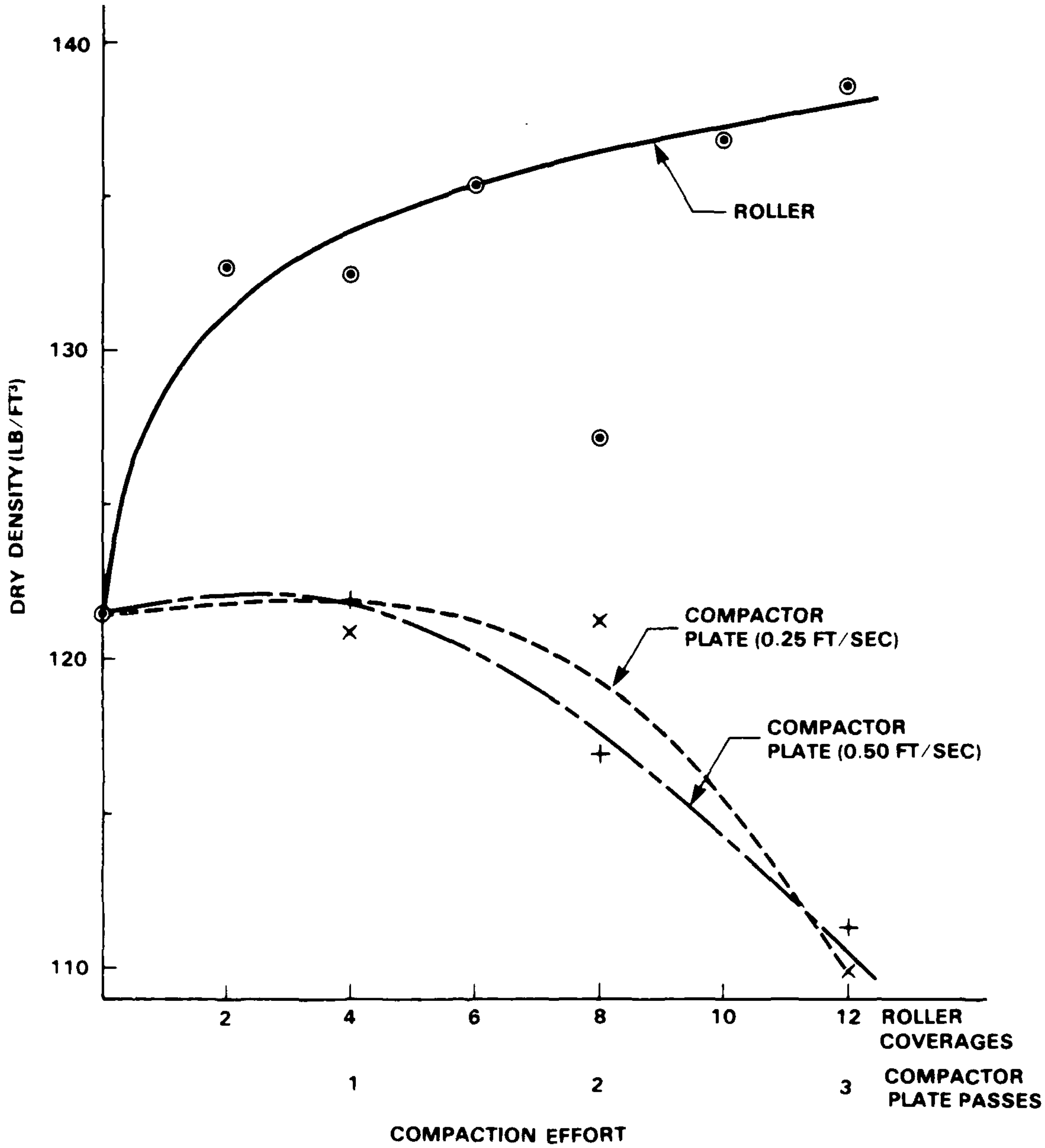


Figure 127. 6-Inch Dry Density Versus Compaction Effort - Test 2, Excavator Compactor Evaluation.

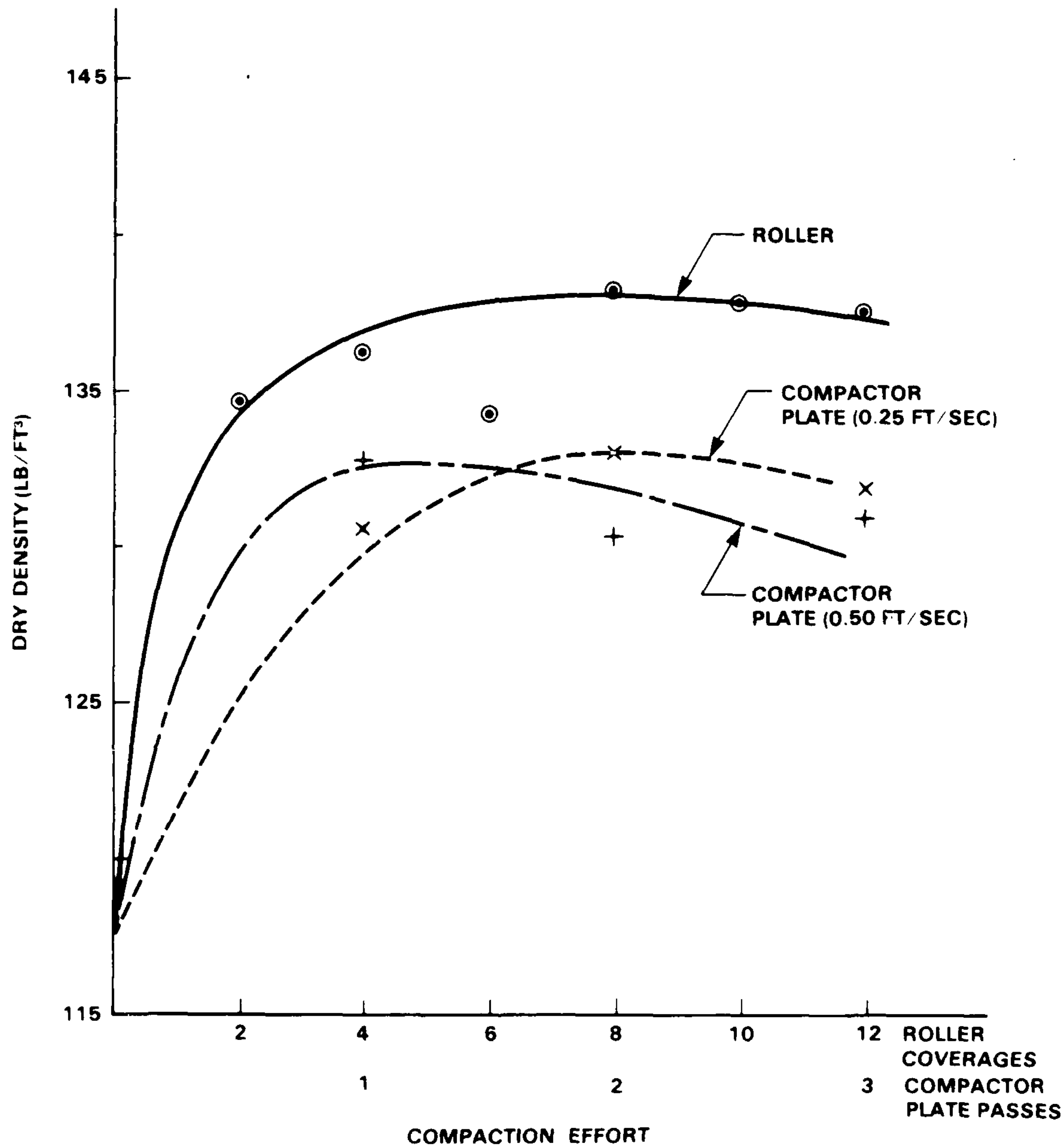


Figure 128. 6-Inch Dry Density Versus Compaction Effort - Test 3, Excavator Compactor Evaluation.

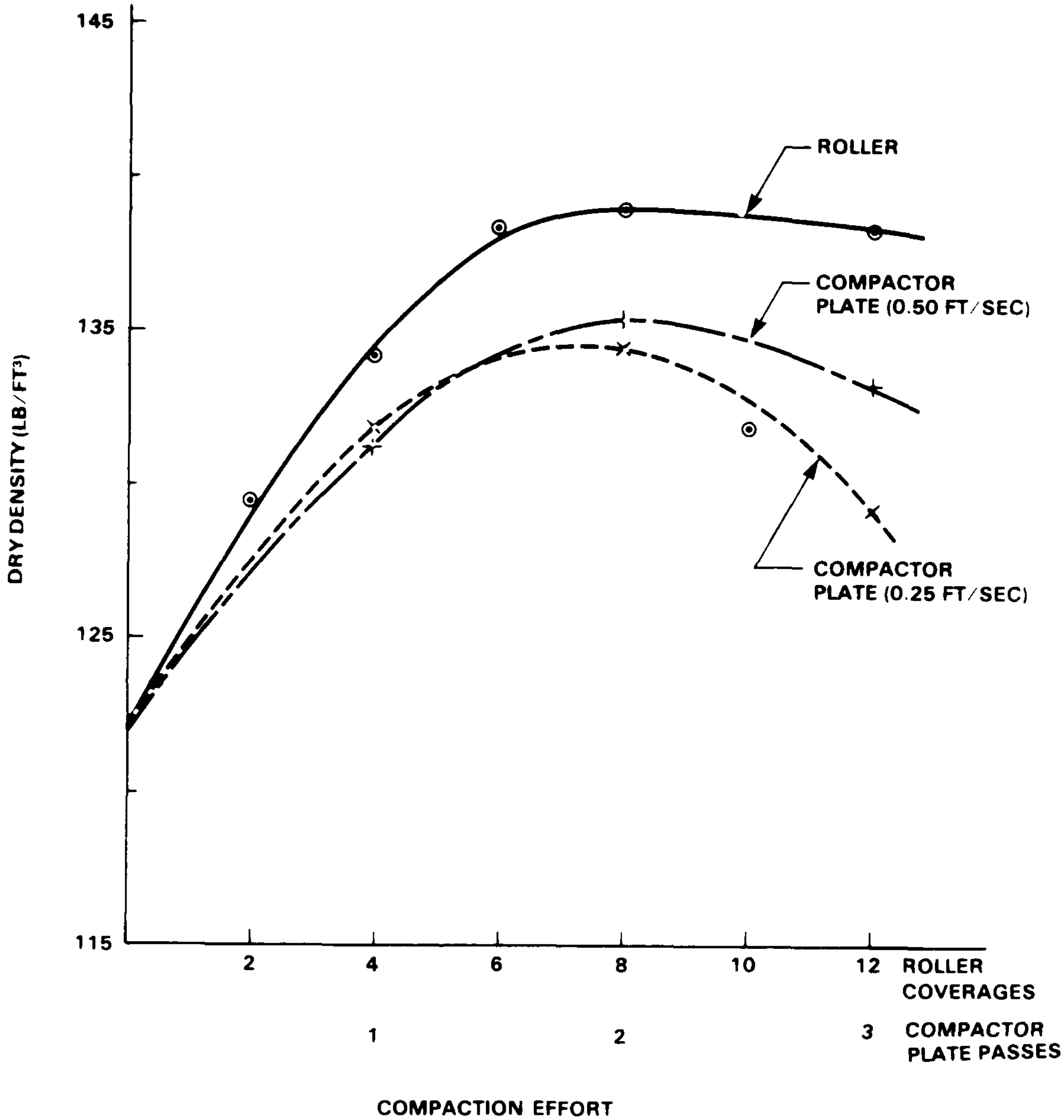


Figure 129. 6-Inch Dry Density Versus Compaction Effort - Test 4, Excavator Compactor Evaluation.

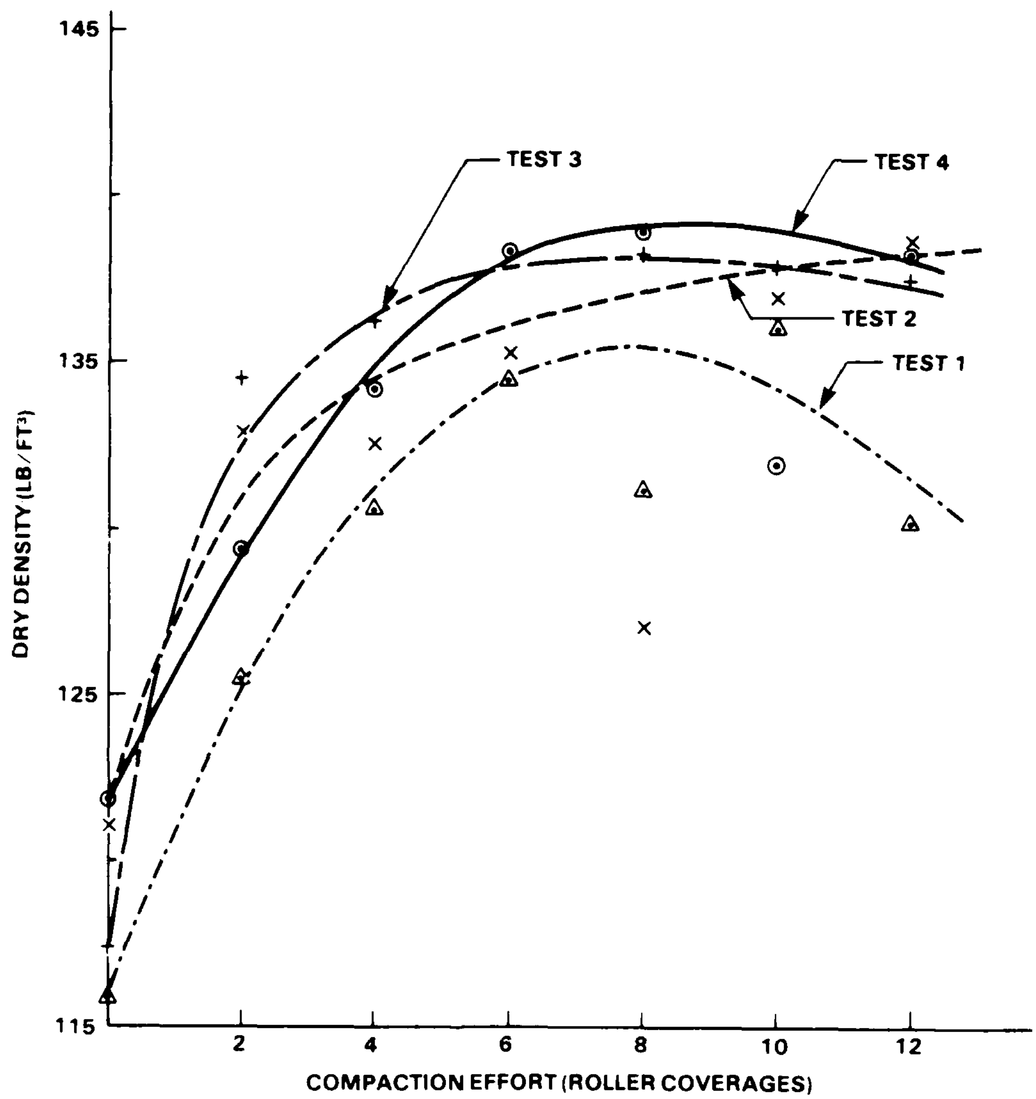


Figure 130. 6-Inch Dry Density Versus Compaction Effort - Vibratory Roller, Excavator Compactor Evaluation.

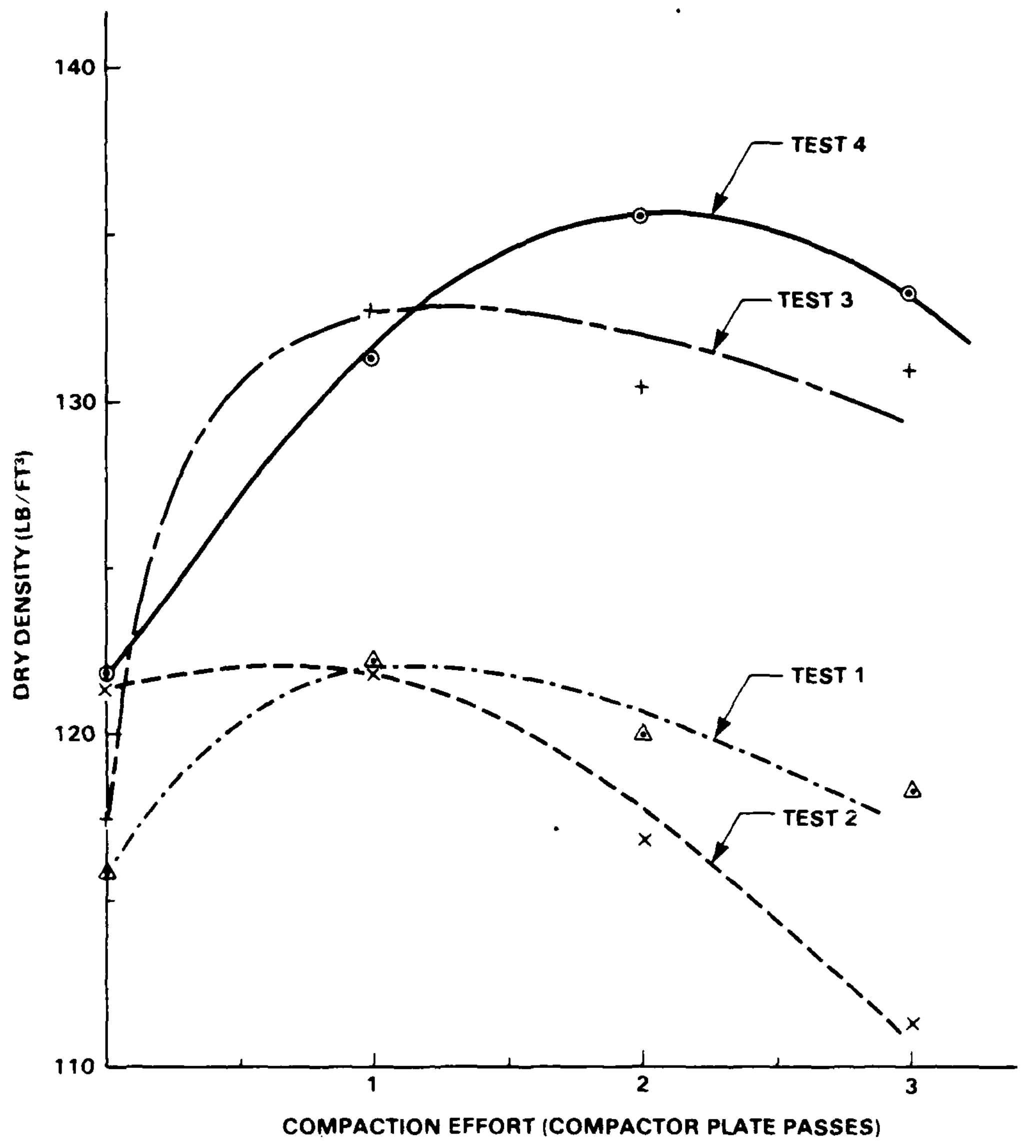


Figure 131. 6-Inch Dry Density Versus Compaction Effort - Compactor Plate (0.5 ft/sec), Excavator Compactor Evaluation.

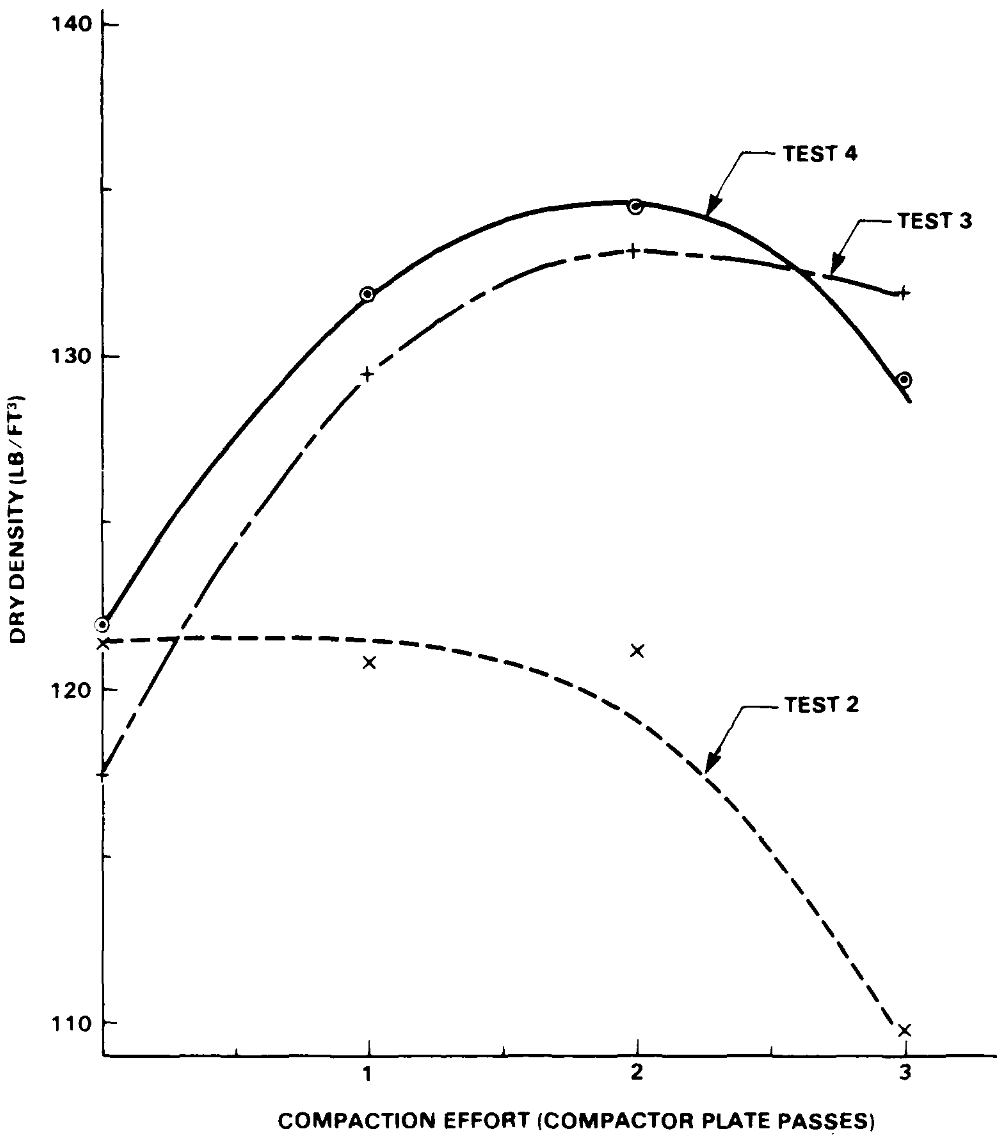


Figure 132. 6-Inch Dry Density Versus Compaction Effort - Compactor Plate (0.25 ft/sec), Excavator Compactor Evaluation.

0.25 ft/sec and at 0.50 ft/sec. In addition, statistical analyses (provided in Appendix D) indicated that at a 6-inch depth, roller dry densities were greater than compactor plate dry densities at the 95-percent confidence level. Also, the average dry density after two compactor plate passes at the faster rate is equal to the average dry density after two plate passes at the slower rate at the 95-percent confidence level.

Figures 130 through 132 depict dry density at a 6-inch depth versus compaction effort for the vibratory roller, the compactor plate moving 0.50 ft/sec, and the compactor plate moving 0.25 ft/sec. As seen in Figure 65, the dry densities achieved with the roller were similar for all tests and ranged from 130 to 135 lb/ft^3 after 6 to 10 roller coverages for the test section with 3 inches of crushed stone, to 135 to 140 lb/ft^3 after 6 to 10 roller coverages for test sections with thicker crushed stone layers. Maximum dry density observed was greatest for the test section with 24 inches of crushed stone (Test 4) and least for the test section with 3 inches of crushed stone (Test 1). Figures 131 and 132 show that the compactor plate was ineffective for achieving dry densities similar to those obtained with crushed stone layers less than 12 inches at either speed, resulting in dry densities less than 122 lb/ft^3. The maximum field densities observed in Tests 1 and 2 by the compactor plate operating at 0.50 ft/sec were similar, but observed dry density declined much more rapidly with more compaction in Test 2 than in Test 1.

Figure 133 compares the 12-inch and 6-inch depth density readings taken in Test 4 and presented in Table 11. As seen in the figure, the compactor plate provided nearly the same densities at 6- and 12-inch depths. Less compactive influence of the roller was observed at a 12-inch depth.

Statistical analyses of the 6-inch and 12-inch field dry density measurements for both roller and excavator compactor are provided in Appendix C. These analyses show that 12-inch dry densities were equal to 6-inch dry densities for the compactor plate at the 85-percent confidence level, and 12-inch dry densities were lower than 6-inch dry densities for the roller at the 85-percent confidence level.

c. Elevation Data

Elevation data for the four tests are presented in Appendix B, Tables B-13 through B-16. Table 12 summarizes this data and presents average displacements of locations in the center of the pit. Edge location data were discarded when computing the average displacements because in some instances there was upheaval of the surface in the form of small piles of loose crushed stone. The piles of loose crushed stone were formed by the compactor plate as it disturbed some crushed stone along the lane and pulled it to the sides.

The data in Table 12 are presented graphically in Figures 134 through 140. Examination of Figures 134 through 137 shows that

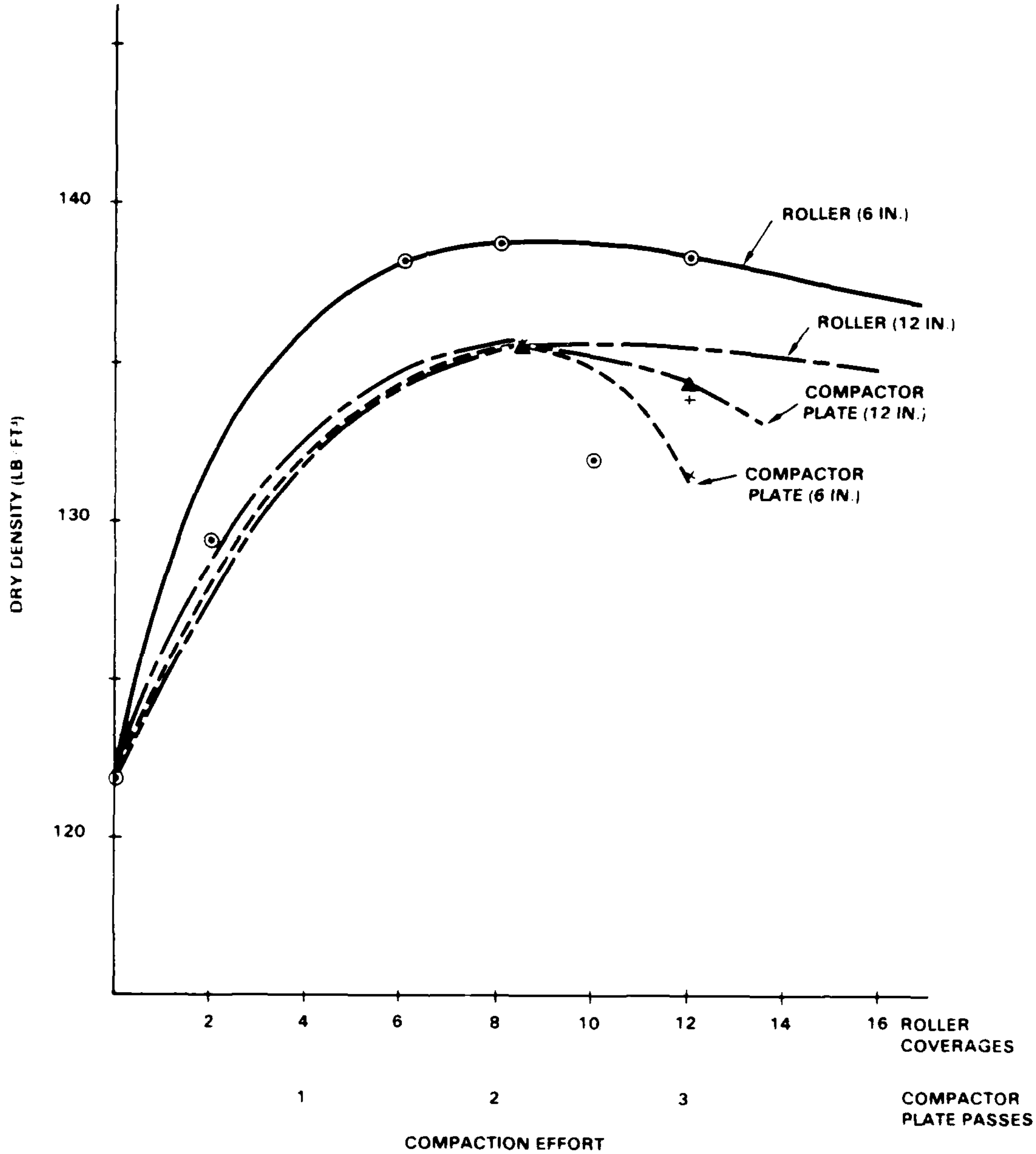


Figure 133. 6-Inch and 12-Inch Dry Densities Versus Compaction Effort, Excavator Compactor Evaluation.

TABLE 11. 12-INCH VS 6-INCH DENSITY DATA, EXCAVATOR COMPACTOR EVALUATION.

WHEN MEASURED	LOCATION	WET DENSITY (LB/FT³) 6 in	WET DENSITY (LB/FT³) 12 in	DRY DENSITY (LB/FT³) 6 in	DRY DENSITY (LB/FT³) 12 in	MOISTURE CONTENT (%) 6 in	MOISTURE CONTENT (%) 12 in
2 EXC PASSES 8 ROLLER CVGS	1	–	142.7	–	138.0	-	3.4
	2		136.5	–	132.6	-	3.2
	3		140.5	–	135.6	-	3.6
	MEAN	-	139.9	-	135.4		3.4
	σn	-	3.14	–	2.21		0.2
	18	137.1	138.3	133.1	134.3	3.0	3.0
	19	142.2	145.6	136.6	140.8	4.1	3.5
	20	141.3	136.1	136.4	131.1	3.6	3.7
	MEAN	140.2	140.0	135.4	135.4	3.6	3.4
	σn	2.72	4.97	1.96	4.94	0.6	0.4
3 EXC PASSES 12 ROLLER CVGS	2	-	144.6	–	141.0	–	2.6
	3		132.7		128.4		3.4
	4	142.0	142.0	137.7	137.6	3.1	3.2
	6	136.3	132.1	131.9	127.8	3.4	3.4
	MEAN	139.2	137.9	134.8	133.7	3.2	3.1
	σn	N/A	6.39	N/A	6.62	N/A	0.4
	18	134.4	137.7	130.8	133.9	2.7	2.9
	19	133.3	137.5	129.0	133.1	3.3	3.3
	20	139.8	142.8	134.8	136.7	3.7	4.4
	MEAN	135.8	139.3	131.5	134.6	3.2	3.5
	σn	3.48	3.00	2.97	1.89	0.5	0.8
3 EXC PASSES 16 ROLLER CVGS	1		139.7	-	135.4	-	3.1
	2		135.0		131.2		2.9
	3		143.7		139.1		3.3
	MEAN		139.5		135.2		3.1
	σn		4.35		3.95		0.2

5117 85W GW26 9

TABLE 12. AVERAGE CRUSHED STONE SURFACE AND BALLAST ROCK SURFACE LEVEL MEASUREMENTS (FT) BEFORE AND AFTER COMPACTION, EXCAVATOR COMPACTOR EVALUATION.

MEASURED WHEN	ROLLER LANE		COMPACTOR PLATE LANES 1&3		COMPACTOR PLATE LANES 2&4	
	LEVEL	DISPLACEMENT	LEVEL	DISPLACEMENT	LEVEL	DISPLACEMENT
			TEST 1			
PRE-COMP (BR)[a]		--	9.53	—	—	
PRE COMP	9.91		10.0		9.95	
4 CVGS	9.89	0.02	9.86	0.14	9.43	0.52
8 CVGS		—		—		-
12 CVGS	9.85	0.06	9.55	0.45	9.35	0.60
			TEST 2			
PRE COMP (BR)	9.49		--		—	
PRE COMP	9.95		9.91		9.90	
4 CVGS	9.87	0.08	9.55	0.36	9.63	0.27
8 CVGS		-		—		
12 CVGS	9.85	0.10	9.49	0.42	9.51	0.39
			TEST 3			
PRE COMP (BR)	9.06		8.93		9.01	
PRE COMP	9.93		9.88		9.90	
4 CVGS	9.89	0.04	9.67	0.21	9.65	0.25
8 CVGS	9.88	0.05	9.68	0.20	9.67	0.23
12 CVGS	9.86	0.07	9.66	0.22	9.64	0.26
			TEST 4			
PRE COMP (BR)						
PRE COMP	9.95		9.89		9.96	
4 CVGS	9.85	0.10	9.76	0.13	9.59	0.37
8 CVGS	9.84	0.11	9.74	0.15	9.57	0.39
16 CVGS	9.82	0.13	9.76	0.13	9.56	0.40

[a]PRE-COMP (BR) — TOP OF BALLAST ROCK SURFACE LEVEL MEASUREMENT

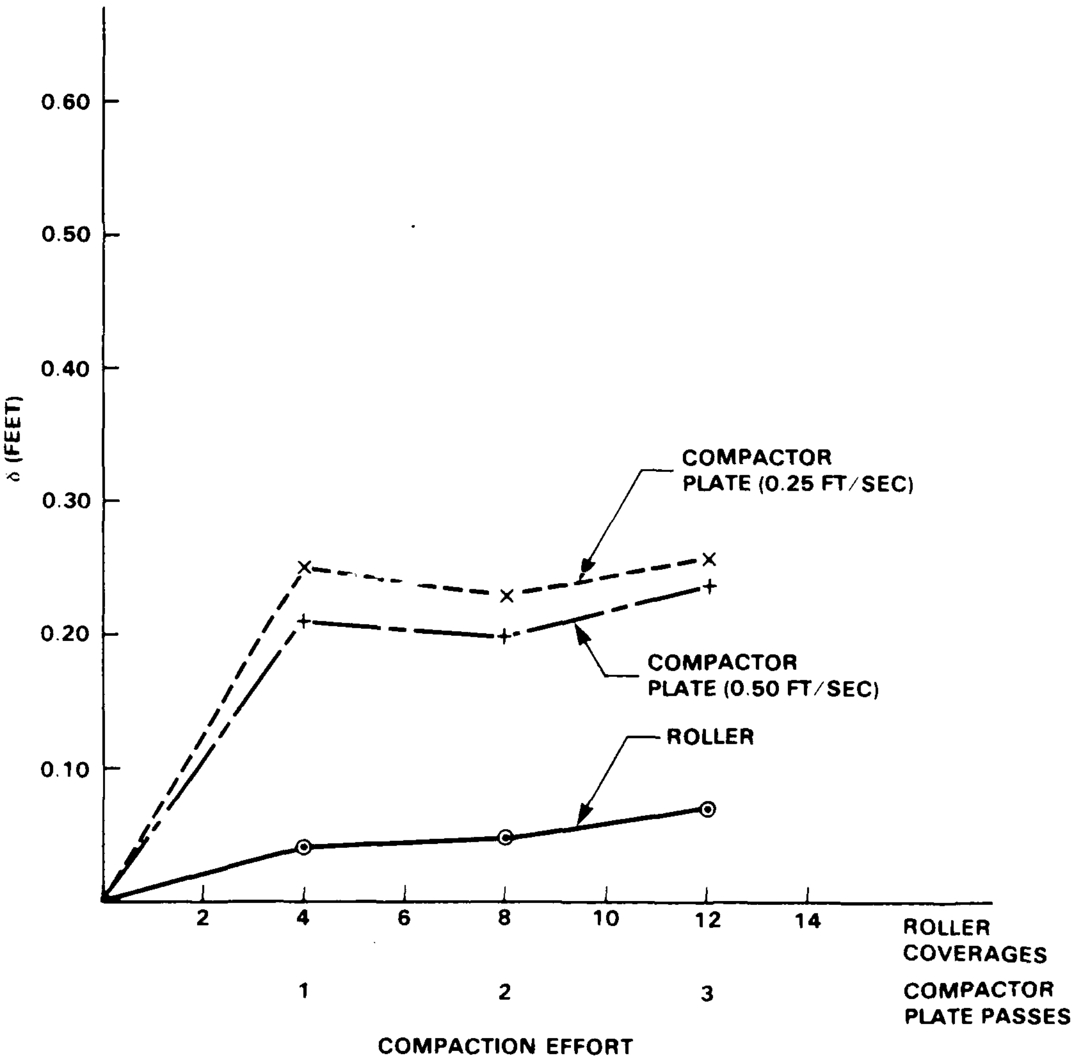


Figure 134. Displacement Versus Compaction Effort - Test 1, Excavator Compactor Evaluation.

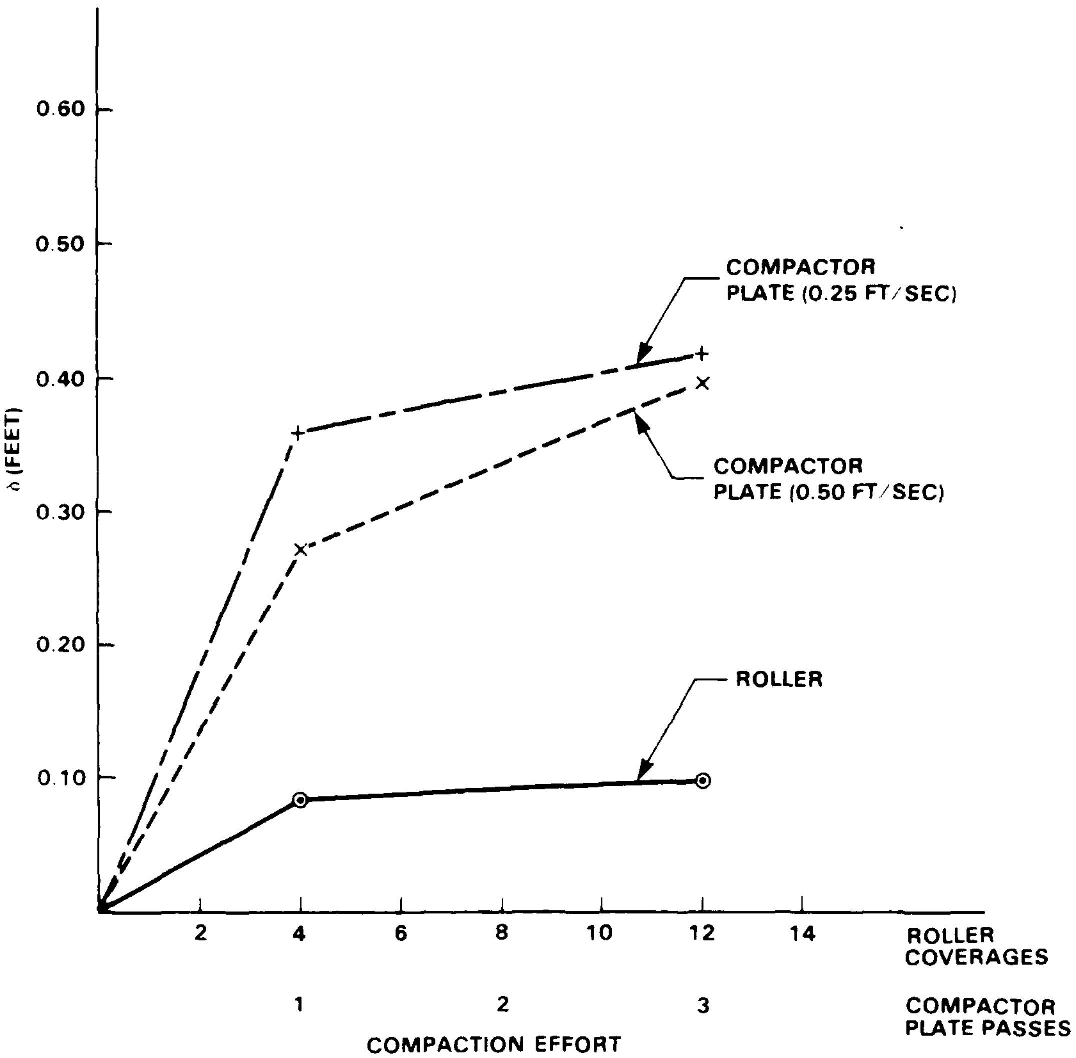


Figure 135. Displacement Versus Compaction Effort - Test 2, Excavator Compactor Evaluation.

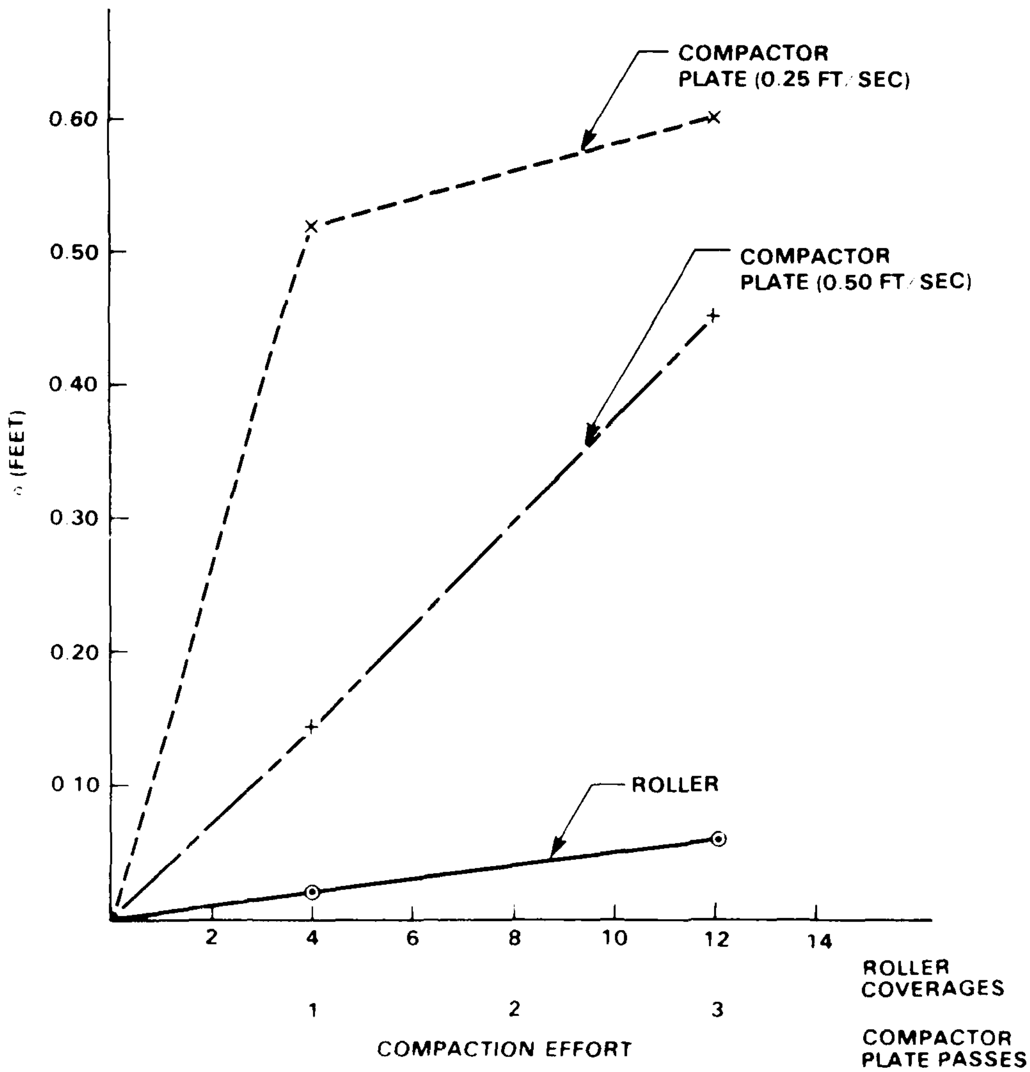


Figure 136. Displacement Versus Compaction Effort - Test 3, Excavator Compactor Evaluation.

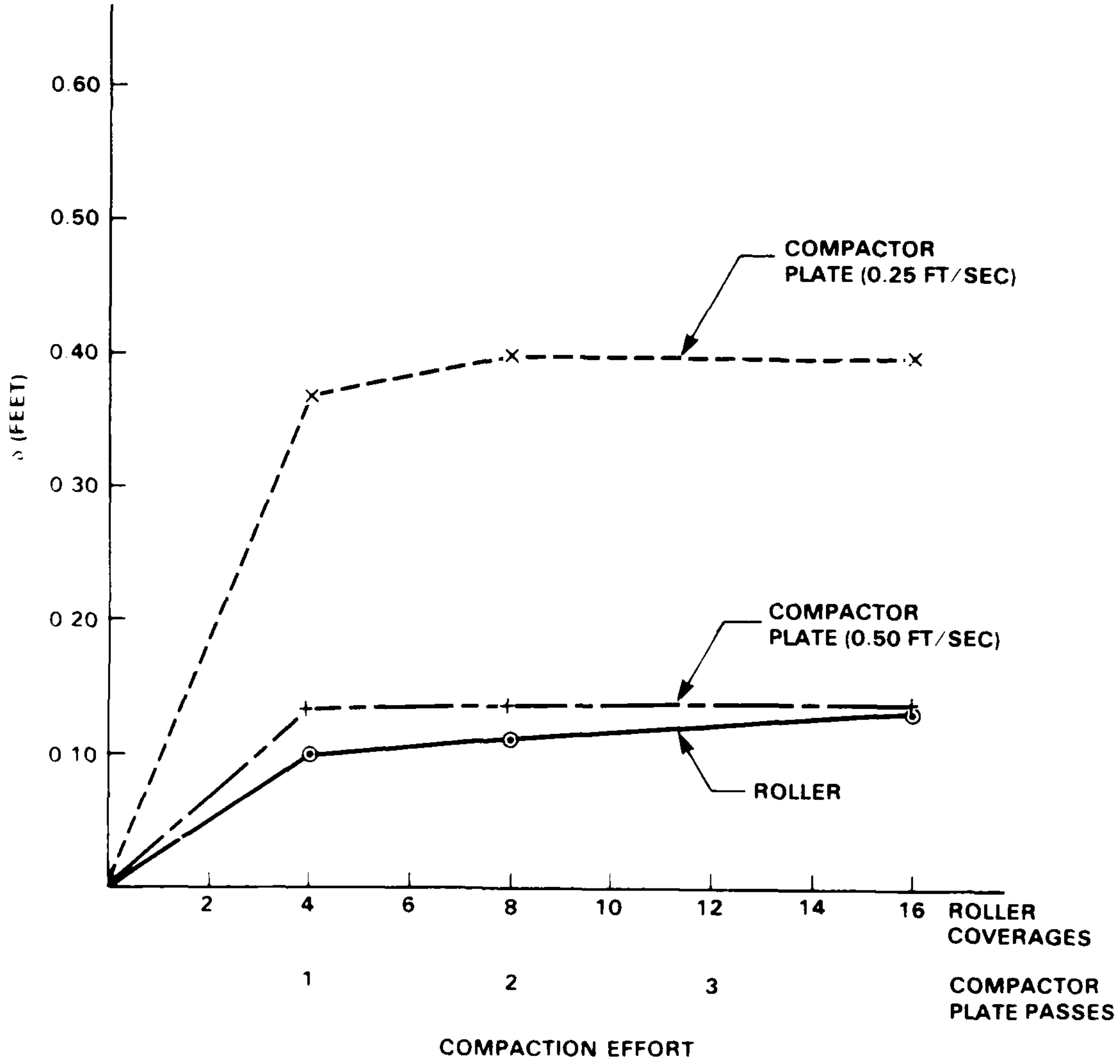


Figure 137. Displacement Versus Compaction Effort - Test 4, Excavator Compactor Evaluation.

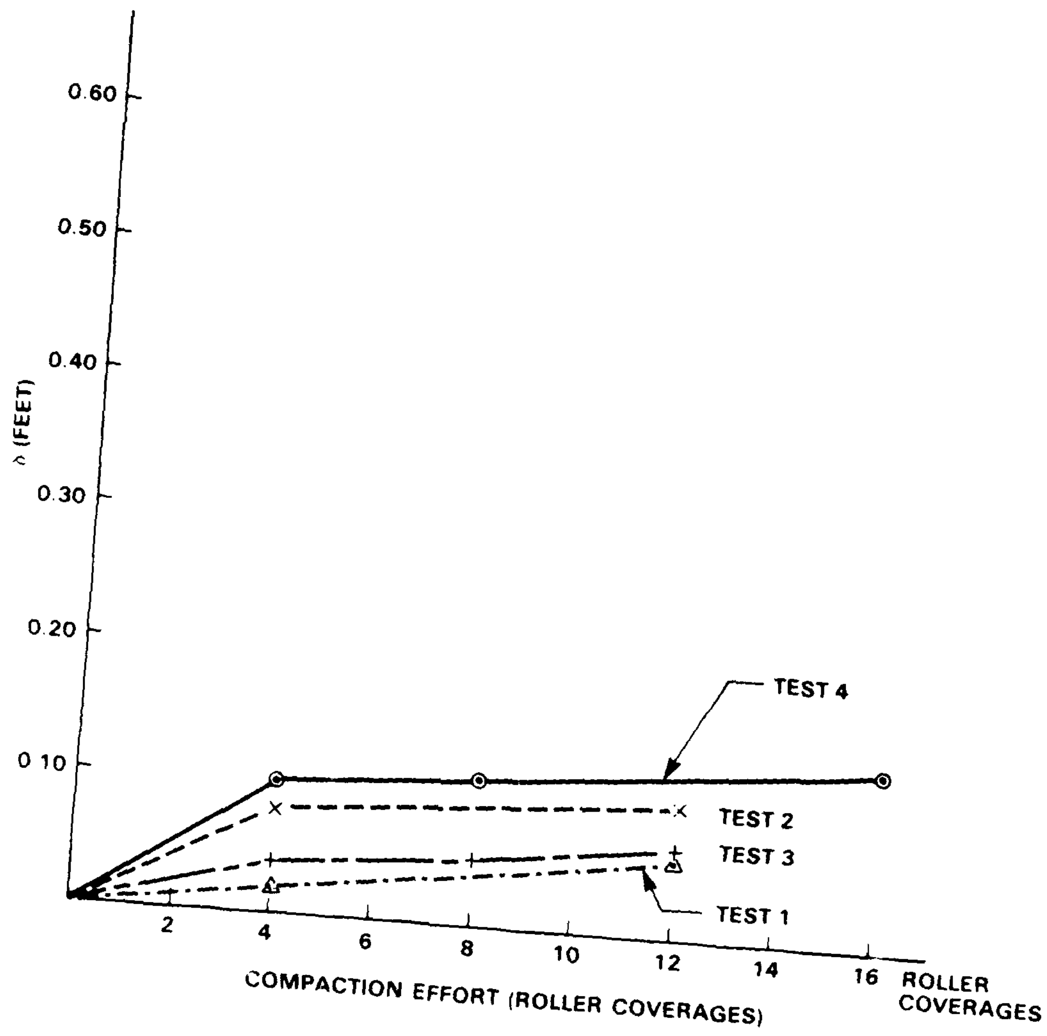


Figure 138. Displacement Versus Compaction Effort - Vibratory Roller, Excavator Compactor Evaluation.

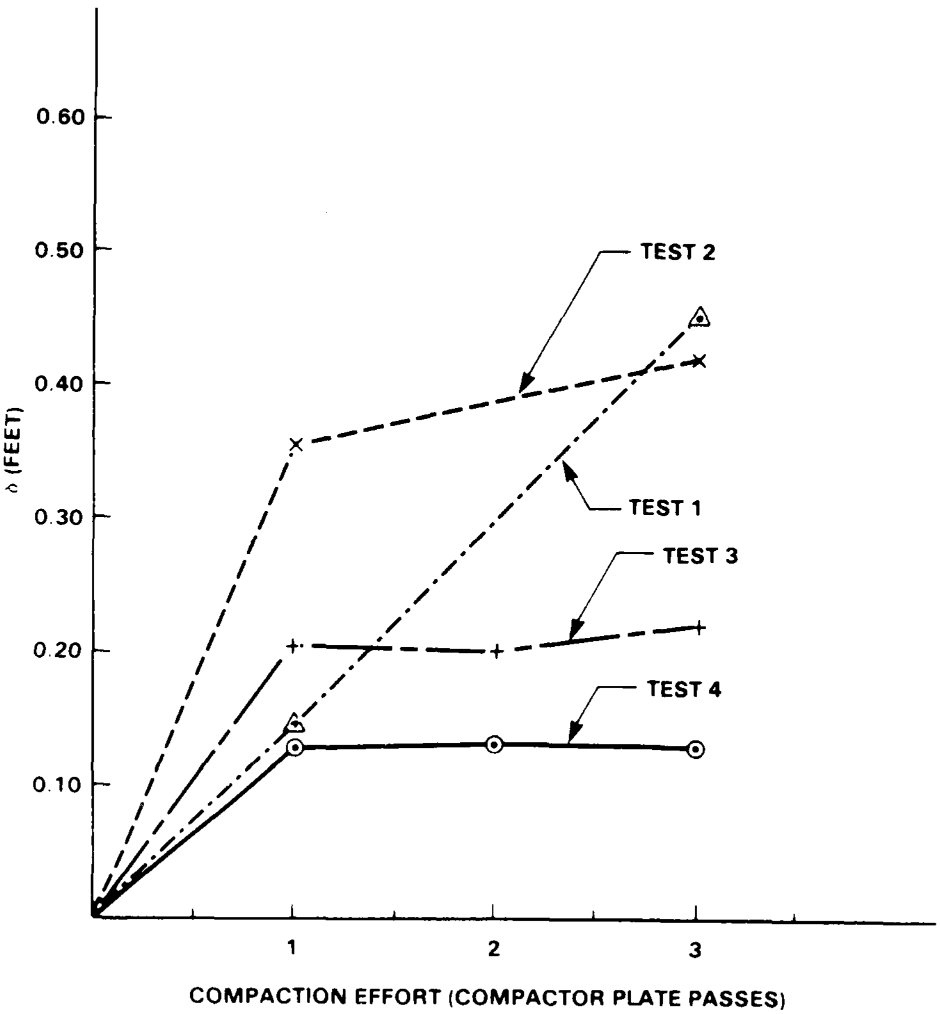


Figure 139. Displacement Versus Compaction Effort - Compactor Plate (0.5 ft/sec), Excavator Compactor Evaluation.

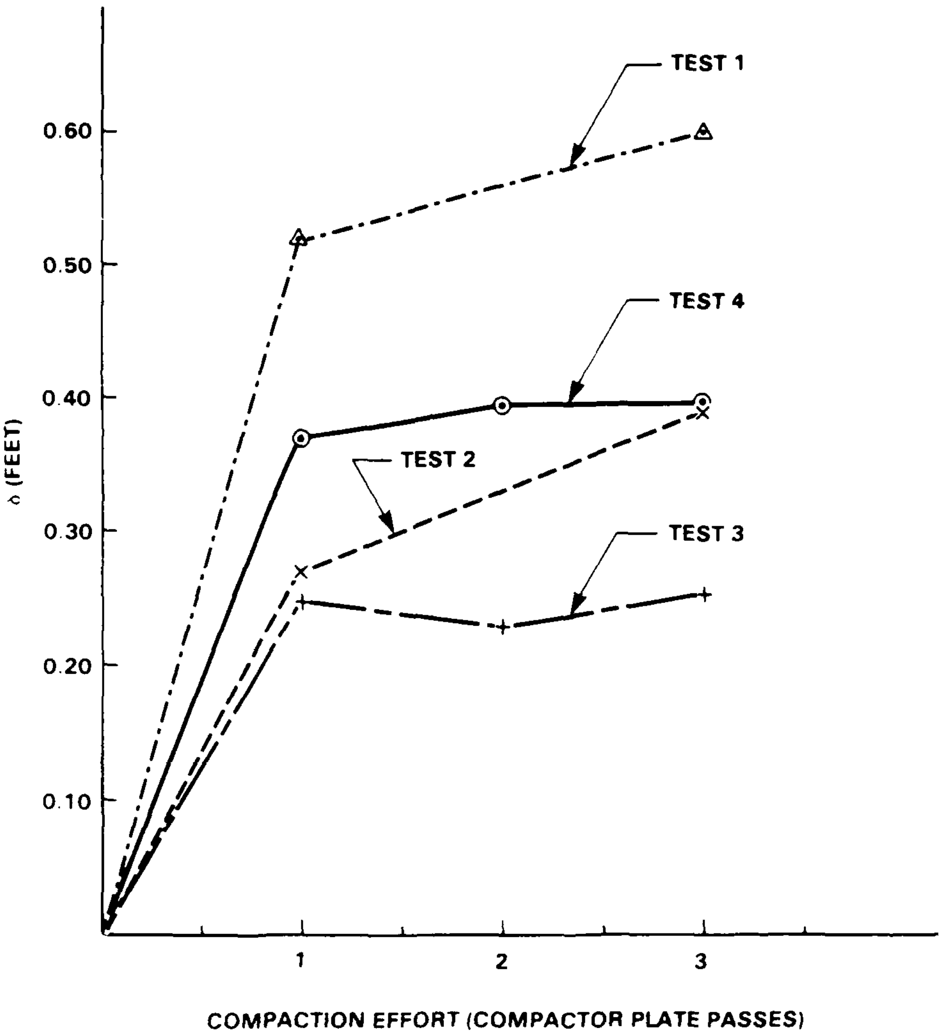


Figure 140. Displacement Versus Compaction Effort - Compactor Plate (0.25 ft/sec), Excavator Compactor Evaluation.

in all tests except Test 4, displacements from the compactor plate operated at both speeds were much larger than displacements caused by the roller. In Test 4 the displacements caused by the roller and the compactor plate operated at 0.50 ft/sec were nearly the same, and the largest displacements resulted from the compactor plate operated at 0.25 ft/sec. Test personnel observed that the plate vibrations caused the finer fractions of the thinner (3- and 6-inch) crushed stone layers to migrate into the voids of the ballast rock, resulting in the higher displacements. These figures also show that, in general, the largest displacements were measured after one compactor plate pass or after four roller coverages.

Figures 138 through 140 show the variance of displacement with crushed stone depth for the roller and the compactor plate moving at both speeds. Figure 138 shows a general trend of decreasing displacement with decreasing crushed stone depth when the roller is used for compaction. Figures 139 and 140 show that in regions compacted with the compactor plate moving 0.5 ft/sec, displacements were greatest on the thinner sections of crushed stone and generally decreased as the thickness of the crushed stone layer increased.

d. Compaction Times Data

The compaction times recorded for each test are provided in Tables C-17 through C-20. Table 13 shows average compaction times, compaction speeds, and area compaction rates. The roller provided a higher area compaction rate than the excavator even when the excavator traveled 0.50 ft/sec. The table also shows the excavator operator's capability to maintain a constant predetermined compaction rate.

4. Conclusions

This test compared the performance of the RayGo® 410A roller and the alto-Pac Model 9801 compactor plate attached to a John Deere 690B excavator for compacting repair sections having varying depths of crushed stone and ballast rock. Evaluation of densities at the 6-inch depth showed the roller performed better than the compactor plate in all tests, and there was no significant difference in performance of the compactor plate moving 0.50 ft/sec or 0.25 ft/sec. The roller generally achieved observed maximum field dry densities of at least 135 pounds per cubic foot (pcf), while the compactor plate only provided maximum dry densities of 135 pcf for sections having crushed stone layers at least 12 inches thick. Further, evaluation of compaction speeds/rates (Table 13) indicates a considerable timesaving advantage by using the vibratory roller to compact large craters.

When the compactor plate was used, maximum field densities were observed after one or two passes, supporting the current recommended procedures which call for two passes. However, moisture content may play a role in compaction and was not evaluated in this test. Maximum field densities were observed after 3 to 10 roller coverages, consistent with the current recommendation of 10 roller coverages. The test also showed that

TABLE 13. AVERAGE COMPACTION SPEEDS FOR TEST 1-4 BY LANE, EXCAVATOR COMPACTOR EVALUATION.

TEST #	LANE TYPE	AVERAGE COMPACTION TIME (sec) X	COMPACTION TIME STANDARD DEVIA σx	AVERAGE COMPACTION SPEED (FT SEC)	AREA COMPACTION RATE (SQ FT SEC)
1	ROLLER	17.7	2.40	2.26	15.85[a]
	PLATE (LANES 1, 3)	21 7	1 20	0 46	1.30[b]
	PLATE (LANES 2, 4)	43.3	2.11	0 23	0 65
2	ROLLER	17 4	4.42	2 29	16 05
	PLATE (LANES 1, 3)	21 6	2 68	0 47	1 32
	PLATE (LANES 2, 4)	40 2	3 25	0 25	0 70
3	ROLLER	24 2	5 42	1 65	11 58
	PLATE (LANES 1, 3)	23 8	0.98	0.42	1 19
	PLATE (LANES 2, 4)	39 8	0.45	0 25	0 71
4	ROLLER	16 1	2.32	2.48	17 28
	PLATE (LANES 1, 3)	22 4	2 17	0 45	1 26
	PLATE (LANES 2, 4)	42 0	2.69	0 24	0 68

NOTE THE ROLLER WAS OPERATED AT FULL THROTTLE DURING THE TEST THE ACTUAL RPM ARE GOVERNED BY THE SPEED AS WELL THE PLATE STRIKE FREQUENCY WAS 2,200 RPM

[a] RAYGO 410A VIBRATORY ROLLER WIDTH 84"
[b] ALTO PAC MOD 9801 COMPACTOR PLATE WIDTH 34"

the density of compacted areas is not significantly affected by compaction in adjacent areas.

Based upon the results of this test, it is recommended that additional tests be conducted to obtain data for faster compactor plate rates like 0.75 ft/sec and 1.0 ft/sec to determine whether similar observed field dry densities will be achieved at these rates. The excavator compactor plate should not be used normally with crushed stone layers less than or equal to 6 inches. It is also recommended that procedures be established for using the Bomag 160 dual-vibratory roller, since it will be used in the future by RRR teams.

C. QUALITY EVALUATION PROCEDURE/COMPACTION WITH EXCAVATOR

1. Purpose

This test was conducted, as recommended in the Excavator Compactor Evaluation, to determine whether the compactor plate speed has a significant effect on the densities achieved. Test personnel used the alto-Pac® Model 3301 compactor plate attached to the John Deere 690B excavator to perform the compaction. Test personnel compacted the repair section in lanes, using a different speed of the compactor plate for each lane.

2. Test Description

a. Test Section Description and Compaction Procedure

Test personnel constructed the test section of crushed stone over clay subgrade in the same test pit used for the Excavator Compactor Evaluation at SCTF. Personnel added crushed stone up to 1 1/2 inches above the pavement surface level before compaction so that the repair surface would be flush with the pavement surface after compaction.

Test personnel marked the test section into seven lanes, 34 inches wide (the width of the compactor plate) as shown in Figure 141 before compaction began. The excavator operator compacted each lane with the excavator plate moving at a different predetermined compaction speed. Based on recommendations from the Compactor Evaluation Test, the compactor plate operated at speeds close to 0.25 feet per second, 0.50 feet per second, 0.75 feet per second, and 1.0 feet per second.

b. Data Collection

Test personnel measured nuclear moisture and density in the clay subgrade after compaction. Dry density averaged 99.0 pcf, and moisture content averaged 27.9 percent. The average of penetrometer readings was a CBR value of 2.

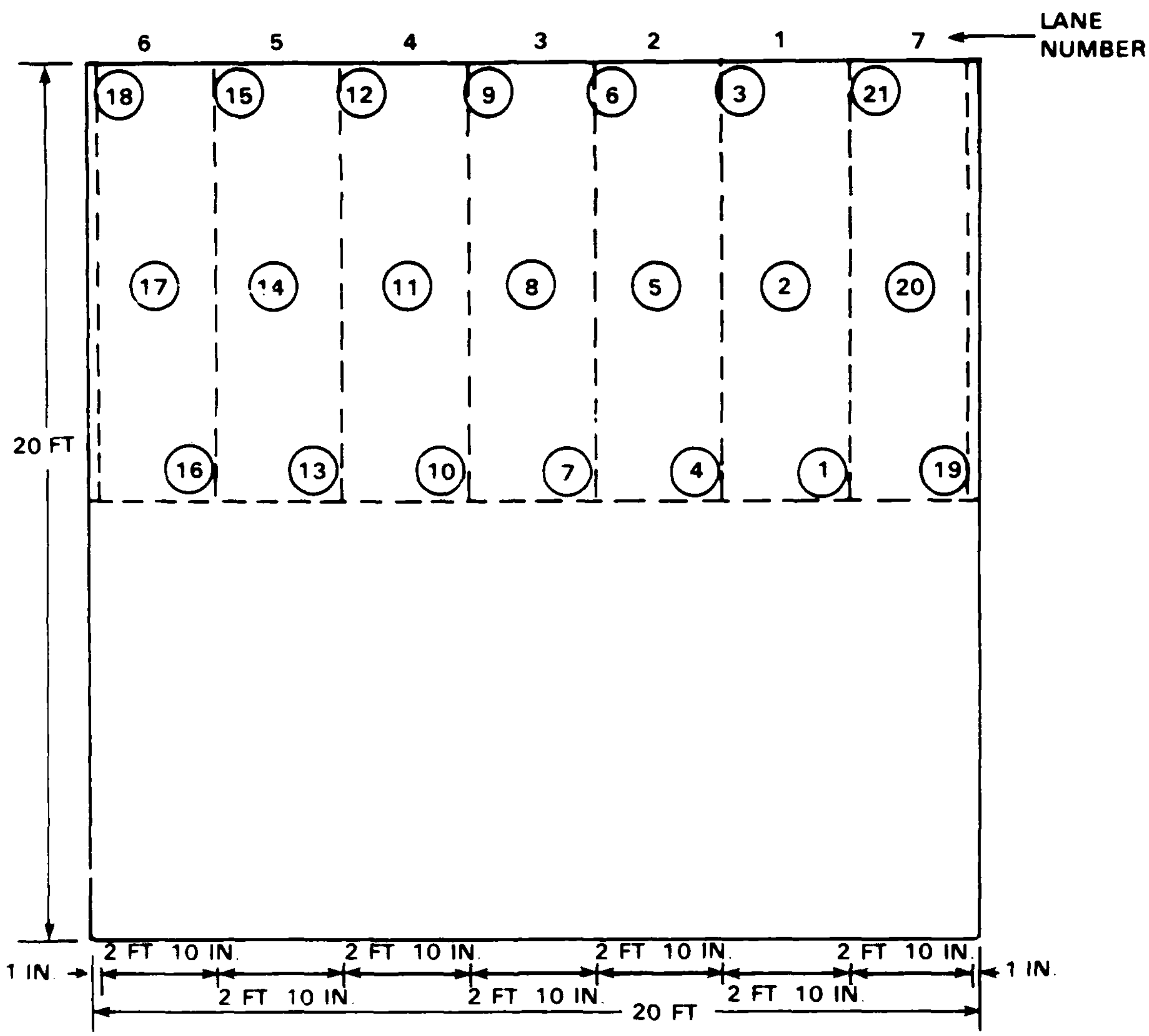


Figure 141. Compaction Lanes and Moisture-Density Measurement Locations, Quality Evaluation Procedure.

Test personnel recorded nuclear moisture-density measurements taken at 12- and 6-inch depths in the crushed stone at the locations shown in Figure 141, before compaction and after each compactor plate pass. Three compactor plate passes were applied to all lanes.

3. Results

Crushed stone moisture-density readings obtained before compaction and after each pass are presented in Tables D-1 through D-4. Average lane dry densities and compaction rates are presented in Table 14. Table 15 shows average dry densities for each pair of lanes where the compaction speed was nearly the same.

The data in Table 15 are presented graphically in Figures 142 and 143. These figures compare 6-inch and 12-inch dry densities to average compaction speeds for one, two, and three compactor plate passes. Average compaction speeds were used because the speed in each lane was not constant over all three passes.

Figure 142 shows that the densities measured at a depth of 6 inches were highest after three compactor plate passes when compacted at 0.94 ft/sec and lowest when compacted at 0.29 ft/sec. Densities increased when the compaction effort was increased from two to three plate passes at all speeds except 0.29 ft/sec. At this speed, the maximum density was obtained after two plate passes. Figure 142 does not show a consistent trend of increasing density with increased compaction speed, the density for compaction at 0.72 ft/sec being less than the density for compaction at 0.49 ft/sec.

The compaction results obtained at a depth of 12 inches are shown in Figure 143. The effect of compaction speed on densities measured at a 12-inch depth was less significant than the effect on densities measured at a 6-inch depth. Maximum densities were obtained after three compactor plate passes at all speeds.

Crushed stone surface elevation data are presented in Table D-5 and are summarized in Table 16. The data in Table 16 are presented graphically in Figure 144, which shows minimum displacement for a compactor plate moving at 0.72 ft/sec and maximum displacements at 0.29 ft/sec although the lowest densities were observed at this speed. The largest displacement increments were measured after one plate pass, as shown in Figure 144.

4. Conclusions

This test compared the compactor plate's performance moving at four speeds, 0.29 ft/sec, 0.49 ft/sec, 0.72 ft/sec, and 0.94 ft/sec for compacting crushed stone repair sections. At speeds from 0.49 ft/sec to 0.94 ft/sec, the compaction results after three passes did not vary significantly with the best results obtained at 0.94 ft/sec. The compaction

TABLE 14. CRUSHED STONE AVERAGE LANE DRY DENSITIES AND COMPACTION RATES, QUALITY EVALUATION PROCEDURE.

PASS # DENSITY	LANE NO.	COMPACTION TIME (SEC)	COMPACTION RATE (FT/SEC)	AVERAGE DRY DENSITY (LB/FT^3) (12 IN.)	AVERAGE DRY (LB/FT^3) (6 IN.)
	1	20.0	0.50	132.2	131.4
	2	20.0	0.50	138.2	133.1
	3	14.5	0.69	133.0	130.5
1	4	13.0	0.77	135.0	131.1
	5	12.0	0.83	133.2	130.8
	6	12.0	0.83	137.8	135.2
	7	34.0	0.29	131.1	126.3
	1	21.0	0.48	138.9	130.7
	2	23.0	0.43	138.7	133.1
	3	15.0	0.67	140.3	135.5
2	4	15.0	0.67	136.8	130.9
	5	11.5	0.87	135.3	129.4
	6	10.5	0.95	136.0	129.7
	7	35.0	0.29	137.4	130.7
	1	19.6	0.51	143.4	141.4
3	2	19.0	0.52	142.7	141.0
	3	13.0	0.77	144.1	137.9
	4	13.4	0.75	139.3	138.4
	5	12.5	0.80	144.0	137.7
	6	7.5	1.33	143.8	137.2
	7	33.0	0.30	139.9	129.6

TABLE 15. CRUSHED STONE AVERAGE DRY DENSITIES, AFTER COMPACTION, QUALITY EVALUATION PROCEDURE.

NUMBER OF PASSES	LANE NUMBER	AVERAGE COMPACTION RATE[a] (FT/SEC)	AVERAGE DRY DENSITY (LB/FT^3)	
			12 IN.	6 IN.
1	1&2	0.49	135.2	132.3
	3&4	0.72	134.0	130.8
	5&6	0.94	135.5	133.0
	7	0.29	131.1	126.3
2	1&2	0.49	138.8	131.9
	3&4	0.72	138.6	133.2
	5&6	0.94	135.7	129.6
	7	0.29	137.4	130.7
3	1&2	0.49	143.0	141.2
	3&4	0.72	141.7	138.2
	5&6	0.94	143.9	137.4
	7	0.29	139.9	129.6

[a]AVERAGE COMPACTION RATE = AVERAGE RATE IN LANE OVER ALL THREE PASSES

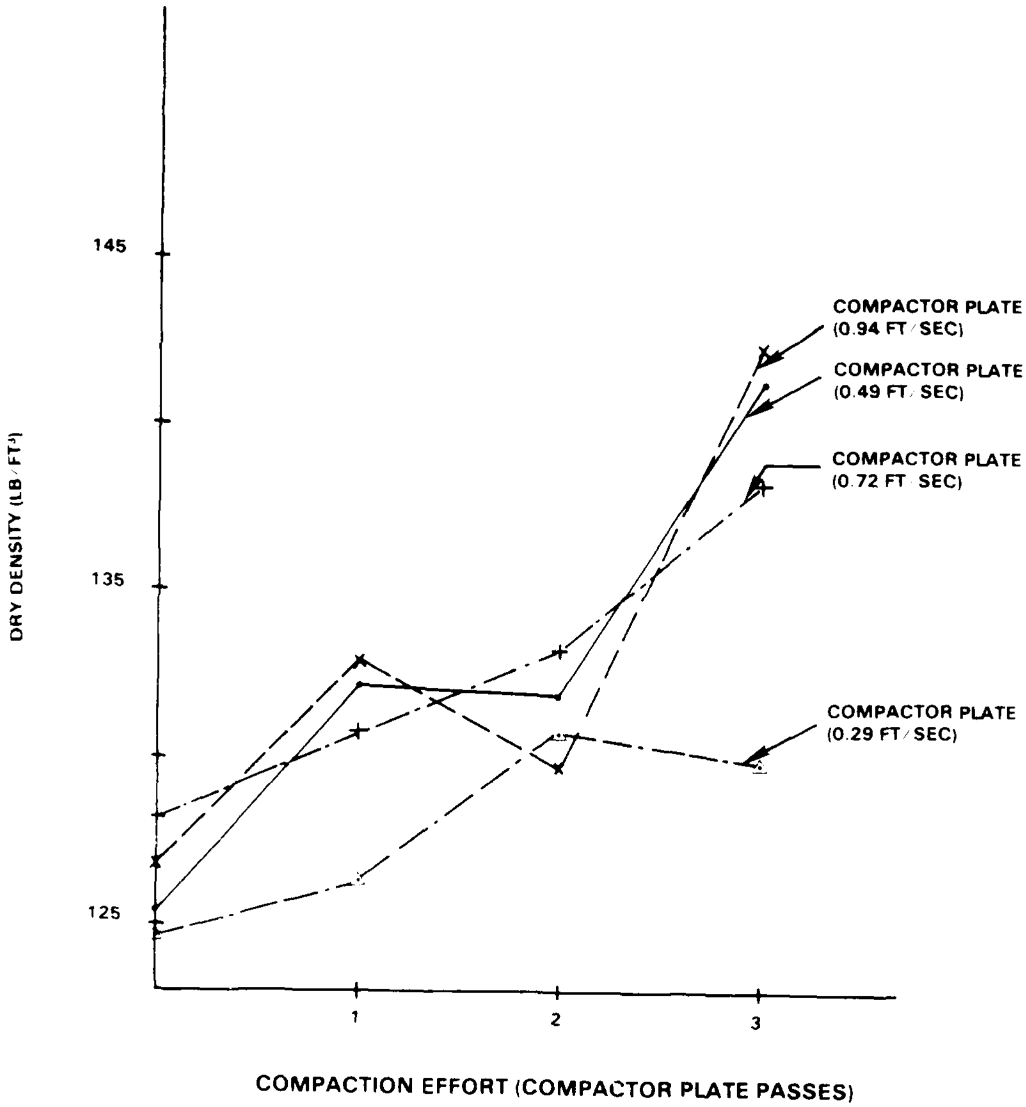


Figure 142. 6-Inch Dry Density Versus Compaction Effort, Quality Evaluation Procedure.

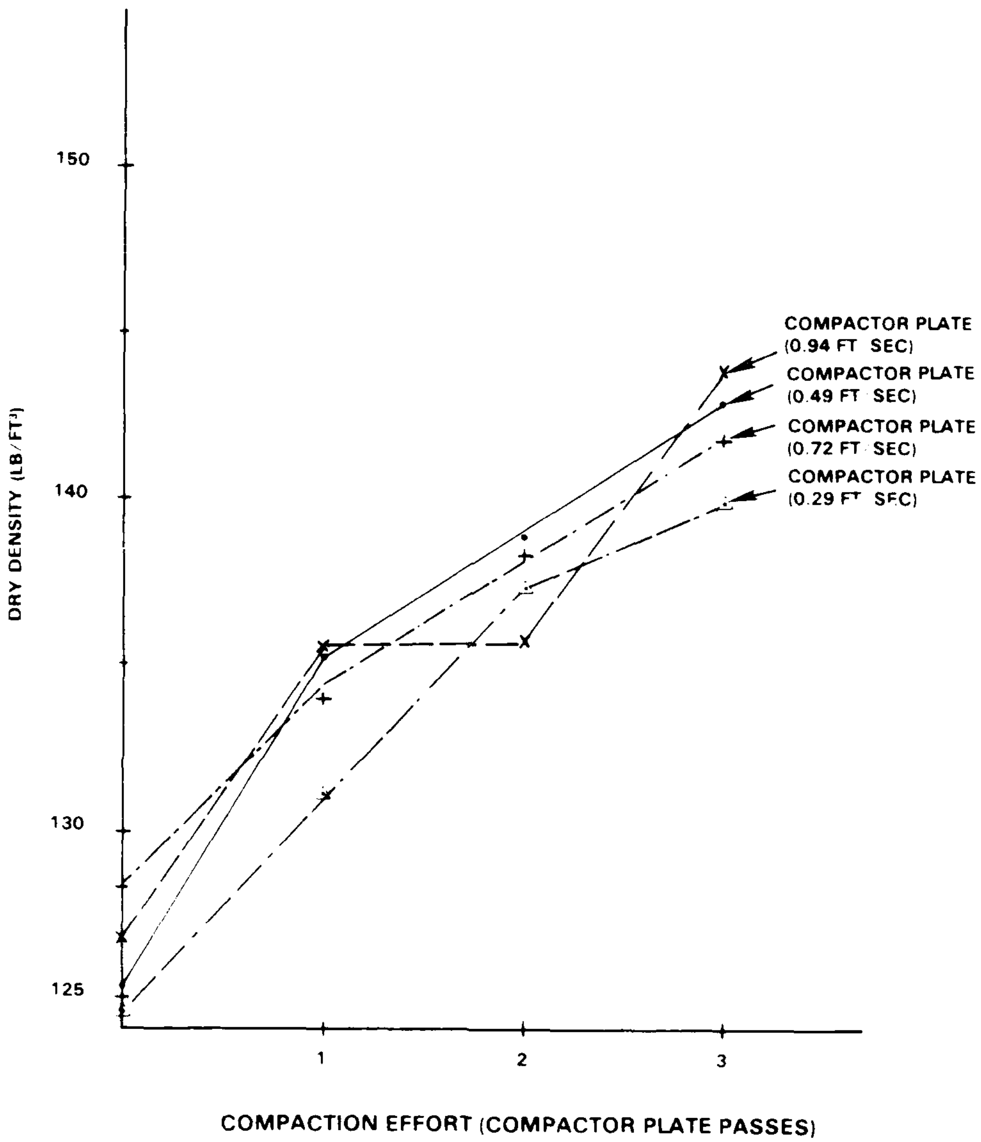


Figure 143. 12-Inch Dry Density Versus Compaction Effort, Quality Evaluation Procedure.

TABLE 16. AVERAGE CRUSHED STONE SURFACE LEVEL MEASUREMENTS BEFORE AND AFTER COMPACTION, QUALITY EVALUATION PROCEDURE.

NUMBER OF PASSES	LANE NUMBER	LEVEL (FT)	SETTLEMENT (FT)
UNCOMPACTED	1&2	10.35	-
	3&4	10.36	-
	5&6	10.35	-
	7	10.31	-
1	1&2	10.02	0.33
	3&4	10.18	0.18
	5&6	10.16	0.19
	7	9.89	0.42
2	1&2	10.05	0.30
	3&4	10.15	0.21
	5&6	10.10	0.25
	7	9.85	0.46
3	1&2	10.04	0.31
	3&4	10.13	0.23
	5&6	10.08	0.27
	7	9.85	0.46

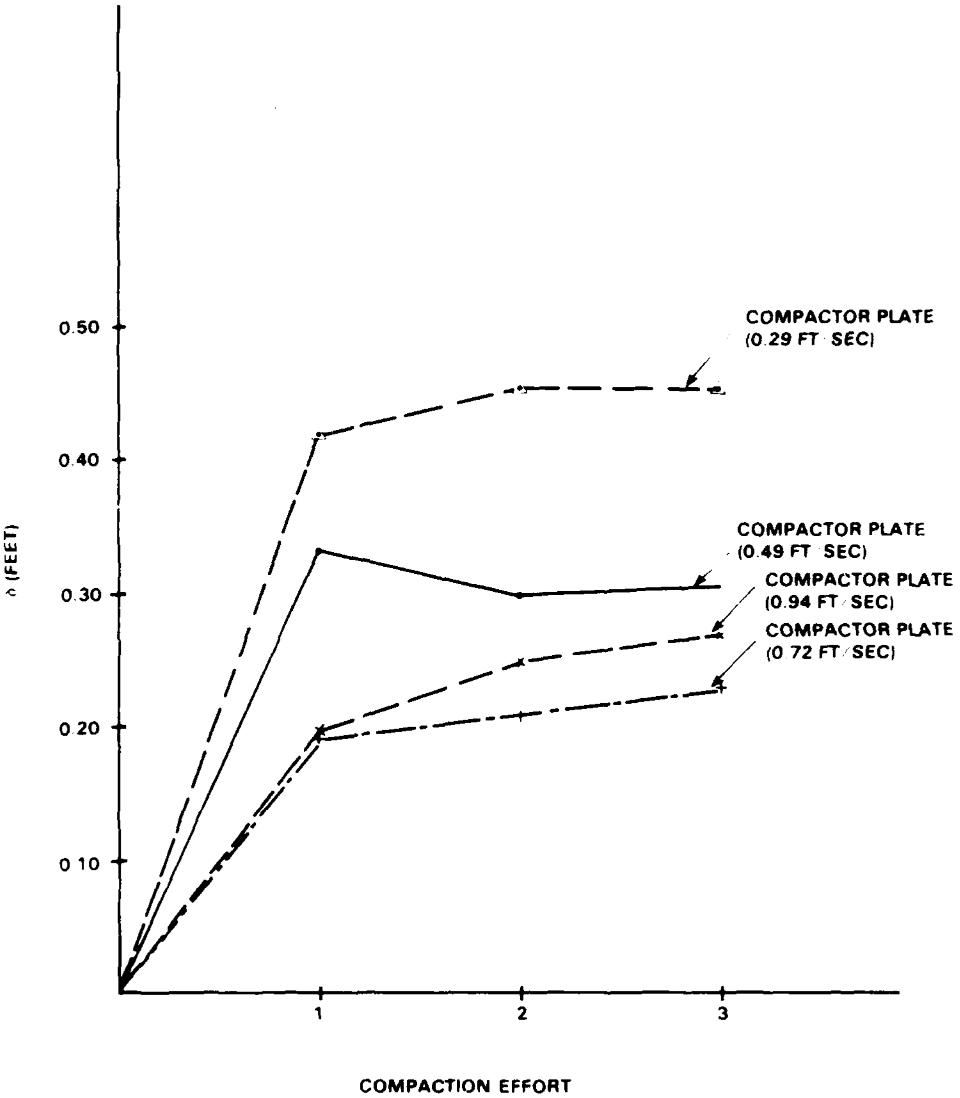


Figure 144. Settlement Versus Compaction Effort, Quality Evaluation Procedure.

densities obtained when the compactor plate traveled 0.29 ft/sec were less than at higher speeds, although the displacements were greatest when the section was compacted at the slower speed. This suggests that better subgrade compaction may have occurred when this speed was used.

In all lanes except Lane 7 where the compaction speed was 0.29 ft/sec, the dry densities were much higher after three plate passes than after two plate passes. Moisture contents for all lanes were comparable, although generally slightly higher in the lanes nearest the edges of the test pit (Lanes 1, 6, 7). Densities after two passes were highest at compaction speeds of 0.49 ft/sec and 0.72 ft/sec.

Based upon the results of this test, it is recommended that three passes of a compactor plate be applied at speeds of 0.75 to 1.0 ft/sec for crushed stone repairs.

D. CONCLUSIONS

Both the vibratory roller and the excavator-mounted compacter plate are feasible for compacting crushed stone/ballast rock repair sections. The vibratory roller provided higher compaction rates and better compaction in the top layer of the repair section while the compactor plate may provide better compaction at a deeper depth.

To provide better compaction results throughout the depth of choked ballast repairs, it is recommended that a minimum crushed stone layer thickness of 6 inches be observed for the vibratory roller and 12 inches for the compactor plate.

Further testing is also recommended where operating rates for the equipment starts off with a slower vibratory roller frequency or compactor plate speed and increases with additional passes. This may determine that an optimum mix of rates exists to provide better control of compaction.

SECTION VI

FIBERGLASS MAT TESTS

A. INTRODUCTION

This section documents the Alternative Fiberglass Mat Test and the Wet Crater Repair Demonstration conducted under the RRR Program in October-November 1983 and February 1984, respectively. In both tests, the repaired sections were covered with a fiberglass mat and traffic-tested with the F-15 loadcart to determine the repair performance under simulated loading. The Alternative Polyurethane Fiberglass Mat Test was conducted at SCTF, and the Wet Crater Repair Demonstration was conducted at SKY TEN.

1. Background

The use of polyurethane-impregnated fiberglass mats over crushed stone bases has been proved through traffic testing (Surface for Crushed Stone, Phase II, ESL-TR-83-38) to be an adequate crater repair technique. Repairs have been constructed under both wet and dry conditions. Prior to the Wet Crater Repair Demonstration, however, none of the wet condition repairs were made on a thoroughly soaked crater with saturated aggregate and simulated rain continuing throughout the repair procedure. Also, prior to the Alternative Fiberglass Mat Test, all of the PU mats tested were fabricated with Ashland resin. To improve procurement strategy for mat fabrication, it was necessary to have more than one source of polyurethane to be used when making the mats. Preliminary investigations indicated that the modified polyurethane developed by ARNCO was at least as good as the Ashland resin.

2. Test Objectives

The major objective of these tests was to determine the ability of fiberglass mats over crushed stone/ballast rock repairs to support simulated F-15 traffic. The first test used two mats, one impregnated with Ashland resin and the other with ARNCO resin.

The second test was conducted under wet, raining conditions to determine the problems encountered, if any, when repairs are made under these conditions.

B. ALTERNATIVE POLYURETHANE FIBERGLASS MAT

1. Purpose

This test's purpose was to evaluate the performance of a polyurethane mat fabricated with ARNCO resins and used as a fiberglass mat for crater repair. Prior to this test, all of the tested polyurethane impregnated mats were fabricated with Ashland resins.

Two fiberglass mats were traffic-tested with the F-15 loadcart in the same pit; one mat fabricated with ARNCO resins (MOD V) and the other fabricated with Ashland resins (PEPSET). The performance of the two mats was compared to determine whether ARNCO polyurethane (MOD V) can be used as a second source of polyurethane for fabrication of fiberglass mats.

2. Test Description

a. Subgrade Preparation

Test personnel constructed the fiberglass mat repair section in SCTF Pit 2. The clay subgrade for this test had measured CBR strength of 4 to 7.

b. Base Course Preparation

Test personnel placed a 24-inch crushed stone (ASTM 2940) base course on the subgrade and compacted the base course with 16 coverages of a Ray-Go® 410 roller. After compaction, personnel graded the stone to ±1 inch of the surface pavement. Data collectors measured the crushed stone's dry density, wet density, and moisture content at the test pit's corners after 0, 8, 12, and 16 roller coverages. Average values for these quantities are presented in Table 17. Results obtained at each sample point are provided in Appendix E, Tables E-1 through E-5.

c. Fiberglass Mat Preparation

After base course compaction, test personnel anchored two 12-foot by 24-foot 2-ply polyurethane fiberglass mats over the test section, with long edges parallel to the direction of traffic and overlapping 1 foot at the center. A plan view of the test layout is shown in Figure 145. The mat placed at the south end of the test pit was fabricated with ARNCO resins (MOD V), and the mat placed on the north end of the pit was fabricated with Ashland resins (PEPSET).

Test personnel fabricated the fiberglass mats prior to testing. The spray system was inoperative at the time of mat fabrication so personnel manually mixed the polyurethane and poured the mixture on the fiberglass fabric using buckets. Before mixing, personnel chilled the polyurethane components in an environmental chamber to slow the set-up time.

d. Traffic Testing

The F-15 loadcart operator trafficked the ARNCO mat and Ashland mat side by side with 13 applications (156 coverages), using the traffic distribution pattern shown in Figure 146. The test director used the double pattern shown in the figure to maximize trafficking along the center lines of the respective fiberglass mats and away from the overlap of the mats.

TABLE 17. MOISTURE-DENSITY RESULTS FOR CRUSHED STONE BASE, ALTERNATIVE POLYURETHANE FIBERGLASS MAT TEST, AFTER 0, 8, 12, AND 16 ROLLER COVERAGES.

NO. OF COVERAGES (4-10 ROLLER)	DEPTH (IN.)	WET DENSITY (LB/FT^3)	DRY DENSITY (LB/FT^3)	MOISTURE CONTENT (PERCENT)
0	12	130.0	124.9	4.0
	4	125.8	120.6	4.2
8	12	143.6	137.5	4.4
	4	145.8	139.6	4.5
12[a]	12	145.7	139.6	4.3
	4	145.8	139.5	4.5
12[b]	12	146.0	138.9	4.2
	4	146.1	138.6	5.3
16	12	148.1	141.1	5.0
	4	1419.5	142.4	5.0

[a]Measured before grading.

[b]Measured after grading.

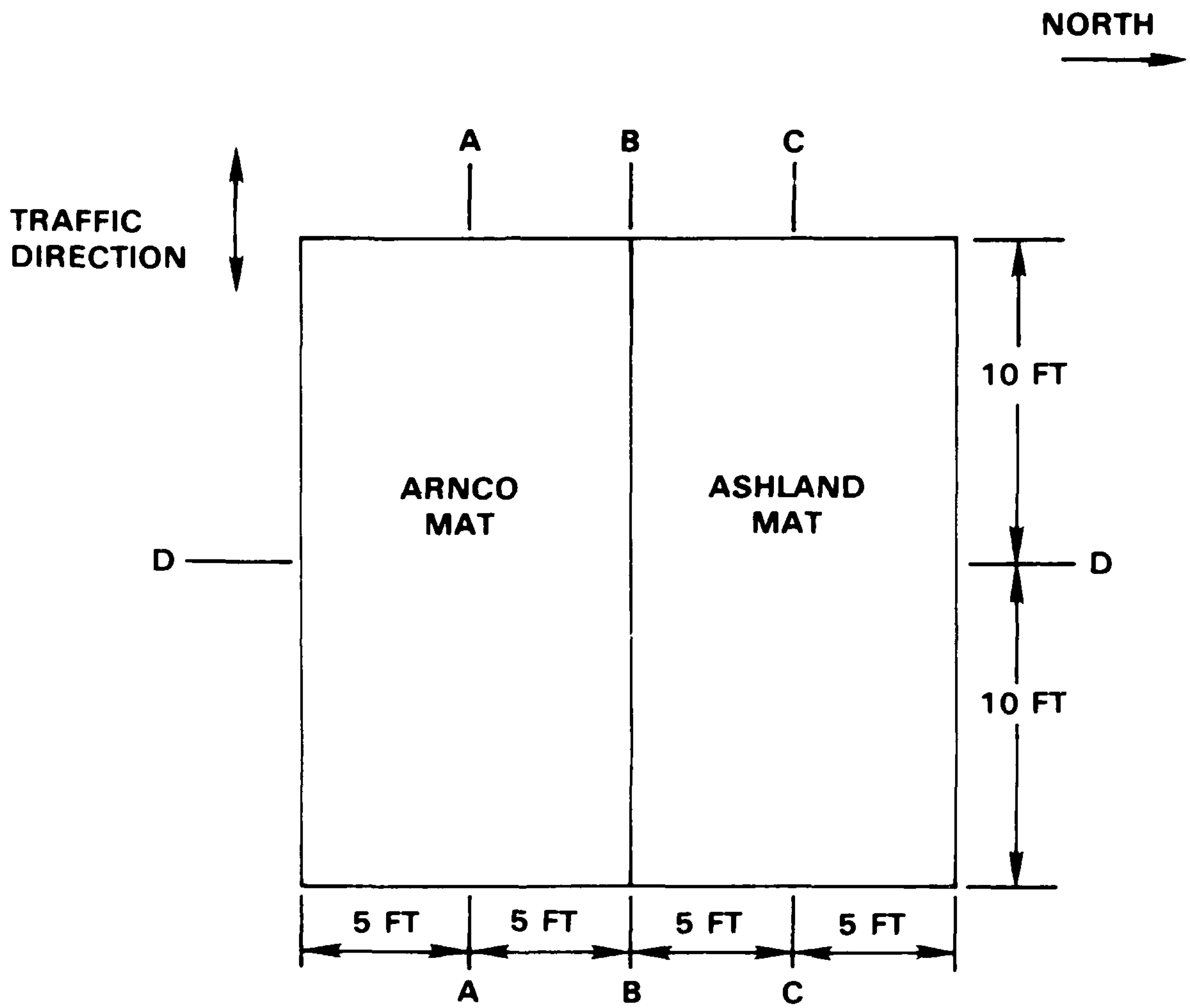


Figure 145. Test Section Plan View, Alternative Polyurethane Fiberglass Mat.

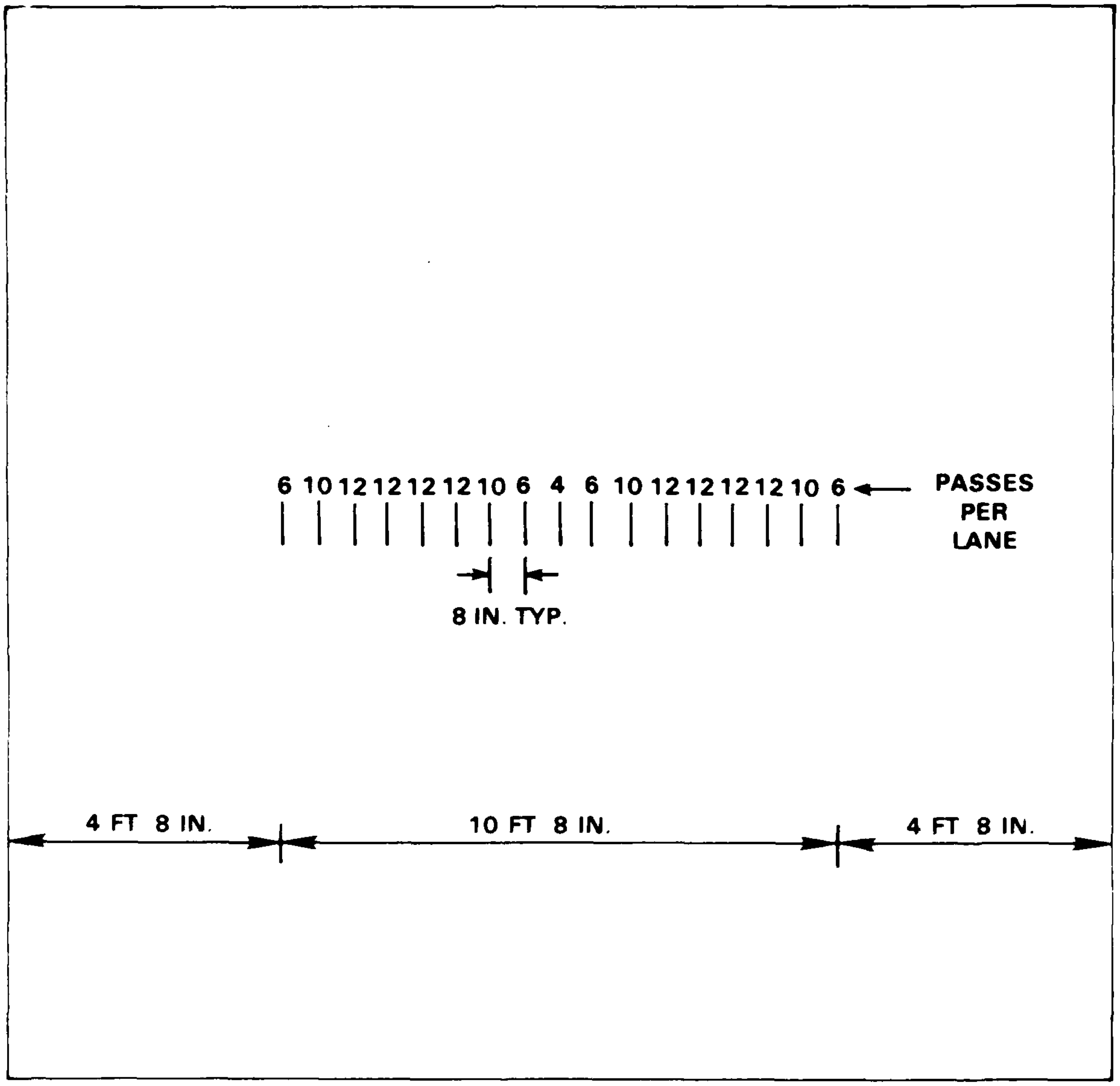


Figure 146. Traffic Distribution Pattern, Alternative Polyurethane Fiberglass Mat.

After 24 F-15 loadcart coverages, test personnel observed aggregate (3/8- to 1/2-inch stones) on the surface of the mat. The stones were possibly forced out at the overlap during trafficking. Test personnel removed the mats and checked base course surface roughness, measuring a peak sag of 2 7/16 inches along the A-A profile. This indicated a need for repair maintenance.

Test personnel performed maintenance of the repair by adding crushed stone to the test pit, to approximately 2 inches above the adjacent pavement, and reattaching the fiberglass mat without additional compaction. Trafficking continued to 156 F-15 loadcart coverages without further maintenance of the repair.

e. Data Collection

During trafficking of the fiberglass mat repair, test personnel collected both profile and surface roughness data. Test personnel used a rod and level to measure elevations at 1-foot intervals along longitudinal profiles A-A, B-B, and C-C and lateral profile D-D (see Figure 145). Data collectors measured top-of-base course elevations after 0, 24, 24a (after maintenance), and 156 load-cart coverages, and top-of-mat elevations after 0, 12, 24, 24a, 48, 96, and 156 loadcart coverages. Test personnel measured surface roughness along the traffic lanes, usually A-A, B-B, and C-C (see Figure 145). Personnel measured top-of-mat sag after 12, 24, 24a, 48, and 96 F-15 loadcart coverages, and top-of-base course measurements when removing the mats for maintenance.

In addition to surface roughness measurements, test personnel took moisture-density readings for the crushed stone base after repairing the base course and after applying 13 F-15 loadcart applications. Average values for the measurements taken at the four corners of the test pit are presented in Table 18. Values collected at each corner are provided in Appendix E, Tables E-6 and E-7.

3. Results

Test personnel collected elevation and surface roughness data in accordance with the test description. Figures 147 through 149 show base course elevation profiles at 0 and 24 (before maintenance) F-15 loadcart coverages. Tables 19 and 20 summarize the profiles in terms of surface roughness criteria. The greatest vertical deformation resulting from 24 coverages occurred along A-A (Table 19). The average vertical deformation within the test pit was 2.41 inches, and the maximum vertical deformation was 2.76 inches. The calculated peak sag along profile A-A was 2.27 inches compared to 2.44 inches peak sag measured from the stringline. Along profile C-C, the calculated peak sag was 1.33 inches (Table 20), and the measured sag was 2.25 inches.

Figures 150 through 152 compare the base course elevations at 24a (after maintenance) and 156 F-15 loadcart coverages. Surface roughness

TABLE 18. MOISTURE-DENSITY RESULTS FOR CRUSHED STONE BASE, ALTERNATIVE POLYURETHANE FIBERGLASS MAT TEST, AFTER REPAIR AND AFTER 156 LOAD CART COVERAGES.

# COVERAGES (F-15 LOAD CART)	DEPTH (IN.)	WET DENSITY (LB/FT^3)	DRY DENSITY (LB/FT^3)	WATER CONTENT (PERCENT)
24 (AFTER MAINTE-NANCE, UNCOMPACTED	BS[a]	108.7	104.5	4.0
156	12	159.2	153.4	3.8
	4	146.4	140.4	3.4

[a]BS - SURFACE READING.

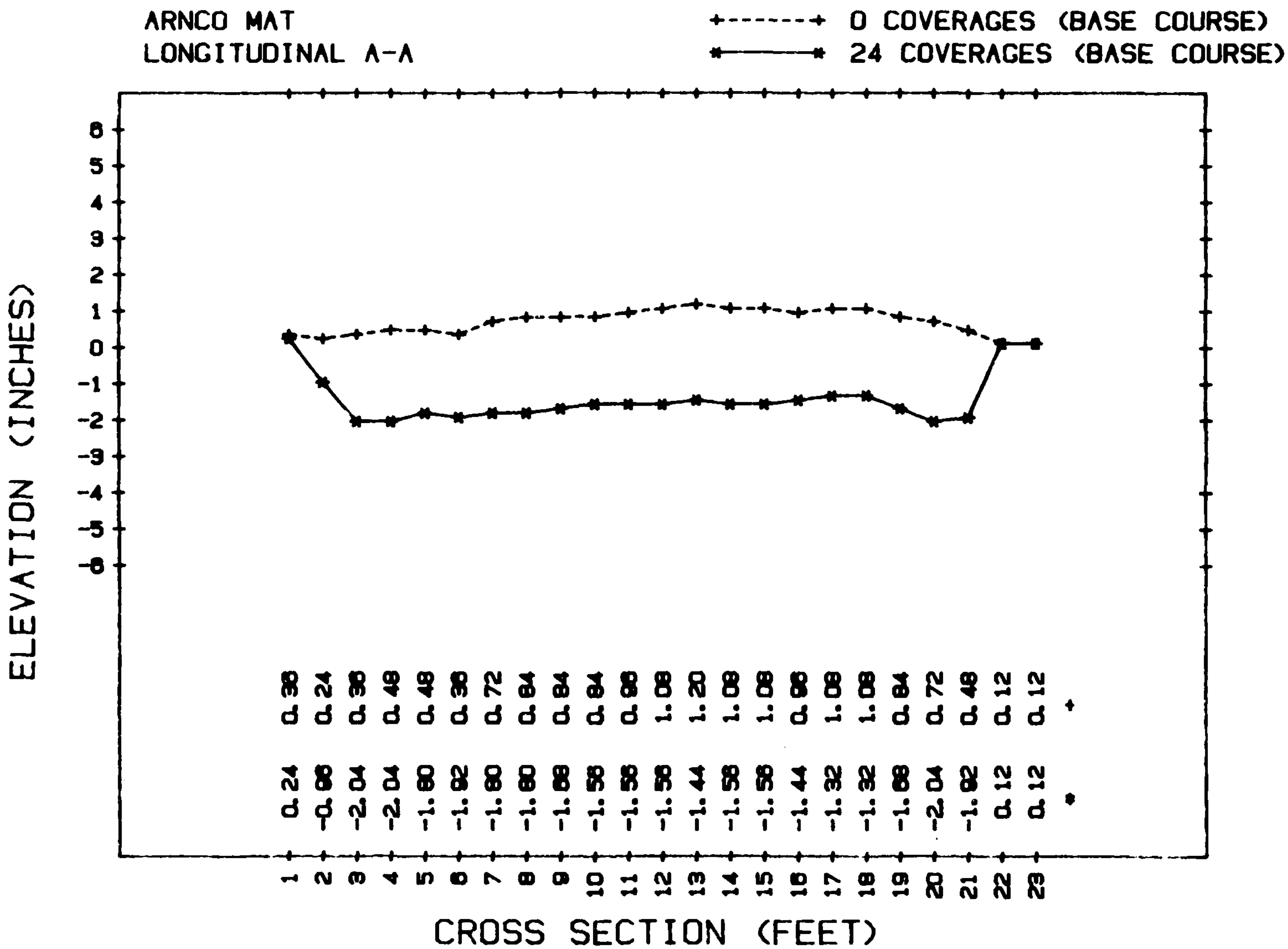


Figure 147. Base Course Elevation Profiles After 0 and 24 (Before Maintenance) F-15 Loadcart Coverages for Alternative Polyurethane Fiberglass Mat - Longitudinal A-A.

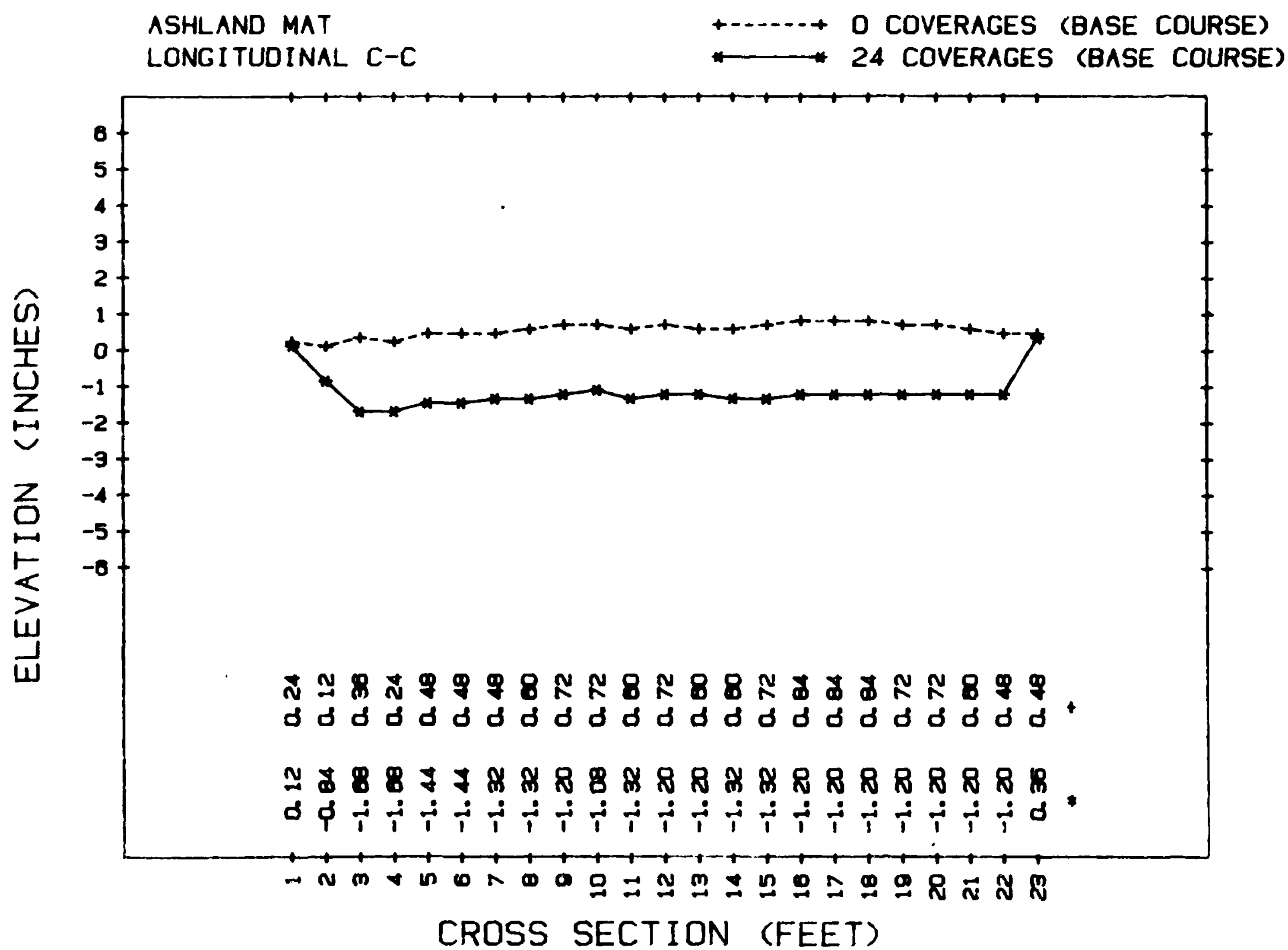


Figure 148. Base Course Elevation Profiles After 0 and 24 (Before Maintenance) F-15 Loadcart Coverages for Alternative Polyurethane Fiberglass Mat - Longitudinal C-C.

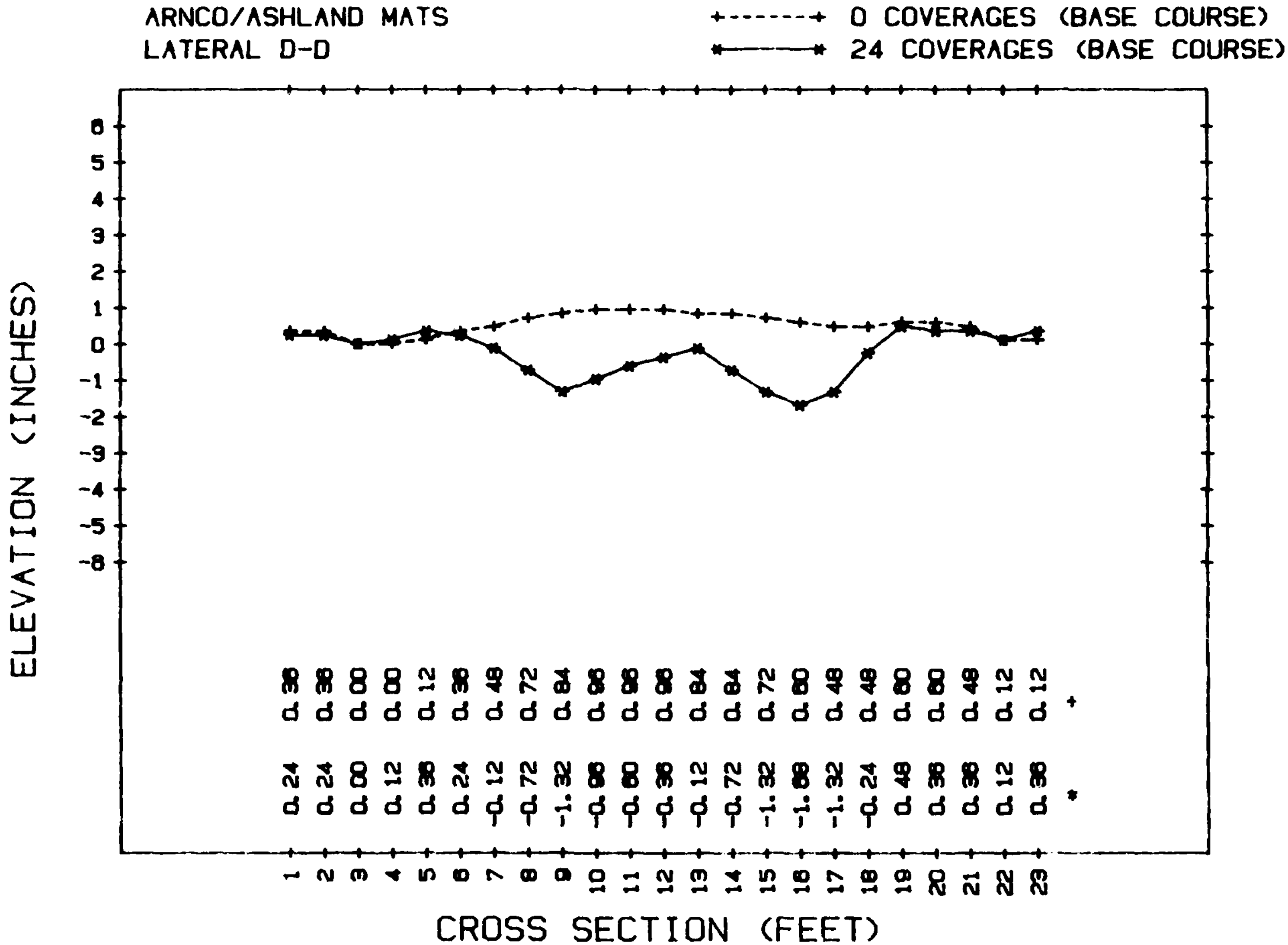


Figure 149. Base Course Elevation Profiles After 0 and 24 (Before Maintenance) F-15 Loadcart Coverages for Alternative Polyurethane Fiberglass Mat - Longitudinal D-D.

TABLE 19. ALTERNATIVE POLYURETHANE FOD COVER TEST - LONGITUDINAL A-A 0 AND 24 (BEFORE MAINTENANCE) F-15 LOADCART COVERAGES.

	ARNCO MAT LONGITUDINAL A-A			
	0 COVERAGES (BASE COURSE)		24 COVERAGES (BASE COURSE)	
	X (FT)	Y (IN.)	X (FT.)	Y (IN.)
MAXIMUM UPHEAVAL		0.97		0.00
REPAIR PEAKS	1.00	0.36	1.00	0.24
	13.00	1.20	23.00	0.12
PEAK SAG		0.35		2.27
PEAK SAG LOCATION	6.00	0.36	3 00	-2.04
AVERAGE VERTICAL DEFORMATION				2.41
VERTICAL DEFORMATION ZONE: START			2.00	
END			22.00	
MAXIMUM VERTICAL DEFORMATION				2.76
MAXIMUM VERTICAL DEFORMATION LOCATION			20.00	
MINIMUM VERTICAL DEFORMATION				0.00
MINIMUM VERTICAL DEFORMATION LOCATION			22.00	

TABLE 20. ALTERNATIVE POLYURETHANE FOD COVER TEST - LONGITUDINAL C-C 0 AND 24 (BEFORE MAINTENANCE) F-15 LOADCART COVERAGES.

ASHLAND MAT LONGITUDINAL C-C	0 COVERAGES (BASE COURSE)		24 COVERAGES (BASE COURSE)	
	X (FT)	Y (IN.)	X (FT.)	Y (IN.)
MAXIMUM UPHEAVAL		0.44		0.00
REPAIR PEAKS	9.00	0.72	1.00	0.12
	16.00	0.84	23.00	0.36
PEAK SAG		0.21		1.83
PEAK SAG LOCATION	14.00	0.60	4.00	-1.68
AVERAGE VERTICAL DEFORMATION				1.83
VERTICAL DEFORMATION ZONE: START			1.00	
END			22.00	
MAXIMUM VERTICAL DEFORMATION				2.04
MAXIMUM VERTICAL DEFORMATION LOCATION			3.00	
MINIMUM VERTICAL DEFORMATION				0.12
MINIMUM VERTICAL DEFORMATION LOCATION			1.00	

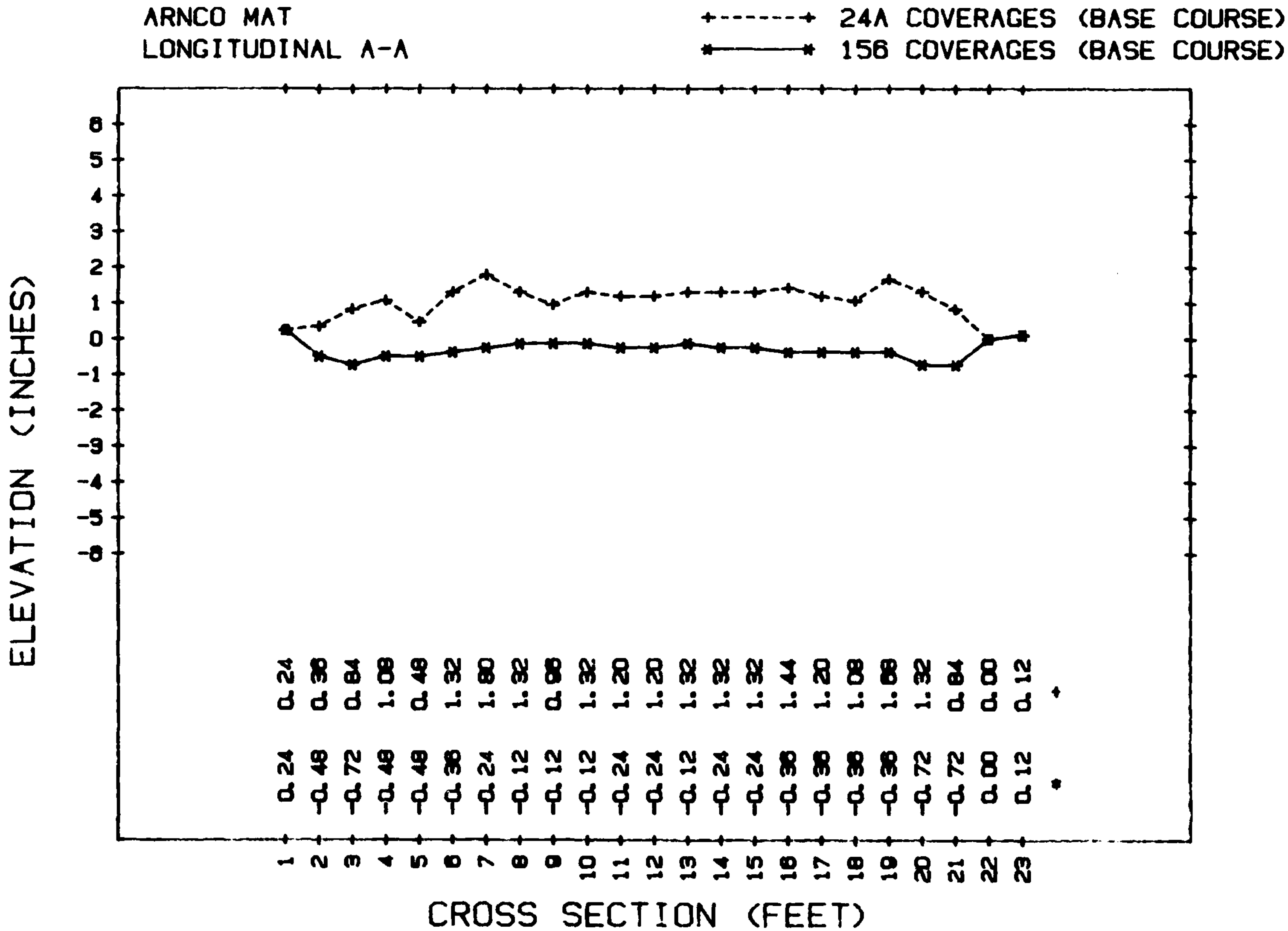


Figure 150. Base Course Elevation Profiles After 24A (After Maintenance) and 156 F-15 Loadcart Coverages for Alternative Polyurethane Fiberglass Mat - Longitudinal A-A.

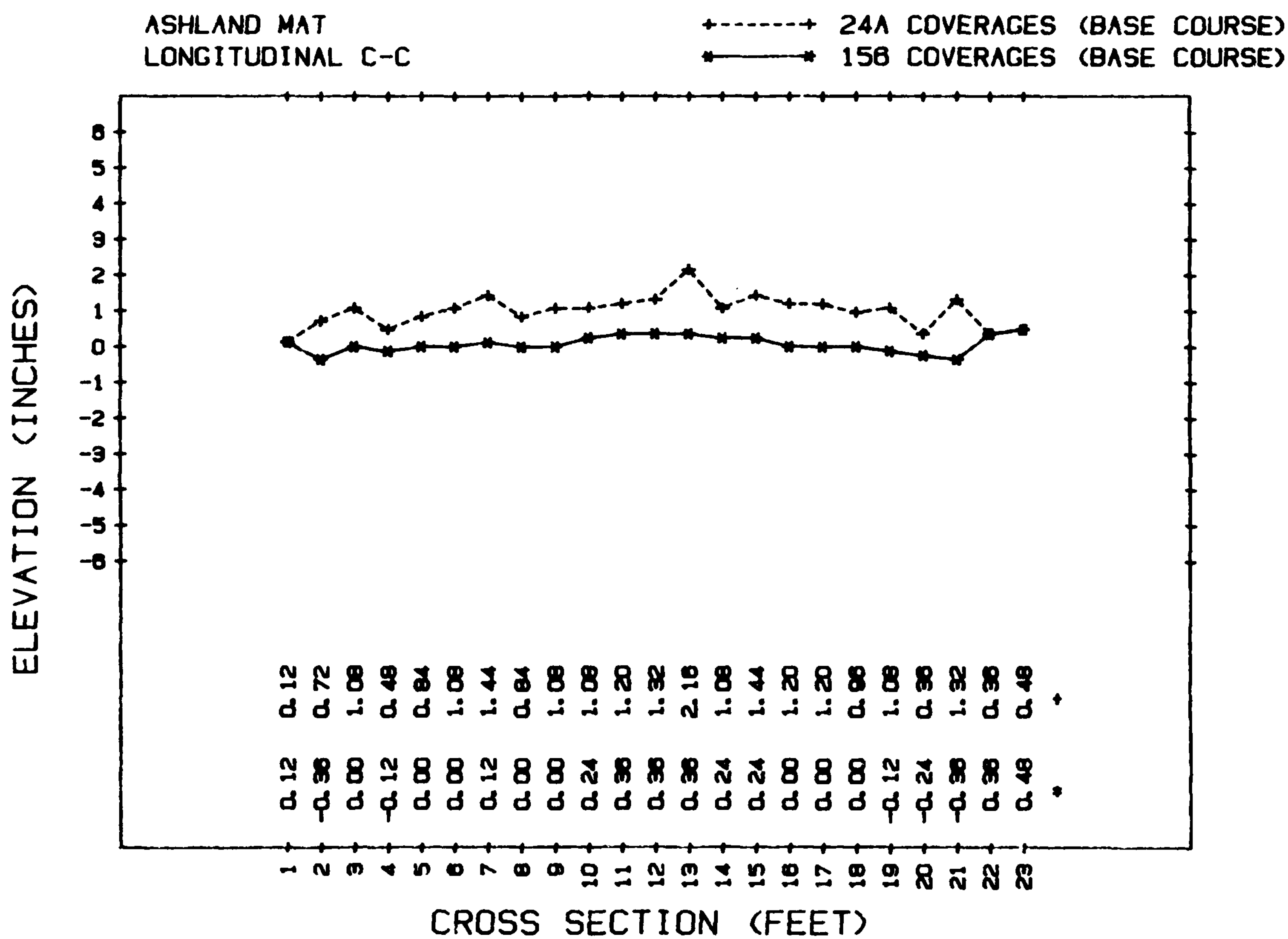


Figure 151. Base Course Elevation Profiles After 24A (After Maintenance) and 156 F-15 Loadcart Coverages for Alternative Polyurethane Fiberglass Mat - Longitudinal C-C.

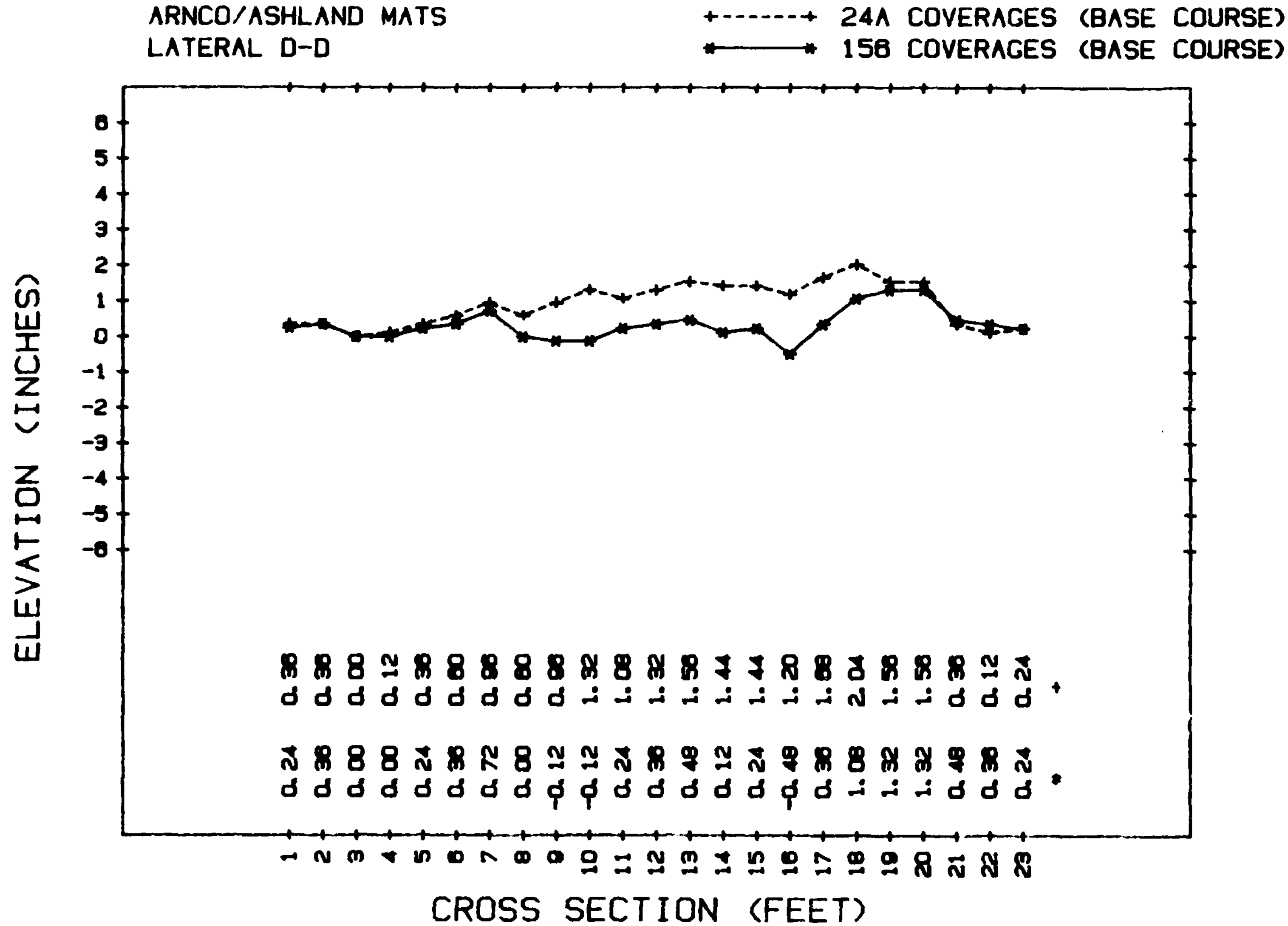


Figure 152. Base Course Elevation Profiles After 24A (After Maintenance) and 156 F-15 Loadcart Coverages for Alternative Polyurethane Fiberglass Mat - Longitudinal D-D.

TABLE 21. ALTERNATIVE POLYURETHANE FOD COVER TEST - LONGITUDINAL A-A 24A (AFTER MAINTENANCE) AND 156 F-15 LOADCART COVERAGES.

ARNCO MAT
LONGITUDINAL A-A

	24A COVERAGES (BASE COURSE)		156 COVERAGES (BASE COURSE)	
	X (FT)	Y (IN.)	X (FT.)	Y (IN.)
MAXIMUM UPHEAVAL		1.59		0.00
REPAIR PEAKS	3.00	0.84	1.00	0.24
	7.00	1.80	23.00	0.12
PEAK SAG		1.84		0.95
PEAK SAG LOCATION	5.00	0.48	3.00	-0.72
AVERAGE VERTICAL DEFORMATION				1.50
VERTICAL DEFORMATION ZONE: START			2.00	
END			22.00	
MAXIMUM VERTICAL DEFORMATION				2.04
MAXIMUM VERTICAL DEFORMATION LOCATION			19.00	
MINIMUM VERTICAL DEFORMATION				0.00
MINIMUM VERTICAL DEFORMATION LOCATION			22.00	

TABLE 22. ALTERNATIVE POLYURETHANE FOD COVER TEST - LONGITUDINAL C-C 24A (AFTER MAINTENANCE) AND 156 F-15 LOADCART COVERAGES.

	ASHLAND MAT LONGITUDINAL C-C			
	24A COVERAGES (BASE COURSE)		156 COVERAGES (BASE COURSE)	
	X (FT)	Y (IN.)	X (FT.)	Y (IN.)
MAXIMUM UPHEAVAL		1.84		0.08
REPAIR PEAKS	13.00	2.16	11.00	0.36
	21.00	1.32	23.00	0.48
PEAK SAG		1.07		0.82
PEAK SAG LOCATION	20.00	0.36	21.00	-0.36
AVERAGE VERTICAL DEFORMATION				1.01
VERTICAL DEFORMATION ZONE: START			1.00	
END			22.00	
MAXIMUM VERTICAL DEFORMATION				1.80
MAXIMUM VERTICAL DEFORMATION LOCATION			13.00	
MINIMUM VERTICAL DEFORMATION				0.00
MINIMUM VERTICAL DEFORMATION LOCATION			1.00	

results are shown in Tables 21 and 22. The maximum vertical deformation was 2.04 inches along A-A, and the average vertical deformation was 1.50 inches. The calculated peak sag was 0.95 inches.

4. Conclusions

This test compared the performance of a 2-ply Ashland polyurethane mat and a 2-ply ARNCO polyurethane mat. Both mats were placed over a 24-inch crushed stone base course and were trafficked with 156 coverages of the F-15 loadcart. Maintenance was performed on the base course after 24 coverages.

Performance of the two mats was similar. When the mats were removed for maintenance after 24 coverages, base course surface roughness measurements showed a peak sag of 1.83 inches under the Ashland mat and a peak sag of 2.27 inches under the ARNCO mat. After 156 coverages there was a peak sag of 0.82 inches under the Ashland mat, and a peak sag of 0.95 inches under the ARNCO mat. Although deformations under the ARNCO mat are slightly greater than those under the Ashland mat, the difference in performance is negligible because the test was not closely controlled. Variations in density, moisture content, loadcart speed, etc. could account for the difference. Thus, these results support using ARNCO polyurethane as a second polyurethane source for fabrication of fiberglass mats.

Since maintenance of the base course was required only once during the 156 F-15 loadcart coverages, the results of this test also indicate that 2-ply polyurethane (UF) mats are adequate for F-15 traffic.

C. WET CRATER REPAIR DEMONSTRATION

1. Purpose

This section describes repair of an explosively formed crater in wet, high-water table, heavy-rain conditions. The repair procedure used a polyurethane-impregnated fiberglass mat over choked ballast rock and was completed under simulated rain conditions. Investigators timed all repair procedure events and recorded them in event/time logs. Data collectors also used 35mm still photography and color video recordings.

The demonstration's major objectives were to verify, by loadcart testing, the integrity of the fiberglass mat over ballast rock crater repair method on an exploded crater in wet conditions and to evaluate the adequacy of polyurethane as a ramp construction material in wet conditions. The demonstration's subobjectives were to determine the complete repair time of a crater having a repair diameter of approximately 20 feet, as well as the time required to complete the individual repair procedure steps. It also tested the effectiveness of the hardened multipurpose RRR excavator in repairing rain-soaked craters.

2. Test Description

a. Test Location and Test Conditions

Test personnel conducted the demonstration in February 1984 in crater 3C at SKY TEN described in Section II. The crater was explosively formed to give an apparent size of 13 feet North/South by 16 feet East/West by 3 feet 10 inches deep (see Figures 153 and 154). Personnel measured approximately 4 inches of pavement upheaval and debris at the crater lip. After removing the debris, the crater dimensions measured 22 feet, 3 inches North/South by 23 feet 10 inches East/West.

A simple sprinkler system set up at the test site provided the wet, raining conditions necessary for the test, by simulating rain at approximately 2 inches per hour. The sprinkler system included a fire truck/water tanker combination and a 55-ton crane. The fire truck/water tanker supplied water at the required pressure through a 1.5-inch hose and adjustable nozzle. The crane positioned the hose and nozzle high enough above the crater to avoid interfering with excavator operations.

Test personnel operated the sprinkler system the day before testing, filling the crater approximately half-full of water. Sprinkler operations simulated rain and kept the crater saturated until the fiberglass mat and ramp installation operations were complete. The water tanker also saturated the stockpile before testing.

b. Equipment and Personnel

(1) Equipment. Test personnel used a John Deere 690B multipurpose excavator to repair the crater. The crater repair team used two 5-ton dump trucks to haul material from the stockpile to the crater. A front-end loader filled the dump truck with crater repair material and towed the fiberglass mat over the repaired crater.

(2) Personnel. The crater repair team consisted of the noncommissioned officer in charge (NCOIC), an equipment operator, and two laborers. The stockpile team included an equipment operator and two laborers. The mat anchoring team consisted of the NCOIC and five laborers to anchor the mat. Two BDM personnel recorded test activities in event/time logs.

c. Crater Repair and Fiberglass Mat Installation

All equipment, test team personnel, and a prefabricated 26-feet by 29-feet polyurethane fibgerlass mat, with a presaturated hinge and predrilled holes, arrived at the crater site before testing began. Following the beginning signal, the RRR multipurpose excavator removed debris from and around the crater to expose upheaval. Following debris removal, laborers checked surface roughness using a stringline and upheaval

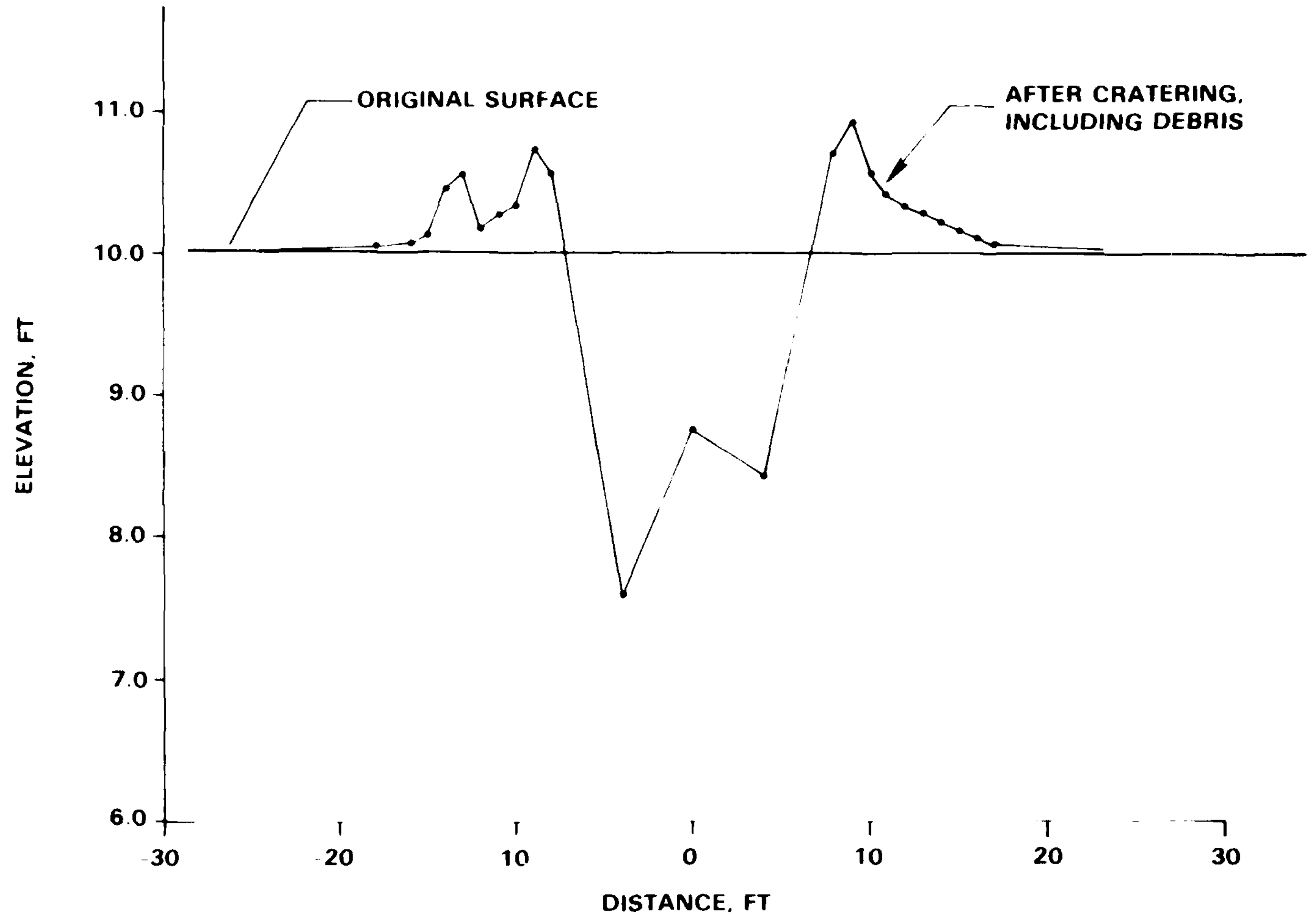


Figure 153. Crater Surface Profile, North-South Direction, Before and After Explosion, Wet Crater Repair Demonstration.

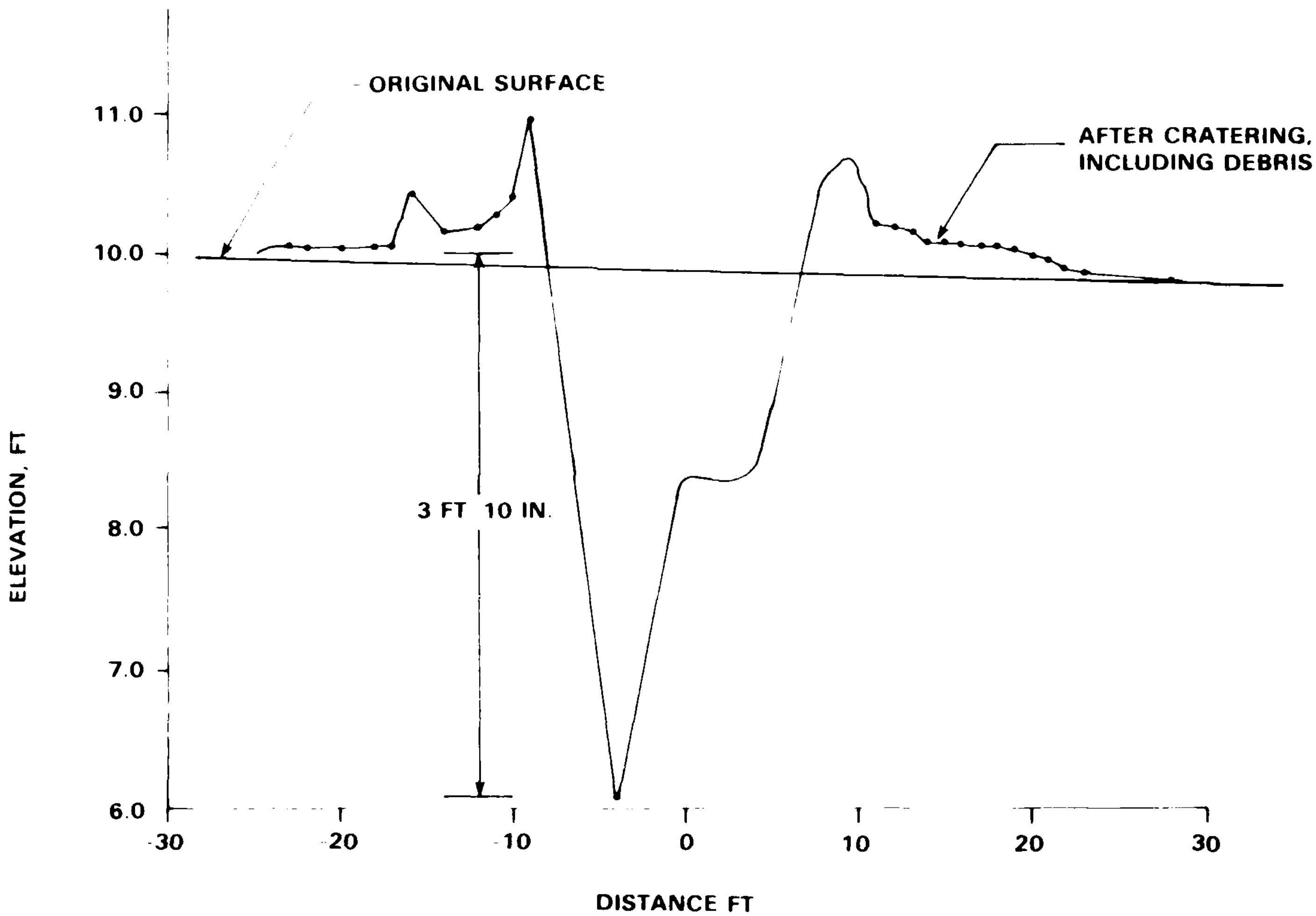


Figure 154. Crater Surface Profile, East-West Direction, Before and After Explosion, Wet Crater Repair Demonstration.

using a RRR straightedge to determine the amount to be removed. The excavator broke up the upheaved pavement using the moil attachment. With this operation complete, the excavator moil was removed and the bucket attached. With the bucket attachment, the excavator removed upheaval and debris from the crater area. At the same time, laborers shoveled ejected material into the crater.

After the upheaved pavement and debris were removed, the dump trucks endloaded ballast rock in to the crater. The excavator bucket worked across the crater to level and compact the ballast rock. Next, the dump trucks placed crushed stone which was initially leveled with the excavator blade and bucket. Laborers shoveled crushed stone to fill low spots. The excavator compactor plate moving 0.5 ft/sec compacted the stone in two passes before leveling with the excavator blade.

Upon completion of final leveling, test personnel measured a maximum upheaval of 5 1/2 inches along A-A (see Figure 155), which exceeded the repair criteria. However, since this test was a demonstration exercise, personnel placed the mat over the crater for traffic testing without correcting the excessive upheaval.

The prefabricated fiberglass mat consisted of two panels, one made with PERCOL 100 polyurethane and the other with Ashland polyurethane, separated by a bare fiberglass hinge along the center line. Test personnel impregnated the hinge with PERCOL 100 liquid and allowed it to solidify to form a rigid hinge before towing the mat over the crater.

Once the crushed stone was leveled, laborers attached a towing harness and chain to the mat, and the front-end loader (FEL) towed it over the crater. Laborers installed nine low-profile bushings along each of the leading and trailing edges of the mat to anchor it in position. Drilling team personnel used two 90-pound jack hammers with pointed bits rather than the normally used concrete drills to drill the anchoring holes. To secure the bolts, test personnel poured liquid polyurethane into the drilled holes and allowed the resin to set while the bolts/bushings were held in place. Figure 155 provides a plan view of the test section showing the anchored mat.

After the mat was anchored over the test section, laborers constructed a ramp for tailhook demonstrations along a portion of the mat's leading edge as shown in Figure 155. Personnel constructed the ramp by adding PERCOL 100 liquid to both sand and gravel (as retained on the #20 sieve), forming mortars with each material. Laborers placed the mortars under raining conditions with a trowel.

d. Tailhook Operations and Traffic Testing

The loadcart testing did not proceed as planned. The test plan called for the repair to be trafficked with two applications (160 passes or 24 coverages) of the F-15 loadcart pattern shown in Figure 156.

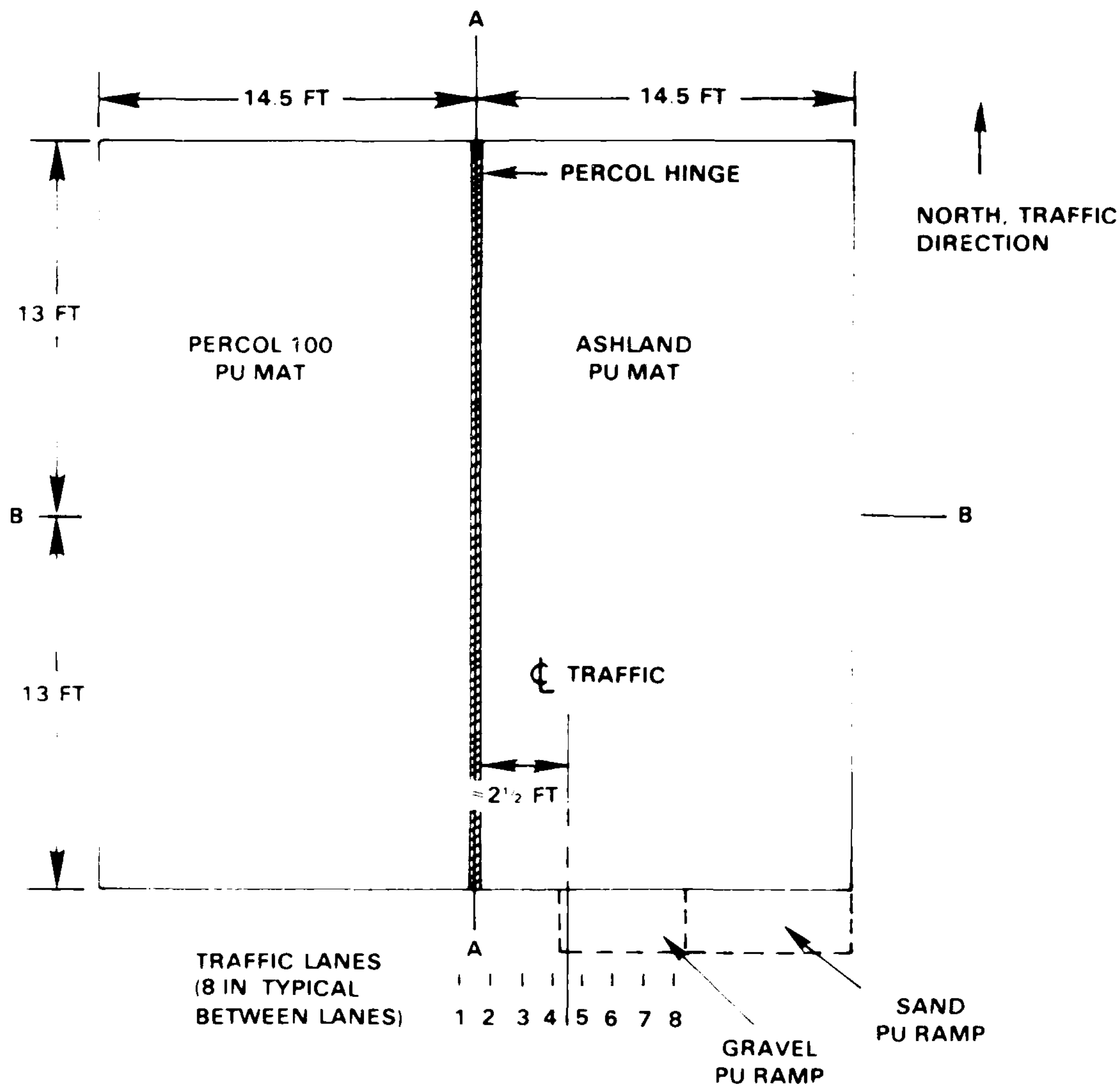


Figure 155. Test Section Plan View, Wet Crater Repair Demonstration.

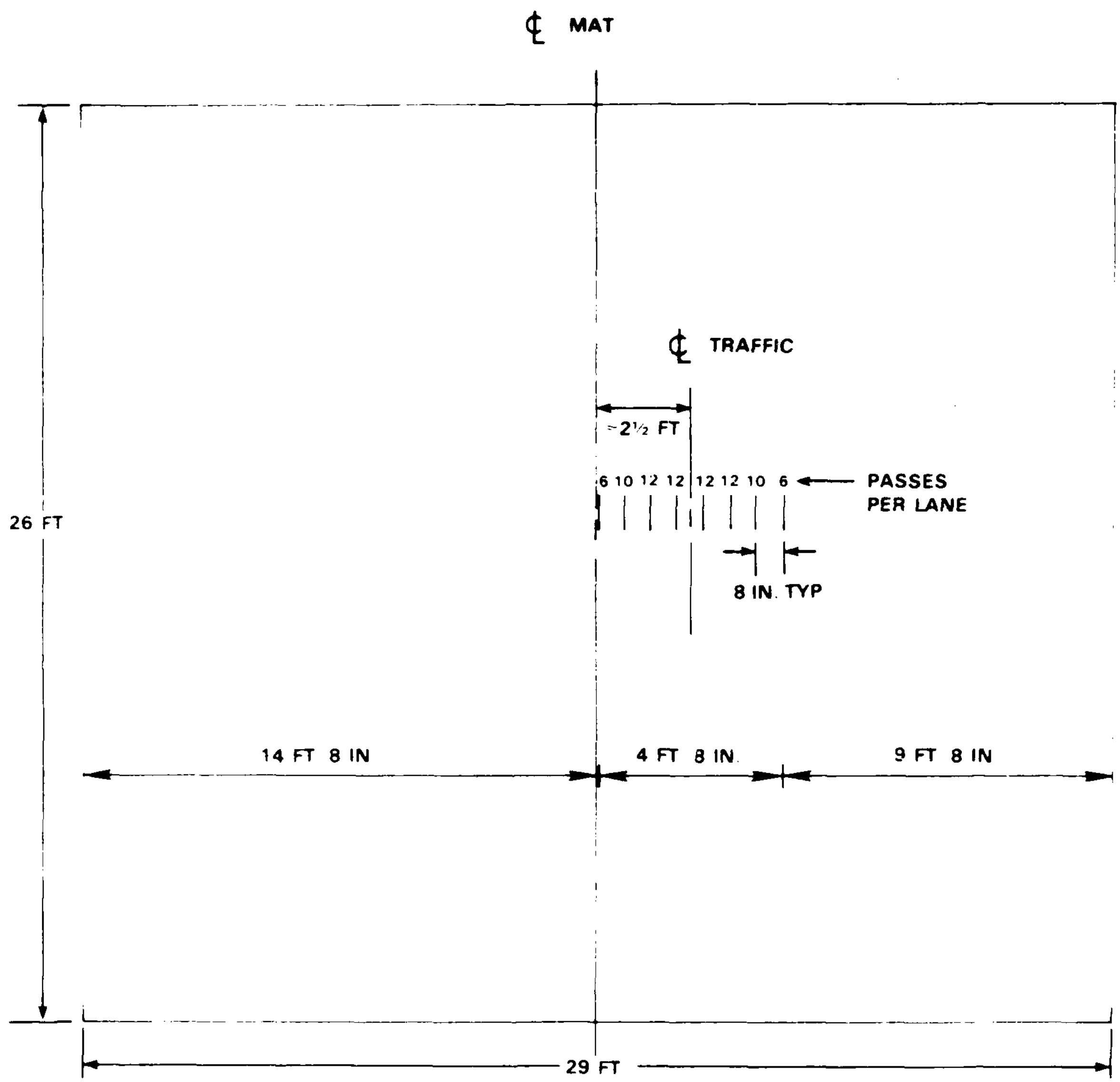


Figure 156. Traffic Distribution Pattern, Wet Crater Repair Demonstration.

Failure criterion was established as incurring damage greater than the SRC requirement of 3 inches after two traffic pattern applications. However, after one pattern application, the repair failed because of a 6 1/2-inch tear along the PERCOL hinge, and traffic testing was stopped. The tearing was attributed to wrinkles in the mat around the hinge. Personnel had not flattened out the wrinkles before adding the polyurethane liquid to the hinge, which became rigid when the polyurethane solidified. Consequently, the wrinkles were subjected to considerable stress when the repair was trafficked which resulted in splitting and tearing along the hinge. In addition, particle movement occurred in the crushed stone base course under loading, resulting in rutting in the traffic lane. Data collectors noted that the tendency for particle movement resulted from the crushed stone's high water content.

Since the mat tear resulted from improper mat preparation and not from base or subgrade failure, traffic testing continued without repairing the tear, using the bimodal traffic distribution shown in Figure 157 to ensure maximum trafficking along the centerline of each half of the mat, away from the mat centerline where the tear had developed. Test personnel applied three applications (108 passes) of the new pattern to each mat, for 138 total loadcart passes. No failures or maintenance actions occurred during loadcart testing with the new pattern. Personnel removed the mat after three loadcart applications to replace the anchors.

Two tailhook tests were also conducted, using the F-4 tailhook simulator, to demonstrate the ability of the mortar ramp, placed in wet conditions, and the fiberglass mat to withstand tailhook operations. The mat and ramp sustained no damage from the tests.

e. Data Collection

Data collectors took six nuclear density/moisture readings prior to trafficking at random points in the repaired crater. The readings are presented in Table 23. The average dry density and moisture content before trafficking were 132.6 lb/ft^3 and 7.5 percent, respectively. The high moisture content represents a severe crater repair environment.

Test personnel collected elevation data during repair trafficking using a rod and level survey. When the mat was trafficked with the first pattern, personnel collected elevation data at 1-foot intervals along longitudinal A-A, along lateral B-B, and along the centerline of traffic (see Figures 155 and 156), obtaining both top-of-mat and top-of-base course elevations after 0 and 12 loadcart coverages. When the repair was trafficked with the second pattern, test personnel measured elevations at 1-foot intervals along longitudinal A-A, B-B, the centerlines of traffic and lateral C-C (see Figure 157), obtaining top-of-mat and top-of-base course elevations after 12 and 36 loadcart coverages.

In addition, data collectors timed all events in the crater repair and fiberglass mat installation procedures. To facilitate data

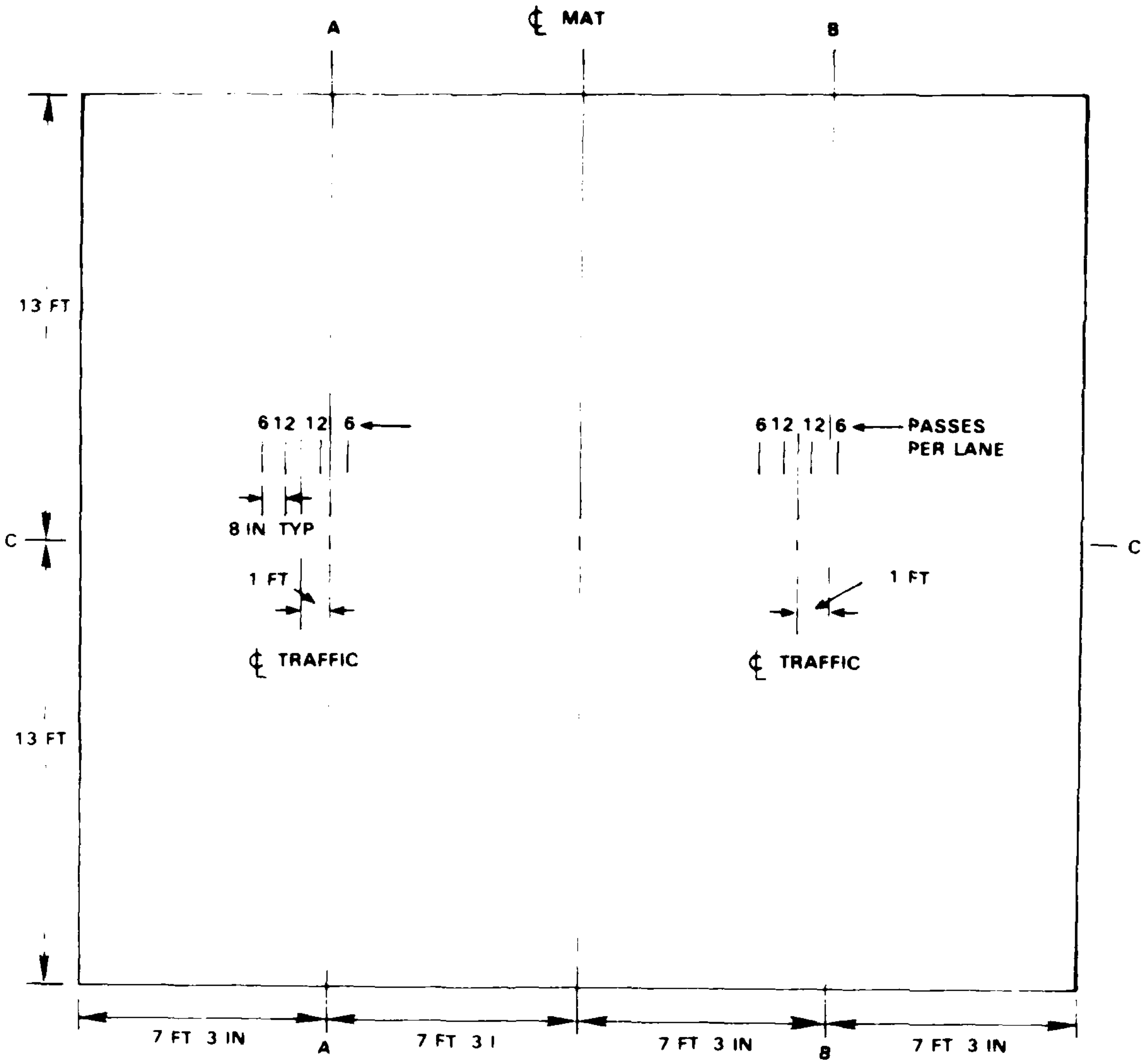


Figure 157. Bimodal Traffic Distribution Pattern, Wet Crater Repair Demonstration.

TABLE 23. MOISTURE-DENSITY RESULTS FOR REPAIRED CRATER, WET CRATER REPAIR DEMONSTRATION.

SAMPLE NUMBER	DEPTH (IN.)	WET DENSITY (LB/FT^3)	DRY DENSITY (LB/FT^3)	MOISTURE CONTENT (PERCENT)
1	BS[a]	146.9	136.0	8.0
2	BS	142.9	132.2	8.1
3	BS	133.5	124.8	6.9
4	BS	150.9	140.2	7.6
5	BS	148.5	137.9	7.7
6	BS	135.5	124.2	9.1

[a]BS - SURFACE READING.

correlation, the test director and data recorders synchronized their watches before the test started.

3. Results

Figures 158 and 159 show base course (BC) elevation profiles along longitudinal A-A, the centerline of traffic (CLT), and lateral B-B after 0 and 12 coverages of the first traffic pattern. Tables 24 and 25 summarize surface roughness and vertical deformation. Before trafficking (zero coverages), the repair surface had a maximum upheaval of 1.97 inches and a peak sag of 1.05 inches.

After 12 F-15 loadcart coverages, personnel measured a 1.86-inch maximum upheaval and a 1.44-inch peak sag along longitudinal A-A, and 1.07-inch maximum upheaval and 2.76-inch peak sag along the centerline of traffic. Average vertical deformation along A-A was 1.04 inches. The maximum deformation was 1.80 inches; the minimum was 0 inches.

Figures 160 and 161 show the longitudinal surface profiles, while Figure 162 shows the lateral surface profiles, after 12 and 36 F-15 load-cart coverages with the new pattern. Surface roughness measurements are not applicable and were not measured at the ramp (point 4, Figure 161). Also, elevation data were not recorded at points 28, 29, and 30 along longitudinal B-B after 12 loadcart coverages. When inputting data into the computer program used to plot the profiles and perform the surface roughness calculations, test analysts entered false elevations, consistent with the general profile shape, at these points (enclosed in squares) to preclude incorrect surface roughness calculations.

Tables 26 through 29 summarize surface roughness. After 12 coverages of the new pattern, personnel measured a maximum upheaval of 2.26 inches and a peak sag of 0.54 inch along longitudinal A-A, and a maximum upheaval of 2.01 inches and a peak sag of 0.41 inch along longitudinal B-B. After 36 coverages, the peak sag and maximum upheaval along longitudinal A-A measured 1.37 inches and 1.36 inches, respectively. Along the centerline of traffic, approximately 1 foot west of A-A (denoted Centerline of Traffic (A) on profile figures and surface roughness tables), these values were 3.40 inches and 1.46 inches. There was a maximum upheaval of 1.56 inches and peak sag of 1.16 inches along B-B and a maximum upheaval of 1.66 inches and peak sag of 3.59 inches along the centerline of traffic just west of B-B (Centerline of Traffic (B)). The maximum vertical deformation after 36 coverages of the second pattern was 1.92 inches along A-A. Average vertical deformation along A-A was 1.30 inches. Deformations along the centerlines of traffic could not be calculated since centerline elevations were not measured until after 36 loadcart coverages.

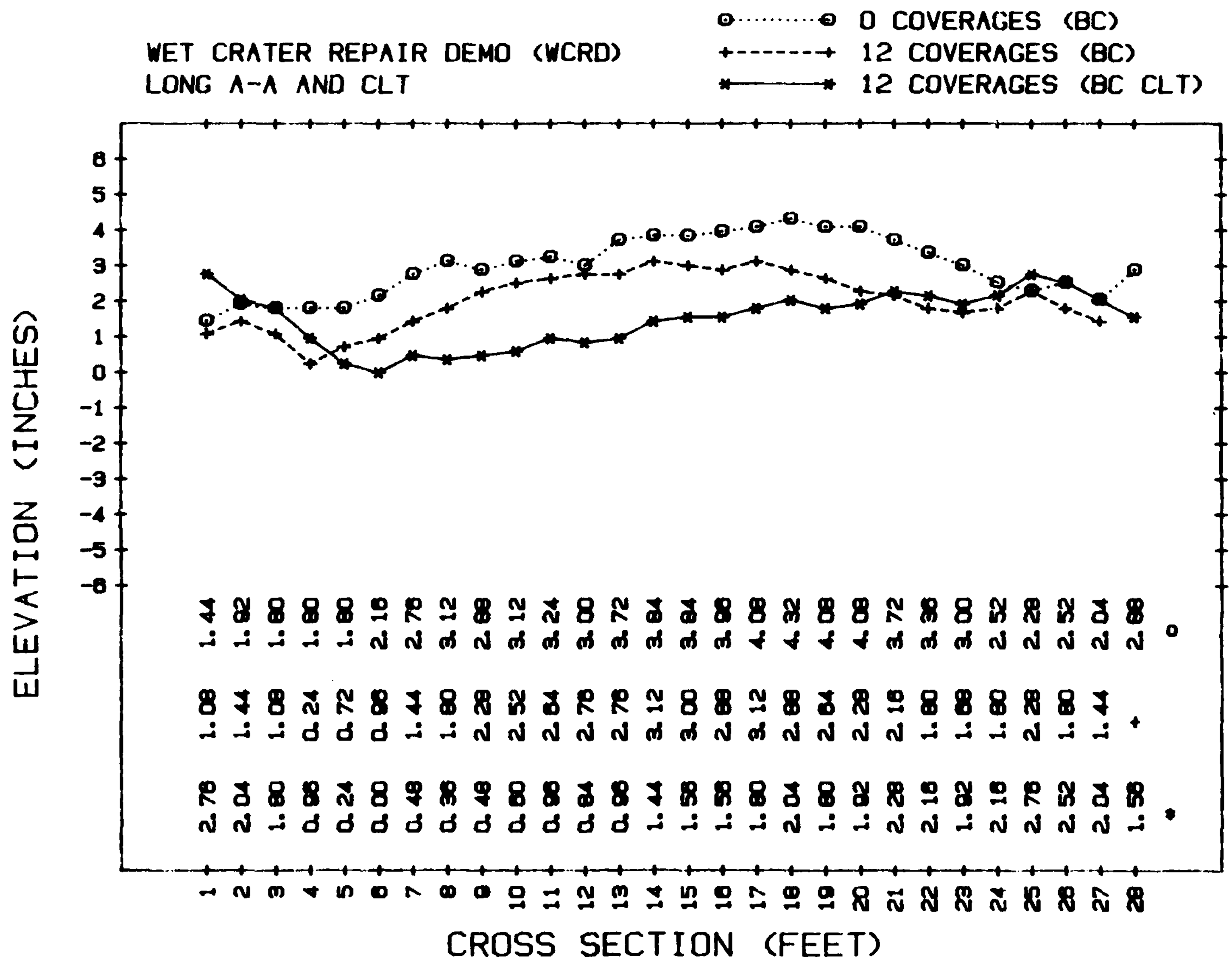


Figure 158. Base Course Elevation Profiles - Longitudinal A-A After 0 and 12 F-15 Loadcart Coverages (First Pattern) and Centerline of Traffic After 12 Coverages - For Wet Crater Repair Demonstration.

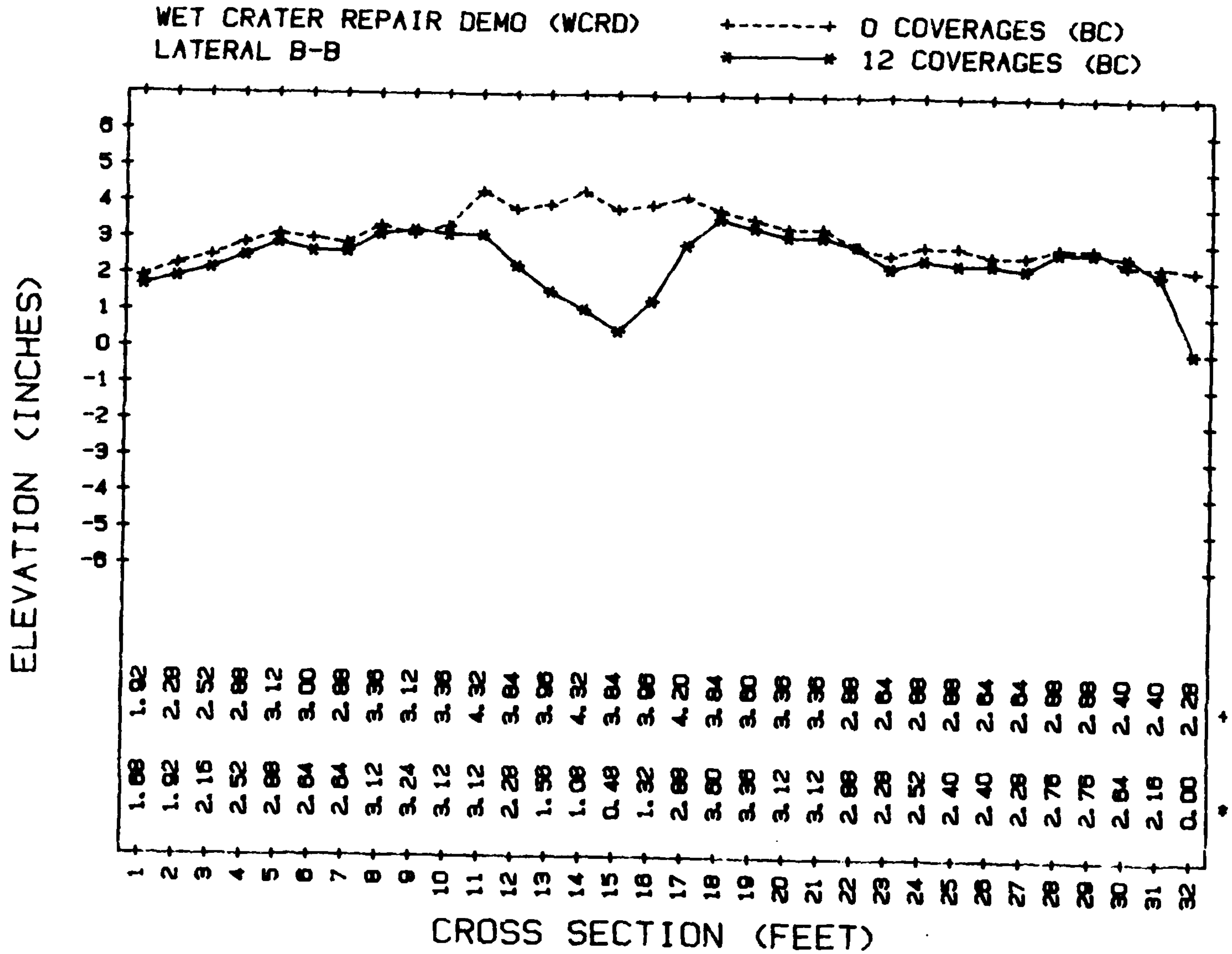


Figure 159. Base Course Elevation Profiles After 0 and 12 F-15 Loadcart Coverages (First Pattern) For Wet Crater Repair Demonstration - Lateral B-B.

TABLE 24. WET CRATER REPAIR DEMONSTRATION - LONGITUDINAL A-A
0 AND 12 F-15 LOADCART COVERAGES (1st PATTERN).

WET CRATER REPAIR DEMO
LONGITUDINAL A-A

	0 COVERAGES (BC)		12 COVERAGES (BC)	
	X (FT)	Y (IN.)	X (FT.)	Y (IN.)
MAXIMUM UPHEAVAL		1.97		1.86
REPAIR PEAKS	20.00	4.08	2.00	1.44
	28.00	2.88	14.00	3.12
PEAK SAG		1.05		1.48
PEAK SAG LOCATION	25.00	2.28	4.00	0.24
AVERAGE VERTICAL DEFORMATION				1.04
VERTICAL DEFORMATION ZONE: START			2.00	
END			25.00	
MAXIMUM VERTICAL DEFORMATION				1.80
MAXIMUM VERTICAL DEFORMATION LOCATION			20.00	
MINIMUM VERTICAL DEFORMATION				0.00
MINIMUM VERTICAL DEFORMATION LOCATION			25.00	

TABLE 25. WET CRATER REPAIR DEMONSTRATION - CENTERLINE OF TRAFFIC 12 F-15 LOADCART COVERAGES (1st PATTERN).

		WET CRATER REPAIR DEMO CENTERLINE OF TRAFFIC	
		12 COVERAGES (BC CLT)	
		X (FT)	Y (IN.)
MAXIMUM UPHEAVAL			1.07
REPAIR PEAKS		1.00	2.76
		25.00	2.76
PEAK SAG			2.76
PEAK SAG LOCATION		6.00	0.00
AVERAGE VERTICAL DEFORMATION			0.00
VERTICAL DEFORMATION ZONE:	START	2.00	
	END	25.00	
MAXIMUM VERTICAL DEFORMATION			0.00
MAXIMUM VERTICAL DEFORMATION LOCATION		2.00	
MINIMUM VERTICAL DEFORMATION			0.00
MINIMUM VERTICAL DEFORMATION LOCATION		2.00	

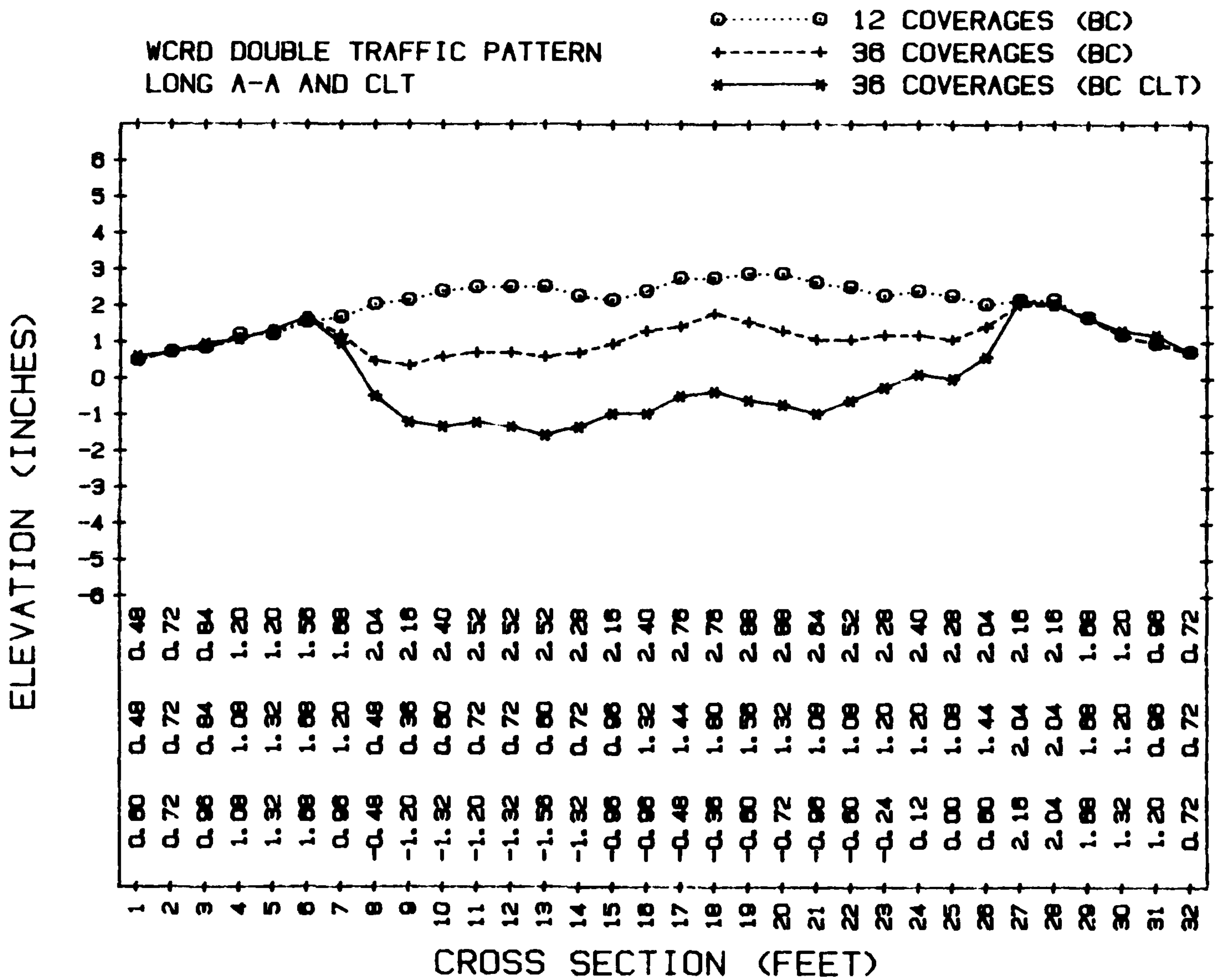
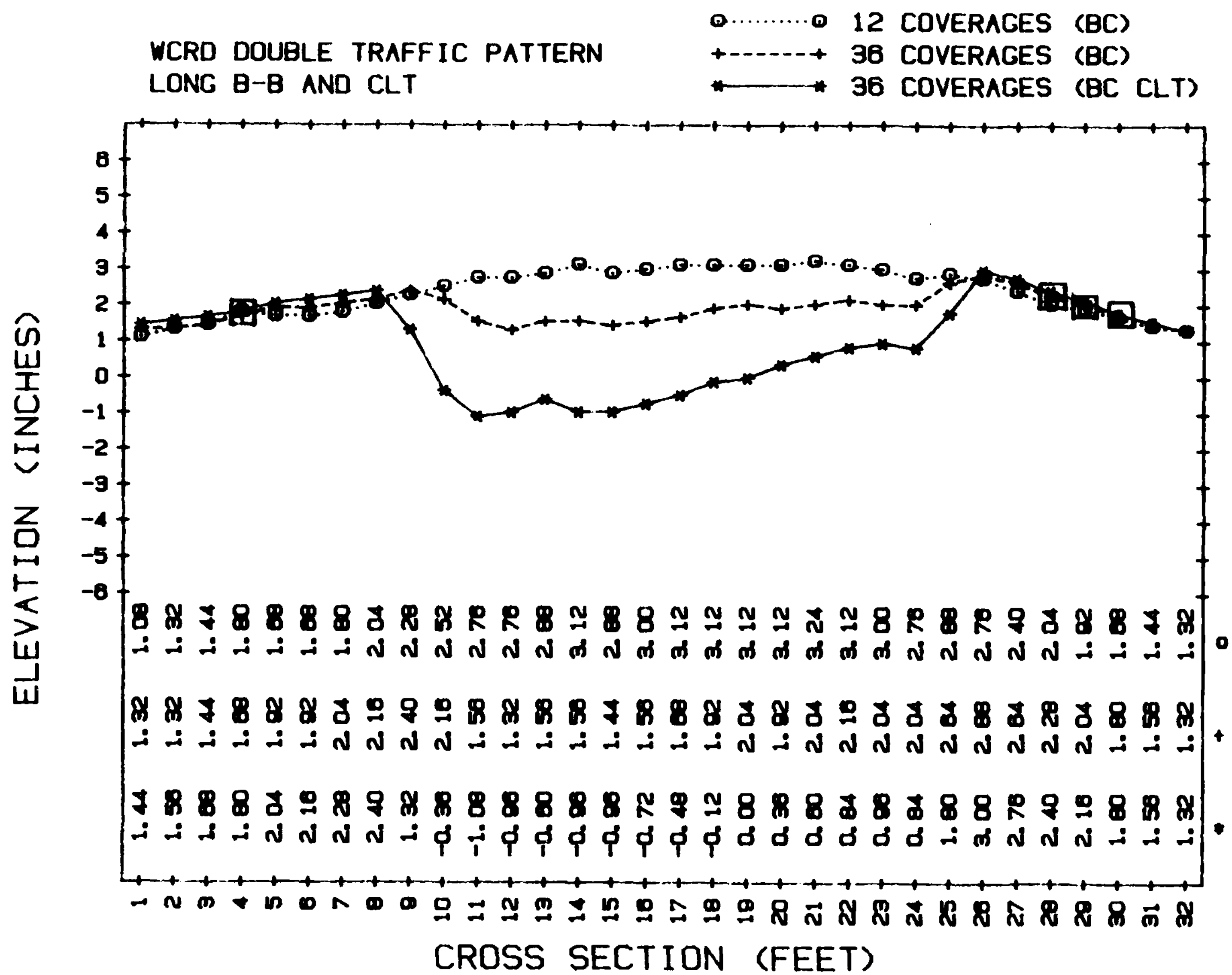


Figure 160. Base Course Elevation Profiles - Longitudinal A-A After 12 and 36 F-15 Loadcart Coverages (Second Pattern) and Centerline of Traffic After 36 Coverages - For Wet Crater Repair Demonstration.



Cross section (ft)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
o	1.08	1.32	1.44	1.80	1.68	1.68	1.80	2.04	2.28	2.52	2.76	2.76	2.88	3.12	2.88	3.00	3.12	3.12	3.12	3.12	3.24	3.12	3.00	2.76	2.88	2.76	2.40	2.04	1.92	1.68	1.44	1.32
+	1.32	1.32	1.44	1.68	1.92	1.92	2.04	2.16	2.40	2.16	1.56	1.32	1.56	1.56	1.44	1.56	1.68	1.92	2.04	1.92	2.04	2.16	2.04	2.04	2.64	2.88	2.64	2.28	2.04	1.80	1.56	1.32
*	1.44	1.56	1.68	1.80	2.04	2.16	2.28	2.40	1.32	-0.36	-1.08	-0.96	-0.60	-0.96	-0.96	-0.72	-0.48	-0.12	0.00	0.36	0.60	0.84	0.96	0.84	1.80	3.00	2.76	2.40	2.16	1.80	1.56	1.32

Figure 161. Base Course Elevation Profiles - Longitudinal A-A After 12 and 36 F-15 Loadcart Coverages (Second Pattern) and Centerline of Traffic After 36 Coverages - For Wet Crater Repair Demonstration.

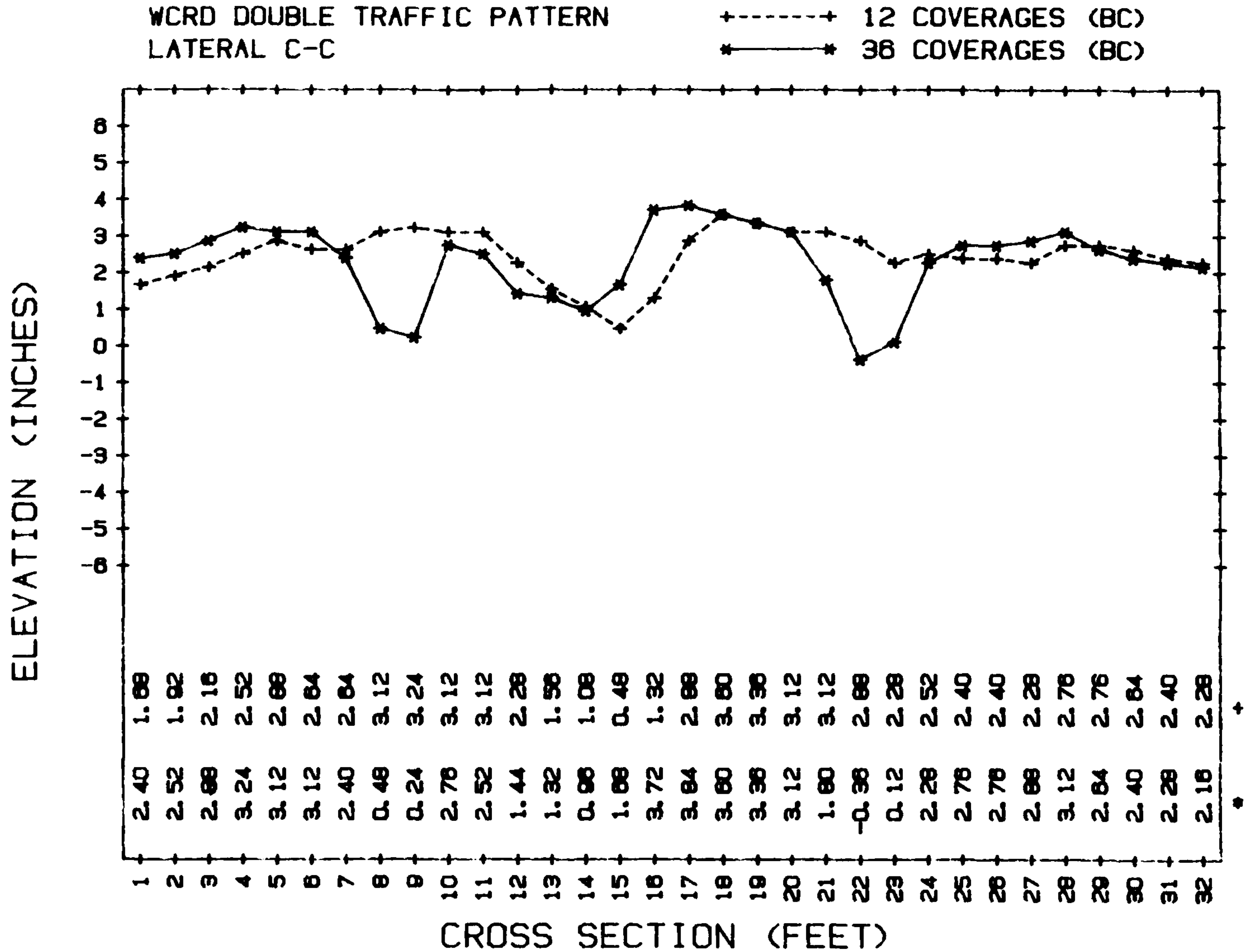


Figure 162. Base Course Elevation Profiles After 12 and 36 F-15 Loadcart Coverages (Second Pattern) For Wet Crater Repair Demonstration - Lateral C-C.

TABLE 26. WET CRATER REPAIR DEMONSTRATION - LONGITUDINAL A-A 12 AND 36 F-15 LOADCART COVERAGES (2nd PATTERN).

WCRD DOUBLE TRAFFIC PATTERN
LONGITUDINAL A-A

	12 COVERAGES (BC)		36 COVERAGES (BC)	
	X (FT)	Y (IN.)	X (FT.)	Y (IN.)
MAXIMUM UPHEAVAL		2.26		1.36
REPAIR PEAKS	11.00	2.52	6.00	1.68
	19.00	2.88	27.00	2.04
PEAK SAG		0.54		1.37
PEAK SAG LOCATION	15.00	2.16	9.00	0.36
AVERAGE VERTICAL DEFORMATION				1.30
VERTICAL DEFORMATION ZONE: START			6.00	
END			27.00	
MAXIMUM VERTICAL DEFORMATION				1.92
MAXIMUM VERTICAL DEFORMATION LOCATION			13.00	
MINIMUM VERTICAL DEFORMATION				-0.12
MINIMUM VERTICAL DEFORMATION LOCATION			6.00	

TABLE 27. WET CRATER REPAIR DEMONSTRATION - CENTERLINE OF TRAFFIC (A) 36 F-15 LOADCART COVERAGES (2nd PATTERN).

WCRD DOUBLE TRAFFIC PATTERN
CENTERLINE OF TRAFFIC (A)

		36 COVERAGES (BC CLT)	
		X (FT)	Y (IN.)
MAXIMUM UPHEAVAL			1.46
REPAIR PEAKS		6.00	1.68
		27.00	2.16
PEAK SAG			3.40
PEAK SAG LOCATION		13.00	-1.56
AVERAGE VERTICAL DEFORMATION			0.00
VERTICAL DEFORMATION ZONE:	START	6.00	
	END	27.00	
MAXIMUM VERTICAL DEFORMATION			0.00
MAXIMUM VERTICAL DEFORMATION LOCATION		6.00	
MINIMUM VERTICAL DEFORMATION			0.00
MINIMUM VERTICAL DEFORMATION LOCATION		6.00	

TABLE 28. WET CRATER REPAIR DEMONSTRATION - LONGITUDINAL B-B
12 AND 36 F-15 LOADCART COVERAGES (2nd PATTERN).

	WCRD DOUBLE TRAFFIC PATTERN LONGITUDINAL B-B			
	12 COVERAGES (BC)		36 COVERAGES (BC)	
	X (FT)	Y (IN.)	X (FT.)	Y (IN.)
MAXIMUM UPHEAVAL		2.01		1.56
REPAIR PEAKS	4.00	1.80	9.00	2.40
	11.00	2.76	26.00	2.88
PEAK SAG		0.41		1.16
PEAK SAG LOCATION	7.00	1.80	12.00	1.32
AVERAGE VERTICAL DEFORMATION				0.81
VERTICAL DEFORMATION ZONE: START			6.00	
END			27.00	
MAXIMUM VERTICAL DEFORMATION				1.56
MAXIMUM VERTICAL DEFORMATION LOCATION			14.00	
MINIMUM VERTICAL DEFORMATION				-0.24
MINIMUM VERTICAL DEFORMATION LOCATION			27.00	

TABLE 29. WET CRATER REPAIR DEMONSTRATION - CENTERLINE OF TRAFFIC (B) 36 F-15 LOADCART COVERAGES (2nd PATTERN).

	WCRD DOUBLE TRAFFIC PATTERN CENTERLINE OF TRAFFIC (B)	
	36 COVERAGES (BC CLT)	
	X (FT)	Y (IN.)
MAXIMUM UPHEAVAL		1.66
REPAIR PEAKS	8.00	2.40
	26.00	3.00
PEAK SAG		3.59
PEAK SAG LOCATION	15.00	-0.96
AVERAGE VERTICAL DEFORMATION		0.00
VERTICAL DEFORMATION ZONE: START	6.00	
END	27.00	
MAXIMUM VERTICAL DEFORMATION		0.00
MAXIMUM VERTICAL DEFORMATION LOCATION	6.00	
MINIMUM VERTICAL DEFORMATION		0.00
MINIMUM VERTICAL DEFORMATION LOCATION	6.00	

4. Conclusions

The polyurethane fiberglass mat over choked ballast rock crater repair method on an exploded crater in wet conditions was adequate and supported three applications of the loadcart and sustained a sag slightly greater than 3 inches. In addition, the polyurethane ramp, constructed in wet conditions, and the fiberglass mat withstood two tailhook tests without damage.

A tear developed along the hinge area where wrinkles were present as a result of improper mat fabrication, during application of the first traffic distribution. This distribution centered traffic over the hinge. In order to continue testing without repairing the mat tear, a new bimodal distribution, which concentrated traffic at the centerlines of the halves of the mat, was used.

The repair system was deployed easily and quickly, with the entire repair taking 2 hours, 26 minutes. Individual activity times are shown in Table 30. A detailed repair time log is included in Appendix F. The RRR multipurpose excavator performed adequately at all required activities, including dozing and debris clearing, upheaval breaking, compacting, and leveling. The FEL was also adequate as no difficulties were encountered during mat towing and placement operations. Further, although the anchoring procedure was nonstandard and holes were drilled using jackhammers with pointed bits rather than concrete drills, no difficulties were encountered during mat anchoring.

D. CONCLUSIONS

The fiberglass mat over choked ballast rock concept is a feasible bomb damage repair method for use in wet conditions. The ballast rock/crushed stone base course performed adequately and supported 138 loadcart passes without requiring maintenance. Some rutting in the traffic lane, which resulted from particle movement in the high moisture content crushed stone base course, was observed when the repair was loaded. Rutting could be reduced by confining the base course. In addition, the hardened multipurpose excavator can be used to repair rain-soaked craters.

Mats fabricated with ARNCO resins and Ashland resins and placed over a crushed stone base course performed equally well, and supported 156 F-15 loadcart coverages with only one interruption for base course maintenance.

TABLE 30. INDIVIDUAL EVENT CYCLE TIMES, WET CRATER REPAIR DEMONSTRATION.

REPAIR EVENT	AVERAGE CYCLE TIME	TOTAL EVENT TIME
CLEAR CRATER LIP	11 SEC	NR
UPHEAVAL PAVEMENT BREAKING	8.4 SEC	10 MIN 45 SEC
DEBRIS AND UPHEAVAL REMOVAL	15.7 SEC	22 MIN
INITIAL GRADING OF CRUSHED STONE	28 SEC	NR
COMPACTION - SINGLE PASS	22.2 SEC	14 MIN 30 SEC
DOUBLE PASS	35.4 SEC	
FINAL GRADING		
COVER INSTALLATION	--	40 MIN 15 SEC
- TOWING TIME	--	105 SEC
- DRILLING TIME	129 SEC/HOLE	22 MIN 30 SEC

NR = Not recorded

SECTION VII

SPALL REPAIR TESTS

A. INTRODUCTION

In-house test personnel conducted three spall repair tests to evaluate the feasibility of using three advanced concrete repair materials in the Advanced Spall Repair System. The F-4 loadcart trafficked the repaired spalls to determine the advanced materials' performances under simulated loading conditions. These tests also evaluated the feasibility of using each material, in terms of mixing and spall repair procedures and material formula changes required for different ambient temperature ranges. In-house test personnel conducted a fourth test to determine the feasibility of using Silikal® for multiple-spall repairs.

1. Background

In the Summer of 1983, AFESC began development of prototype equipment for the Advanced Spall Repair System, to dispense advanced material for spall repairs. Project engineers also continued with a study of the material to be dispensed, which must be selected prior to completion of the prototype design phase. Project engineers considered three advanced material concrete systems: modified polyurethane concrete, magnesium polyphosphate cement concrete, and furfuryl alcohol polymer concrete. Subsection B describes testing of these materials' performance in a spall repair situation.

Subsection C describes testing Silikal® polymer concrete for rapid repair of multiple spalls. Although Air Force engineers had tested Silikal® to determine its structural suitability for spall repairs, a large-scale placement test simulating field conditions and considering aspects such as command and control, material reloading, and interference from FOD clearance operations had never been conducted. Test engineers planned a comparison of repair rates for hand mixed repairs versus mechanical mixing, but the specially designed Silikal® mixer under manufacture by the material developer was unavailable by the scheduled test date.

2. Test Objectives

The general test objectives were to assess the feasibility of advanced materials for spall repair and to perform preliminary structural suitability tests on candidate materials. The specific objective of each test was as follows:

a. Spall Repairs with Advanced Materials Tests

To determine the performance of three advanced concrete material systems for spall repair.

b. Multiple-Spall Repair Test

To determine the time required to patch 42 spalls with Silikal® polymer concrete and identify the problems in large-scale placement operations.

B. SPALL REPAIR WITH ADVANCED MATERIALS TESTS

1. Purpose

Test personnel evaluated three advanced material concrete systems-modified PU concrete, furfuryl polymer concrete (FA-PC), and magnesium polyphosphate cement concrete (MPP) to repair spalls under wet and dry conditions in both PCC and AC pavements. Key issues for the spall repair tests included finished surface smoothness, concrete, and bonding to adjacent pavement. Traffic testing subjected the repairs to 150 F-4 load-cart passes to evaluate structural integrity.

The qualitative failure criteria for spall placement considered significant surface roughness (foaming, swelling, loose aggregate, or uneven finished surface) and weakness of cured material (spongy texture, non-uniform appearance). Distress such as excessive cracking, aggregate loosening or popouts, rocking, or sagging during trafficking indicated structural failure.

2. Test Description

a. Test Site Layout and Test Sections Description

Personnel tested the three material systems independently during September and October 1983 at SKY TEN.

The modified polyurethane concrete was tested on September 6, 1983, furfuryl alcohol polymer concrete was tested September 8, 1983, and magnesium polyphosphate cement concrete was tested on October 11, 1983. Test temperatures typically ranged from the mid 80's to 90°F.

Test personnel jackhammered 42 holes for the spall tests into the test bed at the SKY TEN facility, as shown in Figure 163, and stripped the asphalt off for spall tests in PCC pavement. Personnel formed five different types of spalls, in hemispherical and flat bottomed shapes, from 3 to 10 inches deep. The spall cross sections are presented in Figure 164.

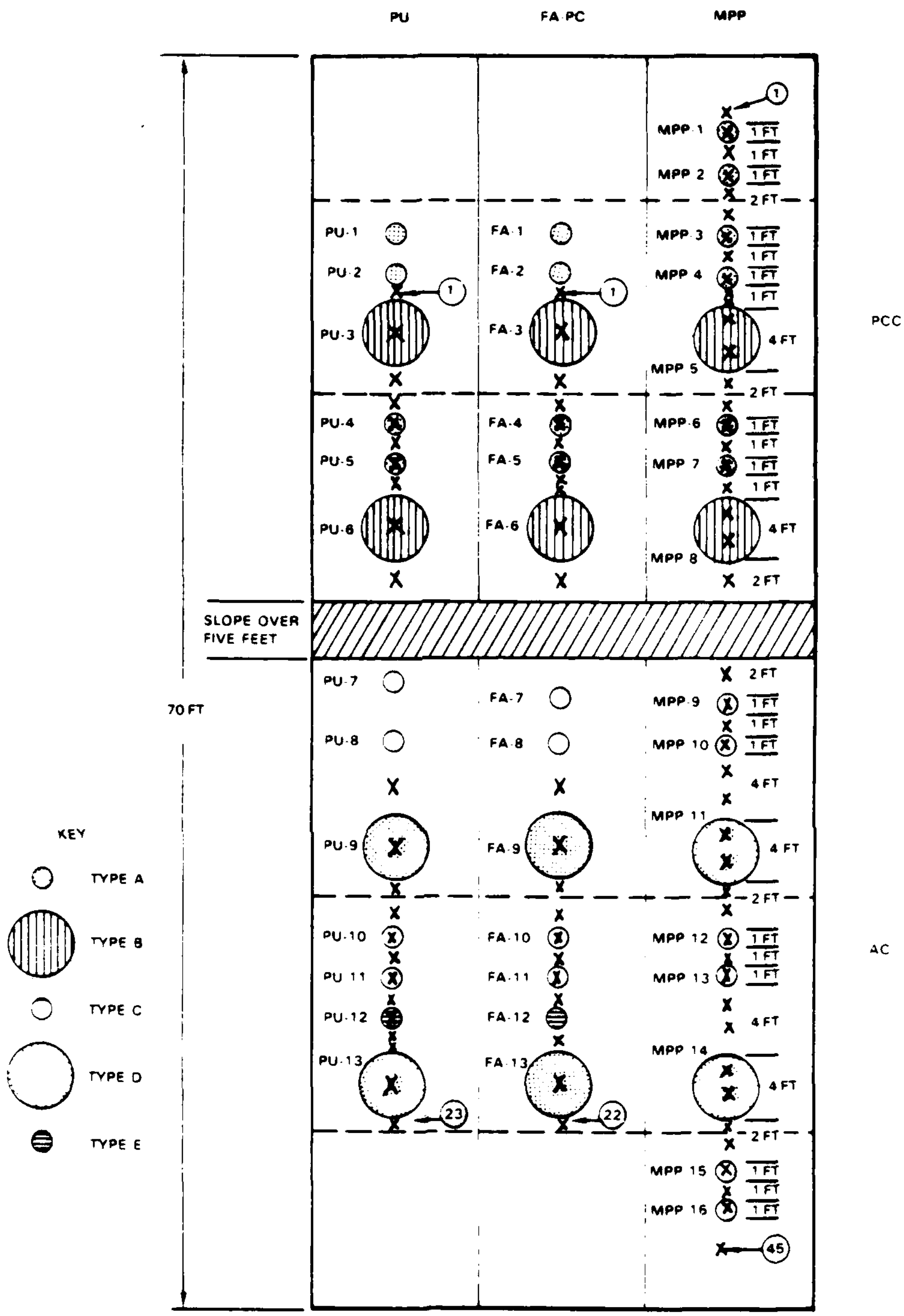


Figure 163. Plan View of Test Bed, Spall Repair with Advanced Materials.

Test personnel repaired the spalls with each material under three repair conditions. The repair conditions were:

- Dry Spall Sidewalls/Dry Aggregate,
- Wet Spall Sidewalls/Dry Aggregate, and
- Wet Spall Sidewalls/Wet Aggregate.

For each material, personnel first repaired the spalls in the PCC pavement, and dry spalls were repaired before wetting aggregate and sidewalls with buckets of water for the wet spalls.

b. Material Descriptions and Repair Procedures

Material quantities, in cubic feet, for each type of spall repair are indicated on Figure 164. Personnel repaired 13 spalls with modified polyurethane concrete, 13 with furfuryl alcohol polymer concrete, and 16 with magnesium polyphosphate cement concrete. Table 31 summarizes of the types of spalls repaired with each concrete system and the required total volume of repair material for each material system. The components and spall repair procedures for each material system are described below.

(1) Modified Polyurethane Concrete. The modified PU concrete system consists of a uniformly graded aggregate (pretreated with silane to improve concrete strength under wet conditions) and a two component (A and B) modified polyurethane binder. The "A" side component of the modified polyurethane binder is an isocyanate resin, and the "B" side component is a polyol resin. Equal volumes of components "A" and "B" are mixed together, giving a set-time of approximately 2 minutes. The temperature of components "A" and "B" used for this test was approximately 105°F.

Sixteen gallons (i.e. 1/3 drum) of components "A" and "B" and 12 ft^3 of silanated aggregate (ASTM Number 57) were required. Test personnel placed the aggregate in the spall prepared according to the test plan conditions (i.e. wet or dry spall walls with wet or dry aggregate) and leveled the stone with a screed. Personnel then withdrew the required batch quantities (see Appendix G) from each drum, blending and mixing by hand in buckets for 15 to 30 seconds before pouring the mixture over the preplaced aggregate prior to setting.

(2) Furfuryl Alcohol Polymer Concrete (FA-PC). The furfuryl alcohol polymer concrete system requires the materials listed in Table 32. The percent composition of the materials depends upon the ambient temperature but lies in the specified range. Physical properties of FA-PC components are described in Appendix H. For this test, test personnel used the mix shown in Table 33. The resulting polymer concrete density was approximately 152 lb/ft^3. The total weight required of each material was computed based on this density and a total repair volume of 12 ft^3 (includes 1-percent safety factor).

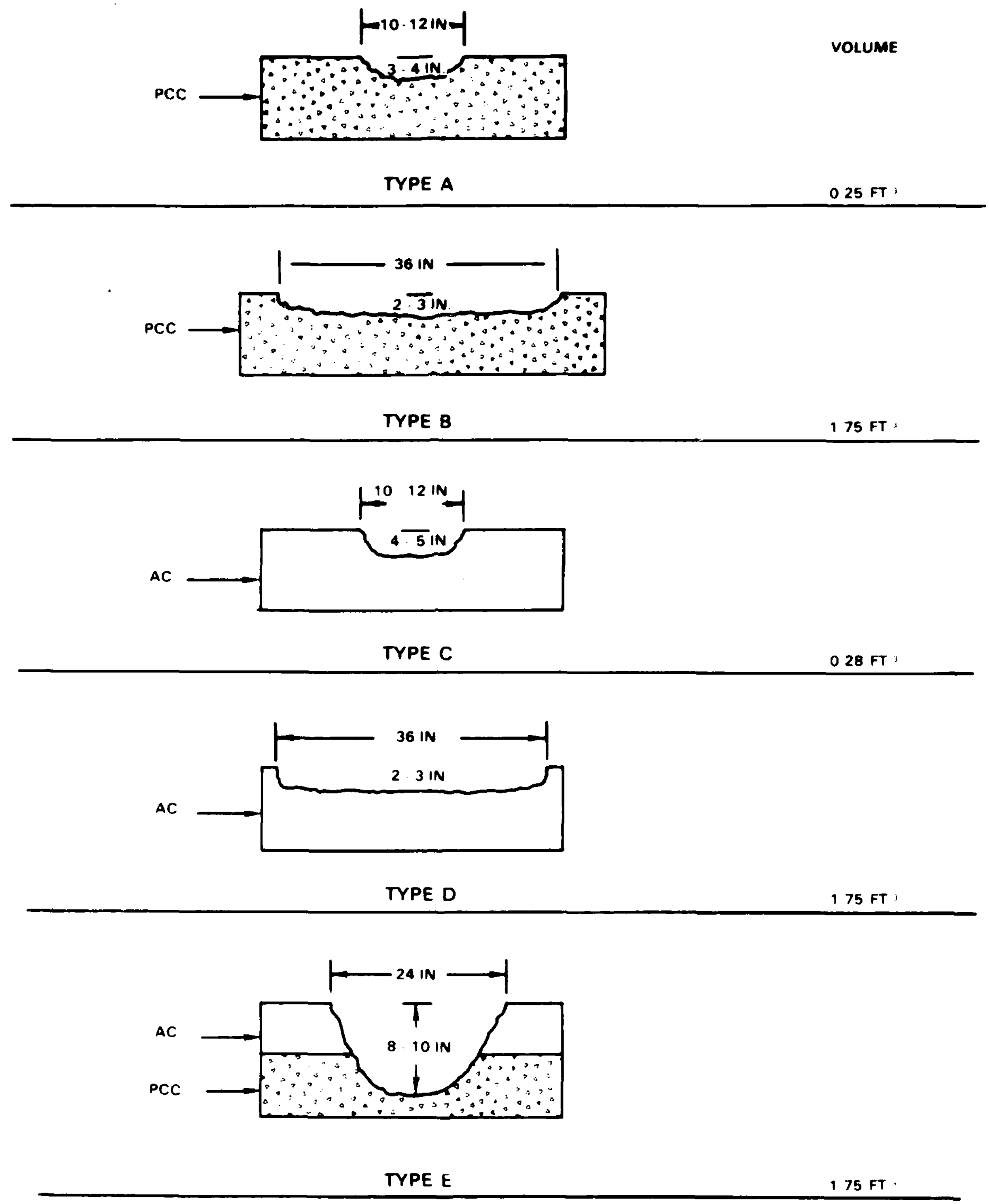


Figure 164. Cross Section of Spall Repairs, Spall Repair with Advanced Materials.

TABLE 31. SPALL REPAIR SUMMARY.

MATERIAL SYSTEM	SPALLS REPAIRED	VOLUME OF REPAIR MATERIAL (FT^3)
MODIFIED POLYURETHANE CONCRETE	4 TYPE A	4(0.25) = 1.0
AND	2 TYPE B	2(1.75) = 3.5
FURFURYL ALCOHOL POLYMER CONCRETE	4 TYPE C	4(0.28) = 1.12
TESTS	2 TYPE D	2(1.75) = 3.5
	1 TYPE E	1(1.75) = 1.75
	13 TOTAL	10.75
MAGNESIUM POLYPHOSPHATE CEMENT CONCRETE TESTS	6 TYPE A	6(0.25) = 1.50
	2 TYPE B	2(1.75) = 3.50
	6 TYPE C	6(0.28) = 1.68
	2 TYPE D	2(1.75) = 3.5
	16 TOTAL	10.00

TABLE 32. FA-PC COMPOSITION.

MATERIAL	PERCENT BY WEIGHT
MONOMER, FURFURYL ALCOHOL (FA)	7 - 12
INITIATOR, α, α, α, - TRICHLOROTOLUENE (TCT)	0.1 - 0.2
PROMOTOR, ZINC CHLORIDE ($ZnCl_2$)	4.5 - 7.5
RETARDER, PYRIDINE	0.06 - 0.12
COUPLING AGENTS, SILANE A-1120	0.07 - 0.12
AGGREGATE, SILICA	59 - 56
SILICA FLOUR	19 - 21

MIXER SEQUENCE:

1. Add course silica aggregate, fine silica aggregate, and zinc chloride to mixer; mix for 4 mintues.

2. Add silica flour and FA blend (FA, pyridine, TCT, silane) to mixer; mix for 3 more minutes.

TABLE 33. TEST FA-PC COMPOSITION.

MATERIAL	PERCENT BY WEIGHT	TOTAL MATERIAL REQUIRED (LB)
FA	9	170
TCT	1[a]	3.4
$ZnCl_2$	5.85	106
PYRIDINE	1.25[a]	2.12
SILANE A-1120	1.0[a]	1.7
COURSE SILICA GRAVEL	38.3	700
FINE SILICA AGGREGATE	25.6	466
SILICA FLOUR	21.3	388

[a]PERCENT BY WEIGHT OF FA.

Before the test, the FA and pyridine were preblended, as were the TCT and silane. Personnel combined these two mixtures in the FA drum during the test, forming a blend to mix with the remaining materials. Test personnel installed a valve in the bung of the FA drum and placed the drum on its side in an elevated position to allow easy pouring. Personnel added required batch quantities (Appendix G) of the materials to a 3 ft^3 concrete mixer in the order shown in Table 32 and mixed as indicated to prepare the FA-PC concrete. Personnel dispensed the self-leveling FA-PC mix into the spalls.

(3) Magnesium Polyphosphate Cement Concrete (MPP). This system consists of the following components:

- Cation (Leachable powder), Magnesium Oxide (MgO);
- Cement (Forming liquid), Ammonium polyphosphate (Poly-N);
- Activator, Monoammonium Phosphate (MAmP);
- Retarder, Disodium Octaborate Tetrahydrate (Poly-Bor); and
- Aggregate, Silica or limestone.

Properties of the components are shown in Appendix G, and the mix design for this test is specified in Table 34. The resulting concrete density was approximately 155 lb/ft^3, with a 7 to 8 minute working time. Test engineers calculated material requirements based on 11 ft^3 (including a safety factor) total repair volume. Percent compositions depend upon ambient temperature, as with FA-PC.

Test personnel prepared five batches, using the material quantities specified in Appendix G, by adding the components to the mixer in the following order: aggregate (coarse and sand), water, MAmP, Poly-N, Borax, and MgO Number 10. The test personnel then filled the spalls with the MPP concrete, which hardened in 15 to 25 minutes.

c. Traffic Testing

Test personnel trafficked the repaired sections with 150 F-4 loadcart passes. Data collectors measured elevation profiles after 0, 20, and 150 passes at the positions shown in Figure 163. Personnel did not perform spall repair maintenance.

TABLE 34. TEST MPP COMPOSITION.

MATERIAL	PERCENT BY WEIGHT REQUIRED	TOTAL MATERIAL REQUIRED (LB)
MgO Number 10	30	500
POLY-N	18	300
MAmP	30[a]	90
COARSE SILICA AGGREGATE	31.2	530
SAND	20.8	352
BORAX	12[a]	36
WATER	1 (DRY)	17
	4 (WET)	69

[a]PERCENT BY WEIGHT OF POLY-N.

3. Results

a. Modified Polyurethane Concrete

Test personnel prepared the modified polyurethane concrete and repaired the spalls as outlined in the test description. Two small asphalt spalls placed under dry conditions expanded approximately 1/2 inch after placement. Expansion in all other dry spalls was negligible. In some of the spalls placed under wet conditions, especially those in the asphalt pavement, detectable expansion occurred. In a few cases, the expansion resulted from excess water in addition to the required wetting of the spall walls poured in during placement of the saturated aggregate.

Test personnel traffic tested the spalls, collecting elevation data (presented in Table 35) as planned. All spalls survived the loadcart testing without distress or pavement bond failure, although some wet spalls experienced surface wear where expansion was apparent.

b. Furfuryl Alcohol Polymer Concrete

Test personnel prepared the first FA-PC batch as planned but modified the mix for subsequent batches when the material set up too quickly (approximately 1 minute). Technicians had already added TCT, so they reduced $ZnCL_2$ in the next batch from 11 pounds to 9 pounds and used 2 percent (1/2 gallon) water. Spalls repaired with this modified mix set slowly. Technicians prepared the third, fourth, and fifth batches to fill one large dry concrete spall and one large dry asphalt spall each and used 9.5 to 10 pounds of $ZnCl_2$ per batch and 0.25 gallons (1 percent by weight) of water.

The sixth, seventh, and eighth batches were "wet mixes" and included 3 percent water. The batch sizes, approximately one-half the size of batch Type II (Appendix G), contained 9.5 pounds $ZnCL_2$. The sixth batch filled one large concrete wet spall, the seventh batch filled one large and one small wet asphalt spall, and the eighth batch filled two small wet concrete spalls and one small, wet asphalt spall. Personnel filled the large concrete spall in several pours. After 7 minutes, a film appeared on the surface of the large concrete spall repair, and after 10 minutes the FA-PC was hard in the center but still soft around the edges. Personnel did not record the final hardening time. The wet asphalt spall repairs cured in 5 to 8 minutes. Personnel observed green bubbling in one of the small asphalt spalls, and extra bubbling and exotherm were noted as the two small wet, concrete spalls set. A final batch prepared with limestone coarse aggregate never cured.

In 7 of the 12 repairs, the furfuryl alcohol polymer concrete failed to bond to the pavement and broke into small fragments in two repairs. Spall FA-12, in the wet asphalt concrete, failed due to bad cracking and fracturing after the first loadcart pass, and spall FA-9 rocked on the first pass. Spall FA-6, in the wet concrete pavement, began

TABLE 35. ELEVATION MEASUREMENTS FOR MODIFIED POLYURETHANE TEST.

		ELEVATION (FT)		
MEASUREMENT LOCATION	SPALL CONDITION/ AGGREGATE CONDITION	AFTER 0 PASSES	AFTER 20 PASSES	AFTER 150 PASSES
1		4.81	4.82	4.83
2	DRY/DRY	4.55	4.57	4.59
3		4.69	4.69	4.68
4		4.37	4.36	4.37
5		3.33	3.32	3.32
6		4.36	4.37	4.38
7	WET/WET	3.46	3.46	3.57
8		4.48	4.49	4.51
9		3.52	3.58	3.61
10		4.65	4.67	4.67
11		5.57	5.56	5.65
12	DRY/DRY	4.85	4.86	4.86
13		4.79	4.86	4.94
14		4.50	4.54	4.62
15		3.81	3.86	3.91
16		4.34	4.39	4.47
17		3.18	3.17	3.26
18	WET/WET	4.17	4.22	4.45
19		2.21	2.23	2.26
20		3.94	3.97	4.12
21		3.93	3.97	3.98
22		3.34	3.23	3.26
23		4.21	4.26	4.29

rocking after the loadcart Pass 68, and spalls FA-4, FA-5, FA-8, and FA-12 rocked when trafficked with the remaining loadcart passes. Table 36 presents elevation data measured during the loadcart trafficking.

c. Magnesium Phosphate Polymer Concrete

The MPP test required 6.5 Type I (Appendix G) batches. Personnel mixed the first two batches as planned and used these for the dry aggregate/dry spall side walls repair condition. In the third through the sixth batches, personnel decreased the quantity of Borax was decreased and increased content Poly-N. The set-times for the spalls ranged from 15 to 25 minutes.

Loadcart testing was conducted over 2 days. Sixty loadcart passes were completed on October 11, 1983, and the remaining 90 passes were applied on October 26, 1983, a much cooler day. The temperature difference between the two dates was about 25 °F and may have affected the metal ruler, probe, and beam used to obtain the elevation data (presented in Table 37).

After 60 loadcart passes, data collectors did not observe any cracking or edge separation in the spalls. After 150 loadcart passes, personnel noted only two hairline fractures along the seam of spall MPP-5.

4. Conclusions

The *modified polyurethane* concrete and magnesium polyphosphate cement concrete repairs withstood 150 F-4 loadcart passes. Magnesium polyphosphate, however, is less feasible as a crater repair material because of the significant mix alterations for different ambient temperature ranges. Spalls repaired with furfuryl alcohol polymer concrete rocked during loadcart trafficking and, in several cases cracked and fractured before 150 F-4 loadcart passes had been completed. Modified polyurethane performed best of the three advanced material concrete systems tested for use in spall repairs.

The tests also indicated that expansion in asphalt concrete pavement spalls was greater than Portland Cement Concrete spalls, and was most severe in wet spalls.

C. MULTIPLE SPALL REPAIR TEST

1. Purpose

This test determined the time required for a Prime Beef spall repair team to patch 51 spalls with Silikal® polymer concrete, and evaluated the amount of interference on the spall repairs from FOD clearance operations. The observed repair time also provides a baseline for comparing other spall repair techniques.

TABLE 36. ELEVATION MEASUREMENTS FOR FURFURYL ALCOHOL.

POLYMER CONCRETE TEST

MEASUREMENT LOCATION	SPALL CONDITION/ AGGREGATE CONDITION	ELEVATION (FT) AFTER 0 PASSES	AFTER 20 PASSES	AFTER 150 PASSES
1		4.84	4.84	4.82
2	DRY/DRY	4.72	4.69	4.73
3		4.46	4.46	4.42
4		4.31	4.30	4.20
5		4.41	4.23	4.22
6		4.35	4.36	4.33
7	WET/WET	4.11	4.16	4.15
8		4.40	4.42	4.40
9		4.46	4.46	4.47
10		4.59	4.75	4.80
11		4.68	4.71	4.68
12		5.46	5.60	5.76
13	DRY/DRY	5.25	5.29	5.33
14		5.11	5.28	5.41
15		5.07	5.16	5.25
16		5.08	5.21	5.26
17	WET/WET	5.04	5.10	5.17
18		4.72	4.87	4.82
19		4.90	5.04	5.09
20		4.42	4.46	4.43
21		4.03	4.21	4.13
22		4.39	4.46	4.43

TABLE 37. ELEVATION MEASUREMENTS FOR MAGNESIUM.

POLYPHOSPHATE TEST

MEASUREMENT LOCATION	SPALL CONDITION/ AGGREGATE CONDITION	ELEVATION (FT) AFTER 0 PASSES	AFTER 20 PASSES	AFTER 150 PASSES
1		4.90	4.90	4.90
2		4.48	4.50	4.47
3	WET/DRY	4.50	4.51	4.48
4		4.40	4.41	4.38
5		4.43	4.46	4.40
6		4.43	4.43	4.43
7		4.52	4.52	4.51
8		4.46	4.45	4.44
9		4.59	4.57	4.62
10	WET/WET	4.53	4.54	4.53
11		4.68	4.67	4.64
12		5.34	5.33	5.32
13		5.47	5.56	5.51
14		4.92	4.94	4.87
15		5.18	5.19	5.18
16		5.43	5.43	5.40
17		4.25	4.26	4.22
18	DRY/DRY	4.38	4.41	4.35
19		4.51	4.54	4.44
20		4.97	4.98	4.95
21		5.15	5.16	5.13
22		5.33	5.44	5.46

TABLE 37. ELEVATION MEASUREMENTS FOR MAGNESIUM (CONCLUDED).

POLYPHOSPHATE TEST

MEASUREMENT LOCATION	SPALL CONDITION/ AGGREGATE CONDITION	ELEVATION (FT) AFTER 0 PASSES	AFTER 20 PASSES	AFTER 150 PASSES
23		5.04	5.06	5.08
24		5.03	5.07	5.09
25		4.96	4.98	5.01
26	WET/WET	4.97	5.03	5.03
27		4.89	4.96	4.92
28		4.78	4.83	4.81
29		5.11	5.10	5.07
30		5.14	5.17	5.13
31		5.04	5.01	5.00
32		5.25	5.23	5.21
33		5.33	5.33	5.31
34		5.32	5.33	5.31
35	DRY/DRY	5.41	5.43	5.41
36		5.34	5.36	5.37
37		3.68	3.72	3.73
38		3.57	3.60	3.58
39		3.65	3.69	3.67
40		3.52	3.48	3.51
41		3.66	3.62	3.68
42		3.75	3.79	3.81
43	WET/DRY	3.91	3.90	3.92
44		4.22	4.30	4.31
45		5.05	5.04	5.14

a. Test Description

Personnel conducted the test on September 24, 1983, on the east taxiway of Field 4 at Eglin AFB. The east taxiway is an asphalt pavement surface from 3 to 5 inches in thickness on a sandy soil base course. Technicians used jackhammers to form spalls in the pavement and simulate an area of extensive spall damage. Since the pavement was so thin, technicians penetrated the base course for approximately one-half of the spalls to more realistically simulate actual spall formation.

To simulate debris present in an area of extensive spall damage, personnel broke the asphalt removed from the spalls into small chunks. Laborers spread the pieces over the test area distributing ballast rock by a dump truck using hand shovels.

b. Equipment and Personnel

(1) Equipment. A John Deere 570 motor grader with an installed hardening kit performed all grading operations. The grader's window armor was not in place during the test. The two spall repair teams used one 3/4-ton pickup truck each. One team pickup truck towed a 1-ton utility trailer. The sweeping team used a John Deere 301 farm tractor with towed rotary broom. The sweeper controls were not operable from the tractor.

(2) Personnel. The grading team consisted of one equipment operator. The spall repair teams included four men total, two men per team. The sweeping team consisted of two men, one to drive the tractor and the other to operate the sweeper controls. The grader and sweeper operators and two spall repair team members were experienced civil engineering personnel. All other personnel were "war-skillers" or emergency augmentees.

All personnel trained in the preparation of Silikal® and practiced the test procedures before the test. Further, all test personnel wore respirators to protect against harmful vapors while mixing Silikal® and to simulate communication difficulties arising from a chemical warfare ensemble.

c. Testing

The grading team, spall repair team, and sweeping team worked simultaneously and independently during the test. The overall order of team progression through the spall field was the grading team, the spall repair team, and the sweeping team.

(1) Grading. The grader and all other equipment and personnel moved from the staging area on the beginning signal to the test site. The grader cleared debris by making high-speed passes over the test site following the pattern shown in Figure 165. A grader pass traverses the test site once from end to end.

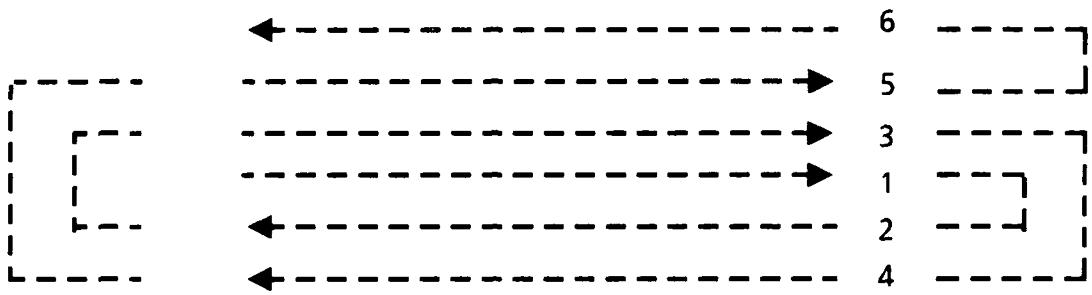


Figure 165. Pattern of Grader Passes During Multiple Spall Repair Test.

(2) Spall Repair. Before the test started, team personnel loaded the spall repair pickup trucks with Silikal® R17/AF components and tools. The Silikal® components consisted of bags of Silikal® powder, packets of benzoyl peroxide (BPO) catalyst, sandbags of crushed stone to extend the Silikal® 100 percent, and 5-gallon cans of liquid hardener. Tools in each truck included a rake, a broom, two shovels, a 2-inch by 4-inch by 5-feet wood screed, a can opener, tape, eye wash, and a garbage barrel. After the spall repair teams exhausted their Silikal® component supply, they returned to the stockpile area to reload their trucks. No other personnel or equipment assisted in the reloading process.

As soon as the grader began debris clearance, the spall repair teams began repair operations. Spall repair began in the area cleared by the grader's first pass and continued as the two spall repair team pickup trucks progressed in parallel down the taxiway and repaired 51 spalls according to the procedures outlined below. The team conducted steps simultaneously in areas of grouped spalls. For example, personnel cleared debris from several spalls in a group before filling any spalls with Silikal®.

The test plan called for repair with Silikal® R7/AF, which is the type of Silikal® stocked at U.S. airbases in Europe. No R7/AF was available for the test, so R17/AF was used instead. R17/AF differs from R7/AF in that R17/AF has premixed benzoyl peroxide catalyst (BPO) and grey powder while R7/AF has separately packaged BPO and grey powder. During the tests, team members added 230 grams of additional BPO to each bag of R17/AF, replicating mixing procedures for R7/AF, because personnel observed unusually slow cure times for batches of R17/AF mixed prior to the test.

The general procedure used for repairing the spalls in this test is described below. One team member cleared out the spall with a shovel or rake, and then swept away loose sand with a broom. The other team member added the bag of 230 grams additional BPO to the gray Silikal® powder and mixed these components for 5 to 6 seconds before adding a sandbag of crushed stone aggregate to the bag. The first team member filled a 2-liter measuring cup from the 5-gallon can of Silikal® liquid hardener (methyl methacrylate) and poured the liquid hardener into the aggregate and powder bag, while his partner mixed and poured the mixture into the spall. After filling the spall, a team member screeded the top with a 5-foot board. Personnel scooped up the screeded material in a shovel for disposal.

(3) Sweeping. The sweeper cleared debris missed by the grader and tossed out of the spalls onto the taxiway by the spall repair teams, beginning when the spall repair teams had reached the halfway point of the test area. A second person was detailed to assist with raising, lowering, and turning the broom since the sweeper controls did not extend to the tractor operator's seat.

The sweeper followed an "expanding racetrack" type of pattern, similar to the grader pattern, to minimize stopping, raising, lowering, and turning the broom. The sweeper made 60 passes of distances ranging from 10 feet to over 100 feet long in the test area. The sweeper stayed at least 100 feet from the spall repair crews to avoid traversing repaired spalls before they had time to harden.

d. Data Collection

AFESC/RDCR and BDM personnel recorded the test activities. Two video camera operators filmed repair operations from the bed of a 5-ton truck and from ground level.

2. Results and Observations

a. Grading

The grader left no debris directly behind the blade during the clearing operation, but scraped much debris off the pavement into the spalls. On Passes 3 and 5, some debris also spilled from the blade into the cleared area. A 5-inch wide, approximately 30-foot long row of ballast rock formed on Pass 3, and, on Pass 5, several rocks spilled out randomly.

The grader created a problem for the spall repair team by pushing debris into the spalls. Spall repair procedures required removal of debris that was above 6 inches below the pavement surface. In the large spalls, debris removal was a significant and taxing activity for spall repair team members. Where there were groups of small spalls, laborers unintentionally scraped debris removed from one spall into another.

The spall repair team also interfered with the grader by beginning repair operations before a sufficient area had been cleared. During Passes 2, 3, 4, and 5, the spall repair equipment and personnel were too close to the grader, causing the grader to slow down until clear of the spall repair team.

Clearance times for each pass are shown in Table 38, along with grader turnaround time. At the turnaround points, the taxiway was 43 feet wide, but the grader required the full 50-foot width of the MOS to turn around. This may have placed the grader closer to unexploded ordnance than anticipated.

The grading pattern was well-suited for clearing the area without building up a large pile of debris in front of the grader. On Passes 3 and 5, the grader pushed debris approximately 30 feet beyond the edge of the debris field before starting to turn.

The respirator did not cause any communication or visibility problems for the grader operator.

TABLE 38. GRADER DATA.

PASS NUMBER	CLEARANCE TIME (SECONDS)	TURNAROUND TIME (SECONDS)	CLEARANCE WIDTH (FEET)
1	34	40	9
2	46	48	9
3	61	43	10
4	57	32	5
5	53	45	8
6	69	-	2

TOTAL GRADER OPERATION TIME: 527 SECONDS
8.78 MINUTES

LENGTH OF DEBRIS FIELD: 379 FEET

b. Spall Repair

The times that the spall repair teams were operating, including reload time, were on the critical path. Spall repair team members manually reloaded each truck during the test. Reloading was time-consuming, requiring 19 minutes for Truck 1 (with trailer) and 16 minutes for Truck 2, and prevented the repair team members from having any breaks.

With additional BPO added, the R17/AF Silikal® mix required 15 to 30 minutes to harden sufficiently for vehicle loadings. The last 12 spalls were repaired without additional BPO added to the Silikal® R17/AF, and a "time-out" period was called to permit the spalls to harden before the sweeper completed FOD clearance operations. After team personnel repaired 39 of the 51 spalls, the supply of additional BPO was exhausted. Team members completed the last spall repair 2 hours and 55 minutes after repairs began. With the 26-minute "time out", effective baseline repair time, including final sweeping, was 3 hours and 12 minutes.

Table 39 details the times required to repair each of the spalls or a group of small spalls and the dimensions and volume of each spall. Large spalls, 5 feet in diameter, required about 20 bags of Silikal® and an average time of 22 minutes to complete the repair. The small spalls, 18 inches in diameter, averaged between 2 to 5 minutes to repair and required approximately 1.5 bags of Silikal®. On the average, team personnel repaired the closely grouped spalls more quickly, than the solitary spalls. Specific observations made during the repairs are discussed below:

- Inspection of the spalls immediately after repair and several hours after the test revealed 17 spalls where the Silikal® had not hardened. The unhardened Silikal® resulted from improper mixing rather than material defects. Despite training and instruction in the test description to mix each bag of Silikal® for 45 to 60 seconds, the maximum mixing time per bag observed during the test was 15 seconds.

- Mixing for only 15 seconds, the team member agitating the bag had no difficulty keeping pace with the team member preparing the bag. However, if the team member mixes the bag for 1 minute, as required, he likely will fall behind the preparer, suggesting an inefficiency in the spall repair team configuration of two men per pickup truck. A proposed spall repair team composition addressing this is described in Subsection D.

- The spall repair team members were careless. First, three of the four repair personnel lacked proper equipment when the test started. Second, in several locations, personnel left material screeded off the spalls on the pavement rather than disposing the excess properly. The sweeper broom did not remove this excess material, although it was often broken off with hand pressure. These pieces could have been kicked up by vehicles or aircraft traffic and caused FOD damage. Also, personnel did not clean the two-by-four screeds after each use and hardened Silikal®

TABLE 39. SPALL DETAILS.

Spall Number	Depth (inches)	Diameter (inches)	Bottom of Spall	Spall Volume (cubic feet)	Repair Time [a] (minutes)
1	7	59	sand	9.15	29
2	6	19	asphalt	.56	
3	5	18	asphalt	.41	5
4	6	18	sand	.51	
5	6	20	sand	.61	5
6	5	18	asphalt	.41	
7	6	19	sand	.56	
8	4	21	asphalt	.42	22
9	4	20	asphalt	.38	
10	5	19	sand	.45	
11	5	63	sand	7.50	31
12	6	17	sand	.46	
13	7	18	sand	.62	
14	4	20	asphalt	.38	17
15	7	19	dirt	.68	
16	5	19	asphalt	.45	
17	3	18	asphalt	.23	
18	8	62	dirt	11.69	33
19	3	17	asphalt	.21	
20	4	18	asphalt	.31	8
21	5	19	dirt	.45	
22	6	61	dirt	8.41	37
23	5	21	dirt	.54	5

[a] Does not include cure time

*7-1-MCL3-000057-057

TABLE 39. SPALL DETAILS (CONTINUED).

Spall Number	Depth (inches)	Diameter (inches)	Bottom of Spall	Spall Volume (cubic feet)	Repair Time [a] (minutes)
24	3	18	asphalt	.23	
25	8	19	sand	.81	10
26	6	20	sand	.61	
27	4	18	asphalt	.31	
28	3	19	asphalt	.25	
29	5	18	sand	.41	7
30	4	18	asphalt	.31	
31	5	18	asphalt	.41	8
32	4	18	asphalt	.31	
33	7	23	sand	.95	
34	7	19	sand	.68	7
35	5	19	asphalt	.45	
36	3	17	asphalt	.21	
37	6	19	sand	.56	
38	6	20	sand	.61	8
39	5	18	asphalt	.41	
40	6	60	sand	8.12	29
41	5	20	sand	.49	
42	5	19	sand	.45	
43	4	19	asphalt	.35	10
44	5	18	sand	.41	
45	6	18	sand	.51	

[a] Does not include cure time

*7-1-MCL3-000057-058

TABLE 39. SPALL DETAILS (CONCLUDED).

Spall Number	Depth (inches)	Diameter (inches)	Bottom of Spall	Spall Volume (cubic feet)	Repair Time [a] (minutes)
46	6	18	sand	.51	
47	6	18	sand	.51	
48	6	19	sand	.56	
49	6	19	sand	.56	11
50	6	19	sand	.56	
51	8	24	sand	1.20	5

[a] Does not include cure time

TOTAL VOLUME OF REPAIR MATERIAL: 67.14 cubic feet
2.48 cubic yards

AVERAGE LARGE SPALL VOLUME: 8.97 cubic feet
.33 cubic yards

AVERAGE SMALL SPALL VOLUME: .48 cubic feet
.017 cubic yards

NUMBER OF SILIKAL® BAGS USED: 180 bags

*7-1-MCL3-000057-059

accumulated on the bottoms of the boards. Consequently, the screeds did not level the spalls but formed shallow depressions, ranging from 0.5 inches to 1 inch deep. Since the depressions were not any greater than 1 inch, there was no surface roughness problem.

c. Sweeping

The sweeper, which was not on the critical path for this test, could remove all debris with one pass except where spall repair crews had piled debris from large spalls on adjacent pavement. In those cases, the sweeper required two or three passes to clear the pile. The sweeper easily removed debris from small spalls.

There was a major interference problem between the spall repair and sweeping operations. Sweeping operations were scheduled to wait until the spall repair crew had reached the halfway point on the taxiway to avoid traversing unhardened spalls were never to approach closer than 100 feet to the spall repair crew. In several instances, though, the sweeper came very close to the spall repair crews, once within 8 feet. Consequently, the sweeper ran over several unhardened spalls causing severe rutting. These spalls require maintenance, which was conducted to meet surface roughness criteria after the test ended.

The second sweeping team member, detailed for raising, lowering, and turning the sweeper broom was superfluous. Safety precautions restricted him from riding on the broom or tractor. He had to run alongside the sweeper.

3. Conclusions

Based upon the results discussed in the previous section, the following conclusions and recommendations are made.

- The overall repair time recorded in this test does not reflect certain wartime factors. First, the teams did not wear the chemical ensembles that would be required in most repair scenarios. Second, the weather during the test was mild. More extreme temperatures would increase fatigue, especially in full or partial chemical ensembles. Third, there was no attrition of the team members. Because the team members are in the open during almost the entire repair operation, there is a high probability that exploding munitions would injure or incapacitate some of the crew. Fourth, the towing vehicles will probably be unarmored, making them vulnerable to shrapnel as well. Fifth, the test crews only mixed the components for one-fourth the required time. Factoring in just the proper mixing time would have extended the repair time from 3 hours and 12 minutes to approximately 5 hours and 7 minutes. For these reasons, the time recorded for this test is much less than would occur in many wartime scenarios.

- The NCOIC must closely monitor repair activities to ensure that all personnel are properly equipped, that all team members stop to drink water approximately every 45 minutes in high temperatures to prevent premature fatigue, that all repair equipment is retrieved when the test area is left to preclude FOD, and that all spalls are filled.

- Operate the grader at high speed when making passes to clear debris from the spall field. Set the blade on "float" during the clearance operation. The spall site by making the first pass 10 to 12 feet off-center of the MOS and moving toward one edge, changing the blade angle for each pass. After reaching the edge of the MOS, return to the center and clear towards the opposite side. Although FOD clearance requirements state that an additional 18 feet will be cleared on each side of the MOS, the first priority in spall-damaged areas is clearing the area where spall repair operations must be conducted. After the spall area is cleared, additional passes by the grader can be made to meet FOD clearance requirements.

- To facilitate truck reloading, store the Silikal® components and aggregate bags on standard wooden pallets,covered with a tarpaulin. Attach wooden sideboards to the pallets to prevent material spillage. When the Silikal® components are needed, remove the tarpaulin and use a forklift to load one pallet onto the bed of a pickup truck and two pallets onto an airdrome utility trailer. For manning purposes, no dedicated forklift operator would be required if one person on each spall repair team operated a forklift. As part of the initial base recovery procedures, position a forklift (from any source on base, such as the base transportation squadron) near the Silikal® stockpile.

- Stock bags of Silikal® powder, packets of BPO, bags of crushed stone aggregate, and 2-liter cans of liquid hardener on each pallet. Use the 2-liter cans to eliminate pouring liquid hardener from a 5-gallon can to a 2-liter measuring cup. Store one 30-gallon garbage barrel for each three pallets, but not placed on a pallet. When reloading, place the barrel in the pickup truck.

- Include actual mixing of Silikal® in bags in spall repair team training. Particularly emphasize the proper time for mixing the components. (In current training procedures, the trainees do not mix Silikal® components, but observe the instructors mixing the components.) Emphasize also the collection of all equipment, removal of any loose Silikal®, and immediate disposal of the empty bags in garbage barrels. The grader clearance operations did not significantly hinder the spall repair teams; thus, instruct the spall repair crews to begin repairing spalls as soon as the grader begins clearing the spall field.

- Restructure the spall repair team to improve the overall repair capability. With the same four-man team, task the first person with clearing spalls, for which the procedure and equipment is described in the following paragraph. Assign the other three members to use a 3/4-ton pickup towing an airdrome utility trailer, with one pallet of Silikal® materials in the back of the pickup truck and two pallets on the trailer.

The three men would mix the Silikal® and place it in the spall. One person would combine the components, while the other two agitate the bags and pour them into the spall. At half-hour intervals, the crew members would switch positions evenly distribute the more fatiguing jobs.

- Include an air compressor for each spall repair team to clear debris from the spall. The air compressor would speed debris, mud, and water removal from the spall, and should be used in all spall repair procedures. The compressor would be towed from a pintle hook by the team's second pickup truck, driven by the first person in the spall team. The driver would perform all necessary clearing operations and, when finished, would park the truck off of the MOS and assist the other spall repair team members with mixing Silikal®.

- Establish the following pattern for repairing extensive areas of spall damage on a MOS. The pickup truck towing the air compressor would move down the spall field about 6 feet from the edge of the MOS. Upon reaching the end of the spall field, the truck would turn around and proceed back down the MOS toward the beginning point in a line offset 16 feet from the first pass. The next pickup truck, towing the trailer with Silikal® pallets, would enter the spall field about 6 feet from the edge of the MOS. Spalls would be repaired directly behind the trailer and 6 feet to both sides. After completing the first pass, the second pass should be made in the opposite direction, approximately 16 feet offset from the first pass. These patterns would permit other traffic through the spall field, reduce the number of times the truck must turn around and allow the placed Silikal® to harden before encountering vehicular traffic.

- Include more than one operator in the sweeping crew.

- Connect the sweeper controls to the tractor to allow the operator to raise, lower, and turn the broom without leaving the cab. Identified or develop the necessary equipment and install on all towed sweepers.

- Allow the sweeper to approach no closer than 100 feet to the rear of the spall repair crew.

- Fit all rotary sweepers with a rubber shroud in front of the broom so the broom does not kick up debris and create a dust cloud.

- To coordinate sweeping with the new spall repair pattern (making passes up and down the MOS), do not allow the sweeper to clear areas on the half of the MOS where spall repair operations start until the spall repair team crosses the MOS centerline. This will permit the Silikal® to harden sufficiently to accept the weight of the sweeper.

- Make the first pass of the sweeper down the edge of the MOS and progress towards the opposite edge of the MOS, with the changing the angle of the broom every other pass. This pattern maintains an open pathway for other crater repair vehicles and prevents the sweeper from running over unhardened spalls, while reducing the lag time between spall repair and sweeping operations. As with the grader, use the sweeper to clear debris an additional 18 feet outside each edge side of the MOS. The first priority is still to clear the MOS. However, during periods when the Silikal® is drying and when the spall teams are moving down the first side of the MOS, the sweeper can make passes outside of the MOS to meet FOD clearance requirements.

- The recommended grader, spall repair, and sweeping patterns are intended to be used in areas containing only spalls. In areas where both spalls and craters are present, the repetitive passes would be modified to accommodate the crater repair operations. Also, the spall debris would be expected to be mostly soil. The sequence of operations (grader, spall repair, sweeper) would remain the same in spall and spall/crater areas, but further testing is required to determine the most effective spall repair procedures when spalls and craters are intermingled.

D. CONCLUSIONS

The use of advanced concrete material systems is feasible for spall repair as long as the material system does not require numerous components to be mixed together or ranges in percentages of components according to ambient temperature. Both the furfuryl alcohol polymer concrete and magnesium polyphosphate cement concrete mixes consist of several components, and the mix formulas are temperature dependent. These mixes are not feasible in a wartime environment because of formula alterations for different ambient temperature ranges and long mix times (approximately 7 minutes, compared to 15 to 30 seconds mix time for modified polymer concrete). Thus, future research should concentrate on developing advanced systems that require field mixing of only a few components not dependent on ambient temperature.

The multiple-spall repair test suggested several inefficiencies with the repair teams and procedures. The test also indicated the need for improved training procedures and increased emphasis on the correct implementation of repair procedures.

SECTION VIII

OVERALL CONCLUSIONS AND RECOMMENDATIONS

This report documents several tests relating to Bomb Damage Repair methods. Included are tests for compaction of aggregate, fiberglass mats, and precast slabs for crater repairs and tests of various rapid-setting materials for spall repairs. Specific conclusions from each test and recommendations for further testing are provided in each section. Following are the general results and conclusions for each area tested.

A. PRECAST SLAB TESTS

The tests indicated that precast slabs over ballast rock with a leveling aggregate course are capable of supporting criteria traffic loads, requiring only one maintenance during 156 F-4 or F-15 loadcart coverages. Early settlement and rocking can be reduced by refining placement procedures and optimizing leveling and joint filler materials.

Joint spacing between slabs should be minimized to reduce the potential for lateral movement, but slab contact should be prevented to avoid edge damage. Dry sand was not effective as a joint filler as it was rapidly lost under the slabs into the underlying aggregate layer.

Early base deformation, differential settlement, and rocking during trafficking can be reduced by compacting the aggregate layers prior to placing the slabs. However, care must be used to prevent the need for early maintenance of the repair. It is therefore recommended that compaction be accomplished on the leveling course (which can quickly be adjusted to achieve grade) rather than on top of the slabs.

B. COMPACTION TESTS

Both the vibratory roller and the excavator-mounted compactor plate can be used to compact crushed stone/ballast rock for crater repairs. The vibratory roller provides a faster compaction rate and better compaction in the top layer of the repair section, while the compactor plate may provide better compaction throughout the depth of the repair.

The current practice of compacting crushed stone/ballast rock repairs with 3 to 10 vibratory roller coverages or one to two compactor plate passes is adequate.

C. FIBERGLASS MAT TESTS

The fiberglass mat over ballast rock choked with crushed stone is a feasible repair concept for use in wet, rainy conditions, and the hardened multipurpose excavator is useful in constructing the repair.

The tests indicated the 2-ply PU mats are adequate for F-15 traffic, supporting 156 F-15 loadcart coverages with only one interruption for base course maintenance.

Both Ashland and ARNCO polyurethane can be used for fabricating fiberglass mats.

D. SPALL REPAIR TESTS

Furfuryl polymer concrete (FA-PC) and magnesium polyphosphate cement concrete (MPP) are not effective for repairing spalls because their mixes are temperature dependent and have to be altered for different ranges in ambient temperature. In addition, FA-PC repaired spalls were unable to support simulated traffic loading.

Modified PU concrete PU proved to be the best of the advanced material concrete systems tested. The PU mix is not temperature dependent, and spall repairs in both PCC and AC pavements withstood 150 F-4 loadcart passes.

The repair procedures for multiple spalls need to be improved. Modifications to procedures have been proposed to more efficiently repair multiple spalls. Also, there is a need to better train spall repair teams, with emphasis on adhering to recommended procedures.

APPENDIX A

CYCLE TIME MEASUREMENT DURING PRECAST SLAB TEST 2

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APPENDIX A

SLAB PLACEMENT TIMES - TEST 2

May 17, 1983

Start	10:08	Slab 1	12 min.
		2	8 min.
		3	8 min.
		4	8 min.
		5	7 min.
		6	9 min.
		7	7 min.
		8	7 min.

FINISH 11:13

Slab 9 not timed

NOTE: Travel time to slabs 2 min.
Travel with slab to pit 2 1/2 min.
Total travel time per slab 4 1/2 min.

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APPENDIX B
DATA FROM EXCAVATOR COMPACTOR EVALUATION

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TABLE B-1. ROLLER LANE DRY DENSITIES (LB/FT^3) - TEST 1, EXCAVATOR COMPACTOR EVALUATION.

MEASURED AFTER	LOCATION NUMBER	AFTER COMPACTION	AFTER PLATE COMPACTION LANES 1 & 3	AFTER PLATE COMPACTION LANES 2 & 4
PRE-COMPACTION	1	110.3	-	-
	2	124.8	-	-
	3	121.4	-	-
	MEAN	118.8	-	-
	σn	7.58	-	-
2 ROLLER COVERAGES	1	124.9	-	-
	2	125.7	-	-
	3	125.5	-	-
	MEAN	125.4	-	-
	σn	0.42	-	-
4 ROLLER COVERAGES, 1 PLATE PASS	4	136.4	135.0	138.7
	5	128.7	126.0	129.8
	6	133.7	130.1	136.6
	7	125.9	117.8	121.2
	8	132.5	131.0	133.2
	9	126.4	125.6	129.7
	MEAN	130.6	127.6	131.5
	σn	4.25	5.92	6.21
6 ROLLER COVERAGES	1	133.1	-	-
	2	135.3	-	-
	3	134.5	-	-
	MEAN	134.3	-	-
	σn	1.11	-	-
8 ROLLER COVERAGES, 2 PLATE PASSES	4	137.5	133.4	125.6
	5	133.3	129.4	-
	6	136.8	130.3	131.8
	7	128.1	127.8	129.7
	8	128.2	121.9	-
	9	122.4	142.1	126.5
	MEAN	131.1	130.8	128.4
	σn	5.85	6.71	2.86

TABLE B-1. ROLLER LANE DRY DENSITIES (LB/FT^3) - TEST 1, EXCAVATOR COMPACTOR EVALUATION (CONCLUDED).

MEASURED AFTER	LOCATION NUMBER	AFTER COMPACTION	AFTER PLATE COMPACTION LANES 1 & 3	AFTER PLATE COMPACTION LANES 2 & 4
10 ROLLER COVERAGES	1	128.4	-	-
	2	138.8	-	-
	3	140.9	-	-
	MEAN	136.0	-	-
	σn	6.69	-	-
12 ROLLER COVERAGES, 3 PLATE PASSES	4	140.8	141.3	136.7
	5	135.6	136.7	-
	6	120.9	132.2	136.8
	7	129.8	123.7	133.7
	8	121.9	131.8	-
	9	125.4	139.2	132.6
	MEAN	129.1	134.2	135.0
	σn	7.90	6.35	2.12

TABLE B-2. COMPACTOR PLATE LANES 1 AND 2 DRY DENSITIES (LB/FT^3) - TEST 1, EXCAVATOR COMPACTOR EVALUATION.

MEASURED AFTER	LOCATION NUMBER	AFTER COMPACTION	AFTER PLATE COMPACTION OVER LANES 3 AND 4	AFTER ROLLER COMPACTION OVER NEXT LANE	LOCATION NUMBER	AFTER COMPACTION	AFTER PLATE COMPACTION OVER LANES 3 AND 4	AFTER ROLLER COMPACTION OVER NEXT LANE
4 ROLLER COVERAGES, 1 PLATE PASS	10	130.4	129.5	-	14	-	-	-
	11	128.0	-	125.7	15	-	-	-
	12	125.8	-	124.1	16	-	-	-
	13	117.4	114.0	-	17	-	-	-
	MEAN	125.4	121.8	124.9	MEAN	-	-	-
	σn	5.65	N/A	N/A	σn	-	-	-
8 ROLLER COVERAGES, 2 PLATE PASSES	10	112.6	117.2	-	14	-	-	-
	11	120.6	-	109.9	15	-	-	-
	12	115.1	-	122.6	16	-	-	-
	13	129.7	126.5	-	17	-	-	-
	MEAN	119.5	121.9	116.3	MEAN	-	-	-
	σn	7.58	N/A	N/A	σn	-	-	-
12 ROLLER COVERAGES, 3 PLATE PASSES	10	121.7	116.9	-	14	-	-	-
	11	117.3	-	-	15	-	-	-
	12	120.4	-	-	16	-	-	-
	13	119.2	116.8	-	17	-	-	-
	MEAN	119.7	116.9	-	MEAN	-	-	-
	σn	1.87	N/A	-	σn	-	-	-

TABLE B-3. COMPACTOR LANES 3 AND 4 DRY DENSITIES (LB/FT^3) - TEST 1, EXCAVATOR COMPACTOR EVALUATION.

MEASURED AFTER	LOCATION NUMBER	AFTER COMPACTION	AFTER ROLLER COMPACTION IN ROLLER LANE	LOCATION NUMBER	AFTER COMPACTION	AFTER ROLLER COMPACTION IN ROLLER LANE
8 ROLLER COVERAGES, 1 PLATE PASS	18	127.6	134.0	21	-	-
	19	112.4	-	22	-	-
	20	114.1	128.7	23	-	-
	MEAN	118.0	131.4	MEAN	-	-
	σn	8.33	N/A	σn	-	-
12 ROLLER COVERAGES, 2 PLATE PASSES	18	125.8	122.0	21	-	-
	19	113.6	-	22	-	-
	20	116.4	125.2	23	-	-
	MEAN	120.3	123.6	MEAN	-	-
	σn	4.92	N/A	σn	-	-
3 PLATE PASSES	18	117.7	-	21	-	-
	19	115.3	-	22	-	-
	20	116.6	-	23	-	-
	MEAN	116.5	-	MEAN	-	-
	σn	1.15		σn	-	-

TABLE B-4. ROLLER LANE DRY DENSITIES (LB/FT^3) - TEST 2, EXCAVATOR COMPACTOR EVALUATION.

MEASURED AFTER	LOCATION NUMBER	AFTER COMPACTION	AFTER PLATE COMPACTION LANES 1 & 3	AFTER PLATE COMPACTION LANES 2 & 4
PRE-COMPACTION	1	121.3	-	-
	2	118.3	-	-
	3	123.5	-	-
	MEAN	121.03	-	-
	σn	2.61	-	-
2 ROLLER COVERAGES	1	151.4[a]	-	-
	2	140.3	-	-
	3	125.3	-	-
	MEAN	132.8	-	-
	σn	N/A	-	-
4 ROLLER COVERAGES, 1 PLATE PASS	4	137.0	141.5	139.0
	5	129.6	142.6	134.6
	6	128.3	142.0	131.6
	7	137.2	139.4	133.2
	8	136.9	139.7	133.8
	9	127.1	129.6	123.1
	MEAN	132.6	139.1	132.6
	σn	4.83	4.34	5.25
6 ROLLER COVERAGES	1	136.6	-	-
	2	136.7	-	-
	3	132.6	-	-
	MEAN	135.3	-	-
	σn	2.34	-	-
8 ROLLER COVERAGES, 2 PLATE PASSES	4	129.1	134.9	132.4
	5	128.5	139.7	-
	6	128.3	136.6	134.8
	7	130.4	134.7	139.7
	8	124.3	136.1	-
	9	121.2	140.8	135.7
	MEAN	127.0	137.1	135.7
	σn	3.48	2.54	3.72

TABLE B-4. ROLLER LANE DRY DENSITIES (LB/FT^3) - TEST 2, EXCAVATOR COMPACTOR EVALUATION (CONCLUDED).

MEASURED AFTER	LOCATION NUMBER	AFTER COMPACTION	AFTER PLATE COMPACTION LANES 1 & 3	AFTER PLATE COMPACTION LANES 2 & 4
10 ROLLER COVERAGES	1	137.2	-	-
	2	137.9	-	-
	3	145.4	-	-
	MEAN	136.8	-	-
	σn	8.76	-	-
12 ROLLER COVERAGES, 3 PLATE PASSES	4	140.1	-	134.8
	5	138.0	-	137.8
	6	139.1	-	133.2
	7	139.0	-	143.2
	8	138.3	-	136.4
	9	136.3	-	130.5
	MEAN	138.5	-	136.0
	σn	1.29	-	4.35

[a]AVERAGE CALCULATED EXCLUDING THIS POINT

TABLE B-5. COMPACTOR PLATE LANES 1 AND 2 DRY DENSITIES (LB/FT^3) - TEST 2, EXCAVATOR COMPACTOR EVALUATION.

MEASURED AFTER	LOCATION NUMBER	AFTER COMPACTION	AFTER PLATE COMPACTION OVER LANES 3 & 4	AFTER ROLLER COMPACTION OVER NEXT LANE	LOCATION NUMBER	AFTER COMPACTION	AFTER PLATE COMPACTION OVER LANES 3 & 4	AFTER ROLLER COMPACTION OVER NEXT LANE
4 ROLLER COVERAGES, 1 PLATE PASS	10	127.4	118.4	-	14	129.7	-	108.8
	11	127.9	-	124.2	15	113.6	-	108.5
	12	123.2	-	108.5	16	110.2	103.6	-
	13	121.8	116.8	-	17	-	113.2	-
	MEAN	125.1	117.6	116.4	MEAN	117.8	108.4	108.7
	σn	3.03	N/A	N/A	σn	10.42	N/A	N/A
8 ROLLER COVERAGES, 2 PLATE PASSES	10	113.8	111.3	-	14	116.5	-	113.4
	11	109.2	-	117.7	15	115.7	-	111.1
	12	102.8	-	113.8	16	-	101.4	-
	13	118.0	119.4	-	17	113.9	114.7	-
	MEAN	111.0	115.4	115.8	MEAN	115.4	114.7	112.3
	σn	6.51	N/A	N/A	σn	1.33	N/A	N/A
12 ROLLER COVERAGES, 3 PLATE PASSES	10	-	110.2	-	14	-	120.2	-
	11	-	105.5	-	15	-	111.9	-
	12	-	102.6	-	16	-	109.4	-
	13	-	109.6	-	17	-	115.8	-
	MEAN	-	107.0	-	MEAN	-	114.3	-
	σn	-	3.59	-	σn	-	4.72	-

TABLE B-6. COMPACTOR PLATE LANES 3 AND 4 DRY DENSITIES (LB/FT^3) - TEST 2, EXCAVATOR COMPACTOR EVALUATION.

MEASURED AFTER	LOCATION NUMBER	AFTER COMPACTION	AFTER ROLLER COMPACTION IN ROLLER LANE	LOCATION NUMBER	AFTER COMPACTION	AFTER ROLLER COMPACTION IN ROLLER LANE
8 ROLLER COVERAGES, 1 PLATE PASS	18	124.2	120.8	21	125.1	126.1
	19	110.9	-	22	125.5	-
	20	116.4	110.5	23	-	112.9
	MEAN	117.3	115.7	MEAN	125.3	119.5
	σn	6.68	N/A	σn	N/A	N/A
12 ROLLER COVERAGES, 2 PLATE PASSES	18	134.3	114.7	21	129.5	117.8
	19	126.1	-	22	130.2	-
	20	114.0	116.9	23	-	113.0
	MEAN	124.8	115.8	MEAN	129.9	115.4
	σn	10.2	N/A	σn	N/A	N/A
3 PLATE PASSES	18	117.4	-	21	103.5	-
	19	112.9	-	22	102.0	-
	20	120.5	-	23	105.1	-
	MEAN	116.9	-	MEAN	103.5	-
	σn	3.82	-	σn	1.55	-

TABLE B-7. ROLLER LANE DRY DENSITIES (LB/FT^3) - TEST 3, EXCAVATOR COMPACTOR EVALUATION.

MEASURED AFTER	LOCATION NUMBER	AFTER COMPACTION	AFTER PLATE COMPACTION LANES 1 & 3	AFTER PLATE COMPACTION LANES 2 & 4
PRE-COMPACTION	1	114.1	-	-
	2	113.5	-	-
	3	119.5	-	-
	MEAN	115.7	-	-
	σn	3.30	-	-
2 ROLLER COVERAGES	1	137.0	-	-
	2	132.7	-	-
	3	134.2	-	-
	MEAN	134.6	-	-
	σn	2.18	-	-
4 ROLLER COVERAGES, 1 PLATE PASS	4	133.3	136.9	136.1
	5	136.8	136.1	140.1
	6	136.7	135.9	136.6
	7	133.5	136.8	136.7
	8	136.7	137.0	138.1
	9	140.5	138.8	140.5
	MEAN	136.2	136.9	138.0
	σn	2.69	1.05	1.89
6 ROLLER COVERAGES	1	134.2	-	-
	2	136.0	-	-
	3	132.4	-	-
	MEAN	134.2	-	-
	σn	1.80	-	-
3 ROLLER COVERAGES, 2 PLATE PASSES	4	139.4	141.3	141.3
	5	140.0	139.4	-
	6	138.0	138.9	134.4
	7	138.2	139.5	139.9
	8	135.6	135.6	-
	9	138.7	137.1	140.3
	MEAN	138.3	138.6	139.0
	σn	1.53	2.00	3.11

TABLE B-7. ROLLER LANE DRY DENSITIES (LB/FT^3) - TEST 3, EXCAVATOR COMPACTOR EVALUATION (CONCLUDED).

MEASURED AFTER	LOCATION NUMBER	AFTER COMPACTION	AFTER PLATE COMPACTION LANES 1 & 3	AFTER PLATE COMPACTION LANES 2 & 4
10 ROLLER COVERAGES	1	137.5	-	-
	2	141.4	-	-
	3	134.6	-	-
	MEAN	137.8	-	-
	σn	3.41	-	-
12 ROLLER COVERAGES, 3 PLATE PASSES	4	138.1	-	139.9
	5	136.1	-	140.3
	6	137.9	-	141.3
	7	129.6	-	141.8
	8	140.9	-	137.6
	9	142.6	-	141.0
	MEAN	137.5	-	140.3
	σn	4.53	-	1.50

TABLE B-8. COMPACTOR PLATE LANES 1 AND 2 DRY DENSITIES (LB/FT^3) - TEST 3, EXCAVATOR COMPACTOR EVALUATION.

MEASURED AFTER	LOCATION NUMBER	AFTER COMPACTION	AFTER PLATE COMPACTION OVER LANES 3 & 4	AFTER ROLLER COMPACTION OVER NEXT LANE	LOCATION NUMBER	AFTER COMPACTION	AFTER PLATE COMPACTION OVER LANES 3 & 4	AFTER ROLLER COMPACTION OVER NEXT LANE
4 ROLLER COVERAGES, 1 PLATE PASS	10	131.6	131.2	-	14	129.2	-	130.2
	11	131.9	-	130.3	15	130.2	-	132.0
	12	133.4	-	130.9	16	126.2	122.4	-
	13	127.7	129.1	-	17	132.5	133.1	-
	MEAN	131.2	130.1	130.6	MEAN	129.5	127.8	131.1
	σn	2.11	N/A	N/A	σn	2.61	N/A	N/A
8 ROLLER COVERAGES, 2 PLATE PASSES	10	130.6	131.0	-	14	129.6	-	131.2
	11	129.7	-	129.4	15	131.5	-	130.6
	12	126.6	-	132.3	16	129.0	127.7	-
	13	134.4	130.1	-	17	132.0	129.6	-
	MEAN	130.3	130.6	130.9	MEAN	130.5	128.7	130.9
	σn	3.21	N/A	N/A	σn	1.45	N/A	N/A
12 ROLLER COVERAGES, 3 PLATE PASSES	10	-	128.7	-	14	-	134.2	-
	11	-	127.3	-	15	-	133.1	-
	12	-	128.1	-	16	-	127.5	-
	13	-	133.5	-	17	-	131.6	-
	MEAN	-	129.4	-	MEAN	-	131.6	-
	σn	-	2.79	-	σn	-	2.94	-

TABLE B-9. COMPACTOR PLATE LANES 3 AND 4 DRY DENSITIES (LB/FT^3) - TEST 3, EXCAVATOR COMPACTOR EVALUATION.

MEASURED AFTER	LOCATION NUMBER	AFTER COMPACTION	AFTER ROLLER COMPACTION IN ROLLER LANE	LOCATION NUMBER	AFTER COMPACTION	AFTER ROLLER COMPACTION IN ROLLER LANE
8 ROLLER COVERAGES, 1 PLATE PASS	18	136.0	130.6	21	130.8	128.3
	19	132.2	-	22	128.7	-
	20	136.0	137.4	23	128.5	128.7
	MEAN	134.7	134.0	MEAN	129.3	128.5
	σ_n	2.19	N/A	σ_n	1.27	N/A
12 ROLLER COVERAGES, 2 PLATE PASSES	18	129.0	130.7	21	132.2	139.0
	19	131.1	-	22	137.9	-
	20	129.8	132.0	23	138.6	138.2
	MEAN	130.0	131.4	MEAN	136.2	138.6
	σ_n	1.06	N/A	σ_n	3.51	N/A
3 PLATE PASSES	18	129.7	-	21	130.4	-
	19	133.8	-	22	131.8	-
	20	135.5	-	23	135.0	-
	MEAN	133.0	-	MEAN	132.4	-
	σ_n	2.98	-	σ_n	2.36	-

TABLE B-10. ROLLER LANE DRY DENSITIES (LB/FT^3) - TEST 4, EXCAVATOR COMPACTOR EVALUATION.

MEASURED AFTER	LOCATION NUMBER	AFTER COMPACTION	AFTER PLATE COMPACTION LANES 1 & 3	AFTER PLATE COMPACTION LANES 2 & 4
PRE-COMPACTION	1	115.7	-	-
	2	122.8	-	-
	3	119.2	-	-
	MEAN	119.2	-	-
	σn	3.55	-	-
2 ROLLER COVERAGES,	1	126.5	-	-
	2	130.1	-	-
	3	131.6	-	-
	MEAN	129.4	-	-
	σn	2.62	-	-
4 ROLLER COVERAGES, 1 PLATE PASS	4	127.0	130.2	139.1
	5	132.9	133.1	133.1
	6	136.5	136.7	136.8
	7	133.7	136.0	136.3
	8	139.0	138.9	140.8
	9	135.7	134.9	137.0
	MEAN	134.1	135.0	137.2
	σn	4.11	3.02	2.62
6 ROLLER COVERAGES	1	141.2	-	-
	2	135.8	-	-
	3	137.9	-	-
	MEAN	138.3	-	-
	σn	2.72	-	-
8 ROLLER COVERAGES, 2 PLATE PASSES	4	139.8	137.1	139.3
	5	141.8	135.2	-
	6	138.5	143.2	141.7
	7	134.3	136.9	138.9
	8	139.5	142.6	-
	9	138.5	139.8	141.8
	MEAN	138.7	139.1	140.4
	σn	2.48	3.27	1.54

TABLE B-10. ROLLER LANE DRY DENSITIES (LB/FT^3) - TEST 4, EXCAVATOR COMPACTOR EVALUATION (CONCLUDED).

MEASURED AFTER	LOCATION NUMBER	AFTER COMPACTION	AFTER PLATE COMPACTION LANES 1 & 3	AFTER PLATE COMPACTION LANES 2 & 4
10 ROLLER COVERAGES	1	131.5	-	-
	2	132.7	-	-
	3	131.3	-	-
	MEAN	131.8	-	-
	σn	0.76	-	-
12 ROLLER COVERAGES, 3 PLATE PASSES	4	138.7	-	137.7
	5	136.3	-	133.9
	6	136.6	-	131.9
	7	140.8	-	130.6
	8	137.3	-	137.1
	9	140.1	-	147.5
	MEAN	138.3	-	136.5
	σn	1.87	-	6.09

TABLE B-11. COMPACTOR PLATE LANES 1 AND 2 DRY DENSITIES (LB/FT^3) - TEST 4, EXCAVATOR COMPACTOR EVALUATION.

MEASURED AFTER	LOCATION NUMBER	AFTER COMPACTION	AFTER PLATE COMPACTION OVER LANES 3 & 4	AFTER ROLLER COMPACTION OVER NEXT LANE	LOCATION NUMBER	AFTER COMPACTION	AFTER PLATE COMPACTION OVER LANES 3 & 4	AFTER ROLLER COMPACTION OVER NEXT LANE
4 ROLLER COVERAGES, 1 PLATE PASS	10	130.0	134.3	-	14	132.6	-	125.1
	11	125.1	-	129.7	15	129.5	-	131.4
	12	130.9	-	134.9	16	126.6	126.3	-
	13	132.9	134.9	-	17	131.4	131.9	-
	MEAN	129.7	134.6	132.3	MEAN	130.0	129.1	128.3
	σn	2.87	N/A	N/A	σn	2.62	N/A	N/A
8 ROLLER COVERAGES 2 PLATE PASSES	10	132.5	132.6	-	14	132.1	-	129.2
	11	138.0	-	136.7	15	132.3	-	131.6
	12	136.9	-	135.9	16	135.1	136.6	-
	13	134.1	135.9	-	17	137.0	138.2	-
	MEAN	135.4	134.3	136.3	MEAN	134.1	137.4	130.4
	σn	2.52	N/A	N/A	σn	2.36	N/A	N/A
12 ROLLER COVERAGES, 3 PLATE PASSES	10	-	133.8	-	14	-	126.8	-
	11	-	136.9	-	15	-	133.7	-
	12	-	-	-	16	-	130.7	-
	13	-	133.6	-	17	-	130.7	-
	MEAN	-	134.8	-	MEAN	-	134.9	-
	σn	-	1.85	-	σn	-	9.34	-

TABLE B-12. COMPACTOR PLATE LANES 3 AND 4 DRY DENSITIES (LB/FT^3) - TEST 4, EXCAVATOR COMPACTOR EVALUATION.

MEASURED AFTER	LOCATION NUMBER	AFTER COMPACTION	AFTER ROLLER COMPACTION IN ROLLER LANE	LOCATION NUMBER	AFTER COMPACTION	AFTER ROLLER COMPACTION IN ROLLER LANE
8 ROLLER COVERAGES, 1 PLATE PASS	18	131.9	134.4	21	135.4	137.1
	19	136.0	-	22	130.5	-
	20	132.4	131.6	23	135.9	134.7
	MEAN	133.4	133.0	MEAN	133.9	135.9
	σ_n	2.24	N/A	σ_n	2.93	N/A
12 ROLLER COVERAGES, 2 PLATE PASSES	18	133.1	132.7	21	138.3	136.7
	19	136.6	-	22	131.0	-
	20	136.4	136.7	23	134.9	132.9
	MEAN	135.4	134.7	MEAN	134.7	134.8
	σ_n	1.96	N/A	σ_n	3.65	N/A
3 PLATE PASSES	18	130.8	-	21	129.7	-
	19	129.0	-	22	125.0	-
	20	134.8	-	23	130.5	-
	MEAN	131.5	-	MEAN	128.4	-
	σ_n	2.97	-	σ_n	2.97	-

TABLE B-13. CRUSHED STONE SURFACE LEVEL MEASUREMENTS - TEST 1, EXCAVATOR COMPACTOR EVALUATION.

MEASURED WHEN	MEASUREMENT LOCATION	ELEVATION (FT)
PRE-COMPACTION (TOP OF BALLAST ROCK)	1	9.64
	2	-
	3	-
	4	-
	5	-
	6	9.53
	7	-
	8	-
	9	-
	10	9.62
	11	-
	12	-
	13	-
	14	9.74
	15	9.70
PRE-COMPACTION	1	9.97
	2	9.99
	2	-
	4	10.01
	5	-
	6	9.91
	7	-
	8	-
	9	9.98
	10	9.92
	11	9.93
	12	-
	13	-
	14	10.02
	15	10.02
4 ROLLER COVERAGES, 1 PLATE PASS	1	9.99
	2	9.80
	3	10.05
	4	9.92
	5	9.94
	6	9.89
	7	9.93
	8	9.68
	9	9.43
	10	9.67
	11	9.43
	12	-
	13	-

TABLE B-13. CRUSHED STONE SURFACE LEVEL MEASUREMENTS - TEST 1, EXCAVATOR COMPACTOR EVALUATION (CONCLUDED).

MEASURED WHEN	MEASUREMENT LOCATION	ELEVATION (FT)
12 ROLLER COVERAGES, 3 PLATE PASSES	1	9.95
	2	9.58
	3	9.72
	4	9.52
	5	9.98
	6	9.85
	7	9.92
	8	9.46
	9	9.38
	10	9.70
	11	9.32
	12	-
	13	-

TABLE B-14. CRUSHED STONE SURFACE LEVEL MEASUREMENTS - TEST 2, EXCAVATOR COMPACTOR EVALUATION.

MEASURED WHEN	MEASUREMENT LOCATION	ELEVATION (FT)
PRE-COMPACTION	1	9.54
(TOP OF BALLAST	2	-
ROCK)	3	-
	4	-
	5	-
	6	9.49
	7	-
	8	-
	9	-
	10	9.51
	11	-
	12	10.01
	13	-
	14	9.54
	15	9.54
PRE-COMPACTION	1	9.87
	2	9.94
	2	9.94
	4	9.88
	5	9.92
	6	9.95
	7	-
	8	9.90
	9	9.91
	10	9.91
	11	9.89
	12	-
	13	-
	14	9.98
	15	9.95
4 ROLLER	1	9.92
COVERAGES,	2	9.55
1 PLATE	3	9.71
PASS	4	9.55
	5	9.96
	6	9.87
	7	9.95
	8	9.81
	9	9.67
	10	9.92
	11	9.60
	12	-
	13	-

TABLE B-14. CRUSHED STONE SURFACE LEVEL MEASUREMENTS - TEST 2, EXCAVATOR COMPACTOR EVALUATION (CONCLUDED).

MEASURED WHEN	MEASUREMENT LOCATION	ELEVATION (FT)
12 ROLLER COVERAGES, 3 PLATE PASSES	1	9.89
	2	9.57
	3	9.77
	4	9.41
	5	9.93
	6	9.85
	7	9.92
	8	9.92
	9	9.50
	10	9.76
	11	9.53
	12	-
	13	-

TABLE B-15. CRUSHED STONE SURFACE LEVEL MEASUREMENTS - TEST 3, EXCAVATOR COMPACTOR EVALUATION.

MEASURED WHEN	MEASUREMENT LOCATION	ELEVATION (FT)
PRE-COMPACTION (TOP OF BALLAST ROCK)	1	9.05
	2	8.94
	3	9.07
	4	8.93
	5	9.04
	6	9.06
	7	8.91
	8	8.98
	9	9.03
	10	8.92
	11	8.98
	12	-
	13	-
PRE-COMPACTION	1	10.00
	2	9.86
	2	10.02
	4	9.90
	5	9.99
	6	9.93
	7	9.97
	8	9.94
	9	9.92
	10	9.95
	11	9.87
	12	-
	13	-
4 ROLLER COVERAGES, 1 PLATE PASS	1	9.85
	2	9.72
	3	9.77
	4	9.62
	5	9.93
	6	9.89
	7	10.02
	8	9.81
	9	9.72
	10	9.87
	11	9.58
	12	-
	13	-

TABLE B-15. CRUSHED STONE SURFACE LEVEL MEASUREMENTS - TEST 3, EXCAVATOR COMPACTOR EVALUATION (CONCLUDED).

MEASURED WHEN	MEASUREMENT LOCATION	ELEVATION (FT)
8 ROLLER COVERAGES, 2 PLATE PASSES	1	10.00
	2	9.70
	3	10.06
	4	9.66
	5	9.91
	6	9.88
	7	9.91
	8	10.04
	9	9.71
	10	9.91
	11	9.63
	12	-
	13	-
12 ROLLER COVERAGES, 3 PLATE PASSES	1	9.98
	2	9.66
	3	10.04
	4	9.67
	5	9.92
	6	9.86
	7	9.89
	8	9.82
	9	9.69
	10	9.85
	11	9.60
	12	-
	13	-

TABLE B-16. CRUSHED STONE SURFACE LEVEL MEASUREMENTS - TEST 4, EXCAVATOR COMPACTOR EVALUATION.

MEASURED WHEN	MEASUREMENT LOCATION	ELEVATION (FT)
PRECOMPACTION	1	10.00
	2	9.90
	3	10.08
	4	9.88
	5	10.04
	6	9.95
	7	9.88
	8	9.98
	9	9.97
	10	9.93
	11	9.95
	12	10.05
	13	10.08
4 ROLLER COVERAGES, 1 PLATE PASS	1	9.85
	2	9.76
	3	9.87
	4	9.76
	5	9.95
	6	9.85
	7	9.79
	8	9.80
	9	9.59
	10	9.67
	11	9.58
	12	-
	13	-
8 ROLLER COVERAGES, 2 PLATE PASSES	1	9.82
	2	9.74
	3	9.70
	4	9.75
	5	9.97
	6	9.84
	7	9.88
	8	9.58
	9	9.65
	10	9.28
	11	9.50
	12	-
	13	-

TABLE B-16. CRUSHED STONE SURFACE LEVEL MEASUREMENTS - TEST 4, EXCAVATOR COMPACTOR EVALUATION (CONCLUDED).

MEASURED WHEN	MEASUREMENT LOCATION	ELEVATION (FT)
	1	9.77
16 ROLLER	2	9.72
COVERAGES	3	9.70
3 PLATE	4	9.79
PASSES	5	9.87
	6	9.82
	7	9.77
	8	9.60
	9	9.61
	10	9.46
	11	9.50
	12	-
	13	-

TABLE B-17. COMPACTION TIME LOG - TEST 1, EXCAVATOR COMPACTOR EVALUATION.

ACTIVITY	TIME (SEC)
RAYGO ROLLER	
2 COVERAGES	19.2
4 "	16.1
6 "	15.8
8 "	15.9
10 "	17.2
12 "	21.8
EXCAVATOR	
LANE 1 - 1ST PASS	21.0
2ND PASS	22.2
3RD PASS	23.0
LANE 2 - 1ST PASS	42.0
2ND PASS	43.6
3RD PASS	43.5
LANE 3 - 1ST PASS	20.2
2ND PASS	20.8
3RD PASS	23.0
LANE 4 - 1ST PASS	41.4
2ND PASS	47.2
3RD PASS	42.0

TABLE B-18. COMPACTION TIME LOG - TEST 2, EXCAVATOR COMPACTOR EVALUATION.

ACTIVITY	TIME (SEC)
RAYGO ROLLER	
2 COVERAGES	16.7
4 "	17.2
6 "	25.2
8 "	13.6
10 "	19.0
12 "	13.0
EXCAVATOR	
LANE 1 - 1ST PASS	23.7
2ND PASS	23.0
3RD PASS	18.0
LANE 2 - 1ST PASS	38.5
2ND PASS	36.0
3RD PASS	39.0
LANE 3 - 1ST PASS	20.0
2ND PASS	25.0
3RD PASS	20.0
LANE 4 - 1ST PASS	43.0
2ND PASS	45.0
3RD PASS	40.0

TABLE B-19. COMPACTION TIME LOG - TEST 3, EXCAVATOR COMPACTOR EVALUATION.

ACTIVITY		TIME (SEC)
RAYGO ROLLER		
2 COVERAGES		30.0
4 "		28.0
6 "		29.0
8 "		18.0
10 "		21.0
12 "		19.0
EXCAVATOR		
LANE 1 -	1ST PASS	23.0
	2ND PASS	25.0
	3RD PASS	23.0
LANE 2 -	1ST PASS	39.0
	2ND PASS	-
	3RD PASS	40.0
LANE 3 -	1ST PASS	23.0
	2ND PASS	25.0
	3RD PASS	24.0
LANE 4 -	1ST PASS	40.0
	2ND PASS	40.0
	3RD PASS	40.0

TABLE B-20. COMPACTION TIME LOG - TEST 4, EXCAVATOR COMPACTOR EVALUATION.

ACTIVITY		TIME (SEC)
RAYGO ROLLER		
2 COVERAGES		13.0
4 "		16.0
6 "		15.6
8 "		16.0
10 "		20.2
12 "		15.6
EXCAVATOR		
LANE 1 -	1ST PASS	22.6
	2ND PASS	22.3
	3RD PASS	24.2
LANE 2 -	1ST PASS	39.8
	2ND PASS	44.8
	3RD PASS	38.0
LANE 3 -	1ST PASS	25.0
	2ND PASS	21.0
	3RD PASS	19.0
LANE 4 -	1ST PASS	43.0
	2ND PASS	44.5
	3RD PASS	41.5

APPENDIX C

STATISTICAL SIGNIFICANCE TESTS

EXCAVATOR COMPACTOR EVALUATION

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APPENDIX C

STATISTICAL SIGNIFICANCE TESTS

EXCAVATOR COMPACTOR EVALUATION

a) H_0: Roller average dry density is greater than excavator plate (High Compaction Rate) dry density $(\overline{D}_R > \overline{D}_P)$

H_1: Roller average dry density is equal or less than excavator plate (High Compaction Rate) Average Dry-Density $(\overline{D}_R \leq \overline{D}_P)$

at the 95% Confidence Level

Decision Rule: Accept if $t_{test} > t_{(n_R + h_P - 2, \frac{\alpha}{2})}$

$$\text{When: } t_{test} = \frac{\overline{D}_R - \overline{D}_P}{\left(\frac{1}{N_R} - \frac{1}{N_P}\right)^{\frac{1}{2}} \left(\frac{\Sigma D_{Ri}^2 - N_R \overline{D}_R^{\,2} + \Sigma D_{Pj}^2 - N_P \overline{D}_P^{\,2}}{N_P + N_R - 2}\right)^{\frac{1}{2}}}$$

N_R = Roller Density Sample Size

N_P = Plate Density Sample Size

D_{Ri} = Roller Density Rates, $i = 1 \div N_R$

D_{Pj} = Exc. Density rates, $j = 1 \div N_P$

α = 1 - Significance Level

$\nu = N_R + N_P - 2$

Test #1

$\nu = 11 \quad \alpha = 0.05$

$t_{test} = 2.638 \quad t_{11,0.025} = 2.210$

$t_{test} > t_{(N_R + N_P - 2, \frac{\alpha}{2})}$

H_0 is Accepted

Test #2

$\nu = 11 \quad \alpha = 0.050$

$t_{test} = 7.233 \quad t_{11,0.025} = 2.210$

$t_{test} > t_{(\nu,2)}$

<u>H_0 is Accepted</u>

As shown in Figures 61 and 62, the difference between roller density rates and excavator plate density rates is obvious in tests 1 and 2, and therefore the significance is in no doubt.

b) 1) H_0: Plate 6-inch dry-densities are equal to plate 12-inch dry densities

H_1: Plate 6-inch dry-densities are not equal to plate 12-inch dry-densities

<u>at the 95% Significance Level</u>

<u>2 passes</u>

$\nu = 4 \quad \alpha = 0.05$

$t_{test} = -1.016 \quad t_{4,0.975} = 2.777$

and since $-t_{\nu,2} \le t_{test} \le t_{\nu,2}$

<u>H_0 is Accepted</u>

<u>3 passes</u>

$\nu = 4 \quad \alpha = 0.05$

$t_{test} = 1 \quad \rightarrow$ <u>H_0 is Accepted</u>

2) H_0: Roller 6-inch dry-densities are higher than roller 12-inch dry-densities

H_1: Roller 6-inch dry-densities are equal or lower than roller 12-inch dry-densities

Decision Rule: Accept H_0 if $t_{test} > t_{\nu,2}$

<u>8 coverages</u>

$\nu = 7^*$ $\quad \alpha = 0.05 \quad \rightarrow \quad t_{7,0.975} = 2.777$

$t_{test} = 1.848 \quad \alpha = 0.15 \quad \rightarrow \quad t_{7,0.925} = 1.618$

<u>12 coverages</u>

$\nu = 8^*$ $\quad \alpha = 0.05 \quad \rightarrow \quad t_{8,0.975} = 2.307$

$t_{test} = 1.652 \quad \alpha = 0.15 \quad \rightarrow \quad t_{8,0.925} = 1.593$

<u>Conclusion</u>: For both tests H_0 is rejected at a significance level of 95 percent, accepted at a significance level of 85 percent.

c) H_0: Average dry-density of high compaction-rate (0.50 ft/sec) by excavator plate is equal to the average dry-density of the low compaction-rate (0.25 ft/sec) by the same plate ($\bar{D}_H = \bar{D}_L$)

H_1: $\bar{D}_H \neq \bar{D}_L$

Decision Rule: Accept H_0 if $-t_{\nu,\frac{\alpha}{2}} \leq t_{test} \leq t_{\nu,\frac{\alpha}{2}}$

In order to verify the hypothesis, three samples were tested:

<u>Test #1 - dry-density after 2 passes</u>

$\nu = 12 \quad \alpha = 0.05$

$t_{test} = 0.897 \quad t_{12,0.975} = 2.180$

$$-t_{12,0.975} < t_{test} < t_{12,0.975}$$

Test #2 - dry-density after 2 passes

$\nu = 12 \qquad \alpha = 0.05$

$t_{test} = -1.6549 \qquad t_{12,0.975} = 2.180$

Test #3 - dry-density after 2 passes

$\nu = 12 \qquad \alpha = 0.05$

$t_{test} = -0.3602 \qquad t_{12,0.975} = 2.180$

Conclusion: For all test results after 2 excavator passes, average dry density of the high compaction rate is equal to the average dry density of the low compaction-rate.

d) H_0: Compaction over adjacent lanes does not have a significant influence on 6-inch dry densities measured in a previously compacted lane
($\overline{DD}_{AC} = \overline{DD}_{BC}$)

H_1: Compaction over adjacent lanes changes the 6-inch dry density measured in a previously compacted lane.

at the 95% significance level

Decision Rule: Accept H_0 if $-t_{\nu,\frac{\alpha}{2}} \leq t_{test} \leq t_{\nu,\frac{\alpha}{2}}$

Checking all available data was too time-consuming so only some of the most "promising" samples (i.e., with more than just a slight difference between sample averages), were checked. The results are summarized in the following table:

TEST NO	LOCATIONS NO	MEASURED AFTER (ROLLER CVGS/ PLATE PASSES)	$\nu = N_{BC} + N_{AC} - 2$	t_{test}	$t_{\nu,0.975}$	H_0 Accepted	H_0 Rejected
1	14-17	N/A/2	4	1.548	2.777	X	
1	21-23	8/1	3	-0.820	3.183	X	
2	14-17	N/A/2	4	1.710	2.777	X	
2	21-23	12/2	3	-0.899	3.183	X	
3	4-9	4/1	10	-2.361	2.230		X
3	4-9	8/2	10	-5.770	2.230		X
3	10-13	N/A/1	4	3.211	2.777		X
3	10-13	N/A/2	4	-0.803	2.777	X	
3	14-17	N/A/1	3	1.103	3.183	X	
4	4-9	4/1	10	1.014	2.230	X	

These results and the overall examination of the other samples with much closer average dry densities before and after compaction over an adjacent lane show significant changes in dry densities at a 6-inch depth.

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APPENDIX D

RAW DATA FROM QUALITY EVALUATION PROCEDURE

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TABLE D-1. CRUSHED STONE MOISTURE-DENSITY DATA, BEFORE COMPACTION, QUALITY EVALUATION PROCEDURE.

LOCATION NO.	WET DENSITY[a] (LB/FT^3)	DRY DENSITY[a] (LB/FT^3)	WATER CONTENT[a] (PERCENT)
1	129.7	125.8	3.1
2	125.6	121.4	3.4
3	132.1	124.4	6.1
4	130.0	126.4	2.8
5	131.6	127.6	3.1
6	130.2	126.4	3.1
7	135.2/134.8	130.8/131.0	3.4/2.9
8	135.2/117.8	131.5/113.6	2.8/3.6
9	132.5/130.9	128.3/126.9	3.2/3.1
10	126.0	121.5	3.6
11	135.0	130.6	3.4
12	129.6	125.6	3.2
13	125.0	121.3	3.0
14	131.6	127.8	3.0
15	133.7	128.6	4.0
16	129.3	124.8	3.6
17	135.2	130.8	3.4
18	131.9	127.8	3.2
19	128.9	124.8	3.3
20	124.0	120.1	3.3
21	134.7	128.8	4.6

[a]DEPTH OF READING ASSUMED TO BE 6 IN. WHEN TWO VALUES ARE PRESENTED, DEPTHS OF READINGS ARE 12 IN./6 IN.

TABLE D-2. CRUSHED STONE MOISTURE-DENSITY DATA, AFTER PASS 1, QUALITY EVALUATION PROCEDURE.

		WET DENSITY (LB/FT^3)		DRY DENSITY (LB/FT^3)		MOISTURE CONTENT (PERCENT)	
		12 IN.	6 IN.	12 IN.	6 IN.	12 IN.	6 IN.
	1	139.8	140.9	134.4	135.2	4.0	4.2
LANE 1	2	136.6	132.2	129.8	129.9	5.3	5.1
EXC SPEED =	3	141.3	137.6	132.4	129.2	6.6	6.5
0.50 FT/SEC	MEAN	139.2	136.9	132.2	131.4	5.3	5.3
	n	2.40	4.39	2.31	3.04	1.3	1.2
	4	135.5	132.3	131.6	127.5	3.0	3.7
LANE 2	5	146.6	143.1	140.9	137.0	4.0	4.4
EXC SPEED =	6	148.2	141.0	142.1	134.8	4.3	4.6
0.50 FT/SEC	MEAN	143.4	138.8	138.2	133.1	3.8	4.2
	n	6.92	5.73	5.75	4.97	0.7	0.5
	7	132.3	135.0	127.6	130.6	3.7	3.3
LANE 3	8	139.6	134.9	135.0	130.4	3.4	3.5
EXC SPEED =	9	141.5	135.3	136.5	130.4	3.7	3.7
0.69 FT/SEC	MEAN	137.8	135.1	133.0	130.5	3.6	3.5
	n	4.90	0.21	4.76	0.10	0.2	0.2
	10	140.0	134.1	135.0	129.2	3.7	3.8
LANE 4	11	139.7	137.7	135.1	133.0	3.4	3.5
EXC SPEED =	12	139.4	135.6	135.0	131.2	3.3	3.4
0.77 FT/SEC	MEAN	139.7	135.8	135.0	131.1	3.5	3.6
	n	0.30	1.81	0.06	1.13	0.2	0.2
LANE 5	13	136.6	134.1	131.8	129.1	3.6	3.8
EXC SPEED =	14	139.2	133.8	135.4	129.8	2.8	3.0
0.83 FT/SEC	15	137.2	138.2	132.4	133.5	3.6	3.6
	MEAN	137.7	135.4	133.2	130.8	3.3	3.4
	n	1.36	2.46	0.70	2.22	0.5	0.2
	16	141.6	133.9	137.4	129.4	3.0	3.5
LANE 6	17	140.9	139.7	136.5	135.5	3.2	3.1
EXC SPEED =	18	144.6	145.9	139.2	140.8	3.8	3.6
0.83 FT/SEC	MEAN	142.4	139.8	137.7	135.2	3.3	3.4
	n	1.97	6.00	1.35	4.00	0.4	0.1
	19	138.8	119.7	128.5	114.4	4.1	4.7
LANE 7	20	138.6	136.8	132.5	130.7	4.6	4.6
EXC SPEED	21	139.3	140.4	132.4	133.9	5.1	4.9
0.29 FT/SEC	MEAN	139.9	132.3	131.1	126.3	4.6	4.7
	n	0.36	11.06	2.03	10.46	0.5	0.1

TABLE D-3. CRUSHED STONE MOISTURE-DENSITY DATA, AFTER PASS 2, QUALITY EVALUATION PROCEDURE.

		WET DENSITY (LB/FT^3)		DRY DENSITY (LB/FT^3)		MOISTURE CONTENT (PERCENT)	
		12 IN.	6 IN.	12 IN.	6 IN.	12 IN.	6 IN.
	1	141.9	130.5	137.0	125.9	3.6	3.6
LANE 1	2	143.6	138.8	138.5	133.8	3.7	3.7
EXC SPEED =	3	146.5	138.4	141.0	132.4	3.9	4.5
0.48 FT/SEC	MEAN	144.0	135.9	138.8	130.7	3.7	3.9
	n	2.33	4.68	1.65	3.44	0.2	0.5
	4	144.8	138.5	140.3	134.0	3.2	3.4
LANE 2	5	141.2	136.8	137.1	132.2	3.0	3.5
EXC SPEED =	6	-	-	-	-	-	-
0.43 FT/SEC	MEAN	143.0	137.6	138.7	133.1	3.1	3.4
	n	N/A	N/A	N/A	N/A	N/A	N/A
	7	147.4	139.9	143.1	135.7	3.0	3.1
LANE 3	8	143.3	140.1	139.3	135.9	2.9	3.1
EXC SPEED =	9	143.1	140.0	138.4	134.9	3.4	3.8
0.67 FT/SEC	MEAN	144.6	140.0	140.3	135.5	3.1	3.3
	n	2.43	0.10	2.49	0.53	0.3	0.4
	10	142.3	135.3	137.3	130.4	3.6	3.7
LANE 4	11	143.5	137.5	139.4	133.0	2.9	3.4
EXC SPEED =	12	139.0	134.7	134.0	129.3	3.8	4.2
0.67 FT/SEC	MEAN	141.6	135.8	136.8	130.9	3.0	3.8
	n	2.33	1.47	2.71	1.90	0.5	0.4
	13	138.2	122.3	133.4	127.4	3.6	4.2
LANE 5	14	142.7	140.2	138.1	135.2	3.4	3.7
EXC SPEED =	15	140.7	132.2	134.3	125.6	4.8	5.3
0.87 FT/SEC	MEAN	140.5	131.6	135.3	129.4	3.9	4.4
	n	2.25	8.97	2.49	5.10	0.8	0.8
	16	144.9	130.6	139.2	124.9	4.1	4.5
LANE 6	17	138.7	140.9	133.7	135.7	3.7	3.8
EXC SPEED =	18	139.4	133.1	135.0	128.5	3.2	3.6
0.95 FT/SEC	MEAN	141.0	134.9	136.0	129.7	3.7	4.0
	n	3.40	5.40	2.90	5.50	0.4	0.5
	19	146.6	142.0	140.8	136.7	4.1	3.9
LANE 7	20	140.5	132.7	135.5	127.6	3.7	4.0
EXC SPEED	21	141.2	133.1	136.0	127.7	3.8	4.2
0.29 FT/SEC	MEAN	142.8	135.9	137.4	130.7	3.9	4.0
	n	3.30	5.30	2.90	4.27	0.2	0.2

TABLE D-4. CRUSHED STONE MOISTURE-DENSITY DATA, AFTER PASS 3, QUALITY EVALUATION PROCEDURE.

		WET DENSITY (LB/FT^3)		DRY DENSITY (LB/FT^3)		MOISTURE CONTENT (PERCENT)	
		12 IN.	6 IN.	12 IN.	6 IN.	12 IN.	6 IN.
	1	149.7	146.0	145.8	141.4	2.7	3.2
LANE 1	2	143.3	143.6	138.9	139.2	3.2	3.2
EXC SPEED =	3	151.8	150.2	145.6	143.5	4.3	4.7
0.51 FT/SEC	MEAN	148.3	146.6	143.4	141.4	3.4	3.7
	n	4.43	3.34	3.93	2.15	0.8	0.9
	4	147.0	145.5	142.7	141.2	3.0	3.0
LANE 2	5	145.8	144.9	140.9	139.7	3.5	3.8
EXC SPEED =	6	149.0	146.7	144.5	142.2	3.1	3.2
0.52 FT/SEC	MEAN	147.3	145.7	142.7	141.0	3.2	3.3
	n	1.62	0.92	1.80	1.26	0.3	0.4
	7	147.1	144.4	142.9	139.9	3.0	3.2
LANE 3	8	151.4	146.1	146.5	141.5	3.3	3.2
EXC SPEED =	9	147.4	136.7	143.0	132.4	3.1	3.3
0.77 FT/SEC	MEAN	148.6	142.4	144.1	137.9	3.1	3.2
	n	2.4	5.01	2.05	4.86	0.2	0.1
	10	140.2	142.0	135.8	137.4	3.2	3.3
LANE 4	11	148.2	144.4	143.8	140.2	3.0	3.0
EXC SPEED =	12	142.5	142.5	138.4	137.7	2.9	3.5
0.75 FT/SEC	MEAN	143.6	143.0	139.3	138.4	3.0	3.3
	n	4.12	1.27	4.08	1.54	0.2	0.2
	13	144.3	143.6	139.8	139.2	3.2	3.2
LANE 5	14	155.2	146.7	150.3	141.7	3.2	3.5
EXC SPEED =	15	147.6	137.3	142.0	132.2	3.9	3.9
0.80 FT/SEC	MEAN	149.0	142.5	144.0	137.7	3.4	3.5
	n	5.59	4.79	5.54	4.92	0.4	0.4
	16	151.5	137.9	146.3	132.8	3.6	3.8
LANE 6	17	147.6	153.7	142.6	148.8[a]	3.5	3.3
EXC SPEED	18	147.4	135.2	142.4	130.0	3.5	4.0
1.33 FT/SEC	MEAN	148.8	142.3	143.8	131.4	3.5	3.7
	n	2.31	10.0	2.20	N/A	0.1	0.4
	19	144.0	134.1	139.2	128.9	3.4	4.1
LANE 7	20	145.8	134.3	140.2	128.6	4.0	4.4
EXC SPEED	21	144.7	135.4	140.3	131.2	3.1	3.2
0.30 FT/SEC	MEAN	144.8	134.6	139.9	129.6	3.5	3.9
	n	0.91	0.70	0.61	1.42	0.5	0.6

[a]AVERAGE CALCULATED EXCLUDING THIS POINT

TABLE D-5. CRUSHED STONE SURFACE LEVEL MEASUREMENTS BEFORE AND AFTER COMPACTION (TBM = 10.00 FT), QUALITY EVALUATION PROCEDURE.

NUMBER OF PASSES	SAMPLE NUMBER	ELEVATION (FT)
	1	10.36
UNCOMPACTED	2	10.35
	3	10.30
	4	10.41
	5	10.37
	6	10.29
	7	10.43
	8	10.40
	9	10.32
	10	10.35
	11	10.38
	12	10.30
	13	10.33
	14	10.38
	15	10.35
	16	10.36
	17	10.33
	18	10.34
	19	10.34
	20	10.31
	21	10.29
1	1	9.99
	2	9.85
	3	10.04
	4	10.12
	5	10.10
	6	10.04
	7	10.19
	8	10.22
	9	10.22
	10	10.09
	11	10.20
	12	10.17
	13	10.06
	14	10.19
	15	10.18
	16	10.18
	17	10.17
	18	10.16
	19	9.78
	20	9.94
	21	9.96

TABLE D-5. CRUSHED STONE SURFACE LEVEL MEASUREMENTS BEFORE AND AFTER COMPACTION (TBM = 10.00 FT), QUALITY EVALUATION PROCEDURE (CONCLUDED).

NUMBER OF PASSES	SAMPLE NUMBER	ELEVATION (FT)
2	1	10.01
	2	9.88
	3	10.01
	4	10.12
	5	10.10
	6	10.18
	7	10.16
	8	10.18
	9	10.22
	10	10.05
	11	10.09
	12	10.19
	13	10.03
	14	10.06
	15	10.17
	16	10.08
	17	10.09
	18	10.17
	19	9.88
	20	9.76
	21	9.92
3	1	9.99
	2	9.90
	3	9.99
	4	10.14
	5	10.03
	6	10.17
	7	10.13
	8	10.11
	9	10.22
	10	10.07
	11	10.09
	12	10.18
	13	10.06
	14	10.05
	15	10.14
	16	10.10
	17	10.05
	18	10.05
	19	9.88
	20	9.78
	21	9.88

APPENDIX E

MOISTURE-DENSITY RESULTS FOR CRUSHED STONE BASE ALTERNATIVE POLYURETHANE FIBERGLASS MAT

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TABLE E-1. MOISTURE-DENSITY RESULTS FOR CRUSHED STONE BASE
0 ROLLER COVERAGES.

SAMPLE NUMBER	DEPTH (IN)	WET DENSITY (LB/FT^3)	DRY DENSITY (LB/FT^3)	MOISTURE CONTENT (PERCENT)
1	12	125.2	120.1	4.2
	4	123.0	117.7	4.5
2	12	135.8	130.9	3.7
	4	129.1	124.6	3.5
3	12	131.7	126.6	4.0
	4	126.0	120.6	4.5
4	12	127.1	122.0	4.2
	4	125.1	119.8	4.4

NORTH

REAR

3	4
2	1

LAB

TABLE E-2. MOISTURE-DENSITY RESULTS FOR CRUSHED STONE BASE 8 ROLLER COVERAGES.

SAMPLE NUMBER	DEPTH (IN)	WET DENSITY (LB/FT^3)	DRY DENSITY (LB/FT^3)	MOISTURE CONTENT (PERCENT)
1	12	140.2	135.1	3.8
	4	143.8	138.3	4.0
2	12	144.3	138.5	4.2
	4	147.0	141.2	4.2
3	12	144.8	137.4	5.4
	4	146.8	139.2	5.5
4	12	144.9	139.2	4.1
	4	145.6	139.7	4.2

TABLE E-3. MOISTURE-DENSITY RESULTS FOR CRUSHED STONE BASE 12 ROLLER COVERAGES (BEFORE GRADING).

SAMPLE NUMBER	DEPTH (IN)	WET DENSITY (LB/FT^3)	DRY DENSITY (LB/FT^3)	MOISTURE CONTENT (PERCENT)
1	12	145.2	139.3	4.2
	4	146.1	140.3	4.1
2	12	144.8	138.6	4.4
	4	149.7	143.3	4.4
3	12	146.7	140.7	4.3
	4	142.9	136.2	4.9
4	12	146.1	139.9	4.4
	4	144.5	138.2	4.6

TABLE E-4. MOISTURE-DENSITY RESULTS FOR CRUSHED STONE BASE 12 ROLLER COVERAGES (AFTER GRADING).

SAMPLE NUMBER	DEPTH (IN)	WET DENSITY (LB/FT^3)	DRY DENSITY (LB/FT^3)	MOISTURE CONTENT (PERCENT)
1	12	146.0	141.2	3.5
	4	144.3	138.9	3.8
2	12	142.3	134.5	5.8
	4	147.6	139.2	6.1
3	12	148.1	138.5	7.0
	4	150.0	140.6	6.7
4	12	147.6	141.3	4.5
	4	142.3	135.9	4.7

TABLE E-5. MOISTURE-DENSITY RESULTS FOR CRUSHED STONE BASE 16 ROLLER COVERAGES.

SAMPLE NUMBER	DEPTH (IN)	WET DENSITY (LB/FT^3)	DRY DENSITY (LB/FT^3)	MOISTURE CONTENT (PERCENT)
1	12	145.8	140.4	3.8
	4	147.0	141.3	4.0
2	12	148.3	139.7	6.0
	4	152.2	143.5	5.6
3	12	148.1	140.2	5.6
	4	147.6	139.6	5.7
4	12	150.2	144.1	4.2
	4	151.1	145.1	4.1

TABLE E-6. MOISTURE-DENSITY RESULTS FOR CRUSHED STONE BASE AFTER 24 F-15 LOADCART COVERAGES, AFTER MAINTENANCE, UNCOMPACTED.

SAMPLE NUMBER	DEPTH (IN)	WET DENSITY (LB/FT^3)	DRY DENSITY (LB/FT^3)	WATER CONTENT (PERCENT)
1	BS*	104.1	100.5	3.6
2	BS	112.0	107.8	3.8
3	BS	107.6	103.1	4.3
4	BS	111.1	106.5	4.3

*BS-SURFACE READING

TABLE E-7. MOISTURE-DENSITY RESULTS FOR CRUSHED STONE BASE AFTER 156 LOADCART COVERAGES.

SAMPLE NUMBER	DEPTH (IN)	WET DENSITY (LB/FT^3)	DRY DENSITY (LB/FT^3)	WATER CONTENT (PERCENT)
1	12	158.5	153.1	3.6
	4	145.0	139.5	4.0
2	12	160.0	152.9	4.6
	4	149.8	142.5	5.1
3	12	157.8	152.5	3.4
	4	141.6	136.2	3.9
4	12	160.7	154.9	3.7
	4	149.3	143.5	4.1

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APPENDIX F

REPAIR DATA AND EVENT TIME LOG

WET ENVIRONMENT CRATER REPAIR DEMONSTRATION

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APPENDIX F

REPAIR DATA AND EVENT TIME LOG
WET ENVIRONMENT CRATER REPAIR DEMONSTRATION

A. GENERAL

This test was conducted at SKY TEN on February 22, 1984 to demonstrate the RRR capability to repair an explosively formed crater in wet, raining conditions. The choked ballast rock repair method was used. A polyurethane FOD cover was installed to complete the repair. A polyurethane mixed with sand ramp was installed for approximately 10 feet along one edge to facilitate aircraft tailhook operations, which were demonstrated at the completion of the repair. Numerous visitors from the worldwide RRR arena viewed the demonstration.

B. EQUIPMENT

The following equipment items were used.

- Dump Trucks: (2 total)
  Make and model: IH S1700
  Capacity: 5 tons (3.9 yd^3)

- Excavator:
  Make and model: John Deere 690B
  Bucket
  size: 3 feet high by 3.83 feet wide by 2.67 feet deep
  Blade width: 12 feet
  Compactor plate size: 34- by 42-inch Allied Ho-Pac Mod 9801
  Undercarriage: 6 Wheels (4 foam filled)

- FEL: (used for dump truck loading and FOD cover towing only)
  Make and model: Case W24-C
  Bucket: (8 feet by 4.16 feet by 2.5 feet)

A sprinkler system was used to simulate rain at approximately 2 inches per hour. A fire truck/water tanker supplied the water at the required pressure through a 1.5-inch hose and adjustable nozzle. A large (55-ton) crane positioned the hose and nozzle high above the crater to stay well clear of the excavator operations. The system was simple and worked quite well. The crater was approximately half full of water at the test start time and was kept soaked throughout the test.

- Crater Dimensions:
  Apparent diameter: 18 feet N/S 16 feet E/W
  Repair diameter: 22.25 feet N/S 23.8 feet E/W
  Depth: 3.8 feet

C. OTHER INFORMATION

Distance to stockpile: 150 yd.
Weather: overcast
visibility 5 miles, fog
temperature 56°F
dew point 49
wind E 9 mph
pressure 29.89

D. TEST TEAM CONFIGURATION

Crater repair team:	NCOIC Equipment operator Laborers (2)
Stockpile team:	Equipment operator Truck drivers (2)
FOD cover anchoring team:	NCOIC Laborers (5)

E. TEST LOG

TIME	EVENT
0909:00	Test Start
0909:30	excavator clearing lip to reveal upheaval
0911:00	Begin surface roughness check (SRC) using string
0911:40	excavator clearing debris around crater circular path around crater
0912:00	stop SRC
0914:50	continue SRC
0915:00	excavator waiting
0917:00	surface roughness check using RRR straightedge
0917:45	surface roughness check complete
0917:45	excavator complete upheaval breaking with hammer departs to change hammer to bucket
0927:41	Begin changing hammer to bucket
0930:30	excavator bucket change complete
0931:00	excavator begin upheaval and debris removal with bucket
0939:00	excavator stopped removing debris to doze debris off pavement
0939:25	excavator continue debris removal from crater
0940:00	laborers begin shovelling debris into crater
0942:00	laborers stop shovelling operations - waiting
0943:40	excavator dozing debris off pavement
0944:45	excavator continue debris removal
0945:00	1st dump truck arrives at crater
0945:18	1st dump truck dumps ballast rock into crater

0946:25	2nd dump truck arrives
0946:42	2nd dump truck begin dumping ballast rock into crater
0946:50	dumping complete
0948:12	3rd dump truck arrives
0949:13	3rd dump truck begins dumping ballast rock into crater
0949:24	dumping complete
0950:30	4th dump truck arrives - waiting
0951:00	laborers shovelling debris into crater
0953:30	debris and upheaval removal complete
0953:40	excavator leveling ballast rock
0955:00	4th dump truck begin dumping into crater
0955:18	dumping complete
0955:50	5th dump truck arrives
0959:25	excavator leveling and compacting ballast rock with bucket working across center
0959:55	5th dump truck begins dumping ballast rock into crater
1000:12	dumping complete
1001:00	laborers shovelling excess ballast rock into crater
1002:00	6th dump truck arrives with crushed stone
1003:15	laborers move two large (2'x2') pieces of ac off pavement
1003:35	laborers complete moving ac by hand
1003:53	6th dump truck begins dumping crushed stone into crater
1004:00	dumping complete
1004:11	excavator stops leveling crushed stone to change bucket to compactor plate
1004:34	7th dump truck arrives with crushed stone
1004:58	7th dump truck begins dumping crushed stone into crater
1005:11	dumping complete
1006:00	simulated rain on crater soaking crushed stone
1006:42	8th dump truck arrives with crushed stone
1007:25	excavator change bucket to compactor plate complete
1008:00	excavator dozing debris off pavement laborers clearing excess small debris
1008:46	excavator leveling and grading crushed stone
1009:10	9th dump truck arrives with crushed stone
1010:24	9th dump truck begins dumping crushed stone into crater
1010:36	dumping complete
1011:20	10th dump truck arrives
1013:40	excavator dozing debris
1014:08	10th dump truck begin dumping crushed stone into crater
1014:21	dumping complete
1015:30	excavator leveling crushed stone in crater
1018:00	excavator dozing excess crushed stone from around crater
1022:30	excavator - grading and leveling complete begin compaction
1034:00	laborers shovelling crushed stone to fill in low spots
1035:00	laborers stop
1037:00	compaction complete
1038:00	begin final grading

1047:20	final grading complete excavator clearing excess crushed stone around crater
1048:30	laborers shovelling excess crushed stone from around crater
1049:50	excavator clearing excess crushed stone and debris from around crater
1051:00	laborers stop
1054:45	begin dragging FOD cover to crater with FEL (approx. 150')
1055:00	excavator finished - departing area
1056:30	FOD cover in place over crater
1057:15	FOD cover towing harness removed
1058:00	air compressors arrive (2)
1100:00	begin drilling holes (18) in pavement to anchor FOD cover using 90 lb jackhammers (2) with pointed bit
1109:00	begin pouring ramp - polyurethane and sand
1119:12	begin pouring polyurethane in holes for anchors
1122:30	drilling complete
1128:15	last anchor set in polyurethane
1135:00	last anchor tightened with spanner wrench
1135:00	REPAIR COMPLETE
1136:00	1st tailhook test - no damage
1139:00	2nd tailhook test - no damage
1142:00	1st F-15 loadcart pass

F. INDIVIDUAL EVENT CYCLE TIMES

Cycle times were recorded for several specific events. Except where noted, times are in seconds.

1. Clear Crater Lip - Excavator Using Blade

Only two cycles were recorded for this event. Most of the time the excavator was dozing around the crater in a circular pattern.

- Cycle definition: excavator makes one pass forward and back.

- Cycle times: 12,10

2. Pavement Breaking At Edge of Upheaval - Excavator Using Jackhammer Attachment

- Total time: 10 min 45 sec

- Cycle definition: beginning to end - drilling one hole

- Number of cycles timed: 14

- Cycle times: 11,10,6,6,7,7,7,12,18,11,6,9,9,8

- Average cycle time: 8.4

3. Debris and Upheaval Removal - Excavator Using Bucket

This operation included the excavator doing some dozing of debris off the pavement surface.

- Total time: 22 min

- Cycle definition: Excavator removes one bucket full of debris from the crater and returns for the next bucket full.

- Number of cycles timed: 11

- Cycle times: 13,25,20,20,11,15,17,8,17,12,15

- Average cycle time: 15.7

4. Initial Grading of Crushed Stone - Excavator With Blade

During this operation the excavator also used the bucket to level the crushed stone. Dozing debris off the pavement was also interspersed with this operation.

- Cycle definition: One pass forward and back with the excavator

- Number of cycles timed: 3

- Cycle times: 23,12,49

5. Compaction - Excavator With Compactor Plate

Total time: 14 min 30 sec

a. Single Passes

  - Number of cycles timed: 6

  - Cycle times: 24,17,25,26,18,23

  - Average cycle time: 22.2

b. Double Passes

- Number of cycles timed: 10
- Cycle Times: 32,33,36,35,37,35,36,31,42,37
- Average cycle time: 35.4

6. Final Grading (after compaction) - Excavator With Blade

- Total time: 9 min 30 sec
- Cycle definition: Excavator makes single pass across crater
- Number of cycles timed: 6
- Cycle times: 49,71,32,42,26,48
- Average cycle time: 44.7

7. FOD Cover Installation

This operation was non-standard in that the normally used concrete drills were not used. All anchoring holes were drilled using two 90 lb jackhammers with point bits. The anchoring bolts were secured in the holes with polyurethane.

- Total installation time: 40 min 15 sec
- Towing time (150 ft): 105
- Number of holes drilled: 18
- Total drilling time: 22 min 30 sec
- Drilling cycles timed: 8
- Cycle times: 155,101,110,171,113,99,146,139
- Average drilling time: 129 sec/hole

8. Stockpile Data

Equipment: 5 ton dump trucks (3.9 yd^3) 2 ea.

Case W24-C 2 1/2 yd^3 FEL

Number of loads timed: 10

Truck loading times: 138,120,122,85,70 (ballast rock)

100,105,100,100,104 (crushed stone)

Average loading time: 104

9. Crater Site Dump Truck Data

Transient time from the stockpile to the crater was insignificant due to the very short haul distance (approximately 150 yds) and was not recorded. All fill was dumped directly into the crater.

a. Dump Truck Waiting/Positioning Time

(Time from dump truck arrival to start dumping)

- Number of cycles timed: 10
- Cycle times: 13,17,61,270,245,113,24,105,22,168
- Average cycle time: 104

b. Dumping times

(start to end dumping time)

- Number of cycles timed: 10
- Cycle times: 3,8,11,18,17,7,13,15,15,13
- Average dumping time: 12.5

10. Excavator Attachment Changing Times

- Number of cycles timed: 2
- Cycle times: 3 min 30 sec
  3 min 14 sec

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APPENDIX G

MATERIAL BATCH QUANTITIES

SPALL REPAIR WITH ADVANCED MATERIALS

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TABLE G-1. PU BATCH QUANTITIES.

MATERIAL	MATERIAL QUANTITIES (GALLONS)	
	BATCH TYPE I	BATCH TYPE II
COMPONENT A	1.0	2.5
COMPONENT B	1.0	2.5

VOLUME BATCH TYPE I = 0.6 FT^3

VOLUME BATCH TYPE II = 1.75 FT^3

MIX 4 TYPE I BATCHES AND 5 TYPE II BATCHES

TOTAL VOLUME = 4(0.6 FT^3) + 5(1.75 FT^3) = 11.2 FT^3

TABLE G-2. FA-PC BATCH QUANTITIES.

MATERIAL	MATERIAL QUANTITIES (LB) BATCH TYPE I	BATCH TYPE II
FA/PYR/TCT/SILANE	4.0 GALLONS[a]	3.0 GALLONS
$ZnCl_2$	22.0	18.0
COURSE SILICA GRAVEL	150.0	115.0
FINE AGGREGATE	100.0	75.0
SILICA FLOUR	80.0	64.0

[a]1 GALLON = 9.38 LB

NOTE: FOR WET REPAIR ADD 3 PERCENT WATER TO MIXES

VOLUME BATCH TYPE I = 2.5 FT^3

VOLUME BATCH TYPE II = 2 FT^3

MIX 4 TYPE I BATCHES AND 1 TYPE II BATCH

TOTAL VOLUME = $4(2.5\ FT^3) + 2\ FT^3 = 12.0\ FT^3$

TABLE G-3. MPP BATCH QUANTITIES.

MATERIAL	MATERIAL QUANTITIES (LB) BATCH TYPE I	BATCH TYPE II
MGO No. 10	114.0	47.0
POLY-N	68.4	28
MAMP	20.5	8.4
COURSE SILICA AGGREGATE	120.0	50.0
SAND	80.0	32.0
BORAX	8.2	3.4
WATER - DRY TEST CONDITIONS	0.5 GALLONS	0.2 GALLONS
- WET TEST CONDITIONS	1.8 GALLONS	0.75 GALLONS

VOLUME BATCH TYPE I = 2.5 FT^3

VOLUME BATCH TYPE II = 1.0 FT^3

MIX 4 TYPE I BATCHES AND 1 TYPE II BATCH

TOTAL VOLUME = 4(2.5 FT^3) + 1.0 FT^3 = 11.0 FT^3

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APPENDIX H
PHYSICAL PROPERTIES OF FA-PC AND MPP COMPONENTS

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TABLE H-1. PHYSICAL PROPERTIES OF FA-PC COMPONENTS.

FA + PYRIDINE,	BOILING POINT	338°F (760 mm)
	LIQUID AT AMBIENT TEMPERATURES	
	VISCOSITY AT 77°F	4.62cP
	FLASH POINT	149°F
	IGNITION TEMPERATURE IN AIR	736°F
	VAPOR PRESSURE AT 89.2°F	1mm Hg
	pH	6.2
TCT + SILANE	BOILING POINT	231°F
	LIQUID AT AMBIENT TEMPERATURES	
	VAPOR PRESSURE AT 89.2°F	5mm Hg
	FLASH POINT	280°F
	pH	10.9
SILICA FLOUR + $ZnCL_2$	SOLID AT AMBIENT TEMPERATURES	
	$ZnCL_2$ IS HYGROSCOPIC	
	SOLUBILITY OF $ZnCl_2$ in H_2O	81g/100ml
	NON FLAMMABLE	
AGGREGATE	SOLID	

TABLE H-2. PROPERTIES OF MPP SYSTEM COMPONENTS.

BASIC COMPONENTS	MgO (POWDER)	POLY-BOR RETARDER (GRANULAR)
BOILING POINT, °F	6512	---
MELTING POINT, °F	5072	---
FLASH POINT, °F	DOES NOT APPLY	DOES NOT APPLY
IGNITION TEMP. IN AIR °F	DOES NOT APPLY	DOES NOT APPLY
VAPOR PRESSURE, mm Hg	DOES NOT APPLY	---
DENSITY	3.58	1.73
pH	11.5 AT A 10% SOLUTION	8.0 AT A 10% SOLUTION
VISCOSITY, cP AT 105°F	---	---
AT 5°F	---	---
STORAGE LIFE	---	---
ACUTE ORAL, LD50	---	---
ACUTE DERMAL, LD50	---	---
EYE IRRITATION	NONE	YES
SKIN IRRITATION	NONE	YES
ACUTE INHALATION	---	---
MUTAGENIC TEST	---	---
SKIN SENSITIZING	NONE	NONE
TLV (OR 8-HR. PEL)	---	---
SOLUBILITY IN WATER	---	

TABLE H-2. PROPERTIES OF MPP SYSTEM COMPONENTS (CONCLUDED).

ACIDIC COMPONENTS	POLY-BOR HARDENER (LIQUID)	MAmP ACTIVATOR (GRANULAR)
BOILING POINT, ^{o}F	223	---
MELTING POINT, ^{o}F	---	374
FLASH POINT, ^{o}F	NONE	DOES NOT APPLY
IGNITION TEMP. IN AIR ^{o}F	NONE	DOES NOT APPLY
VAPOR PRESSURE, mm Hg	1 at 212^{o}F	---
DENSITY	1.41	1.8
pH	6.2	4 AT A 5%SOLUTION
VISCOSITY, cP AT 105^{o}F	25	---
AT 5^{o}F	275	---
STORAGE LIFE	---	---
ACUTE ORAL, LD50	RATS; 4000 MG/KG OF BODY WEIGHT	---
ACUTE DERMAL, LD50	RABBITS; DERMAL EXPOSURE IS NONLETHAL	---
EYE IRRITATION	YES	YES
SKIN IRRITATION	YES	YES
ACUTE INHALATION	NONE	---
MUTAGENIC TEST	---	---
SKIN SENSITIZING	YES	YES
TLV (OR 8-HR. PEL)	---	---
SOLUBILITY IN WATER		---

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