Report 2306

FAMECE COMPACTION STUDY – PHASE I

by

Robert E. Dapogny

August 1980

Approved for public release; distribution unlimited.

U.S. ARMY MOBILITY EQUIPMENT
RESEARCH AND DEVELOPMENT COMMAND
FORT BELVOIR, VIRGINIA

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 2306	2. GOVT ACCESSION NO. AD-A092	3. RECIPIENT'S CATALOG NUMBER 583
4. TITLE (and Subtitle) FAMECE COMPACTION STUDY – PHASE I		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Robert E. Dapogny		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Const Equip Engrg Div, DRDME-HK Mech & Const Equip Lab; US Army Mobility Equipment Research & Development Command; Ft. Belvoir, VA 22060		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Mech & Const Equip Lab, DRDME-HK; US Army Mobility Equipment Research and Development Command; Fort Belvoir, VA 22060		12. REPORT DATE August 1980
		13. NUMBER OF PAGES 85
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) MERADCOM		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

FAMECE
Construction Equipment
Earthmoving
Compaction

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

The objective of this study is to establish the best operating guidelines for the FAMECE compactors and new Army soil testing equipment. Report covers compactor design data, instrumentation, test soil characteristics and analyses, test procedures for single- and dual mode configurations, and preparations for Phase II Testing.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

403160

SUMMARY

In tactical areas, rapid construction of roads and airstrips is of vital importance. Before any paving materials can be laid, the subgrade must be compacted to an acceptable density. The objectives of this compaction study are to establish operating guidelines for the FAMECE compactors and general guidelines for the use of new, rapid soil testing equipment being acquired by the Army. These guidelines will encompass the soil-machine combined system, including such items as optimum speeds, weights, lift thicknesses, and soil moisture contents.

The project is divided into two phases. This report covers Phase I — an introduction to the FAMECE system; design data for the FAMECE compactors and water distributor; instrumentation for measuring soil response; information about the test soils; and the test procedure for single- and dual-mode configurations.

Phase II will cover the actual field tests, which will involve acquiring and reducing the field data, plotting and graphing the results, and evaluating the influence of each variable. The reliability of several instrumentation systems will be determined, as will operating guidelines for the FAMECE equipment. These guidelines will be used to develop instructions for training engineers in the effective use of the new Army equipment.

PREFACE

Dr. E. T. Selig of the State University of New York assisted and advised Mr. J. T. Sheakley in completing the initial draft of Phase I. Colonel M. B. Scheider, Project Manager for FAMECE; James H. Yeardley, former Chief of the Construction Equipment Engineering Division; W. Horace Leathers, Jr., Chief of the Construction Engineering Group; and Arthur B. Follansbee, FAMECE Test Director also assisted during the completion of the initial draft, finished in November 1978.

The final draft, completed in August 1980 was written by Robert E. Dapogny. The instrumentation systems and test procedures were modified to reflect new Army equipment and revised test procedures as published by ASTM.

CONTENTS

CONTENTS (Cont'd)

ILLUSTRATIONS

ILLUSTRATIONS (Cont'd)

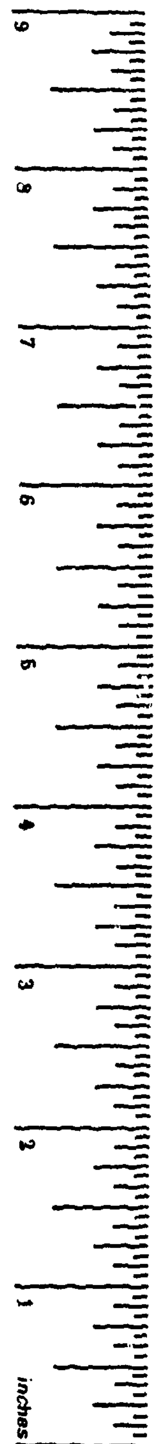
TABLES

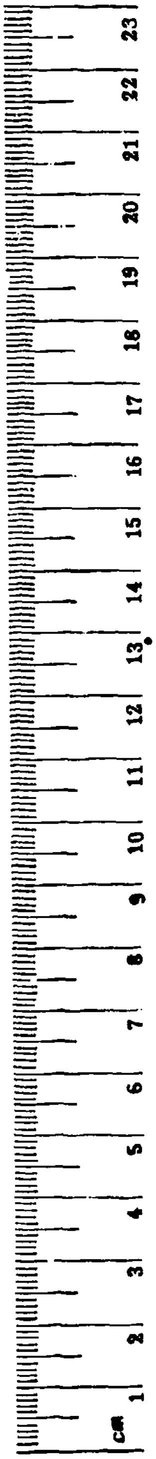
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	metric tons	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	L
pt	pints	0.47	liters	L
qt	quarts	0.95	liters	L
gal	gallons	3.8	liters	L
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

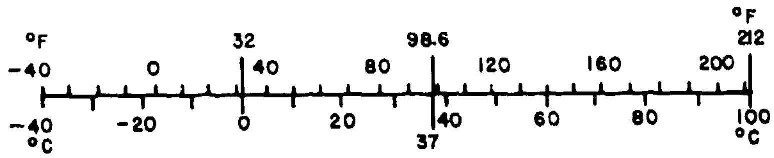
*1 in = 2.54 cm (exactly).





Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10 000 m^2)	2.5	acres	
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	metric tons (1000 kg)	1.1	short tons	
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
L	liters	2.1	pints	pt
L	liters	1.06	quarts	qt
L	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FAMECE COMPACTION STUDY – PHASE I

I. INTRODUCTION

1. Background. The United States Army is currently evaluating a unique concept in earthworking construction equipment. The overall design is based upon a systems approach to earthwork construction machinery. This concept takes the various work functions found in earthwork construction and integrates them through a commonality of design. This system of construction equipment is known as FAMECE (Family of Military Engineer Construction Equipment). The system consists of a single power unit and a family of eight interchangeable work units. In general, the FAMECE items were designed to accommodate the size and weight restrictions imposed by the Army Airborne/Airmobile mission. The family-oriented approach was used to reduce the cost and magnitude of logistics problems associated with the support of independently developed equipment.

The work units include a dozer, bucket loader, grader, scraper, water distributor, dumper, smooth-drum/pneumatic-tire compactor, and tamping-foot/pneumatic-tire compactor (Figure 1). The compactor units are, by far, the most difficult to use effectively. Subgrade preparation must include both compaction to the proper density and compaction at the proper moisture content. Therefore, basic knowledge of both soil analysis and soil response are required in the field in order for the equipment operators to achieve adequate compaction results.

The basic design concept for the compactors was taken from a commercial item developed during the 1950s; several compaction methods are incorporated into one unit. Since most commercial compactors are single-mode design, there is very little technical information available on dual-mode compaction. In order to establish the performance capabilities of the compactors and operating guidelines for Military operators, a study which includes full-scale field testing was initiated in 1977 by the Project Manager's Office.

2. Compaction Study. Phase I of the compaction study begins with introductions to the FAMECE compactors and water distributor. The instrumentation systems and data forms are then presented. The rationale behind the choice of the test soils and soil characteristics is discussed, followed by the test objectives and procedures. Finally, suggestions are made for moving into Phase II.

Phase II will present the field test program; data reduction and analysis; conclusions on instrumentation reliability and compactor performance; and recommendations for the effective use of the FAMECE compactors and the new Army Soil Test Set.

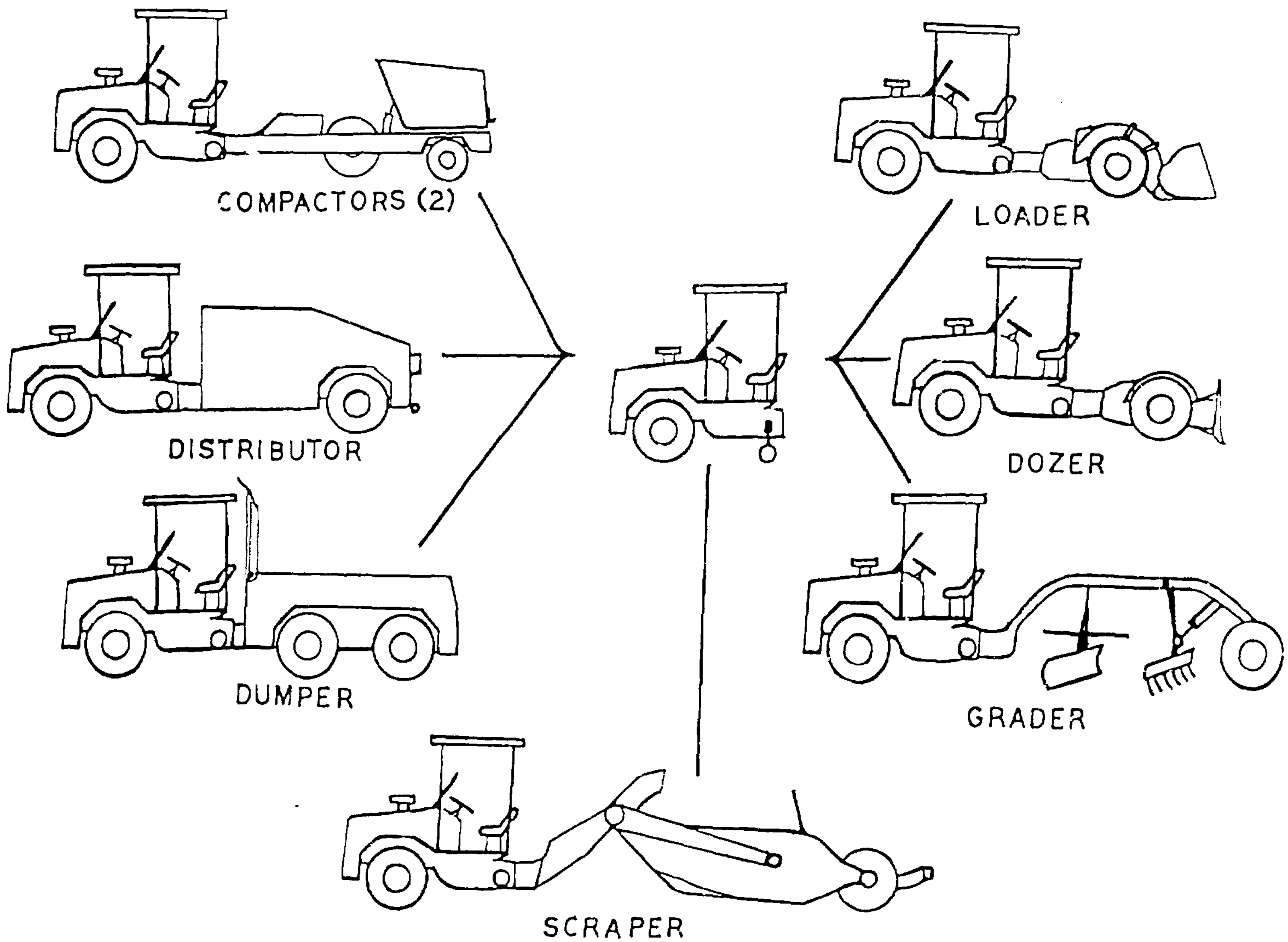


Figure 1. Family of Military Engineer Construction Equipment (FAMECE).

II. FAMECE COMPACTION EQUIPMENT

3. Compactor Descriptions. There are two compactors in the family of construction equipment: the tamping-foot/pneumatic-tire compactor, hereafter called compactor (TF), and the smooth-drum/pneumatic-tire compactor, hereafter called compactor (SD). Each machine is designed with two compacting axles which can be used in single-, dual-, or alternating-mode compacting. The compactors feature a rapid load/unload ballast capacity of 18,000 lb. Ballast will normally be composed of local soil material and can be loaded with the FAMECE 2½-yd^3 loader.

When fully ballasted, the compactors can be run in the pneumatic-tire mode or dual mode without stability problems. However, the intermediate axles should not be used in single-mode compaction when the machine is fully ballasted. Thus, the intermediate axle, single-mode tests will be run in the unballasted or half-ballasted condition. In convoy operations, the intermediate tamping-foot and smooth-drum axles are raised, and the equipment can reach speeds in excess of 30 mi/h. This configuration is also used for pneumatic-tire compaction at speeds of 3 to 6 mi/h. The compactor (TF) is shown attached to the power unit in Figure 2 and the compactor (SD) is shown likewise in Figure 3. Several design parameters common to both compactors are given in Table 1.

The compactor (TF) has a power-driven tamping-foot axle and is best suited for compaction of fine-grained, cohesive soils. For this type of soil, changes in volume due to changes in environmental conditions are important. For clay soils, the percent swell decreases with increasing moisture content until it becomes relatively constant at moisture contents greater than optimum. Wet-of-optimum compaction results in a less random particle orientation, a lower consolidation rate, lower permeability, and less sensitivity to change. In the event that the in-situ moisture content is much greater than optimum, lime stabilization may be required.

It should be noted that dry-of-optimum clay compaction does have several advantages. It results in lower pore water pressure, quicker compaction, and higher initial strength. The advantage of higher strength is lost after saturation. The actual compaction procedure will be decided on by the field engineer after the soil type, moisture content, and in-situ density have been determined. Figures 4, 5, and 6 show the compactor (TF) dimensions and surface contact dimensions for tamping-foot and dual-mode compaction. Table 2 gives tamping-foot parameters.

The compactor (SD) has a smooth, steel drum which can be used statically or in vibratory compaction, the dynamic force being produced by internal rotating eccentric weights. The vibrating frequency is related to engine and travel speeds and is controlled by a hydraulic motor located above the axle. (The drum axle is not power-driven.) Water supply tanks for the drum are located forward of the drum axle toward the power unit.

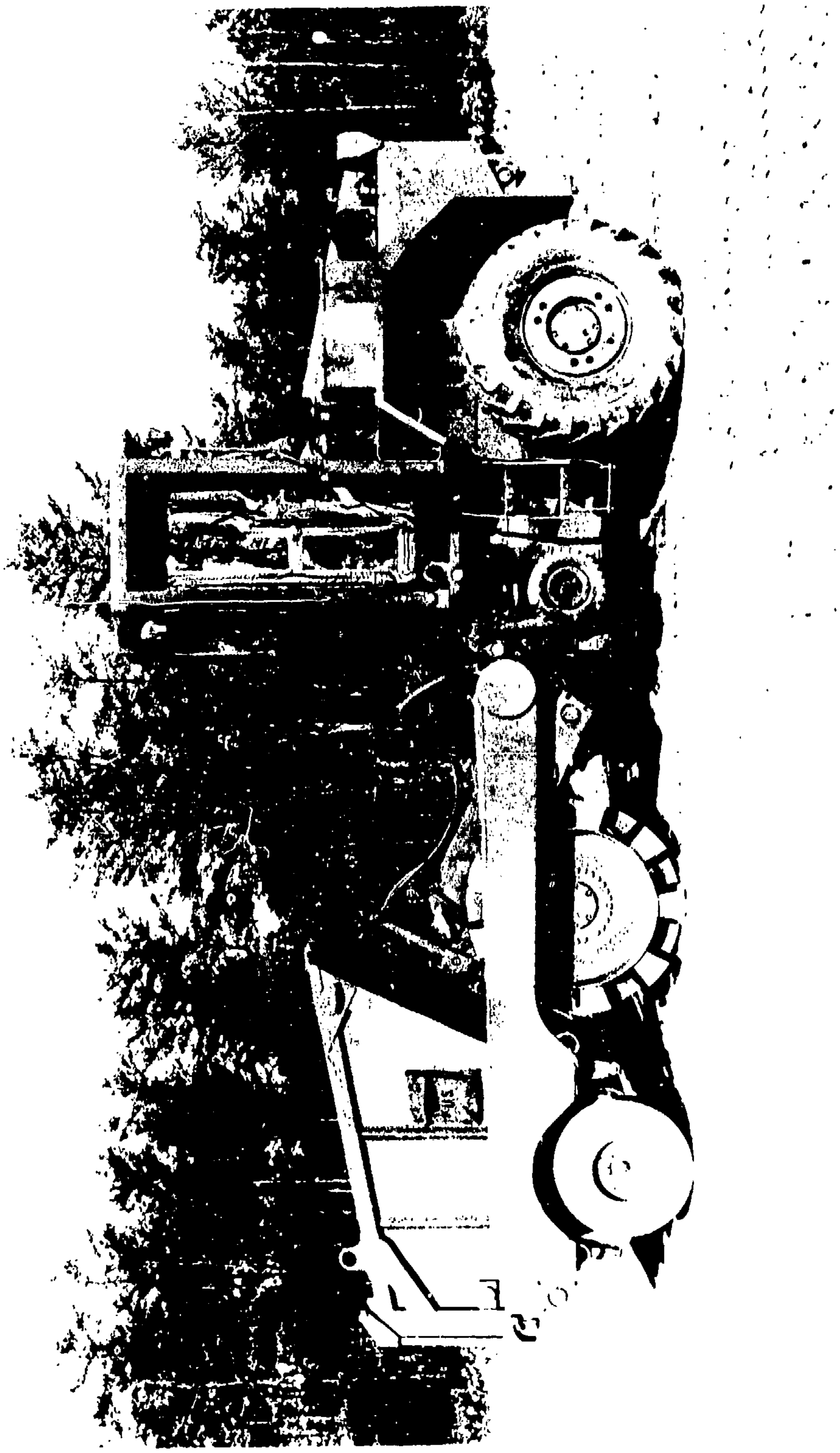


Figure 2. FAMECE compactor (TF).

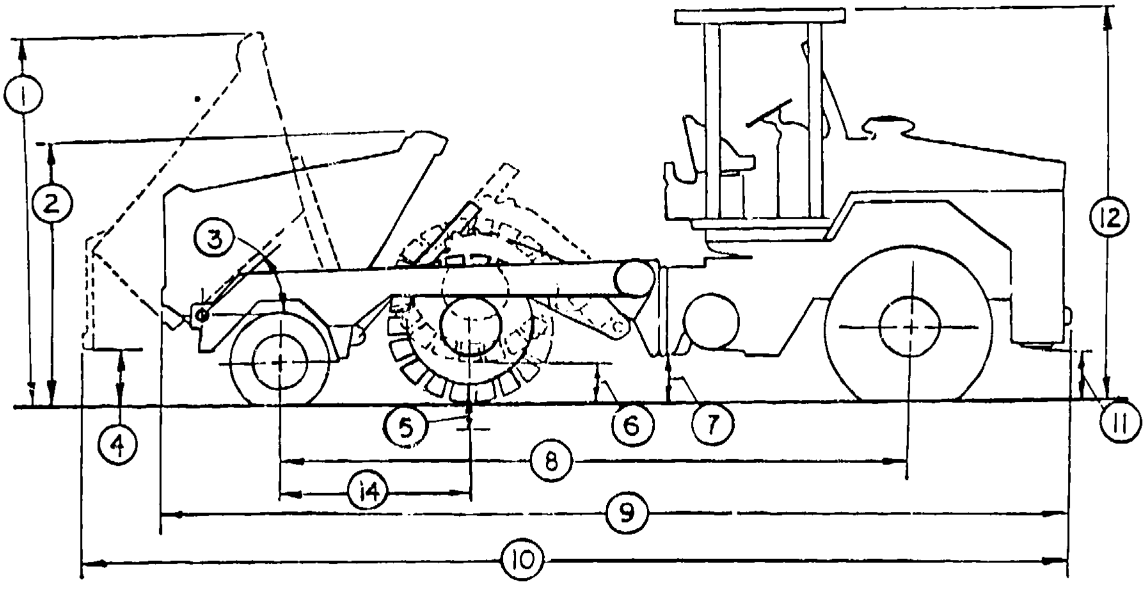
Figure 3. FAMECE compactor (SD).

Table 1. FAMECE Compactor Design Parameters

Parameter	Compactor (TF)	Compactor (SD)
Maximum Speed (mi/h)		
1st gear	4.8	4.8
2nd gear	9.9	9.9
3d gear	19.4	19.0
3d gear (Lock-Up)	22.5	22.0
4th gear	28.0	27.5
4th gear (Lock-Up)	33.4	33.0
Ballast Box Capacity (yd^3)		
Struck	4.9	4.9
Heaped	6.0	6.0
Empty Weight with Power Section & ROPS (lb)	31,120	32,490
Fully Ballasted Weight with Power Section, ROPS & 18^k Ballast (lb)	49,120	50,490
Weight Distribution with Power Section & ROPS (lb)		
No Ballast	Tamping-Foot Mode:	Steel-Drum Mode:
	Front Axle – 13549	Front Axle – 14052
	T. F. Axle – 17571	S. D. Axle – 18438
	Total 31,120	Total 32,490
No Ballast	Pneumatic-Tire Mode:	Pneumatic-Tire Mode:
	Front Axle – 18,920	Front Axle – 19,688
	P. T. Axle – 12,200	P. T. Axle – 30,740
	Total 31,120	Total 50,428
Fully Ballasted	Pneumatic-Tire Mode:	Pneumatic-Tire Mode:
	Front Axle – 19,030	Front Axle – 19,750
	P. T. Axle – 30,090	P. T. Axle – 30,740
	Total 49,120	Total 50,490
Number Pneumatic Tires	8 tube type	8 tube type

Table 1. FAMECE Compactor Design Parameters (Cont'd)

Parameter	Compactor (TF)	Compactor (SD)
Pneumatic Tire Size	7.50 x 15	7.50 x 15
Tire Pressure Range (lb/in.^{2})	50–100	50–100
Maximum Tire Load (lb)		
At Working Speed	3825 each	3750 each
At Convoy Speed	1500 each	1420 each
Overall Tire Spacing (in.)	100¾	100¾



DIMENSIONS

1.	Raised Ballast Box Height	120-1/4 in.
2.	Lowered Ballast Box Height	82 in.
3.	Raised Ballast Box Angle	49°
4.	Tailgate Clearance	14-1/4 in.
5.	Maximum Drum Depth	11 in.
6.	Maximum Raised Drum Height	14-1/2 in.
7.	Coupler Ground Clearance	15-1/4 in.
8.	Wheel Base	185-1/4 in.
9.	Overall Length (Lowered Ballast Box)	270-1/2 in.
10.	Overall Length (Raised Ballast Box)	304 in.
11.	Fuel Tank Clearance	25-7/8 in.
12.	ROPS Height	127 in.
13.	Overall Vehicle Width	105 in.
14.	Distance Between Compacting Axles	56 in.

Figure 4. FAMECE compactor (TF) dimensions.[1]

---

[1] Clark Equipment Company, Construction Machinery Division. *FAMECE Tamping Foot Compactor, Research and Development Acceptance Tests Final Report C-517x 304.* Report to US Army Mobility Equipment Research and Development Command, April 1978.

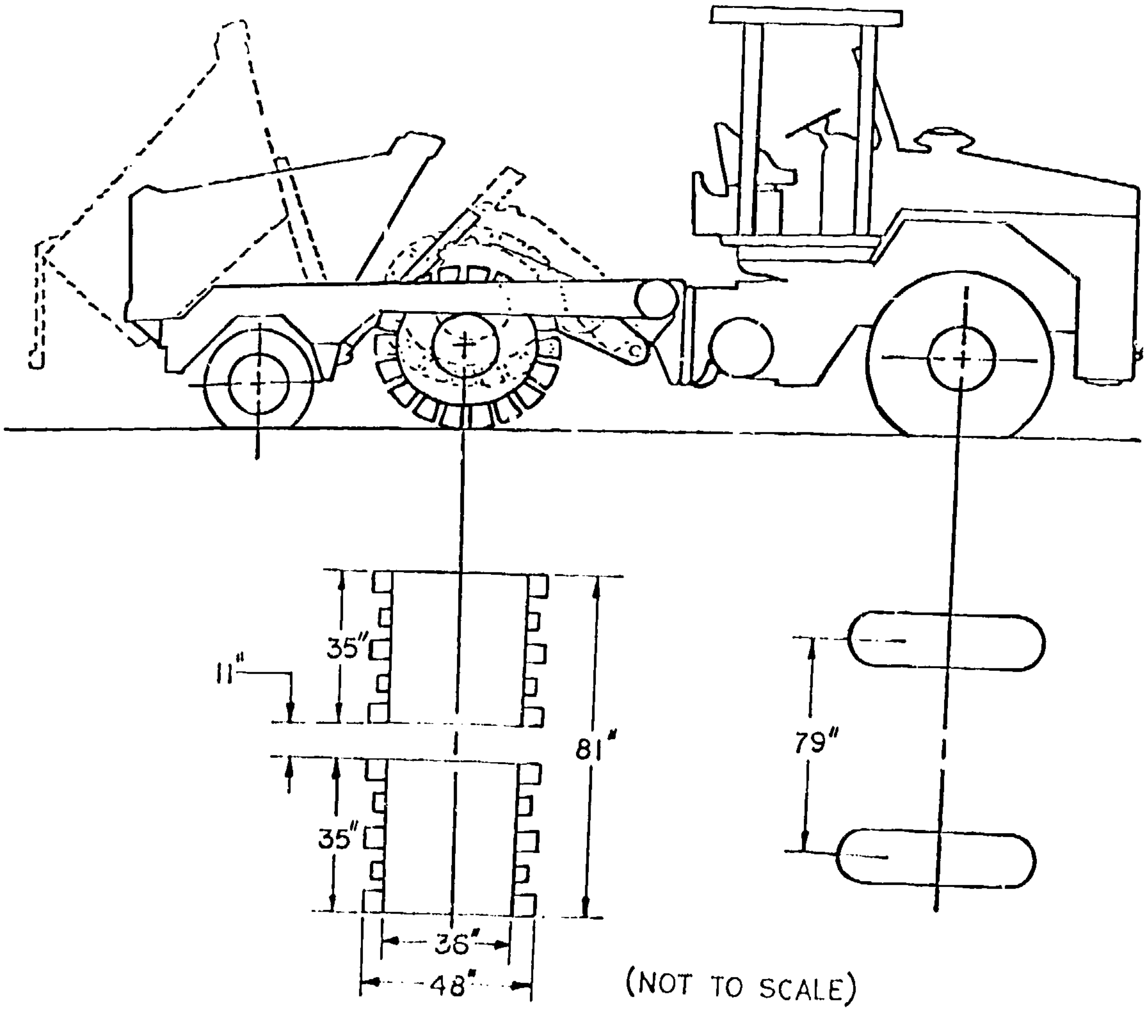


Figure 5. FAMECE tamping-foot compaction surface contact dimensions.

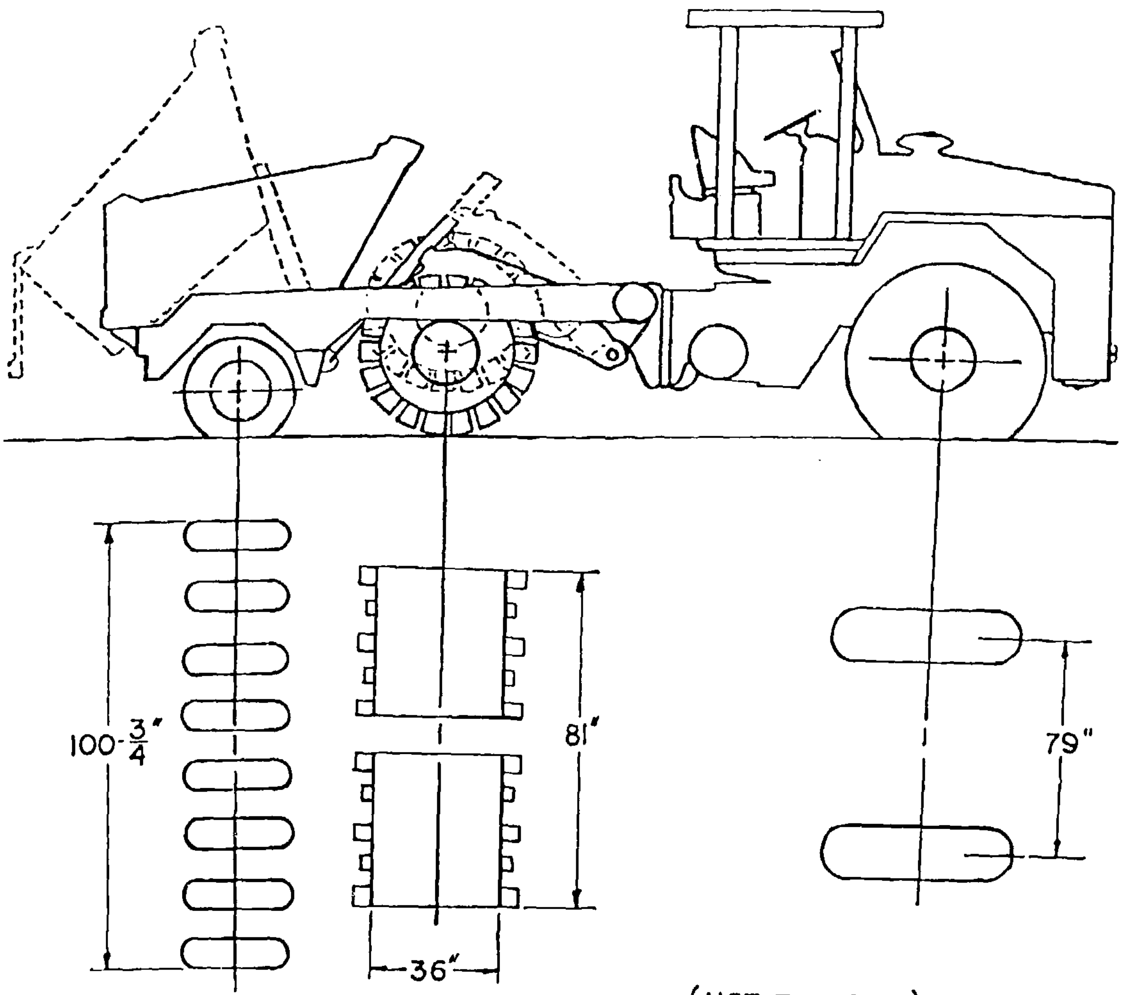


Figure 6. FAMECE compactor (TF) dual-mode surface contact dimensions.

Table 2. Compactor (TF) Parameters[2]

Parameter	Amount
1. Number of Tamping Feet:	45 per drum 90 total
2. Weight on Compacting Axle:	8785 lb per drum 17,570 lb total
3. Feet per Row:	3 & 2, alternating
4. Length of Tamping Foot:	6 in.
5. Tamping-Foot Configuration:	Rectangular
6. Foot Contact Area:	21.0 in.^{2} (nominal) 21.9 in.^{2} (measured)
7. Foot Contact Pressure:	138 to 209 lb/in.^{2}
8. Effective Rolling Diameter:	48 in.
9. Contact Area Ratio:	17 percent
10. Nominal Rolling Width:	81 in.
11. Total Foot Area/Drum Area:	24 percent
12. Weight per Unit Width:	217 lb/in.

[2] E. T. Selig and J. Hussein, *Evaluation of FAMECE Tamping Foot Roller.* Report to US Army Mobility Equipment Research and Development Command, July 1978.

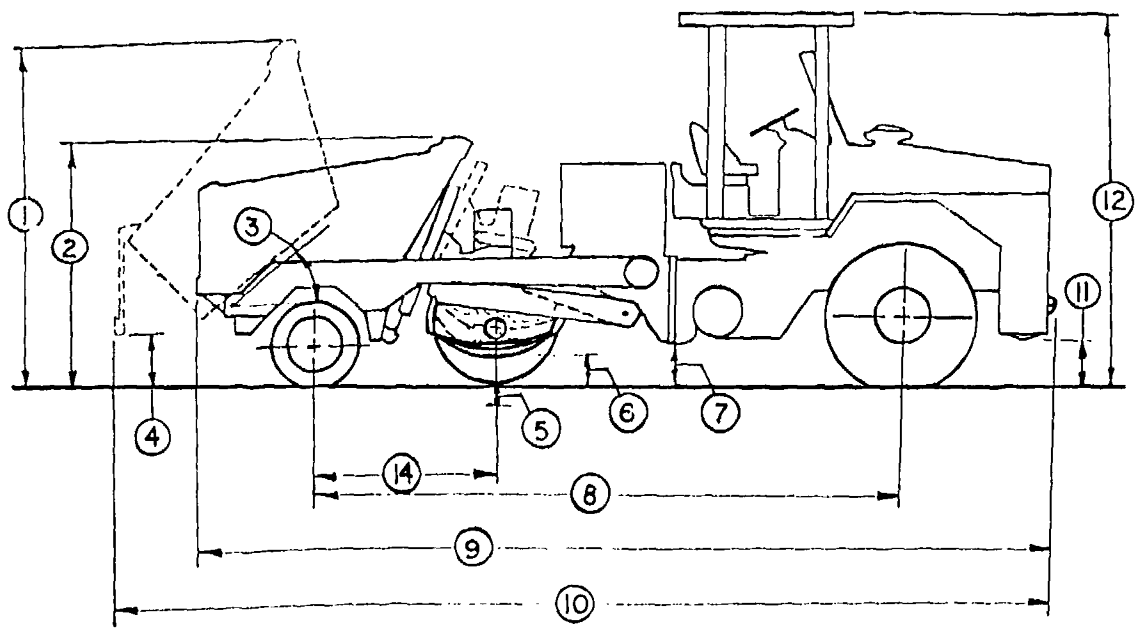
The compactor (SD) is best suited for the compaction of non-cohesive, granular soil and bituminous (asphaltic) concrete. Static rolling achieves compaction from the surface downward; this tends to seal the surface and prevent maximum exhaustion of air voids. Vibratory rolling achieves compaction from the base of the lift to the surface, resulting in more uniform density and enabling higher lift applications. Figures 7, 8, and 9 show the compactor dimensions and surface contact dimensions for vibratory smooth-drum and dual-mode compaction Table 3 gives smooth-drum parameters.

The pneumatic-tire axles on the compactors serve several purposes. They are used in convoy as well as in compaction of subgrade and bituminous concrete surfaces. The eight tires are arranged in four pairs on independently acting axles. The oscillation of the tires allows the compacting effort to follow the ground contour and assures the compaction of soft spots left in the subgrade and pavement due to the bridging action of the smooth drum. Figure 10 shows the surface contact dimensions for pneumatic-tire compaction. Table 4 gives pneumatice-tire parameters.

4. Water Distributor Description. Soils are most efficiently compacted at optimum moisture content and will often need additional water. Thus, the FAMECE water distributor will play a major role in field compaction efforts. It will be used in conjunction with field moisture measuring devices to achieve the moisture content specified by the field engineer.

When natural strata and existing fills are to be compacted, the engineer must choose the compaction method to suit conditions. In some cases, drainage may be needed as opposed to adding water, and the engineer will have to use the soil in its existing condition. When soil from a borrow pit is used as fill, moisture is added most effectively at the borrow site. If clays are present at the borrow site in significant amounts, and the moisture content is not close to optimum, the engineer may again be compelled to use the soil in its existing condition.

The distributor (Figure 11) has a tank capacity of 2527 gallons which can be loaded with an internal, self-priming pump in less than nine minutes. It can distribute the water through one spray head, two spray heads, or a gravity feed. The spray is adjustable from 20 to 70 ft in width, while the gravity feed has a constant width of nine feet. Figure 12 shows the distributor dimensions. Table 5 gives distributor parameters. Spray rates and coverages are given in the Appendix.



DIMENSIONS

1.	Raised Ballast Box Height	123-3/4 in.
2.	Lowered Ballast Box Height	87 in.
3.	Raised Ballast Box Angle	48°
4.	Tailgate Clearance	16 in.
5.	Maximum Drum Depth	8 in.
6.	Maximum Raised Drum Height	14-3/4 in.
7.	Coupler Ground Clearance	15-1/4 in.
8.	Wheel Base	185 in.
9.	Overall Length (Lowered Ballast Box)	274 in.
10.	Overall Length (Raised Ballast Box)	302-1/2 in.
11.	Fuel Tank Clearance	20-5/8 in.
12.	ROPS Height	128-1/2 in.
13.	Overall Vehicle Width	105 in.
14.	Distance Between Compacting Axles	56 in.

Figure 7. FAMECE compactor (SD) dimensions.[3]

[3] Clark Equipment Company, Construction Machinery Division. *FAMECE Smooth Drum Compactor, Research and Development Acceptance Tests Final Report C-561x 304.* Report to US Army Mobility Equipment Research and Development Command, April 1978.

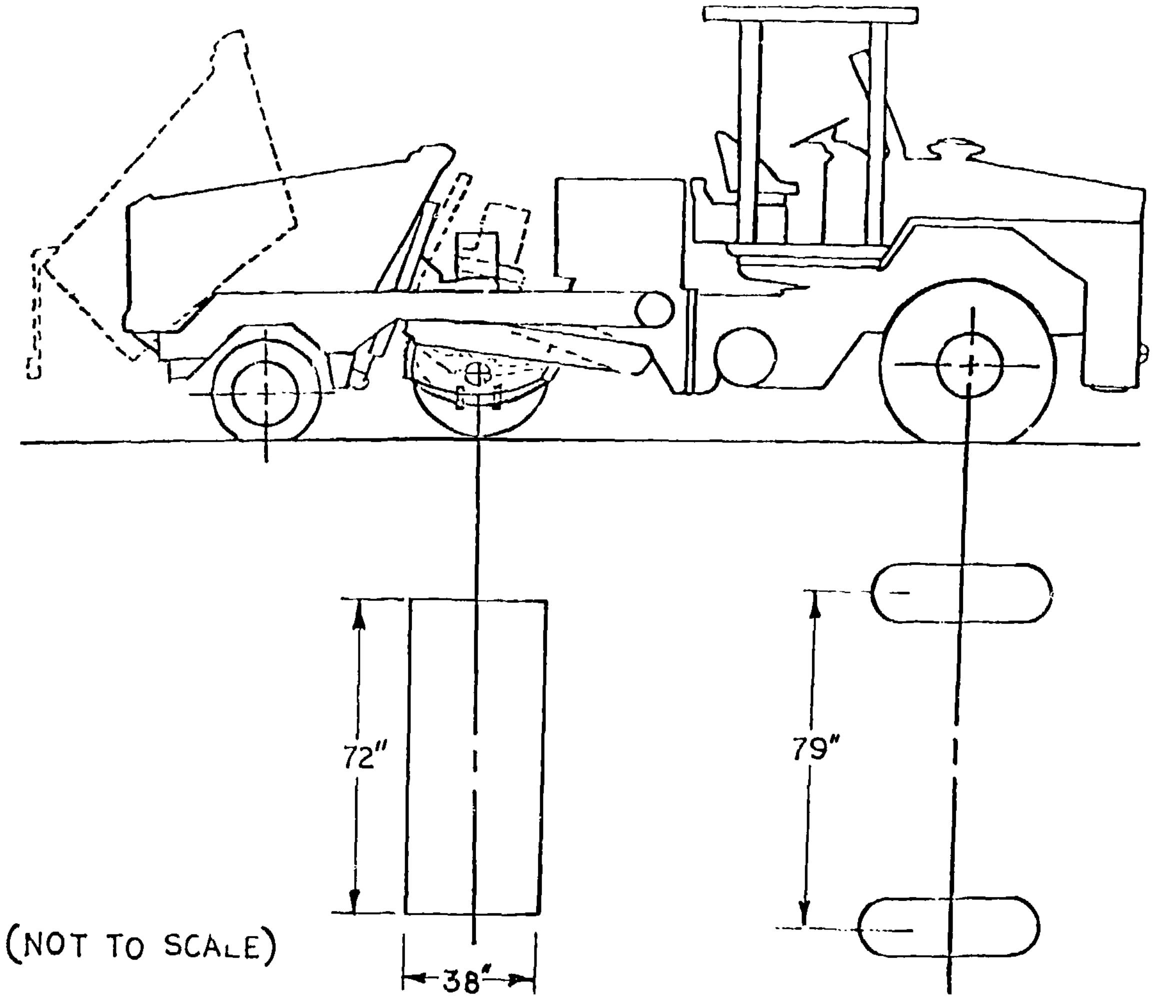


Figure 8. FAMECE vibratory steel-drum compaction surface contact dimensions.

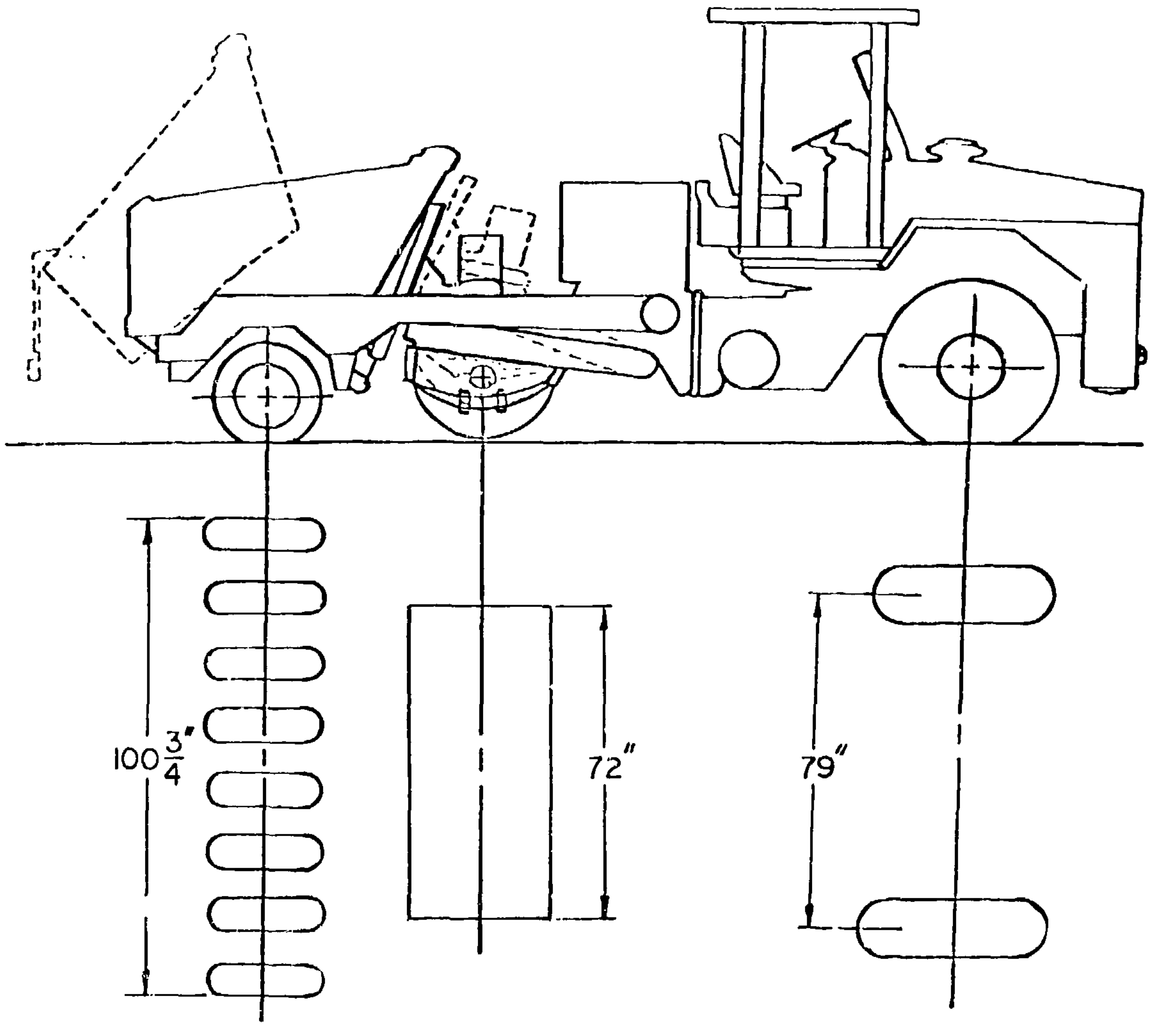


Figure 9. FAMECE compactor (SD) dual-mode surface contact dimensions.

Table 3. Compactor (SD) Parameters.[4]

Parameter	Amount
1. Weight on Compacting Axle	
Motor & Hood Assembly:	1,700 lb
Drum & Axle:	2,600 lb
Compactor on Axle:	14,138 lb
Total	18,438 lb
2. Generated Dynamic Force:	21,000 lb } at 1400 r/min
3. Transmitted Dynamic Force:	28,800 lb } at 1400 r/min
4. Eccentic Moment:	447 lb-in.
5. Normal Vibrating Frequency:	1300–1400 vibrations/min.
6. Static Linear Drum Weight on Ground (No Ballast):	245 lb/in.
7. Compacting Speed:	4.6–4.8 mi/h
8. Operating Speed/Frequency	3.6–3.9 in./vibration
9. Drum Diameter:	38 in.
10. Drum Width:	72 in.

4 E. T. Selig and J. Hussein, *Evaluation of FAMECE Static and Vibratory Smooth Wheel Roller.* Report to US Army Mobility Equipment Research and Development Command, July 1978.

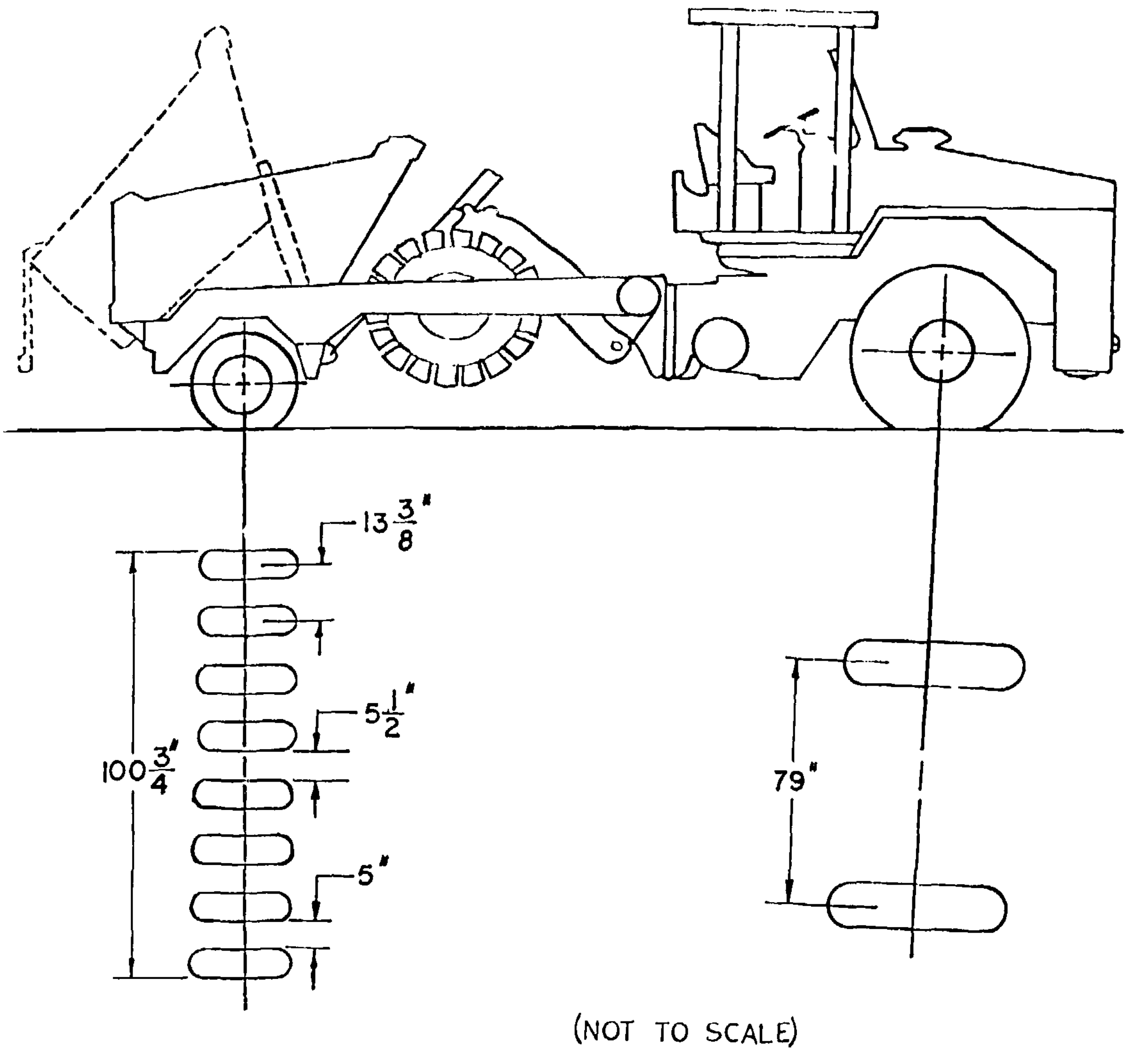


Figure 10. FAMECE pneumatic-tire compaction surface contact dimensions.

Table 4. FAMECE Pneumatic-Tire Compactor Parameters[5]

Parameter	Amount
1. Weight on Compacting Axle	
No Ballast:	12,501 lb average
18,000 Pounds Ballast:	30,415 lb average
2. Compacting Pneumatic Tires	
Number:	8 single axle
Size:	7.50 x 15
Inflation Pressure:	100-lb/in.^{2}
3. Pneumatic Tire Soil Contact Pressure:	87 lb/in^2 (Approximately)
4. Center to Center Wheel Spacing:	13.38 in.
5. Static Vertical Force per Unit Width:	
No Ballast:	121–127 lb/in.
18,000 Pounds Ballast:	299–305 lb/in.

5 E. T. Selig and J. Hussein, *Evaluation of FAMECE Pneumatic-Tire Roller.* Report to US Army Mobility Equipment Research and Development Command, July 1978.

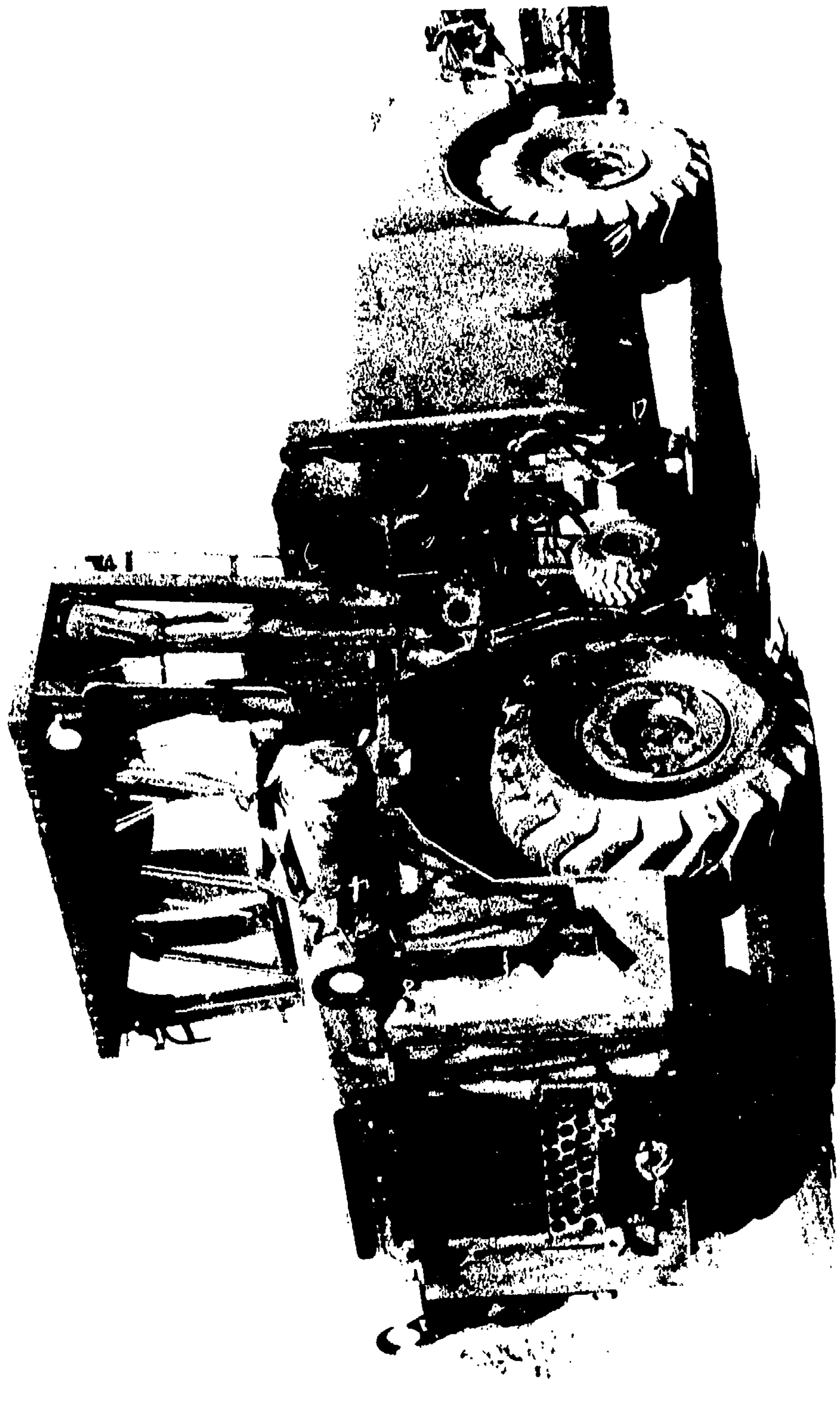
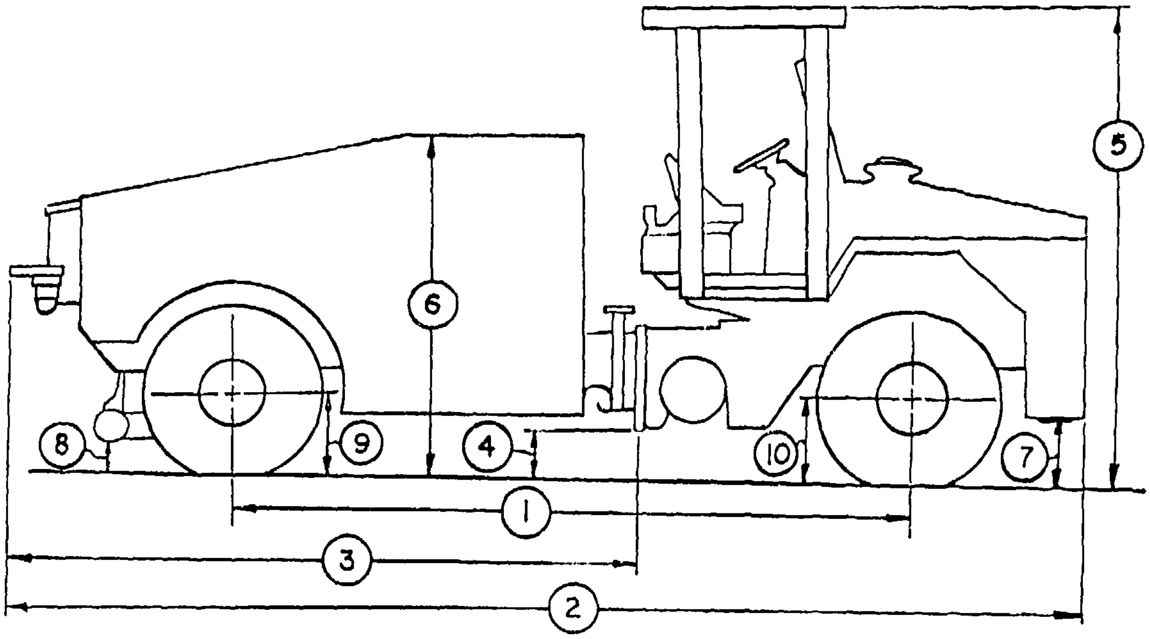


Figure 11. FAMECE water distributor.



DIMENSIONS

1.	Wheel Base		182-3/16 in.
2.	Vehicle Length		282-3/4 in.
3.	Distributor Section Length		162 in.
4.	Coupler Ground Clearance		14-3/4 in.
5.	Overall Height		127-1/2 in.
6.	Distributor Section Height		90-3/4 in.
7.	Fuel Tank Ground Clearance		19-1/8 in.
8.	Gravity Spray Bar Ground Clearance		14-7/8 in.
9.	Empty R.R.	Front:	23-3/4 in.
		Rear:	23-7/8 in.
10.	Loaded R.R.	Front:	23-1/4 in.
		Rear:	22-5/8 in.
11.	Maximum Width		103 in.

Figure 12. FAMECE water distributor dimensions.[6]

[6] Clark Equipment Company, Construction Machinery Division. *FAMECE Distributor RDAT Final Report C-591-304.* Report to US Army Mobility Equipment Research and Development Command, April 1978.

Table 5. FAMECE Distributor Parameters[7]

Parameter	Amount
1. Tank Capacity	2,527 gal.
2. Distributor Weight	
Empty	13,320 lb
Loaded	34,320 lb
3. Maximum Speeds (empty, level surface)	
4th gear	27 mi/h
4th gear lock-up	33.5 mi/h
4. Loading Time Requirements	
Remove/connect hoses	1 min 25 s
Prime pump (internal)	3 min 15 s
Fill Tank (high idle)	5 min 10 s
Store hoses	1 min 35 s
5. Average Turn Radius	28 ft
6. Fuel Capacity (power unit)	71 gal.
7. Travel Capacity	300 mi/tank
8. Work Capacity	15.6 h/tank.

[7] Clark Equipment Company, Construction Machinery Division. *FAMECE Distributor RDAT Final Report C-591-304.* Report to US Army Mobility Equipment Research and Development Command, April 1978.

III. INSTRUMENTATION

5. General. Soil response can be measured by numerous methods, usually with a trade-off between the time required to obtain data and the accuracy obtained. The most significant soil parameters for compaction are soil type, lift thickness, and moisture content. These parameters constitute the soil variables for all single-mode tests. Soil type and lift thickness will be varied according to the test procedure as the test strips are constructed. The soil moisture content will be measured by the instrumentation. The soil density, a function of moisture content, soil type, and compactive effort, will also be measured.

In order to obtain sufficiently high confidence intervals for the final results, a large amount of data will be recorded. In devising the instrumentation systems, the following criteria were borne in mind:

a. The system should provide a range of measurement techniques to sufficiently represent the soil properties affecting compactor performance.

b. The techniques and procedures used should be accepted by the profession.

c. Measurement time should be minimized.

d. The systems must consist of standard Army field equipment except for three accelerometers to be used for frequency measurements during the vibratory-smooth-drum tests.

e. The data should overlap for analysis purposes.

The instrumentation systems chosen to meet the above requirements are:

- Nuclear moisture-density meter — used to rapidly measure wet density and moisture content. Dry density can be determined from these quantities.

- Sand-cone density apparatus — used to measure the volume of field samples as they are taken. The volume is used to determine wet and dry densities.

- Soil penetrometer — used to measure the bearing capacity of a soil. The data consist of the force required for a penetration depth of ¼ inch.

- Field laboratory equipment — standard Army soils test set will be used for determining soil type, gradation, moisture content, and density. Sand-cone apparatus and penetrometer are part of this set.

- Accelerometers — used to measure vibratory compactor accelerations at key locations to give data on frequency-versus-compactor efficiency.

All instrumentation systems will be used for single-mode tests. For dual-mode tests, only the nuclear meters will be used. The systems are described below.

6. **Nuclear Moisture-Density Meter.** This field instrument measures the in-situ density and moisture content of a soil. The biggest advantage of this gauge is the relatively short time required for results. Older methods require lengthy oven drying of the soil to determine the dry density and, thus, cannot give the field engineer immediate compaction results. Nuclear testing devices are being accepted commercially as more experience is gained with them. One drawback of these machines is that they must be calibrated for the materials they will be used with, particularly for density measurements.

For density, the nuclear method is based upon a source which emits gamma rays (photons) into the soil and a detector which measures the radiation intensity at a set distance from the source. For a given geometry, the intensity (count) should depend only on the absorption capacity of the soil. A calibration curve is used to convert the count to a wet density value. The calibration curve is essentially a straight line on semi-log paper. The measurement of density by the nuclear method is covered by standard ANSI/ASTM D 2922-78.

For moisture, the nuclear method is based upon a source which emits fast neutrons into the soil and a detector for slow neutrons. The decrease in energy of the neutrons is due almost exclusively to the collision of the neutrons with the nucleus of hydrogen, a proton of approximately equivalent mass. Nearly all hydrogen in a soil is bound in water molecules so the slow neutron count is an accurate measure of soil moisture content. A plot of moisture content is essentially a straight line on standard plot paper. Measurement of moisture content by the nuclear method is covered by standard ANSI/ASTM D 3017-78.

Moisture and density are two completely different phenomenon, with the nuclear source being the only common factor. The calibration curves for density and moisture are easy to make and are readily adjusted to field conditions. Proper use of the equipment and curves requires technical training and certification. Once the operator is trained, the nuclear meter will give consistent, fast, and accurate data with a minimum of operator error. These constitute the major advantages of nuclear testing devices.

There are two nuclear test methods. The backscatter method is used with the source and detector both at the soil surface, while the direct-transmission method has the source below the soil surface (Figure 13). A third method, the air-gap method, is now obsolete since the error involved with calcium soils (limestone) has been designed out of the machines. Early machines showed errors of as much as 15 lb/ft^3 with calcium soils.

The Army has about 200 nuclear meters which have been issued to the field engineering units, construction battalions, the Army Engineer School, and the National Guard. They are produced by Campbell Pacific Nuclear Corporation of Pacheco, California. The meter currently in use is the MC-1 Simultest with a Campbell part number M82AB-114 (MC-1). The meter registers both density and moisture counts and will be used as the primary instrumentation system for the FAMECE compaction study. Data will be taken at various depths in the soil mass, in accordance with the test procedure, and recorded on the data form shown in Figure 14.

7. Sand-cone Density Apparatus. This apparatus (Figure 15) is used to determine the volume of soil samples. The basic procedure is: excavate a soil sample (generally 4 to 14 $in.^3$); fill the excavation with a uniformly graded sand of known density (usually Ottawa sand); subtract the final apparatus weight and the known weight of the sand cone from the initial apparatus weight; this gives the weight of sand in the excavation, which is converted to volume. The wet density of the soil is found by dividing the sample weight by the volume. The in-place dry density is found in the same manner once the sample has been dried. The moisture content, in percent of dry density, can be determined by the following equation:

$$w = \frac{\gamma_w - \gamma_d}{\gamma_d} \cdot 100, \qquad \text{(Eq. 1)}$$

where w = moisture content

γ_w = wet density

and γ_d = dry density.

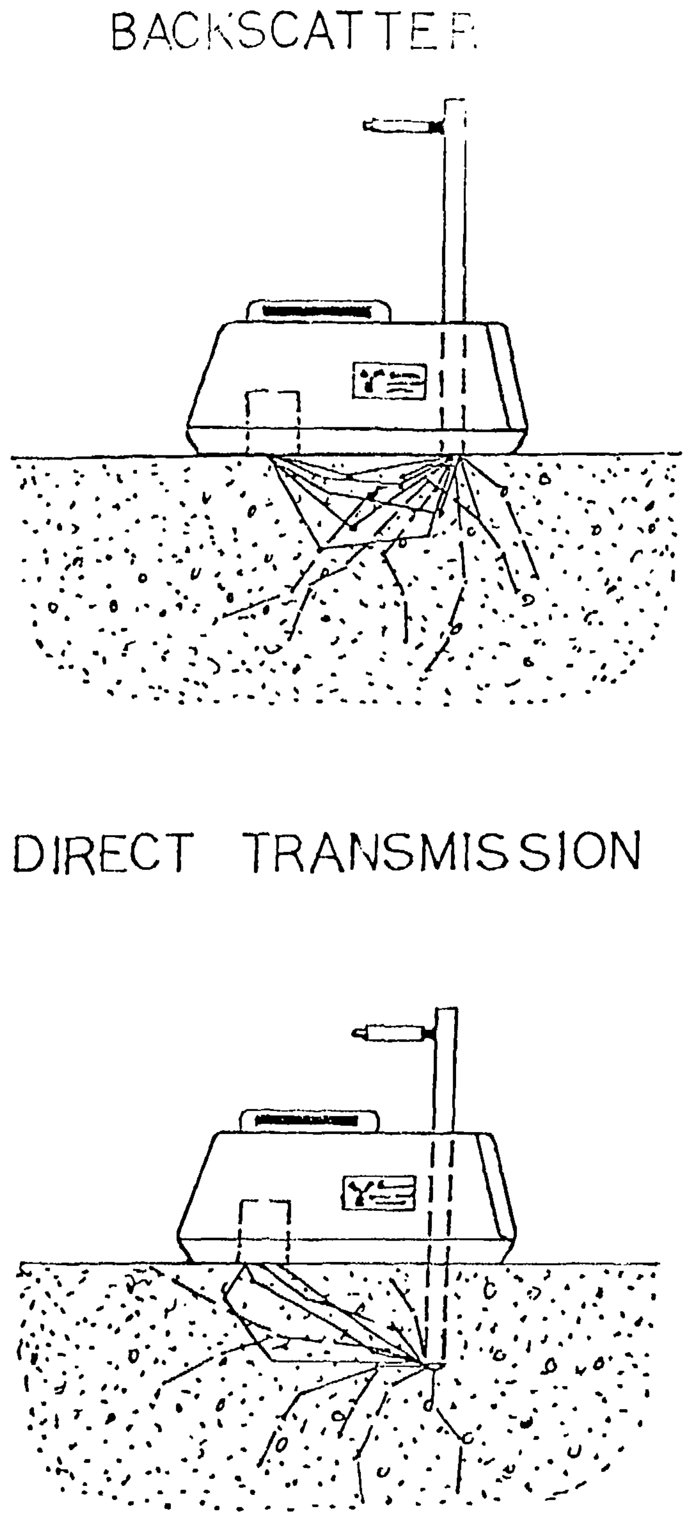


Figure 13. Nuclear moisture-density meter measurement techniques.

DENSITY DETERMINATION (NUCLEAR DENSOMETER)		Date
Project	Lift Thicknes	Type Dir Back
Location	w Range %- %	γ Range - PCF
Discription	w Standard 1	γ Standard 2

Station								
3 γ Count								
γ Count Ratio								
4 γw PCF (chart)								
5 w Count								
w Count Ratio								
6 w PCF (chart)								
7 γd (4-6)								
%w (6/7)x100								
Corrective Actions	Scarify							
	Aerate							
	Add H_2O							
	Compact							
	Retest							
Station								
3 γ Count								
γ Count Ratio								
4 γw PCF (chart)								
5 w Count								
w Count Ratio								
6 w PCF (chart)								
7 γd (4-6)								
%w (6/7)x100								
Corrective Actions	Scarify							
	Aerate							
	Add H_2O							
	Compact							
	Retest							

Remarks

γ Count Ratio = 3/2
w Count Ratio = 5/1

Technician	Computed by	Checked by

Figure 14. Data form, nuclear moisture-density meter.

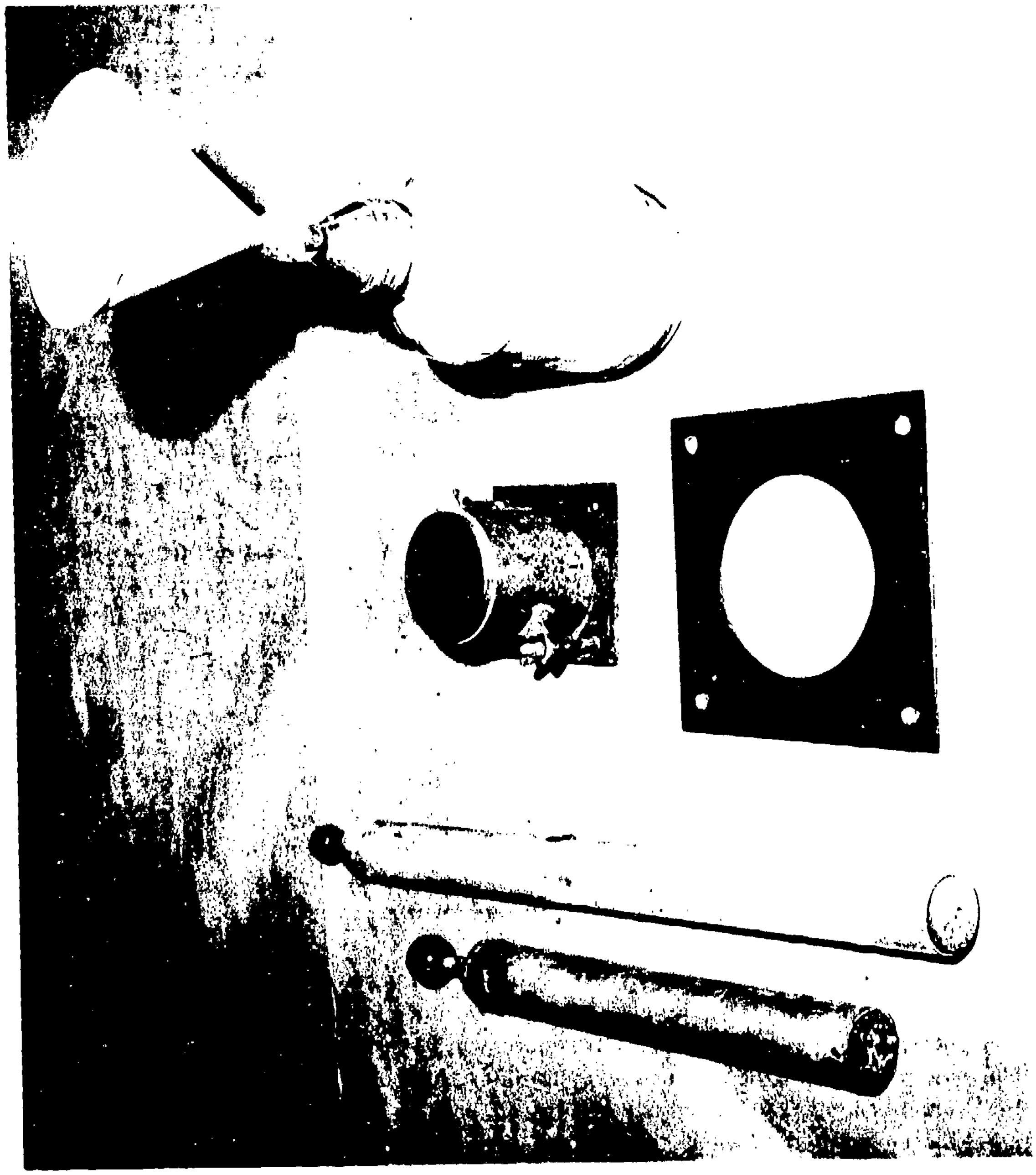


Figure 15. Sand-cone density apparatus.

The sand-cone apparatus chosen for the compaction study is model CN-992, manufactured by Soiltest, Inc., of Evanston, Illinois. This model is part of the Army Soil Test Set for field use. The sand-cone method is slow (about 30 min), and is more susceptible to operator bias than is the nuclear meter. In accordance with the test procedure, it will be used periodically to establish the performance of the apparatus in relation to other field equipment. The test method is covered by Standard ASTM 1556-64. The data will be recorded on the form shown in Figure 16.

8. Soil Penetrometer. When a cohesive soil is compacted dry-of-optimum, it has a high shear strength. This can be attributed to negative pore pressures (capillary pressure). Penetration resistance decreases as the optimum moisture content is approached, and continues to decrease for wet-of-optimum conditions. (The effective stress is reduced by increases in pore water pressure.) Compaction of a soil at moisture contents slightly dry-of-optimum often results in increased soil strength.

The penetrometer is used as a rapid, approximate measure of soil shear strength. The force required for penetration is an indicator of the soil bearing capacity. The equipments use is generally limited to fine-grained soils. The penetrometer chosen for the compaction study (Figure 17) is model CL-700, manufactured by Soiltest, Inc., of Evanston, Illinois. It has a foot adapter (CL-701) for low-shear-strength soils. It will be used in accordance with the test procedure and the results will be recorded in the form shown in Figure 18. The data will be taken at a depth of ¼ in. in tons/ft^2. If the foot adapter is used, the readings must be divided by sixteen.

9. Army Soil Test Set. This set of field equipment is used to perform a wide variety of soil tests. The particular equipment chosen for the compaction study include the sand-cone apparatus and the soil penetrometer described above. A set of sieves will be used to derive the gradation curves for the soils. Other equipment (rams, cylinders, etc.) will be used to derive the moisture-density curves. In addition, the test set includes an oven and a balance for drying and weighing the samples taken with the sand-cone apparatus. The newest set of equipment will be available in late 1980.

10. Vibration Analysis Apparatus. Three accelerometers will be used to measure the vibrating frequency of the smooth drum in order to establish frequency versus displacement curves for each soil. A strip chart recorder will be used to acquire the data. One accelerometer will be mounted on the drum-shaft bearing housing and will measure the drum vibration. The second one will be mounted on the hood assembly which supports the motor used to rotate the eccentric weights. The third accelerometer will be mounted on the frame and will measure the effectiveness of the leaf springs in isolating the vibration from the rest of the machine. These locations are shown in Figure 19.

UNIT WEIGHT DETERMINATION "VOLUME OF HOLE" METHODS		DATE
PROJECT	TEST SITE	SAMPLE NUMBER

"VOLUME OF HOLE"

	UNITS				
10. INITIAL WEIGHT OF APPARATUS + MATERIAL					
11. FINAL WEIGHT OF APPARATUS + MATERIAL					
12. WEIGHT OF MATERIAL RELEASED (10.-11.)					
13. WEIGHT OF MATERIAL IN HOLE (For oil, same as 12. For sand, 12.-9.) (9) 3.835 lb					
14. VOLUME OF HOLE (13./6.) (6) 136.8 pcf					

WATER CONTENT DETERMINATION

	UNITS						
TARE NUMBER							
15. WEIGHT WET SOIL & TARE							
16. WEIGHT DRY SOIL & TARE							
17. WEIGHT WATER (15.-16.)							
18. WEIGHT TARE							
19. WEIGHT DRY SOIL (16.-18.)							
20. WATER CONTENT ($\frac{17.}{19.}$ x 100)							
21. AVERAGE WATER CONTENT	PERCENT						

UNIT WEIGHT DETERMINATION

	UNITS			
TARE NUMBER				
22. WEIGHT WET SOIL & TARE				
23. WEIGHT TARE				
24. WEIGHT WET SOIL (22.-23.)				
25. WET UNIT WEIGHT (24./14.)	LB./CU. FT.			
26. DRY UNIT WEIGHT (25. x $\frac{100}{100+21.}$)	LB./CU. FT.			

REMARKS

TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)

Figure 16. Data form, sand-cone density apparatus.

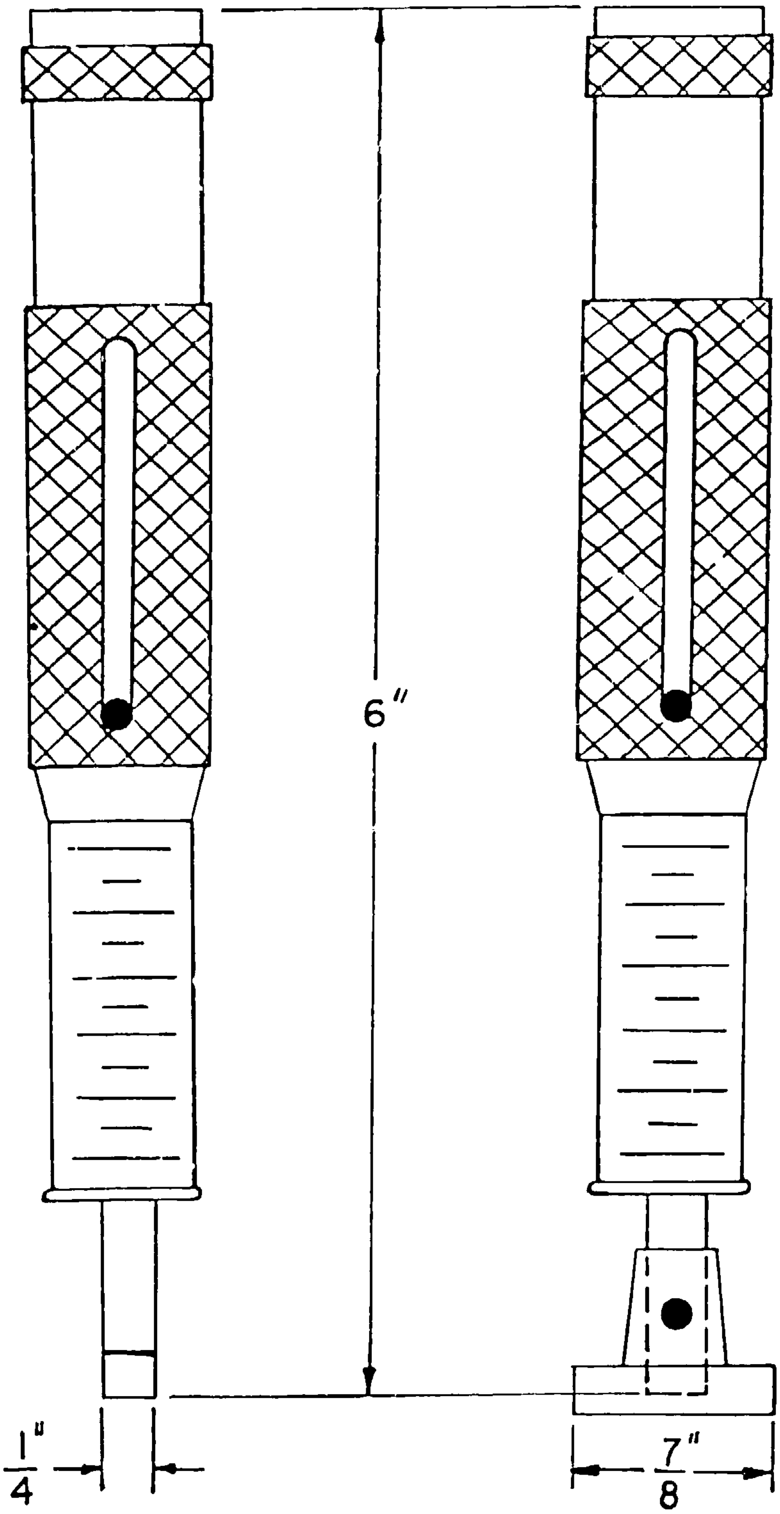


Figure 17. Soil penetrometer.

PROJECT	DATE
ADDITIONAL SPECIFICATIONS	

TEST NO.		CL-700 ☐	CL-701 ☐		
MEASURENT NO.	AFTER PASS NO.				
	INITIAL STATIC SD (tsf)	4 (tsf)	8 (tsf)	12 (tsf)	16 (tsf)
1					
2					
3					
4					
AVERAGE					

TEST NO.	CL-700 ☐	CL-701 ☐			
MEASURENT NO.	AFTER PASS NO.				
	INITIAL STATIC SD (tsf)	4 (tsf)	8 (tsf)	12 (tsf)	16 (tsf)
1					
2					
3					
4					
AVERAGE					

TECHNICIAN	COMPUTED BY	CHECKED BY

Figure 18. Data form, soil penetrometer.

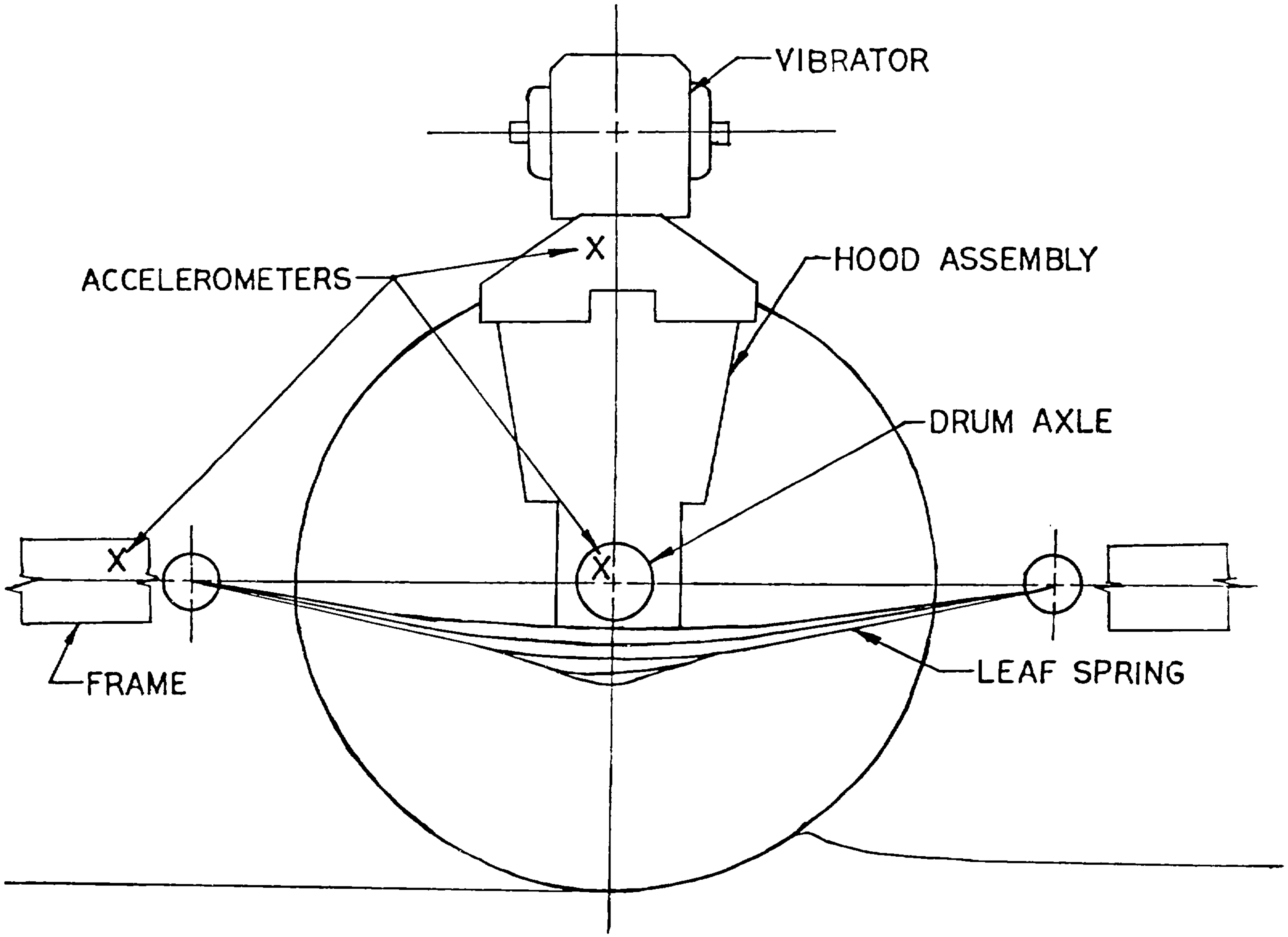


Figure 19. FAMECE smooth drum.[8]

[8] E. T. Selig, *Dynamic Analysis of FAMECE Vibratory Compactor.* Report to US Army Mobility Equipment Research and Development Command, March 1978.

Only the vertical displacements will be measured since the lateral displacements caused by the eccentric weights cancel one another. The vibrating frequencies and average peak-to-peak accelerations will be taken from the strip chart recorder. The average displacements can then be found from the following formula:

$$X = A/(2\pi F)^2 \qquad \text{(Eq. 2)}$$

where X = vertical displacement (in.)

A = acceleration (in./s²)

and F = frequency (cycles per s)

Typical accelerometer results are shown in Figure 20.

IV. TEST SOILS

11. Soil Types. Three soil types were chosen to represent the range of soils found in the field. They are classified according to the Unified Soil Classification System (USCS) and have dual-symbol classifications. The first is predominantly a coarse-grained gravel-sand-silt mixture and is designated GP/GM. The second soil type is a sandy silty clay and is designated SC/SM. The third is a clay of moderate plasticity. The Atterberg limits for this soil place it just inside the highly plastic range, but the clay will be designated CL/CH to denote moderate plasticity.

12. Soil Characteristics. Samples of the three soil types were analyzed with standard soils testing equipment. Sieve, or gradation, analyses were performed on the GP/GM and SC/SM soils. Atterberg limits were determined, which include liquid limit, plastic limit, and, if applicable, the plasticity index. T-99 AASHTO and T-180 Modified AASHTO compaction tests were performed to derive moisture-density curves. With this information, the soils were classified according to USCS.

The GP/GM soil type might be found in river basins, lateral and terminal moraines (glacial deposits), and elsewhere. The test soil was excavated from a borrow site on Fort Belvoir and hauled to the Fort Belvoir Proving Ground. The test soil, being a granular soil, is most effectively compacted with a vibratory roller. The gradation curve for this soil is given in Figure 21. The T-99 and T-180 curves are shown in Figure 22.

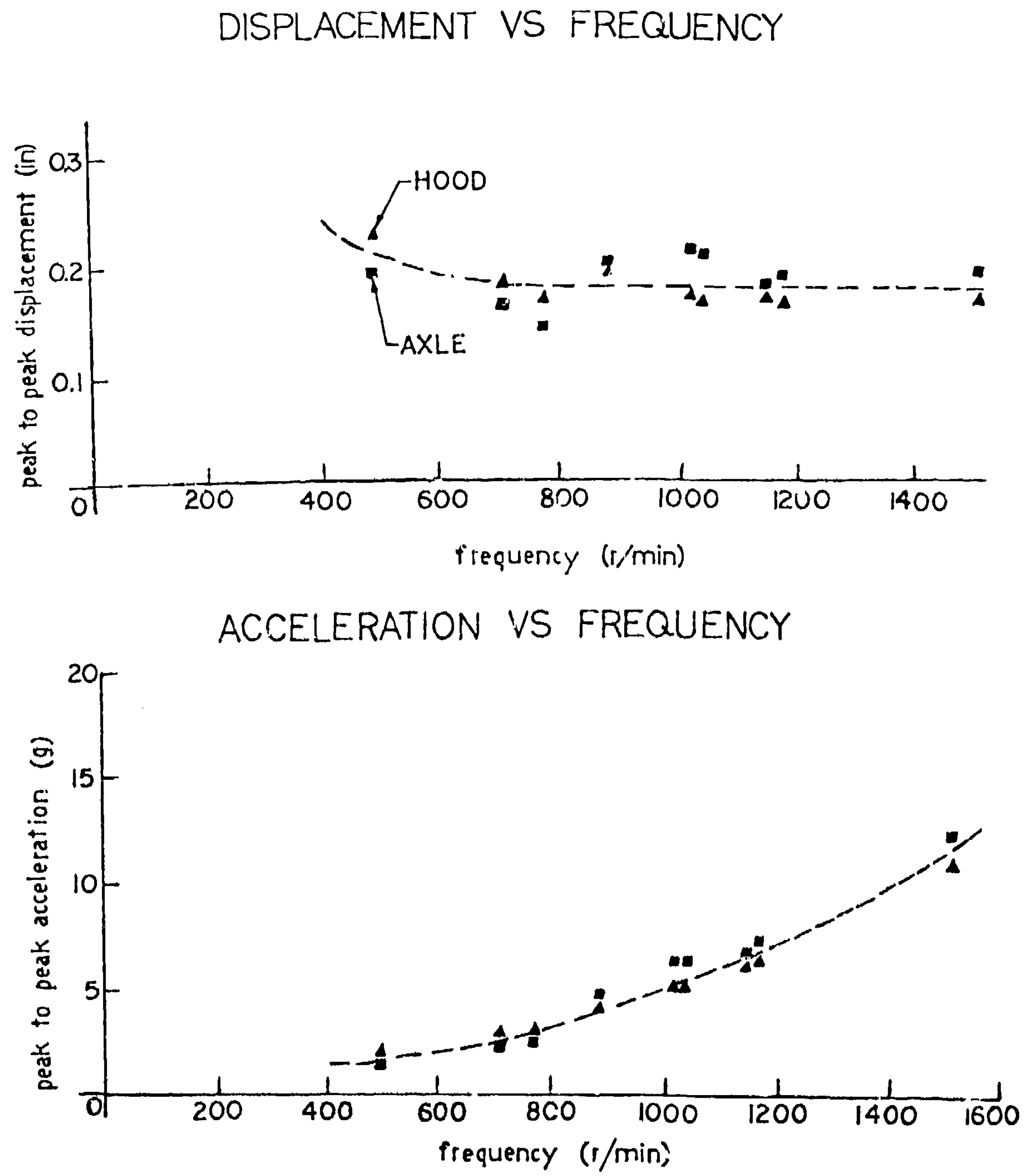


Figure 20. Typical accelerometer results.[9]

[9] E. T. Selig, *Dynamic Analysis of FAMECE Vibratory Compactor.* Report to US Army Mobility Equipment Research and Development Command, March 1978.

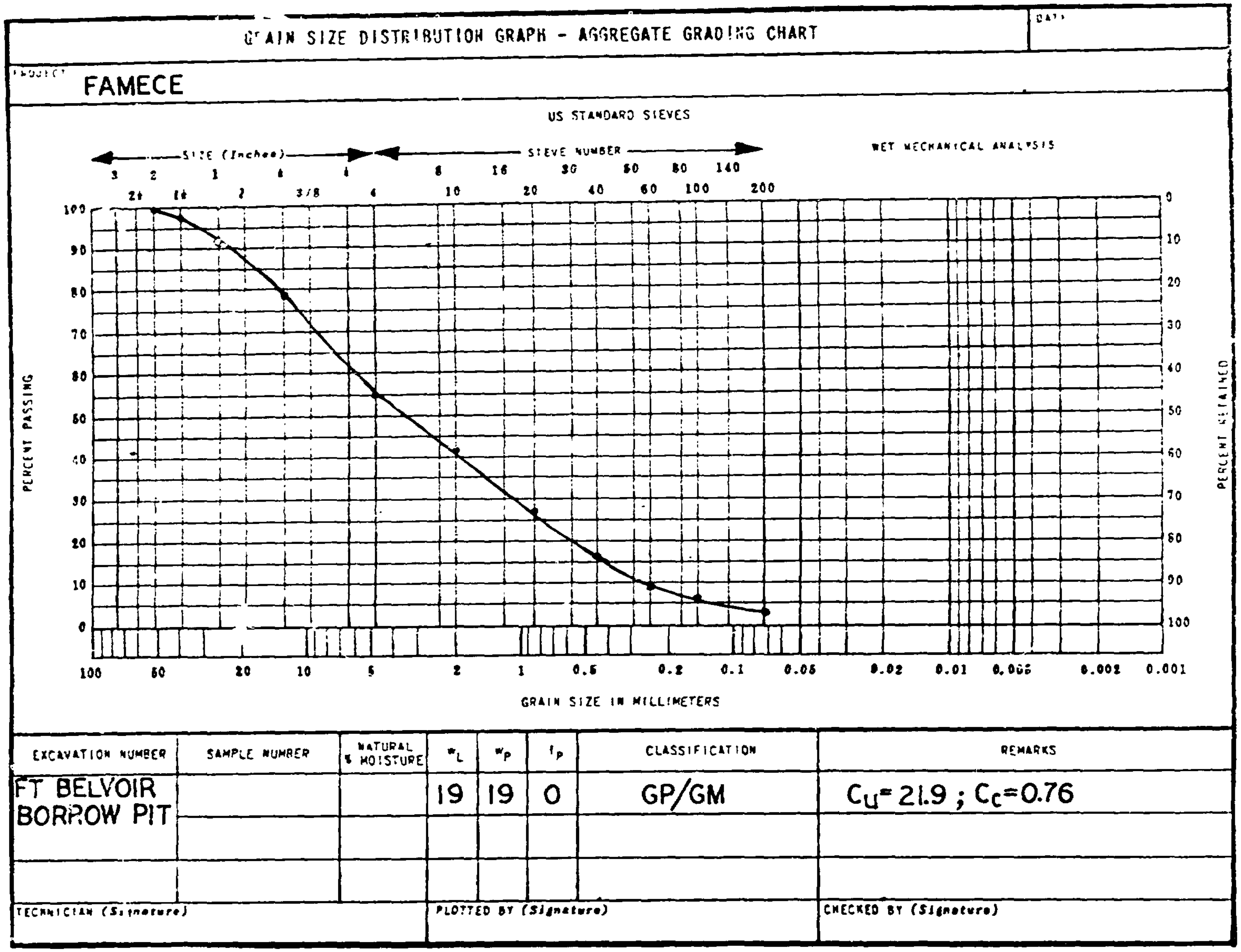


Figure 21. Gradation curve for GP/GM soil.

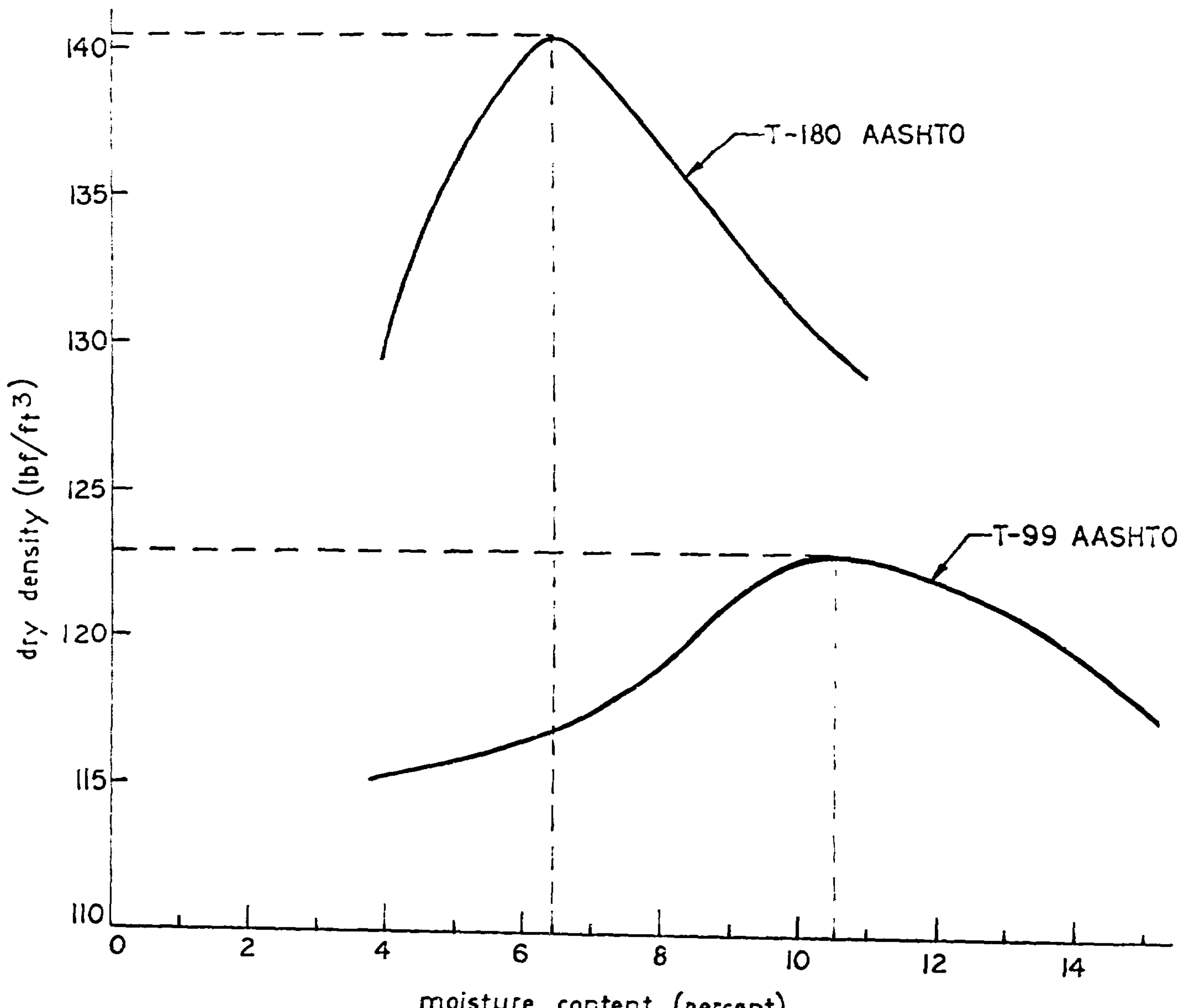


Figure 22. Laboratory moisture-density curves for GP/GM soil.

The SC/SM soil type might be encountered as alluvial sediment, weathered sandstone, or other weathered parent rock. The test soil is the natural soil at the Fort Belvoir Proving Ground. Since it can be compacted with a vibratory roller or kneading rollers (pneumatic-tire or tamping-foot), this soil will be used in all single- and dual-mode tests. The gradation curve is given in Figure 23. The T-99 and T-180 curves are shown in Figure 24.

The CL/CH soil type might be encountered as alluvial sediment or as weathered parent rock. The characteristics of the clay (degree of plasticity, swell potential, and others) depend on the characteristics of the parent material. The test soil was excavated from a large deposit located at Hilltop Sand and Gravel, a soil and aggregate company near the Fort Belvoir Proving Ground. This soil type is most effectively compacted with tamping-foot and pneumatic-tire rollers. The T-99 and T-180 curves are shown in Figure 25. A summary of soil properties is given in Table 6.

V. TEST PROCEDURE

13. General. The main objective of the FAMECE compaction study is to determine the best soil-machine combinations for FAMECE equipment. In addition, the compaction study is a convenient opportunity to test the relative performances of the newest Army soil testing equipment. In order to accomplish these objectives, a large number of tests and measurements will be made.

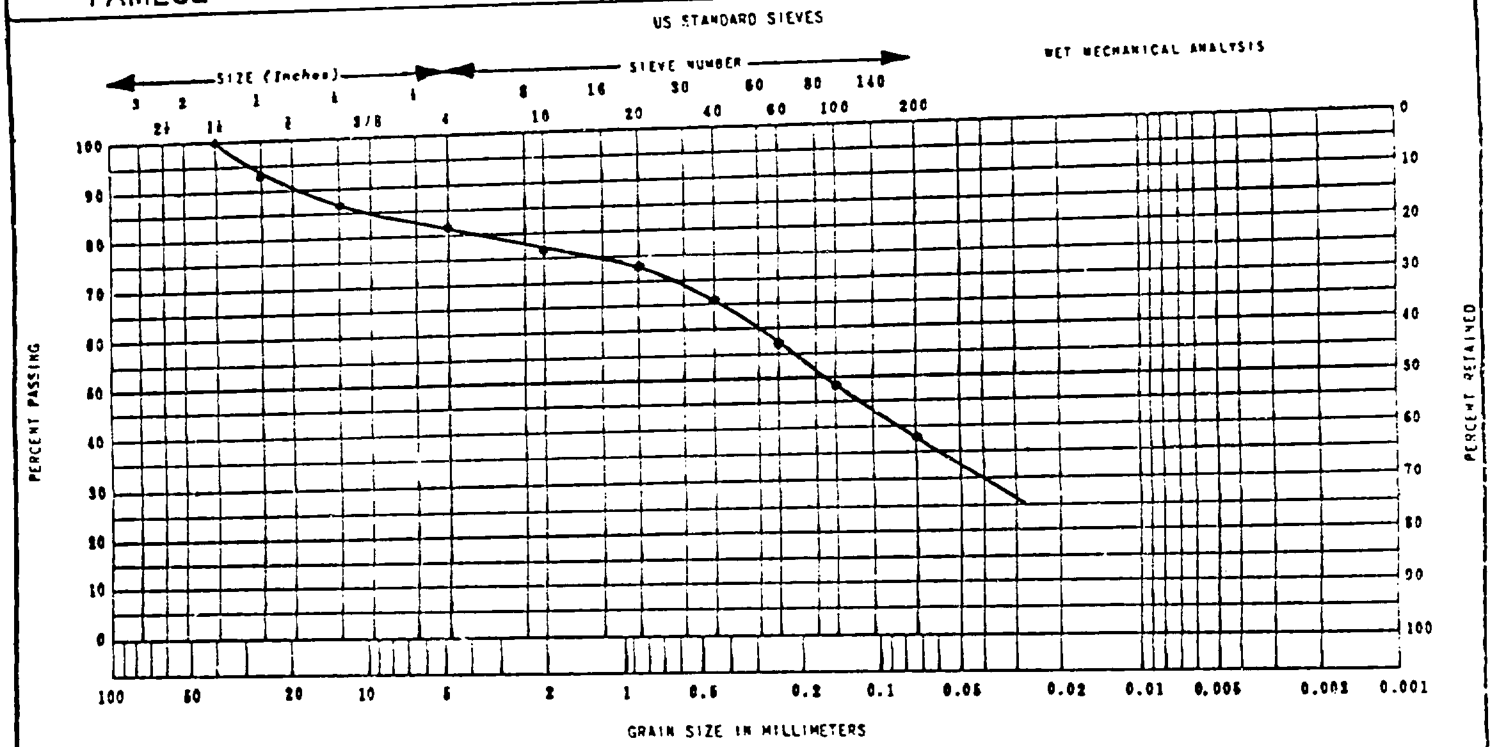
In general, the most significant changes in density occur during the first few compactor coverages, with additional coverages yielding less densification. It was decided that 16 passes would be used for all single-mode tests. The final densities will serve as one basis for soil-machine performance comparisons. For dual-mode tests, the termination criteria will be a 95-percent modified AASHTO density, which is the established criteria for road and airstrip subgrades.

The test strips will be constructed in Building T-2030 at the Fort Belvoir Proving Ground. Each soil type will occupy a strip 10 ft wide and 100 ft long. One half of the length will be 7 or 12 in. thick and the other half will be 14 or 20 in. thick (Figure 26). Once the machine parameters are set, 4, 6, or 8 tests will be conducted simultaneously, depending on the test series being performed. The corrective actions specified in the test procedure will be performed by FAMECE work modules and various small equipment.

The detailed procedures for single- and duel-mode tests are presented in paragraphs 14 and 15. The measurement schedules for all tests are discussed in paragraph 16, followed by a general statement about analyzing the data.

GRAIN SIZE DISTRIBUTION GRAPH - AGGREGATE GRADING CHART

PROJECT	DATE
FAMECE	



EXCAVATION NUMBER	SAMPLE NUMBER	NATURAL % MOISTURE	w_L	w_P	I_P	CLASSIFICATION	REMARKS
FT. BELVOIR PROVING GROUND			33.0	22.5	10.5	SC/SM	C_u-150.0; C_c-1.93

TECHNICIAN (Signature)	PLOTTED BY (Signature)	CHECKED BY (Signature)

Figure 23. Gradation curve for SC/SM soil.

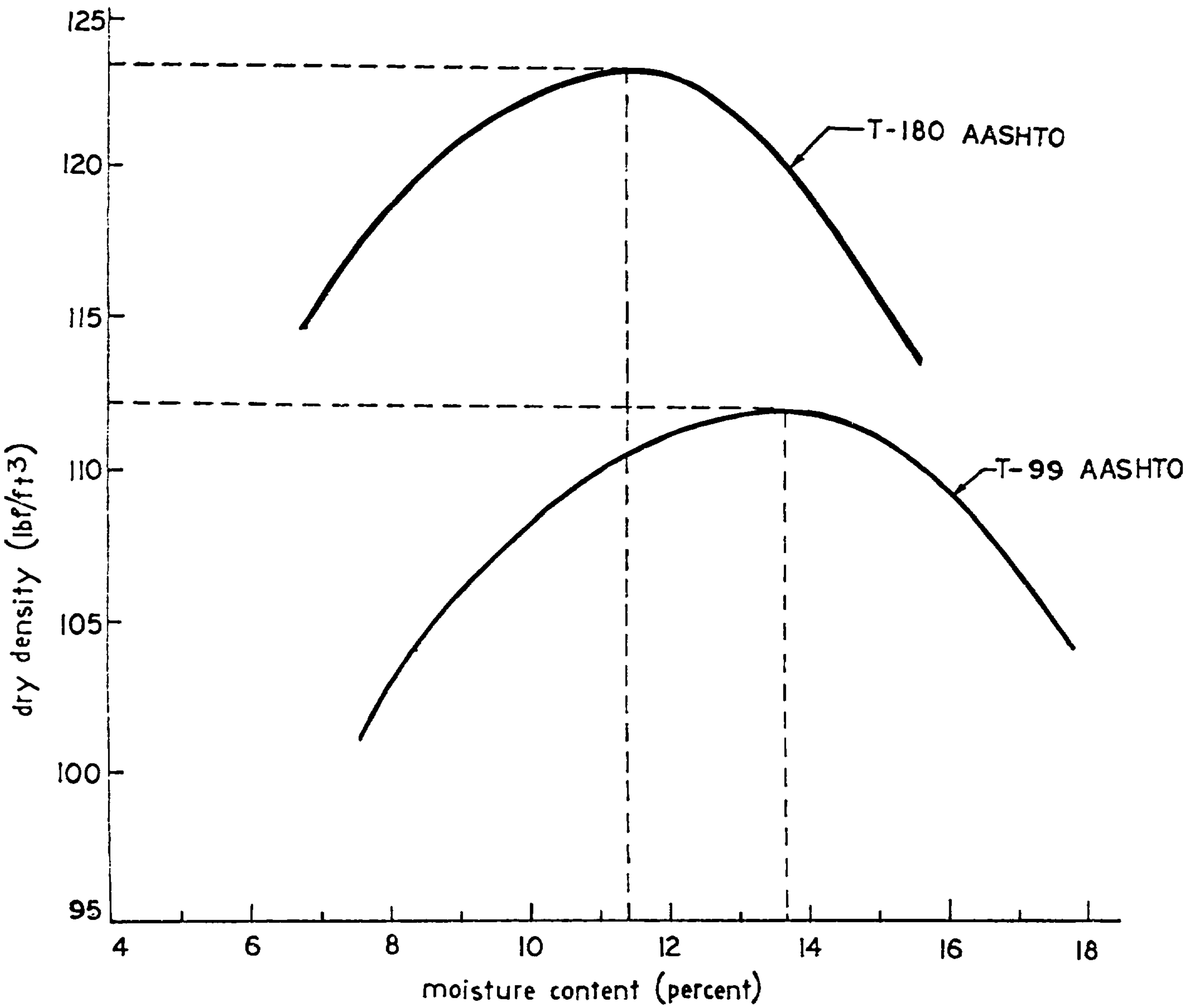


Figure 24. Laboratory moisture-density curves for SC/SM soil.

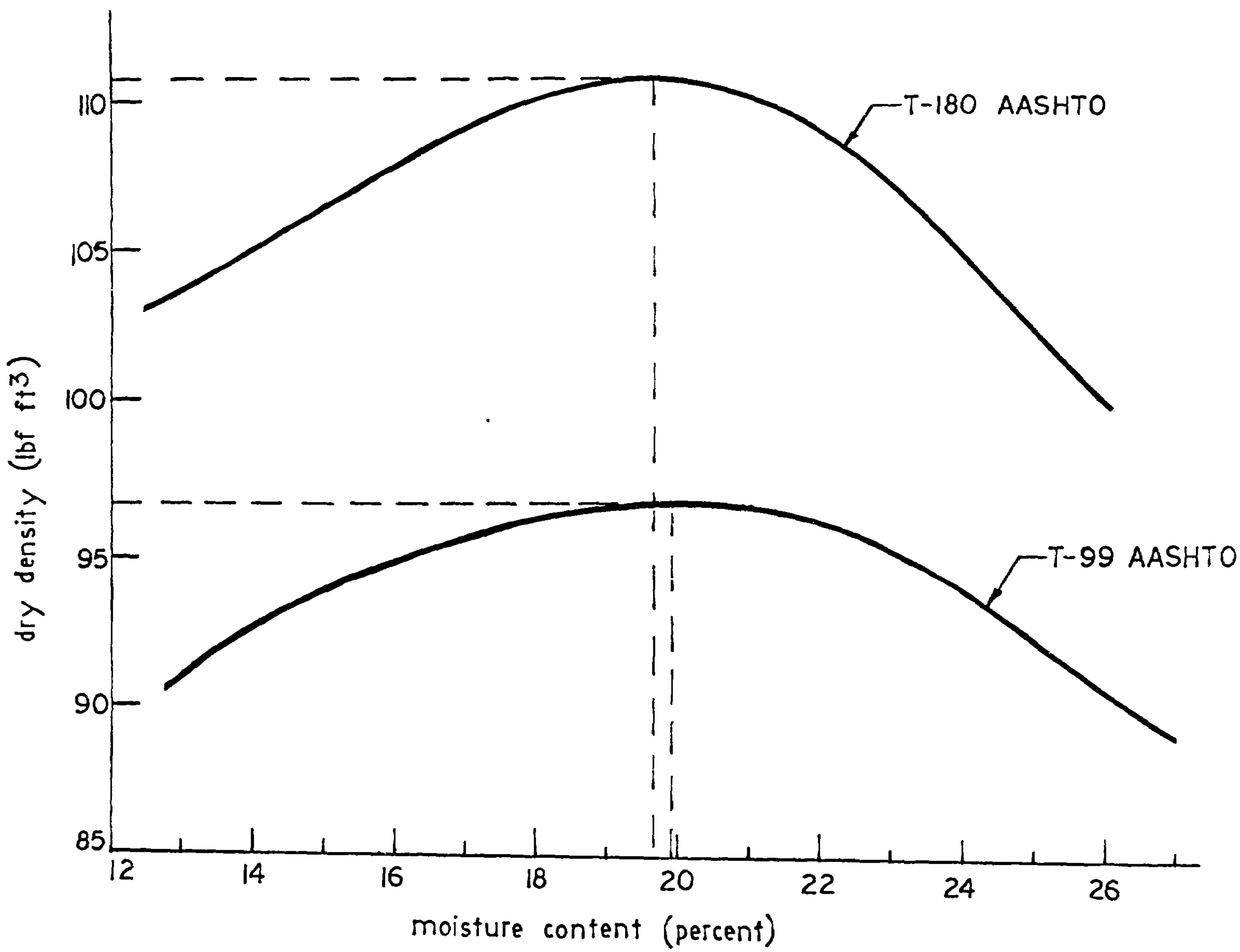
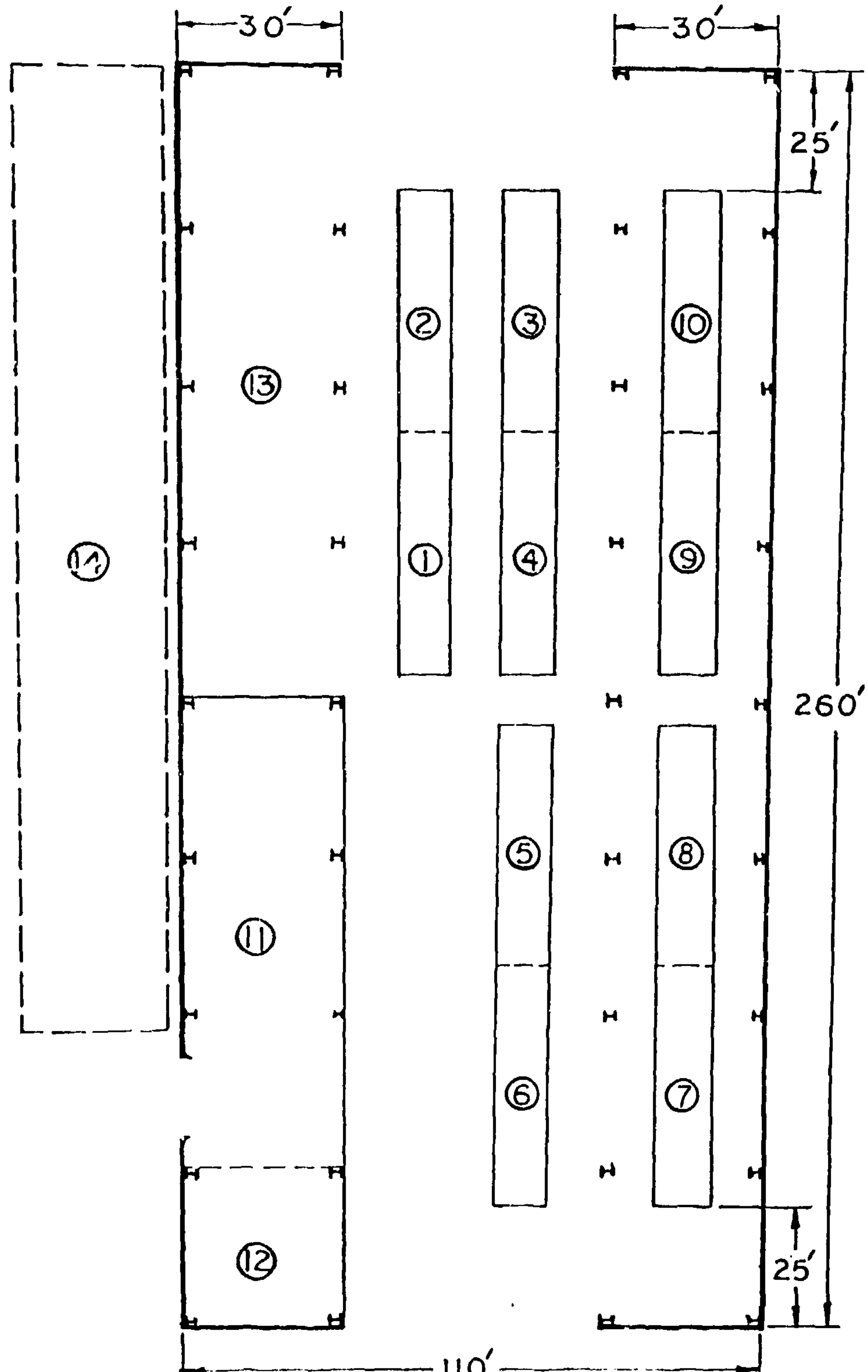


Figure 25. Laboratory moisture-density curves for CL/CH soil.

Table 6. Summation of Soil Properties

USCS Designation	Liquid Limit	Plastic Limit	Plastic Index	Coefficient of Curvature	Coefficient of Uniformity	T-99 Curve		T-180 Curve	
						Optimum Moisture (%)	Maximum Density (pcf)	Optimum Moisture (%)	Maximum Density (pcf)
GP/GM	19.0	19.0	0	0.76	21.9	10.5	123	6.2	141
SC/SM	33.0	22.5	10.5	1.93	150.0	13.7	112	11.4	123
CL/CH	60.7	33.1	27.6	–	–	20.0	97	19.6	111



AREAS

1. 7" GP/GM
2. 14" GP/GM
3. 7" SC/SM
4. 14" SC/SM
5. 12" CL/CH (dry)
6. 20" CL/CH (dry)
7. 12" CL/CH (opt)
8. 20" CL/CH (opt)
9. 12" CL/CH (wet)
10. 20" CL/CH (wet)
11. Existing slab; use for soils analysis and compiling data
12. Restroom area
13. Small equipment
14. Soil stockpiles

Note: Not to scale

Figure 26. Test facility layout.

14. Single-Mode Tests. There are five series of tests in this section. They are: static smooth-drum mode (S-Series); vibratory smooth-drum mode (V-Series); tamping-foot mode (T-Series-1 and 2); and pneumatic-tire mode (P-Series). For each series, the soil and machine variables are given below along with a test matrix.

The S-Series will be run at a constant speed; maximum in first gear. The ballast, soil type, moisture content, and lift thickness will be varied as shown in Table 7. Two soil types, GP/GM and SC/SM, will be used. The V-Series will be run in the half-ballasted condition. The vibration frequency/forward speed ratio will be varied from minimum, to intermediate, to maximum. In addition, the soil type, moisture content, and lift thickness will be varied as shown in Table 8. Again, the GP/GM and SC/SM soil types will be used. Accelerometer data will be recorded during this series.

The T-Series-1 will be run at a constant speed maximum in first gear. The ballast, soil type, moisture content, and lift thickness will be varied as shown in Table 9. The T-Series-2 will be run in the half-ballasted condition and at optimum soil moisture content. The forward speed, soil type, and lift thickness will be varied as shown in Table 10. Two soil types, SC/SM and CL/CH, will be used with both test series.

The P-Series will be run at a constant speed maximum in first gear. The tire pressure and ballast are the machine variables. The soil type, moisture content, and lift thickness will also be varied as shown in Table 11. All three soil types will be used.

15. Dual-Mode Tests. The four test sets in this paragraph were designed to measure any significant improvement in compaction results using the dual- and alternating-mode capabilities of the FAMECE compactors. For the first three test sets, the percent of total coverage by alternating single and dual modes will be varied. The fourth set will only be run in the dual mode, but the speed will be varied. Percent of total coverage is broken down so that small numbers of alternating passes can be used. For example, in tests SP-13 to SP-16 (Table 12), one pass will be made with the static smooth-drum, two passes in the dual mode, and one pass in the pneumatic-tire mode. This order will be continued until 95 percent Modified AASHTO density is achieved.

The static smooth-drum/pneumatic-tire tests (SP-Series) will be run at a constant speed maximum in first gear. The soil moisture content will be close to laboratory optimum. The percent of total coverage, tire pressure, ballast, soil type, and lift thickness will be varied as shown in Table 12. Two soil types, GP/GM and SC/SM, will be used.

The vibratory smooth-drum/pneumatic-tire tests (VP-Series) will be run in the half-ballasted condition on two soils, GP/GM and SC/SM. Both will have soil moisture contents close to laboratory optimum. The percent of total coverage, tire pressure, soil type, lift thickness, and frequency/speed ratio will be varied as shown in Table 13. Accelerometer data will be taken during this test.

Table 7. S-Series Test Matrix

Test	Lift Thickness (in.)	Soil Type	Moisture Content	Ballast Condition	Corrective Action
	Parameter				
S-1	7	GP/GM	D	U	
S-2	14	GP/GM	D	U	
S-3	7	SC/SM	D	U	
S-4	14	SC/SM	D	U	
					S
S-5	7	GP/GM	D	H	
S-6	14	GP/GM	D	H	
S-7	7	SC/SM	D	H	
S-8	14	SC/SM	D	H	
					S/A
S-9	7	GP/GM	O	U	
S-10	14	GP/GM	O	U	
S-11	7	SC/SM	O	U	
S-12	14	SC/SM	O	U	
					S
S-13	7	GP/GM	O	H	
S-14	14	GP/GM	O	H	
S-15	7	SC/SM	O	H	
S-16	14	SC/SM	O	H	
					S/A
S-17	7	GP/GM	W	U	
S-18	14	GP/GM	W	U	
S-19	7	SC/SM	W	U	
S-20	14	SC/SM	W	U	
					S
S-21	7	GP/GM	W	H	
S-22	14	GP/GM	W	H	
S-23	7	SC/SM	W	H	
S-24	14	SC/SM	W	H	
					R

Nomenclature:

Moisture Content: D– 3-5% dry of optimum
O– optimum ± 1%
W– 3-5% wet of optimum

Ballast Condition: U– unballasted
H– half-ballasted
F– fully ballasted

Corrective Action: S– scarify
A– add water
R– remove

Table 8. V-Series Test Matrix

	Parameter				
Test	Lift Thickness (in.)	Soil Type	Moisture Content	Frequency Speed	Corrective Action
V-1	7	GP/GM	D	Minimum	
V-2	14	GP/GM	D	Minimum	
V-3	7	SC/SM	D	Minimum	
V-4	14	SC/SM	D	Minimum	
					S
V-5	7	GP/GM	D	Intermediate	
V-6	14	GP/GM	D	Intermediate	
V-7	7	SC/SM	D	Intermediate	
V-8	14	SC/SM	D	Intermediate	
					S
V-9	7	GP/GM	D	Maximum	
V-10	14	GP/GM	D	Maximum	
V-11	7	SC/SM	D	Maximum	
V-12	14	SC/SM	D	Maximum	
					S/A
V-13	7	GP/GM	O	Minimum	
V-14	14	GP/GM	O	Minimum	
V-15	7	SC/SM	O	Minimum	
V-16	14	SC/SM	O	Minimum	
					S
V-17	7	GP/GM	O	Intermediate	
V-18	14	GP/GM	O	Intermediate	
V-19	7	SC/SM	O	Intermediate	
V-20	14	SC/SM	O	Intermediate	
					S
V-21	7	GP/GM	O	Maximum	
V-22	14	GP/GM	O	Maximum	
V-23	7	SC/SM	O	Maximum	
V-24	14	SC/SM	O	Maximum	
					S/A
V-25	7	GP/GM	W	Minimum	
V-26	14	GP/GM	W	Minimum	
V-27	7	SC/SM	W	Minimum	
V-28	14	SC/SM	W	Minimum	
					S
V-29	7	GP/GM	W	Intermediate	
V-30	14	GP/GM	W	Intermediate	
V-31	7	SC/SM	W	Intermediate	
V-32	14	SC/SM	W	Intermediate	
					S
V-33	7	GP/GM	W	Maximum	
V-34	14	GP/GM	W	Maximum	
V-35	7	SC/SM	W	Maximum	
V-36	14	SC/SM	W	Maximum	
					R

Corrective Action: S – scarify; A – add water; R – remove

Moisture Content: D – 3-5% dry of optimum; O – optimum ± 1%; W – 3-5% wet of optimum

Table 9. T-Series 1 Test Matrix

Test	Parameters: Lift Thickness (in.)	Soil Type	Moisture Content	Ballast Condition	Corrective Action
T-1-1	7	SC/SM	D	U	
T-1-2	14	SC/SM	D	U	
T-1-3	12	CL/CH	D	U	
T-1-4	20	CL/CH	D	U	
					S
T-1-5	7	SC/SM	D	H	
T-1-6	14	SC/SM	D	H	
T-1-7	12	CL/CH	D	H	
T-1-8	20	CL/CH	D	H	
					S/A
T-1-9	7	SC/SM	O	U	
T-1-10	14	SC/SM	O	U	
T-1-11	12	CL/CH	O	U	
T-1-12	20	CL/CH	O	U	
					S
T-1-13	7	SC/SM	O	H	
T-1-14	14	SC/SM	O	H	
T-1-15	12	CL/CH	O	H	
T-1-16	20	CL/CH	O	H	
					S/A
T-1-17	7	SC/SM	W	U	
T-1-18	14	SC/SM	W	U	
T-1-19	12	CL/CH	W	U	
T-1-20	20	CL/CH	W	U	
					S
T-1-21	7	SC/SM	W	H	
T-1-22	14	SC/SM	W	H	
T-1-23	12	CL/CH	W	H	
T-1-24	20	CL/CH	W	H	
					R

Moisture Content: D – 3-5% dry of optimum; O – optimum ± 1%; W – 3-5% wet of optimum

Corrective Action: S – scarify; A – add water; R – remove

Ballast Condition: U – unballasted; H – half-ballasted; F – fully ballasted

Table 10. T-Series 2 Test Matrix

Test	Parameters: Life Thickness (in.)	Soil Type	Ballast Condition	Forward Speed (mi/h)	Corrective Action
T-2-1	7	SC/SM	U	3	
T-2-2	14	SC/SM	U	3	
T-2-3	12	CL/CH	U	3	
T-2-4	20	CL/CH	U	3	
					S
T-2-5	7	SC/SM	H	3	
T-2-6	14	SC/SM	H	3	
T-2-7	12	CL/CH	H	3	
T-2-8	20	CL/CH	H	3	
					S
T-2-9	7	SC/SM	U	7	
T-2-10	14	SC/SM	U	7	
T-2-11	12	CL/CH	U	7	
T-2-12	20	CL/CH	U	7	
					S
T-2-13	7	SC/SM	H	7	
T-2-14	14	SC/SM	H	7	
T-2-15	12	CL/CH	H	7	
T-2-16	20	CL/CH	H	7	
					S
T-2-17	7	SC/SM	U	11	
T-2-18	14	SC/SM	U	11	
T-2-19	12	CL/CH	U	11	
T-2-20	20	CL/CH	U	11	
					S
T-2-21	7	SC/SM	H	11	
T-2-22	14	SC/SM	H	11	
T-2-23	12	CL/CH	H	11	
T-2-24	20	CL/CH	H	11	
					R

Corrective Action: S – Scarify; A – add water; R – remove

Ballast Condition: U – unballasted; H – half-ballasted; F – fully ballasted

Table 11. P-Series Test Matrix

	Parameters					
Test	Lift Thickness (in.)	Soil Type	Moisture Content	Tire Pressure (lbf/in.^{2})	Ballast Condition	Corrective Action
P-1	7	GP/GM	D	50	U	
P-2	14	GP/GM	D	50	U	
P-3	7	SC/SM	D	50	U	
P-4	14	SC/SM	D	50	U	
P-5	12	CL/CH	D	50	U	
P-6	20	CL/CH	D	50	U	
						S
P-7	7	GP/GM	D	50	F	
P-8	14	GP/GM	D	50	F	
P-9	7	SC/SM	D	50	F	
P-10	14	SC/SM	D	50	F	
P-11	12	CL/CH	D	50	F	
P-12	20	CL/CH	D	50	F	
						S
P-13	7	GP/GM	D	100	U	
P-14	14	GP/GM	D	100	U	
P-15	7	SC/SM	D	100	U	
P-16	14	SC/SM	D	100	U	
P-17	12	CL/CH	D	100	U	
P-18	20	CL/CH	D	100	U	
						S
P-19	7	GP/GM	D	100	F	
P-20	14	GP/GM	D	100	F	
P-21	7	SC/SM	D	100	F	
P-22	14	SC/SM	D	100	F	
P-23	12	CL/CH	D	100	F	
P-24	20	CL/CH	D	100	F	
						S/A
P-25	7	GP/GM	O	50	U	
P-26	14	GP/GM	O	50	U	
P-27	7	SC/SM	O	50	U	
P-28	14	SC/SM	O	50	U	
P-29	12	CL/CH	O	50	U	
P-30	20	CL/CH	O	50	U	
						S

Table 11. P-Series Test Matrix (Cont'd)

	Parameters					
Test	Lift Thickness (in.)	Soil Type	Moisture Content	Tire Pressure ($lbf/in.^2$)	Ballast Condition	Corrective Action
P-31	7	GP/GM	O	50	F	
P-32	14	GP/GM	O	50	F	
P-33	7	SC/SM	O	50	F	
P-34	14	SC/SM	O	50	F	
P-35	12	CL/CH	O	50	F	
P-36	20	CL/CH	O	50	F	
						S
P-37	7	GP/GM	O	100	U	
P-38	14	GP/GM	O	100	U	
P-39	7	SC/SM	O	100	U	
P-40	14	SC/SM	O	100	U	
P-41	12	CL/CH	O	100	U	
P-42	20	CL/CH	O	100	U	
						S
P-43	7	GP/GM	O	100	F	
P-44	14	GP/GM	O	100	F	
P-45	7	SC/SM	O	100	F	
P-46	14	SC/SM	O	100	F	
P-47	12	CL/CH	O	100	F	
P-48	20	CL/CH	O	100	F	
						S/A
P-49	7	GP/GM	W	50	U	
P-50	14	GP/GM	W	50	U	
P-51	7	SC/SM	W	50	U	
P-52	14	SC/SM	W	50	U	
P-53	12	CL/CH	W	50	U	
P-54	20	CL/CH	W	50	U	
						S
P-55	7	GP/GM	W	50	F	
P-56	14	GP/GM	W	50	F	
P-57	7	SC/SM	W	50	F	
P-58	14	SC/SM	W	50	F	
P-59	12	CL/CH	W	50	F	
P-60	20	CL/CH	W	50	F	
						S

Table 11. P-Series Test Matrix (Cont'd)

Test	Parameters					Corrective Action
	Lift Thickness (in.)	Soil Type	Moisture Content	Tire Pressure (lbf/in.^{2})	Ballast Condition	
P-61	7	GP/GM	W	100	U	
P-62	14	GP/GM	W	100	U	
P-63	7	SC/SM	W	100	U	
P-64	14	SC/SM	W	100	U	
P-65	12	CL/CH	W	100	U	
P-66	20	CL/CH	W	100	U	
						S
P-67	7	GP/GM	W	100	F	
P-68	14	GP/GM	W	100	F	
P-69	7	SC/SM	W	100	F	
P-70	14	SC/SM	W	100	F	
P-71	12	CL/CM	W	100	F	
P-72	20	CL/CH	W	100	F	
						R

Moisture Content: D – 3-5% dry of optimum
O – optimum ± 1%
W – 3-5% wet of optimum

Corrective Action: S – Scarify
A – add water
R – remove

Ballast Condition: U – unballasted
H – half-ballasted
F – fully ballasted

Table 12. SP-Series Test Matrix

Test	Lift Thickness (in.)	Soil Type	Percent of Total Coverage S	SP	P	Tire Pressure (lbf/in.^{2})	Ballast Condition	Corr Action
SP-1	7	GP/GM	80	0	20	50	U	
SP-2	14	GP/GM	80	0	20	50	U	
SP-3	7	SC/SM	80	0	20	50	U	
SP-4	14	SC/SM	80	0	20	50	U	
								S
SP-5	7	GP/GM	50	0	50	50	U	
SP-6	14	GP/GM	50	0	50	50	U	
SP-7	7	SC/SM	50	0	50	50	U	
SP-8	14	SC/SM	50	0	50	50	U	
								S
SP-9	7	GP/GM	20	0	80	50	U	
SP-10	14	GP/GM	20	0	80	50	U	
SP-11	7	SP/SM	20	0	80	50	U	
SP-12	14	SP/SM	20	0	80	50	U	
								S
SP-13	7	GP/GM	25	50	25	50	U	
SP-14	14	GP/GM	25	50	25	50	U	
SP-15	7	SP/SM	25	50	25	50	U	
SP-16	14	SP/SM	25	50	25	50	U	
								S
SP-17	7	GP/GM	0	100	0	50	H	
SP-18	14	GP/GM	0	100	0	50	H	
SP-19	7	SP/SM	0	100	0	50	H	
SP-20	14	SP/SM	0	100	0	50	H	
								S
SP-21	7	GP/GM	80	0	20	100	H	
SP-22	14	GP/GM	80	0	20	100	H	

Table 12. SP-Series Test Matrix (Cont'd)

Test	Lift Thickness (in.)	Soil Type	Percent of Total Coverage S	SP	P	Tire Pressure (lbf/in.^{2})	Ballast Condition	Corr Action
SP-23	7	SP/SM	80	0	20	100	H	
SP-24	14	SP/SM	80	0	20	100	H	
								S
SP-25	7	GP/GM	50	0	50	100	H	
SP-26	14	GP/GM	50	0	50	100	H	
SP-27	7	SC/SM	50	0	50	100	H	
SP-28	14	SC/SM	50	0	50	100	H	
								S
SP-29	7	GP/GM	20	0	80	100	H	
SP-30	14	GP/GM	20	0	80	100	H	
SP-31	7	SP/SM	20	0	80	100	H	
SP-32	14	SP/SM	20	0	80	100	H	
								S
SP-33	7	GP/GM	25	50	25	100	H	
SP-34	14	GP/GM	25	50	25	100	H	
SP-35	7	SP/SM	25	50	25	100	H	
SP-36	14	SP/SM	25	50	25	100	H	
								S
SP-37	7	GP/GM	0	100	0	100	F	
SP-38	14	GP/GM	0	100	0	100	F	
SP-39	7	SP/SM	0	100	0	100	F	
SP-40	14	SP/SM	0	100	0	100	F	
								R

Ballast Condition: U – unballasted
H – half-ballasted
F – fully ballasted

Corrective Condition: S – scarify
A – add water
R – remove

Table 13. VP-Series Test Matrix

Test	Lift Thickness (in.)	Soil Type	Percent of Total Coverage V	Percent of Total Coverage VP	Percent of Total Coverage V	Tire Pressure (lbf/in.^{2})	Frequency/Speed	Corr Action
VP-1	7	GP/GM	50	0	50	50	Min	
VP-2	14	GP/GM	50	0	50	50	Min	
VP-3	7	SC/SM	50	0	50	50	Min	
VP-4	14	SC/SM	50	0	50	50	Min	
								S
VP-5	7	GP/GM	50	0	50	50	Max	
VP-6	14	GP/GM	50	0	50	50	Max	
VP-7	7	SC/SM	50	0	50	50	Max	
VP-8	14	SC/SM	50	0	50	50	Max	
								S
VP-9	7	GP/GM	25	50	25	50	Min	
VP-10	14	GP/GM	25	50	25	50	Min	
VP-11	7	SC/SM	25	50	25	50	Min	
VP-12	14	SC/SM	25	50	25	50	Min	
								S
VP-13	7	GP/GM	25	50	25	50	Max	
VP-14	14	GP/GM	25	50	25	50	Max	
VP-15	7	SC/SM	25	50	25	50	Max	
VP-16	14	SC/SM	25	50	25	50	Max	
								S
VP-17	7	GP/GM	0	100	0	50	Min	
VP-18	14	GP/GM	0	100	0	50	Min	
VP-19	7	SC/SM	0	100	0	50	Min	
VP-20	14	SC/SM	0	100	0	50	Min	
								S

Table 13. VP-Series Test Matrix (Cont'd)

Test	Lift Thickness (in.)	Soil Type	Percent of Total Coverage V	Percent of Total Coverage VP	Percent of Total Coverage V	Tire Pressure ($lbf/in.^2$)	Frequency/Speed	Corr Action
VP-21	7	GP/GM	0	100	0	50	Max	
VP-22	14	GP/GM	0	100	0	50	Max	
VP-23	7	SC/SM	0	100	0	50	Max	
VP-24	14	SC/SM	0	100	0	50	Max	
								S
VP-25	7	GP/GM	50	0	50	100	Min	
VP-26	14	GP/GM	50	0	50	100	Min	
VP-27	7	SC/SM	50	0	50	100	Min	
VP-28	14	SC/SM	50	0	50	100	Min	
								S
VP-29	7	GP/GM	50	0	50	100	Max	
VP-30	14	GP/GM	50	0	50	100	Max	
VP-31	7	SC/SM	50	0	50	100	Max	
VP-32	14	SC/SM	50	0	50	100	Max	
								S
VP-33	7	GP/GM	25	50	25	50	Min	
VP-34	14	GP/GM	25	50	25	50	Min	
VP-35	7	SC/SM	25	50	25	50	Min	
VP-36	14	SC/SM	25	50	25	50	Min	
								S
VP-37	7	GP/GM	25	50	25	50	Max	
VP-38	14	GP/GM	25	50	25	50	Max	
VP-39	7	SC/SM	25	50	25	50	Max	
VP-40	14	SC/SM	25	50	25	50	Max	
								S

Table 13. VP-Series Test Matrix (Cont'd)

Test	Lift Thickness (in.)	Soil Type	Percent of Total Coverage V	VP	V	Tire Pressure ($lbf/in.^2$)	Frequency/Speed	Corr Action
VP-41	7	GP/GM	0	100	0	100	Min	
VP-42	14	GP/GM	0	100	0	100	Min	
VP-43	7	SC/SM	0	100	0	100	Min	
VP-44	14	SC/SM	0	100	0	100	Min	
								S
VP-45	7	GP/GM	0	100	0	100	Max	
VP-46	14	GP/GM	0	100	0	100	Max	
VP-47	7	SC/SM	0	100	0	100	Max	
VP-48	14	SC/SM	0	100	0	100	Max	
								R

Corrective Action: S – scarify
A – add water
R – remove

The tamping-foot/pneumatic-tire tests (TP-Series 1) will be run at a constant speed, maximum in first gear. Two soil types, SC/SM and CL/CH, will be used with the soil moisture contents at close to laboratory optimum. The percent of total coverage, lift thickness, tire pressure, and ballast will be varied as shown in Table 14. The TP-Series 2 will be run on SC/SM and CL/CH soils in the dual mode only. The SC/SM soil will be compacted at close to the laboratory optimum moisture content. The CL/CH soil, however, will be compacted over a range of moisture contents and compactor speeds as shown in Table 15. The reason for the special treatment of the CL/CH soii type is that it takes a great deal of time to adjust the moisture content of clays. Troops in forward areas, where the FAMECE is designed to go, will not have adequate time for such an exercise and will have to use clays in their natural condition. The other soil types can be readily adjusted to moisture contents specified by the field engineer.

16. Measurement Schedule. In order to obtain meaningful results, all test strips will be prepared in the same manner. The soils will be placed or scarified. Any adjustment of water content will then be made with the FAMECE distributor. All test strips will receive one pass with the static smooth-drum roller in the unballasted condition. At this point, the strips will be ready for testing and initial readings will be taken.

All soil instrumentation systems will be used during the single-mode tests. After every other pass, the data will be taken according to the schedule shown in Table 16. It was decided that two sand-cone readings per test section would require about 30 minutes. In the same time, four nuclear meter readings can be taken at the surface and at 6 in. below the surface. The data will be averaged for each system and will be used to derive field moisture/density curves.

The penetrometer will be used for initial readings and after every four compactor passes. Four readings will be taken and the results averaged for comparison with the moisture-density curves. The location of all measurements will be chosen at random. These locations should be representative of the total strip (e.g., locations near the center and edges of the strip, and the beginning, middle, and end of the section).

For dual-mode tests, the nuclear meter will be the only instrumentation system. This decision was based on the time involved in taking comparative data for the other systems. The results of the single-mode tests should be sufficient to determine their relative performances. The nuclear data will be taken after every other pass, the dual-mode results will be compared with single-mode results taken at identical intevals.

Table 14. TP-Series I Test Matrix

	Parameters							
	Lift Thickness		Percent of Total Coverage			Tire Pressure		
Test	(in.)	Soil Type	T	TP	P	(lbf/in.^{2})	Ballast Condition	Corr Action
TP-1-1	7	SC/SM	50	0	50	50	U	
TP-1-2	14	SC/SM	50	0	50	50	U	
TP-1-3	12	CL/CH	50	0	50	50	U	
TP-1-4	20	CL/CH	50	0	50	50	U	
								S
TP-1-5	7	SC/SM	25	50	25	50	U	
TP-1-6	14	SC/SM	25	50	25	50	U	
TP-1-7	12	CL/CH	25	50	25	50	U	
TP-1-8	20	CL/CH	25	50	25	50	U	
								S
TP-1-9	7	SC/SM	0	100	0	50	H	
TP-1-10	14	SC/SM	0	100	0	50	H	
TP-1-11	12	CL/CH	0	100	0	50	H	
TP-1-12	20	CL/CH	0	100	0	50	H	
								S
TP-1-13	7	SC/SM	50	0	50	50	H	
TP-1-14	14	SC/SM	50	0	50	50	H	
TP-1-15	12	CL/CH	50	0	50	50	H	
TP-1-16	20	CL/CH	50	0	50	50	H	
								S
TP-1-17	7	SC/SM	25	50	25	50	H	
TP-1-18	14	SC/SM	25	50	25	50	H	
TP-1-19	12	CL/CH	25	50	25	50	H	
TP-1-20	20	CL/CH	25	50	25	50	H	
								S

Table 14. TP-Series I Test Matrix (Cont'd)

Test	Parameters							
	Lift Thickness (in.)	Soil Type	Percent of Total Coverage			Tire Pressure ($lbf/in.^2$)	Ballast Condition	Corr Action
			T	TP	P			
TP-1-21	7	SC/SM	0	100	0	50	F	
TP-1-22	14	SC/SM	0	100	0	50	F	
TP-1-23	12	CL/CH	0	100	0	50	F	
TP-1-24	20	CL/CH	0	100	0	50	F	
								R
TP-1-25	7	SC/SM	50	0	50	100	U	
TP-1-26	14	SC/SM	50	0	50	100	U	
TP-1-27	12	CL/CH	50	0	50	100	U	
TP-1-28	20	CL/CH	50	0	50	100	U	
								S
TP-1-29	7	SC/SM	25	50	25	100	U	
TP-1-30	14	SC/SM	25	50	25	100	U	
TP-1-31	12	CL/CH	25	50	25	100	U	
TP-1-32	20	CL/CH	25	50	25	100	U	
								S
TP-1-33	7	SC/SM	0	100	0	100	H	
TP-1-34	14	SC/SM	0	100	0	100	H	
TP-1-35	12	CL/CH	0	100	0	100	H	
TP-1-36	20	CL/CH	0	100	0	100	H	
								S
TP-1-37	7	SC/SM	50	0	50	100	H	
TP-1-38	14	SC/SM	50	0	50	100	H	
TP-1-39	12	CL/CH	50	0	50	100	H	
TP-1-40	20	CL/CH	50	0	50	100	H	
								S

Table 14. TP-Series I Test Matrix (Cont'd)

Test	Parameters: Lift Thickness (in.)	Soil Type	Percent of Total Coverage: T	TP	P	Tire Pressure (lbf/in.^{2})	Ballast Condition	Corr Action
TP-1-41	7	SC/SM	25	50	25	100	H	
TP-1-42	14	SC/SM	25	50	25	100	H	
TP-1-43	12	CL/CH	25	50	25	100	H	
TP-1-44	20	CL/CH	25	50	25	100	H	
								S
TP-1-45	7	SC/SM	0	100	0	100	F	
TP-1-46	14	SC/SM	0	100	0	100	F	
TP-1-47	12	CL/CH	0	100	0	100	F	
TP-1-48	20	CL/CH	0	100	0	100	F	
								R

Ballast Condition: U – unballasted
H – half-ballasted
F – fully ballasted

Corrective Action: S – scarify
A – add water
R – remove

Table 15. TP-Series I Test Matrix

Test	Parameters						Corr Action
	Lift Thickness (in.)	Soil Type	Moisture Content	Tire Pressure (lb/in.^{2})	Forward Speed	Ballast Condition	
TP-2-1	7	SC/SM	0	50	3	H	
TP-2-2	14	SC/SM	0	50	3	H	
TP-2-3	12	CL/CH	D	50	3	H	
TP-2-4	20	CL/CH	D	50	3	H	
TP-2-5	12	CL/CH	0	50	3	H	
TP-2-6	20	CL/CH	0	50	3	H	
TP-2-7	12	CL/CH	W	50	3	H	
TP-2-8	20	CL/CH	W	50	3	H	
							S
TP-2-9	7	SC/SM	0	50	7	H	
TP-2-10	14	SC/SM	0	50	7	H	
TP-2-11	12	CL/CH	D	50	7	H	
TP-2-12	20	CL/CH	D	50	7	H	
TP-2-13	12	CL/CH	0	50	7	H	
TP-2-14	20	CL/CH	0	50	7	H	
TP-2-15	12	CL/CH	W	50	7	H	
TP-2-16	20	CL/CH	W	50	7	H	
							S
TP-2-17	7	SC/SM	0	50	11	H	
TP-2-18	14	SC/SM	0	50	11	H	
TP-2-19	12	CL/CH	D	50	11	H	
TP-2-20	20	CL/CH	D	50	11	H	
TP-2-21	12	CL/CH	0	50	11	H	
TP-2-22	20	CL/CH	0	50	11	H	
TP-2-23	12	CL/CH	W	50	11	H	
TP-2-24	20	CL/CH	W	50	11	H	

Table 15. TP-Series I Test Matrix (Cont'd)

Test	Parameters						Corr Action
	Lift Thickness (in.)	Soil Type	Moisture Content	Tire Pressure (lb/in.^{2})	Forward Speed	Ballast Condition	
							R
TP-2-25	7	SC/SM	0	100	3	H	
TP-2-26	14	SC/SM	0	100	3	H	
TP-2-27	12	CL/CH	D	100	3	H	
TP-2-28	20	CL/CH	D	100	3	H	
TP-2-29	12	CL/CH	0	100	3	H	
TP-2-30	20	CL/CH	0	100	3	H	
TP-2-31	12	CL/CH	W	100	3	H	
TP-2-32	20	CL/CH	W	100	3	H	
							S
TP-2-33	7	SC/SM	0	100	7	H	
TP-2-34	14	SC/SM	0	100	7	H	
TP-2-35	12	CL/CH	D	100	7	H	
TP-2-36	20	CL/CH	D	100	7	H	
TP-2-37	12	CL/CH	0	100	7	H	
TP-2-38	20	CL/CH	0	100	7	H	
TP-2-39	12	CL/CH	W	100	7	H	
TP-2-40	20	CL/CH	W	100	7	H	
							S
TP-2-41	7	SC/SM	0	100	11	H	
TP-2-42	14	SC/SM	0	100	11	H	
TP-2-43	12	CL/CH	D	100	11	H	
TP-2-44	20	CL/CH	D	100	11	H	
TP-2-45	12	CL/CH	0	100	11	H	
TP-2-46	20	CL/CH	0	100	11	H	
TP-2-47	12	CL/CH	W	100	11	H	

Table 15. TP-Series I Test Matrix (Cont'd)

Test	Parameters						Corr Action
	Lift Thickness (in.)	Soil Type	Moisture Content	Tire Pressure (lb/in.^{2})	Forward Speed	Ballast Condition	
TP-2-48	20	CL/CH	W	100	11	H	R

Moisture Content: D – 3-5% dry of optimum
O – optimum ± 1%
W – 3-5% wet of optimum

Ballast Condition: U – unballasted
H – half-ballasted
F – fully ballasted

Corrective Action: S – scarify
A – add water
R – remove

Table 16. Single-Mode Measurement Schedules

Pass Number	Nuclear Meter Surface	Nuclear Meter 6-in. Depth	Sand-cone	Soil Penetrometer
Preliminary Static (SD)	4	4	2	4
2	4	4	2	0
4	4	4	2	4
6	4	4	2	0
8	4	4	2	4
10	4	4	2	0
12	4	4	2	4
14	4	4	2	0
16	4	4	2	4

17. Analysis of Data. In general, the dual-mode tests were designed to correspond to specific single-mode tests. For example, consider a 14-in. lift of SC/SM soil at optimum moisture content. The compactor (SD) is unballasted with the tire pressure set at 50 lb/in.^{2}. The results of dual-mode tests SP-4, 8, 12, and 16, can be compared with the results of single-mode tests S-12 and P-28. In this same fashion, the significance of the machine parameters can be evaluated for any soil condition under consideration. Also, a comparison of the various compactor modes on a single soil type can be made.

During the single-mode tests, a large amount of data will be recorded from the various instrumentation systems. The nuclear meter and sand-cone readings will be compared for general reliability by plotting the moisture-density curves showing the amount of scatter in each system's data. This scatter will be determined mathematically as the statistical standard deviation. The penetrometer results will be analyzed as a function of soil type, moisture content, and density.

18. Preparation for Implementing Phase II. Four major problems must be overcome prior to the start of Phase II testing. The first item concerns the FAMECE compactor prototypes. Since they have been idle for some time, they will need to be checked out and put into working condition. They are currently parked at the Proving Ground near the equipment maintenance facility.

The second item is the test facility, building T-2030 at the Proving Ground. The existing chain link fences and deteriorating wooden partitions must be removed, and a new sheet metal roof should be installed. The existing restroom facilities and electric service should be restored, or temporary facilities should be provided. The area within the building should be graded and compacted to form a suitable test base. Also, the pothole test course covers, currently stacked outside the building, should be installed.

The third item concerns the CL/CH soil. The tests require three different moisture contents. Since clays adjust very slowly, suitable lead time must be provided in order to prepare three separate stockpiles of clay. The moisture content can be adjusted by adding water, tilling the soil, and repeating until the desired levels are reached. Covers will be needed to keep the stockpiles from drying out or being rained on.

The fourth item is the lack of GP/GM soil in sufficient quantities for the tests. There is a small stockpile of the soil at the Proving ground inside building T-2030 at this time. It is suggested that this stockpile be graded into the floor area and compacted as a test base. A new stockpile will have to be trucked in and analyzed for the tests. Approximately 175 cubic yards will be required.

Most of the instrumentation systems are available at this time. The sand-cone apparatus, accelerometers, sieves, and other laboratory apparatus are locked up at the Proving Ground. Four nuclear meters are kept at the Engineer School at Fort Belvoir. The soil penetrometer, however, will not be available until late 1980.

The lead times required for each of the above items will have to be determined when the funding and manpower for Phase II are approved.

VI. CONCLUSION

19. Conclusion. The test procedure, if followed as outlined above, should accomplish the two basic objectives of this study. The capabilities of the FAMECE compactors will be determined; in particular, any advantages of dual- and alternating-mode compaction will be determined. In addition, parts of the new Army Soil Test Set will be evaluated for performance relative to one another, and relative to the nuclear moisture-density meter which is already in the system.

These results could be incorporated into the training manuals for field engineers. The most effective compaction method for a given set of soil conditions can be specified, thus saving time and manpower in situations where both are at a premium. When roads and airstrips must be constructed quickly, the nuclear meter and pocket penetrometer may have their greatest value. Overall, these results could be used to determine, in advance, the most efficient compaction schemes and rapid tests for a wide range of field conditions.

APPENDIX

ASTM Test Methods

ASTM Standard	Test Method for
D 422-63	Particle-Size Analysis of Soils
D 423-66	Liquid Limit of Soils
D 69-7	Moisture-Density Relations of Soils and Soil-Aggregate Mixtures using 5.5-lb (2.49-kg) Rammer and 12-in. (305-mm) Drop
D 1556-64	Density of Soil in Place by the Sand-Cone Method
D 1557-7	Moisture-Density Relations of Soils and Soil-Aggregate Mixtures using 10-lb (4.54-kg) Rammer and 14-in. (457-mm) Drop
D 2216-71	Laboratory Determination of Moisture Content of a Soil
D 2292-7	Density of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)
D 3017-7	Moisture Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

FAMECE Distributor Spray Rates[10]

Both Sprayheads

Sprayhead Opening (in.)	Engine Speed (r/min)	Flow Rate (gal/min)	Maximum Width (ft)	Spray Rate in gal/yd^2			
				First Gear	Second Gear	Third Gear	Fourth Gear
3/8	1500	288	50	.31	.16	.10	.04
3/8	2000	412	60	.25	.12	.06	.04
3/8	2500	517	70	.21	.10	.05	.35
3/8	Hi-Idle	567	71	.18	.09	.04	.03
1/2	1500	317	50	.34	.17	.11	.04
1/2	2000	447	60	.25	.13	.06	.04
1/2	2500	554	70	.23	.11	.05	.04
1/2	Hi-Idle	590	71	.18	.09	.04	.03
5/8	1500	347	48	.37	.19	.12	.05
5/8	2000	482	59	.29	.14	.07	.05
5/8	2500	590	67	.24	.12	.06	.04
5/8	Hi-Idle	615	69	.20	.10	.04	.03
1	1500	390	41	.51	.26	.17	.07
1	2000	506	55	.33	.16	.08	.05
1	Hi-Idle	708	65	.25	.12	.05	.04

[10] Clark Equipment Company, Construction Machinery Division. *FAMECE Distributor RDAT Final Report C-591-304.* Report to US Army Mobility Equipment Research and Development Command, April 1978.

One Sprayhead[11]

Sprayhead Opening (in.)	Engine Speed (r/min)	Flow Rate (gal/min)	Maximum Width (ft)	Spray Rate in gal/yd²			
				First Gear	Second Gear	Third Gear	Fourth Gear
3/	1500	173	26	.36	.18	.12	.05
3/	2000	247	29	.31	.15	.07	.05
3/	2500	310	35	.25	.12	.06	.04
3/	Hi-Idle	340	37	.21	.10	.05	.03
1/2	1500	190	24	.42	.21	.14	.05
1/2	2000	268	27	.33	.17	.08	.05
1/2	2500	332	31	.31	.15	.07	.05
1/2	Hi-Idle	354	35	.22	.11	.05	.04
5/	1500	208	20	.53	.27	.17	.07
5/	2000	289	24	.43	.21	.10	.07
5/	2500	354	27	.36	.18	.09	.06
5/	Hi-Idle	369	33	.25	.12	.05	.04
1	1500	234	18	.70	.35	.23	.09
1	2000	303	22	.50	.24	.12	.08
1	2500	388	26	.43	.20	.10	.07
1	Hi-Idle	425	31	.31	.15	.06	.05

Gravity Feed Rates[11]

Engine Speed (r/min)	Flow Rate (gal/min)	Maximum Width (ft)	Spray Rate in gal/yd²			
			First Gear	Second Gear	Third Gear	Fourth Gear
1500	236	9	1.4	.71	.44	.16
2000	236	9	.97	.48	.29	.15
2500	236	9	.78	.37	.18	.12
Hi-Idle	236	9	.59	.28	.14	.10

[11] Clark Equipment Company, Construction Machinery Division. *FAMECE Distributor RDAT Final Report C-591-304.* Report to US Army Mobility Equipment Research and Development Command, April 1978.

DISTRIBUTION FOR MERADCOM REPORT 2306

No. Copies	Addressee
	Department of Defense
12	Defense Technical Information Center Cameron Station Alexandria, VA 22314
	Department of the Army
1	Commander, HQ TRADOC ATTN: ATEN-ME Fort Monroe, VA 23651
1	HQDA (DAMA-AOA-M) Washington, DC 20310
1	HQDA (DAEN-RDL) Washington, DC 20314
1	HQDA (DAEN-MPE-T) Washington, DC 20314
1	Director Army Materials and Mechanics Research Center ATTN: DRXMR-PL, Tech Lib Watertown, MA 02172
1	Commander US Army Aberdeen Proving Ground ATTN: STEAP-MT-U (GE Branch) Aberdeen Proving Ground, MD 21005
1	Director US Army Materiel Systems Analysis Agency ATTN: DRXSY-CM Aberdeen Proving Ground, MD 21005
1	Director US Army Materiel Systems Analysis Agency ATTN: DRXSY-MP Aberdeen Proving Ground, MD 21005
1	Director US Army Engineer Waterways Experiment Station ATTN: Chief, Library Branch Technical Information Ctr Vicksburg, MS 39180
1	Commander US Army Troop Support and Aviation Materiel Readiness Command ATTN: DRSTS-MES (1) 4300 Goodfellow Blvd St. Louis, MO 63120
2	HQ, 193D Infantry Brigade (Pan) ATTN: AFZU-FE APO Miami 34004
2	Special Forces Detachment, Europe ATTN: PBO APO New York 09050
2	Engineer Representative USA Research & Standardization Group (Europe) Box 65 FPO 09510
1	Commander Rock Island Arsenal ATTN: SARRI-LPL Rock Island, IL 61201

No. Copies	Addressee
1	Commander Frankford Arsenal ATTN: Library, K2400, B151-2 Philadelphia, PA 19137
1	US Army Engineer School Learning Resources Center Bldg 270 Fort Belvoir, VA 22060
1	Commander Headquarters, 39th Engineer Battalion (Cbt) Fort Devens, MA 01433
1	President US Army Armor and Engineer Board ATTN: ATZK-AE-PD-E Fort Knox, KY 40121
1	Commander and Director USA FESA ATTN: FESA-TS Fort Belvoir, VA 22060
1	Director US Army TRADOC Systems Analysis Activity ATTN: ATAA-SL (Tech Lib) White Sands Missile Range, NM 88002
1	HQ, USAEUR & Seventh Army Deputy Chief of Staff, Engineer ATTN: AEAEN-MT-P APO New York 09403
1	HQ, USAEUR & Seventh Army Deputy Chief of Staff, Operations ATTN: AEAGC-FMD APO New York 09403

No. Copies	Addressee
	MERADCOM
1	Commander, DRDME-Z Tech Dir, DRDME-ZT Assoc Tech Dir/R&D, DRDME-ZN Assoc Tech Dir/Engrg & Acq, DRDME-ZE Spec Asst/Matl Asmt, DRDME-ZG Spec Asst/Scs & Tech, DRDME-ZK CIRCULATE
1	C, Ctrmine Lab, DRDME-N C, Elec Pwr Lab, DRDME-E C, Engy & Wtr Res Lab, DRDME-G C, Camo & Topo Lab, DRDME-R C, Mar & Br Lab, DRDME-M C, Ctr Intrus Lab, DRDME-X C, Matl Tech Lab, DRDME-V Dir, Prod A&T Directorate, DRDME-T CIRCULATE
1	Mech & Constr Eqpt Lab, DRDME-H
1	Constr Eqpt Engr Div, DRDME-HK
22	Special Projects Br, DRDME-HKP
8	Tech Reports Ofc, DRDME-WP
3	Security Ofc (for liaison officers), DRDME-S
2	Tech Library, DRDME-WC
1	Programs & Anal Dir, DRDME-U
1	Pub Affairs Ofc, DRDME-I
1	Ofc of Chief Counsel, DRDME-L
	Department of the Navy
2	Commander, Naval Facilities Engineering Command Department of the Navy ATTN: Code 032-B 062 200 Stovall St Alexandria, VA 22332

No. Copies	Addressee
1	Library (Code L08A) Civil Engineering Laboratory Naval Construction Battalion Ctr Port Hueneme, CA 93043
1	Director Earth Physics Program Code 464 Office of Naval Research Arlington, VA 22217
1	Naval Training Equipment Ctr ATTN: Technical Library Orlando, FL 32813
	Department of the Air Force
1	HQ USAF/RDPT ATTN: Mr. Allan Eaffy Washington, DC 20330
1	Mr. William J. Engle Chief. Utilities Branch HQ USAF/PREEU Washington, DC 20332
1	US Air Force HQ Air Force Engineering & Services Ctr Technical Library FL 7050 Tyndall AFB, FL 32403
1	Department of Transportation Library, FOB 10A, M494-6 800 Independence Ave, SW Washington, DC 20591
	Others
1	Professor Raymond R. Fox School of Engineering and Applied Science George Washington University Washington, DC 20052
1	Reliability Analysis Center Rome Air Development Center RADC/RBRAC (I. L. Krulac) Griffiss AFB, NY 13441