

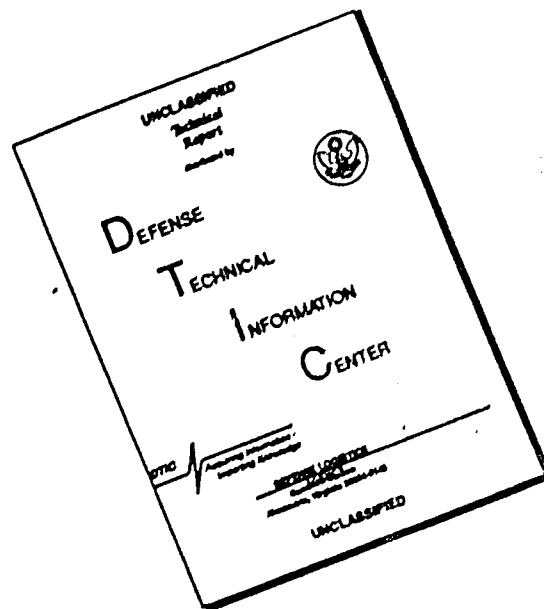
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CONTRACT REPORT NO. 3-152

ONE-PASS PERFORMANCE OF
VEHICLES ON FINE-GRAINED SOILS.

by

(7) final rept.

(10) Clifford — J. Nuttall, Jr.,
—— G. W. Wilson
—— R. A. Werner,



(11) July 1966,

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SUMMARY

Tests were conducted during a one-year field program, ending in November 1964, to study the one-pass performance of self-propelled vehicles in natural, weak, fine-grained soils. Four types of vehicle tests were run: self-propelled, drawbar pull, speed and maneuver. Tests were run with a number of tracked and wheeled vehicles over a range of test weights, tire pressures, and soil strengths, and in two soil types. The field program and subsequent analyses had the following purposes:

- 1) to develop
 - a. a reliable strength index for fine-grained soils with which predictions may be made of the performance of a vehicle on its first pass on a straight, level course, and
 - b. a nominal vehicle load index to be used with the soil strength index to establish whether or not a vehicle will go; and
- 2) to provide means to predict
 - a. one-pass drawbar pull and slope performance in soils having strengths in excess of the minimum required for one vehicle pass on level terrain,
 - b. the increment of soil strength index necessary to permit a vehicle to maneuver freely, and
 - c. the probable maximum speed of a vehicle operating in a terrain situation where the soil strength index exceeds the net vehicle load index.

From mid-October 1963 to mid-January 1964, testing was done in a heavy clay (CH)* at Lake Cen-

*Soil types in this report are classified according to the Unified Soil Classification System.

tenial, Mississippi; and for two weeks in February and March 1964, in a clayey silt (ML) and silty clay (CL) at Grenada, Mississippi. In addition, exploratory tests not programmed in the original one-pass study were conducted at two sites, Fort Stewart, Georgia, and Camp Shelby, Mississippi, during April and May 1964. Soils at these sites were silty sands (SM) with perched water tables (water table less than 15 inches from the soil surface). Both the Lake Centennial and Grenada test sites were revisited during the latter half of 1964, but conditions were unfavorable and it was not possible to develop the full range of test data at these areas that had been anticipated.

Relationships were first developed, from semi-empiric analyses of the basic field measurements and data from past WES trafficability testing, as applicable, between soil strength and vehicle straight-line, level, go/no-go performance. Using these results as a basis, further approximate expressions were then developed for vehicle drawbar pull, maneuver strength requirements, and maximum speed as functions of soil strength.

First-order answers are proposed to the five basic questions posed at the project outset. These answers utilize minor adaptations of techniques and concepts developed by WES in their 50-pass trafficability work, and define modified "vehicle cone indices" (VCI_1) and soil "rating cone index" (RCI_1) procedures appropriate to the one-pass problem. The ratio (VCI_1/RCI_1) is used as the basic soil loading numeric in simple approximate calculations of drawbar pull, grade performance, soil strength increments necessary to permit free maneuvering, and probable maximum speeds, all as influenced by soil strengths.

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PREFACE

Tests conducted during a one-year investigation of the one-pass performance of vehicles in natural soils are reported. Although the data available from this program are not complete enough in any section of the program to permit definitive treatment, the results provide useful first-order answers to basic questions of performance levels of military vehicles during a single pass in weak, fine-grained soils.

This study was conducted by Wilson, Nuttall, Raimond Engineers, Inc. (WNRE), under Contract No. DA 22-079-eng-394 with the U. S. Army Engineer Waterways Experiment Station (WES). It comprises a portion of the mobility environmental research study (MERS), sponsored by the Office, Secretary of Defense (OSD), Advanced Research Projects Agency

(ARPA), Directorate of Remote Area Conflict, for which WES is the prime contractor, and the U. S. Army Materiel Command (AMC) is the service agent. The broad mission of Project MERS is to develop a significant research effort to study the physical environment as it affects design and employment of materiel systems, with special emphasis upon Southeast Asian environments. The funds employed for this study were allocated to WES through AMC, under ARPA Order No. 400. In particular, the work is concerned with the development of one-pass soil trafficability criteria.

Field data were collected by engineers and technicians of the Trafficability Section, Army Mobility Research Branch, Mobility and Environmental Division, under the technical monitorship of WNRE.

ACKNOWLEDGEMENTS

Responsibility for the technical content of this report lies, of course, entirely with the contractor. However, the project was a cooperative effort between WNRE and WES, in all of the best sense; and the support, enthusiasm, constructive criticism, and free release of ideas and data by all WES personnel accounts in large measure for such progress as was made. In particular, it is necessary to acknowledge the help given by the unremitting interest and drive of Mr. A. A. Rula, chief of MERS Branch; the consistent administrative and technical support of his assistants, Messrs. R. D. Wisner and R. R. Friesz; the spirited criticism of Mr. S. J. Knight

and Dr. D. R. Freitag, assistant chief, Mobility Environmental Division, and chief, Army Mobility Research Branch (AMRB), respectively; and the continuous, effective field support of Mr. E. S. Rush, chief of Trafficability Section, AMRB, and of his engineers, Messrs. A. B. Thompson and B. G. Schreiner, and technicians, Messrs. W. J. Hicks and R. G. Temple. Finally, thanks are due Messrs. M. P. Meyer and J. L. Smith, both of AMRB, for generously allowing WNRE project personnel to see their "work in progress" on allied studies which contributed many useful insights, considerable backup data, and much clarification.

LIST OF SYMBOLS

a = running gear material to soil adhesion (psi)	h = tire section height over rim flange (in.)
A = vehicle frontal area (ft ²)	HP _A = driving power available at wheel(s) or sprocket(s) (HP)
b = undeflected tire section width (in.)	k, K = various constants
b _t = track width (in.)	K _r = surface shear strength parameter
BHP = engine brake horsepower (HP)	ℓ = effective contact length of wheel or tire (in.)
c = apparent soil cohesion (psi)	L = length of track on (hard, level) ground (in.)
C = surface intercept of linearized curve of cone index to depth (psi)	M _r = moment resisting rotation of a vehicle during a turn (lb ft)
CI = cone index (psi)	n, m = various constants
CI ^{3/8} = cone index measured with WES cone penetrometer having 3/8" diameter shaft (psi)	n _b = number of bogie wheel stations per track
CI ^{5/8} = cone index measured with WES cone penetrometer having 5/8" diameter shaft (psi)	N = radius ratio/slip parameter
$\overline{CI}$ = average cone index of a soil bed considered to be approximately uniform with depth (psi)	p = average pressure resisting plate penetration (psi)
$\overline{CI}_{(z_1-z_2)}$ = average cone index for soil bed layers between depth z ₁ and z ₂ (psi)	(P) = number of passes completed in same ruts
d = undeflected tire outside diameter (in.)	q = soil bearing capacity (psi)
d _b = bogie wheel diameter (in.)	q ₁ = Evans' nominal peak soil loading under a track (psi)
d _{rr} = wheel diameter over rim flange (in.)	q _{crit} = soil bearing capacity at which vehicle immobilization becomes imminent (psi)
D = maximum drawbar pull of a vehicle in a soil (lb)	q _n = nominal unit ground pressure of a track or wheel (psi)
D ₁ = maximum drawbar pull of a single wheel or track in a soil (lb)	Q _r = driveline torque required to maintain a steady turn of radius r _t (lb ft)
E = Young's modulus for soil (psi)	Q _s = driveline torque required for straight, level, slow-speed operation (lb ft)
f = running gear material to soil coefficient of friction	r = undeflected tire outside radius (in.)
f _r = rubber to soil coefficient of friction	r _t = vehicle turning radius (in.)
G = average gradient of soil cone index with depth (lb/in. ³)	R = gross equivalent motion resistance from soil action (lb)
G _r = vehicle gradeability	IR = total vehicle motion resistance from all sources (lb)

R_A = air resistance (lb)	VCI = standard WES vehicle cone index (psi)
R_P = external motion resistance due to soil plastic flow (lb)	VCI_1 = vehicle cone index for straight, level, self-propelled operation in soil of uniform strength with depth (psi)
R_S = total external motion resistance arising from soil action (lb)	VCI_1' = VCI_1 when soil strength is not uniform with depth, i.e., $K_r \neq 1$ (psi)
R_T = resistance from track or tire internal losses (lb)	VCI_1'' = VCI_1 for free maneuvering during self-propelled operation in level soil whose strength is uniform with depth (psi)
RCI = standard WES rating cone index (psi)	W = gross vehicle weight (lb)
RCI_1 = average rating cone index for one-pass predictions (psi)	W_T = gross vehicle weight (short tons)
$RCI_{1,s}$ = RCI_1 for the surface, 0-1" soil layer (psi)	W_1 = gross vertical load on a single tire or track (lb)
RI = standard WES remolding index	y = track pitch (in.)
RI_1 = remolding correction factor for one-pass predictions	z = vehicle sinkage (in.)
s = soil shear strength as measured by the British vane tester (psi)	z_0, z_1, z_2 = soil depths, measured from the surface (in.)
s_j = slip ratio	δ = radial tire deflection under vertical load on a hard surface (in.)
S = contact area of track(s) or wheel(s) and soil (in. ²)	Δ = tire deflection/tire section height
t = tread width (in.)	η = ratio of horsepower available at wheel(s) or sprocket(s) to overall engine brake horsepower
T = maximum gross traction developable by a vehicle in soil (lb)	σ = unit normal loading on soil in shear (psi)
T_i = traction developed by the inside track	τ = soil unit shearing resistance (psi)
T_o = traction developed by the outside track	$(\tau/\sigma)_{10}$ = τ/σ as determined from Cohron sheargraph measurements, evaluated at $\sigma = 10$ psi
T_1 = maximum gross traction of a single track or tire (lb)	ϕ = apparent angle of internal friction of soil
T' = total traction available while turning	
V = vehicle speed (mph)	
V_s = slip speed (mph)	
V_t = wheel or track peripheral speed (mph)	

INTRODUCTION

The continuing WES research on the relationships between soil strength as measured by the cone penetrometer (and associated procedures) and the performance of a wide range of vehicles has resulted in a practical, reasonably accurate field method for predicting the go/no-go trafficability of a given soft soil terrain to a given vehicle. Moreover, the complete program has produced methods for estimating, from other observations, the effective soil strengths (in terms of cone indices and rating cone indices) for areas where on-the-ground tests are either impractical or impossible. The basic "go" criterion adopted for each vehicle has been the successful completion of 50 passes with the vehicle traveling in the same ruts, on level ground and in a straight line path. At the time this project began, the method had been extended to the prediction of approximate drawbar pull and slope-climbing ability, and, still more approximately, to the estimation of

soil strength required by a vehicle for one-pass, straight, level operation, and for extreme maneuvers.

The one-pass study reported herein is intended to meet, at least temporarily, growing needs for more valid estimates of first-pass performance, both on a go/no-go basis and in terms of probable maximum speed when conditions are "go" but still less than entirely hard. In addition, prediction of vehicle performance in real terrains, encompassing soils and obstacles and slopes, requires estimates of the increment of soil strength necessary for a given vehicle when steering is needed.

At the outset of this study, it was envisioned that the conclusions it reached would be subjected to further checking and refinement during later stages of the MERS effort. However, the MERS work was reprogrammed after the first year to seek somewhat more restricted objectives.

OBJECT

It was the object of this program

- 1) to develop and validate, within one year's time, working first-order definitions of:
 - a. a reliable strength index for fine-grained soils with which predictions may be made of the go/no-go, first-pass performance of a vehicle operating in a straight path over level terrain, and
 - b. its corollary, a nominal vehicle load index to be used with the soil strength index to establish whether or not a vehicle will go; and
- 2) to provide means to predict:
 - a. one-pass drawbar pull and slope performance in soils having strengths in excess of the minimum required for one vehicle pass on level terrain,
 - b. the increment of soil strength index nec-

essary to permit a given vehicle to maneuver freely during a single pass, and
c. the probable maximum speed of a given vehicle operating in a terrain situation where the soil strength index exceeds the net vehicle load index.

It was recognized that a reasonably complete solution to any one of the above problems was, in itself, a tall order. Emphasis was placed rather upon arriving in each case at the best working solutions possible within approximately one year's time, in order to permit concurrent field survey and vehicle test programs to proceed on as sound a basis as possible. These "one-year" answers are supplemented by an estimate of their probable precision and generality, a statement of their known limitations, and an outline of further work required to improve their usefulness.

BASIC APPROACH

Explicit in the project object was the requirement for validated, working answers, within a limited time frame, to a number of practical but complex vehicle/soil performance questions. Implicit was the fact that the nearly twenty-five years of prior field, laboratory, and theoretical work, while it had developed considerable understanding, had not provided the validated, working answers needed. Accordingly, the program to attain the project goals was based upon a flexible, semi-empiric plan using available general understanding of vehicle/soil relationships and results obtained from field tests of prototype vehicles operating in natural soils.

Data available from prior test programs were to be utilized where available, and were to be supplemented by results from a modest field program to be conducted, for support purposes, in the general area of Vicksburg, Mississippi. In the new program, self-propelled, drawbar pull, speed, and maneuver tests were to be conducted with a small selection of tactical military vehicles in several types of fine-grained soils.

The demonstrated, practical field success of the WES cone penetrometer procedures and extensions thereof in meeting 50-pass trafficability prediction problems suggested that these procedures could be further developed to cope with the new, but evidently related, one-pass prediction needs. The program was therefore oriented from the outset towards the use of the cone penetrometer (and subsidiary instruments) as the basic system for measuring soil strengths in conjunction with vehicle performance data. The considerable analytical and laboratory work by Sherratt, Evans, and Uffelmann on vehicle performance in clays [summarized as of 1955 by Uffelmann in Reference 1]* and on-going WES research in controlled laboratory soil bins, using the cone penetrometer as the basic soil instrument [since synthesized by Freitag in Reference 2], further supported such an approach. It was, of course, anticipated that the consolidation of measurements made by the cone penetrometer and associated procedures

into a soil strength index applicable to the one-pass problem might differ from that found suitable for 50-pass predictions. Principal among the 50-pass procedure details which were to be critically reviewed in the new light were the designation of a "critical layer" and appropriate interpretation of "remolding indices" [3].

It was also anticipated that, during a first pass, "slipperiness" or traction failure would often limit vehicle performance rather than bearing failure, although in the 50-pass studies this was rare. In the 1962 field trials in Panama [4], reported "slipperiness" immobilizations were numerous. The cone penetrometer, as might be expected where the action of a thin surface layer governed performance, appeared to be a relatively insensitive indicator of this behavior. Accordingly, an exploratory field study was planned to establish approximate ranges of "slipperiness" indices (such as external and internal friction and/or cohesion of surface soil layers) associated with the test soil types, as functions of the cone indices of the basic soil body, surface and underlying moisture content. The light, portable Cohron sheargraph [5] was selected as the field instrument for use in measuring shear strengths in the soil surface layers.

The semi-empiric analytical framework within which the field test program was designed was outlined at the outset of the project [6]. It included an analytically based, statistically oriented computer program to facilitate objective selections, from analyses of the field data, of an optimum cone penetrometer interpretation and of corresponding numerical values for the one-pass vehicle cone index (VCI_1)* for each test vehicle [7].

Inasmuch as it was planned to base slope, drawbar, maneuver, and speed criteria upon the basic RCI_1 - VCI_1 relationship, the development of VCI_1 information and of corresponding procedures for determining RCI_1 was given priority in both tests and detailed analyses.

*Numbers in brackets refer to references tabulated beginning on page 33.

*Both RCI and VCI are familiar terms in WES 50-pass trafficability work. The subscript "1" is added to each to denote similar concepts in relation to one-pass performance.

TESTING CHRONOLOGY

Selection of the cone penetrometer approach to soil strength measurement made potentially useful much of the unique and extensive vehicle performance/soil strength data collected by WES over the 18 years of their work on 50-pass trafficability. As another part of the overall program, these past WES data were consolidated in a uniform format [8] and, under the present study, were examined for results pertinent to the one-pass study. Unfortunately, the records contained relatively little data useful in the present context. The earlier investigations were concerned primarily with 50-pass criteria, and consequently tests were deliberately conducted in soils of higher strengths than those which produce early immobilizations. Many of the earlier investigations were in prepared lanes and therefore could shed no direct light upon remolding phenomena. Later tests often omitted soil measurements determined previously to be unnecessary for the 50-pass work, but now considered of interest in the one-pass analyses.

As it became clear that usable past data were not as extensive as had been hoped for initially, the program was reoriented to obtain more new basic field data than was originally planned. The required new tests began in haste, on a limited scale, on 21 October 1963 in order to capitalize upon advantageous river-stage conditions which made certain heavy clay (CH) test areas ideal for testing in the immediate vicinity of Vicksburg (Lake Centennial) available at that time (Fig. 1). Considerable data on self-propelled performance of the vehicles were developed during the period 21 October through 18 January 1964. Tests were terminated due to a rise in the Mississippi River level which inundated the test area.



Fig. 1. General view of Lake Centennial test site.

An exploratory two-week program was conducted in clayey silt (ML) and silty clay (CL) in the vicinity of Grenada (Fig. 2) from 25 February through 6 March 1964. Although the soil mass strength levels appeared suitable, frequent, heavy rains caused vehicle drawbar pull to be appreciably lower than was expected on the basis of average cone index values (surface shear strength being the influencing factor rather than the mass soil strength) (Fig. 3). Tests were terminated when rising water flooded all test areas.



Fig. 2. General view of Grenada Lake test site.

The work at Grenada reemphasized the importance of surface soil strength (slipperiness) on vehicle one-pass behavior, particularly with regard to drawbar pull and/or slope performance. A "slipperiness" test program was initiated at WES in mid-March 1964 using three vehicles on two prepared courses, one having a heavy clay and the other a clayey silt. However, this was preempted by an immediate requirement by WES for data on the performance of vehicles in silty sands with perched water tables, necessitating test programs at two areas -- one at Fort Stewart, Georgia (Fig. 4), and the second at Camp Shelby, Mississippi (Fig. 5) -- during April and May 1964. Surface traction tests were resumed at WES during a six-week period in June-July 1964.

Testing in heavy clay at Lake Centennial was resumed in July 1964 and continued until the end of September 1964, when a combination of heavy vegetal growth and surface crusting (and cracking) of the soil (Fig. 6) made further testing unrewarding.



Fig. 3. M37 with 9.00-16 tires. Immobilized due to traction failure. Sinkage=4".



Fig. 4. Fort Stewart test site.



Fig. 5. Camp Shelby test site. Field party making soil measurements.



Fig. 6. Shrinkage cracks in CH soil still present from previous year after 6-8 months of inundation.

A second series of tests in the clayey silt (ML) and silty clay (CL) soils at Grenada was initiated in early October 1964 and continued intermittently until 1 December 1964, at which time all field tests were suspended due to a decision to terminate further investigations under this task. As in the previous program at Grenada, frequent rains caused variations in the surface strength of the soil and these variations are reflected in the data collected,

particularly in the drawbar and maneuver tests.

Eight hundred and thirty-five tests were conducted during the period reported. Of these, 480 tests were conducted in CH soil at Lake Centennial, 127 in ML and CL soils at Grenada, 211 in SM soil at Fort Stewart and Camp Shelby, and 17 tests were conducted on the two surface traction courses at WES.

THE TEST VEHICLES

The field test program ultimately embraced, at one point or another, 20 different vehicles representing a range of running gear types, gross weights up to about 20,000 pounds, and average-to-good overall practical mobility. They are shown in Figures 7 to 26. Several of these vehicles, immobilized in

weak soils on early passes, are shown in Figures 27 to 38. Principal characteristics of each of the 20 vehicles are summarized in Tables 1 and 2.

Five vehicles of particular interest from the research viewpoint were initially selected as the 'backbone' of the test program. These were:

<u>Tracked vehicles</u>	<u>Normal test weight</u>	<u>Nominal unit ground pressure</u>
1) M29C Weasel	5,960 lb.	1.9 psi
2) D4 Standard Tractor w. standard 13" tracks	13,580 lb.	4.6 psi
3) Polecat (a 4-track articulated vehicle using Weasel tracks and suspension)	12,580 lb.	2.0 psi
 <u>Wheeled vehicles</u>		
4) M37, 3/4T, 4x4, w. 9.00-16 8PR tires	7,240 lb.	11.8 psi*
5) M35A1, 2-1/2T, 6x6, w. 11.00-20 12PR single tires	19,410 lb.	14.0 psi*

Vehicles 1, 3, 4, and 5 were instrumented by means of commercial torque meters for the measurement of driveline torque during drawbar pull and maneuver tests.

The D4 (vehicle 3) was tested during the first



Fig. 7. M274, 1/2-ton, 4x4 weapons carrier with 7.50-10 tires.

test phase at Lake Centennial for the development of self-propelled and drawbar pull criteria. It was subsequently replaced as one of the prime vehicles in the program by an M29C Weasel equipped with 12-inch tracks, and hence having a nominal unit ground pressure of 3.2 psi. This vehicle was equipped with a driveline torque meter, so that in the later tests all of the principal vehicles were so equipped.

The six principal vehicles were of particular importance in the planned development of maneuvering and speed criteria, where the tests were designed to examine a number of simple, first-order hypotheses concerning the relationships between each of these desired performance features, VCI_1 and RCI_1 .

* Nominal unit ground pressure for tires is taken to be

$$NUGP = W_1/br$$

where W_1 = average single tire load, lb

b = undeflected tire section width, in.

and r = undeflected tire radius, in.

TABLE 1
WHEELED VEHICLE CHARACTERISTICS

VEHICLE	TIRE	VEHICLE TEST WEIGHT -LBS.-	INFLA- TION PRESSURE -PSI.-	TIRE WIDTH -INS.-	TIRE DIA. -INS.-	CONTACT PRESSURE -PSI.-	GROUND CLEARANCE -INS.-	WHEEL- BASE -INS.-	TREAD -INS.-
M274, 4x4, 1/2 TON	7.50-10, NDCC	1,190	30.0	8.5	22.5	16.3	11.5	57.0	40.5
			10.0	8.5	22.5	11.6	11.5	57.0	40.5
	7.50-10, NDCC	1,940	5.0	8.5	22.5	7.4	11.5	57.0	40.5
			30.0	8.5	22.5	22.2	11.5	57.0	40.5
			10.0	8.5	22.5	11.0	11.5	57.0	40.5
			5.0	8.5	22.5	7.8	11.5	57.0	40.5
M151, 4x4, 1/4 TON	16.00-15 TERRA TIRES	1,325	15.0	15.1	17.4	15.4	9.0	57.0	57.0
			3.0	15.1	17.4	5.4	9.0	57.0	57.0
	16.00-15 TERRA TIRES	1,940	15.0	15.1	17.4	16.2	9.0	57.0	57.0
			3.0	15.1	17.4	4.7	9.0	57.0	57.0
			30.0	7.1	28.6	34.5	10.3	85.0	53.0
			15.0	7.1	28.6	21.6	10.3	85.0	53.0
M37, 4x4 3/4 TON	9.00-14, SMOOTH	3,560	30.0	8.6	26.2	26.7	9.1	85.0	53.0
			20.0	8.6	26.2	20.7	9.1	85.0	53.0
	36.00-20 TERRA TIRES	3,560	15.0	20.2	37.5	15.9	14.8	85.0	71.3
			3.0	20.2	37.5	6.3	14.8	85.0	71.3
			30.0	10.2	32.8	32.9	10.8	112.0	62.0
			15.0	10.2	32.8	22.9	10.8	112.0	62.0
M35A1, 6x6, 2-1/2 TON	9.00-16, NDCC	7,240	6.5	10.2	32.8	14.9	10.8	112.0	62.0
			15.0	20.0	48.0	12.3	18.4	112.0	77.8
	46.00-18 TERRA TIRES	7,240	3.0	20.0	48.0	6.2	18.4	112.0	77.8
			35.5	11.2	43.6	41.7	12.3	178.0	67.4
			13.0	11.2	43.6	24.8	12.3	178.0	67.4
			15.0	20.0	48.0	12.3	18.4	112.0	77.8

TABLE 2
TRACKED VEHICLE CHARACTERISTICS

VEHICLE	VEHICLE TEST WEIGHT -LBS.-	TRACK WIDTH -INS.-	TRACK CONTACT LENGTH -INS.-	CONTACT PRESSURE -PSI-	GROUND CLEARANCE -INS.-	TREAD -INS.-	TRACK PITCH -INS.-	NUMBER OF BOGIES/SIDE	BOGIE SIZE -INS.-
DINAH, 1/2 TON	4,095 4,975	20.0 20.0	80.0 80.0	1.3 1.6	10.5 10.5	40.0 40.0	4 4	3 3	18 18
M29C, WEASEL	4,960 5,960 5,960	20.0 20.0 12.0	78.0 78.0 78.0	1.6 1.9 3.2	11.0 11.0 11.0	45.0 45.0 45.0	4-1/2 4-1/2	8* 8*	8 8
D/4, ENGINEER TRACTOR	12,420 14,870 13,585	13.0 13.0 24.0	61.0 61.0 61.0	8.4 9.2 4.6	11.0 11.0 11.0	44.5 44.5 44.5	6.5 6.5	4 4	8 8
POLECAT, MODEL 941	12,580	20.0	156.0	2.0	11.0	45.0	4-1/2	16*	8
MSA4, HI-SPEED TRACTOR	28,350	17.1	117.5	7.1	19.8	90.4	5-1/2	4	20
MS6, SELF-PROPELLED GUN	15,500	20.0	93	4.2	15.0	78.0	4	4	26-1/8
M113, ARMORED PERSONNEL CARRIER	22,900	15.0	105.0	7.2	16.1	85.0	6	5*	23-7/8
M114, ARMORED PERSONNEL CARRIER	14,750	16.5	102.0	4.4	14.0	73.3	4	4*	21-7/8
M116, CARRIER, CARGO, 1-1/2 TON	8,435 10,610	20.0 20.0	104.0 104.0	2.0 2.6	15.5 15.5	58.0 58.0	4-1/4 4-1/4	5* 5*	22 22
M41 TANK, COMBAT, 76MM GUN	45,000	21.0	128.0	8.4	17.7	102.5	6	5	25-1/2
M59, ARMORED PERSONNEL CARRIER	42,870	21.0	143.0	7.1	18.0	103.0	6	5	25-1/2
M48A1, TANK, COMBAT, 90MM GUN	98,400	28.0	157.5	13.0	15.3	115.0	7	6*	26

* Dual Bogies



Fig. 8. M151, 1/4-ton, 4x4 truck with 7.00-16 tires.



Fig. 12. M151, 1/4-ton, 4x4 jeep with 9.00-14 smooth tires.



Fig. 9. M37, 3/4-ton, 4x4 truck with 9.00-16 tires.



Fig. 13. M151, 1/4-ton, 4x4 jeep with 36.00-20 Terra-Tires.



Fig. 10. M35A1, 2-1/2-ton, 6x6 truck with 11.00-20 single tandem tires.



Fig. 14. M37, 3/4-ton, 4x4 truck with 46.00-18 Terra-Tires.



Fig. 11. M274, 1/2-ton, 4x4 weapons carrier with 16.00-15 Terra-Tires.



Fig. 15. M29C cargo carrier with 20" tracks.



Fig. 16. M29C cargo carrier with 12" tracks.



Fig. 20. M5A4 high-speed tractor.



Fig. 17. "Dinah" articulated cargo carrier.



Fig. 21. D4 engineer tractor.

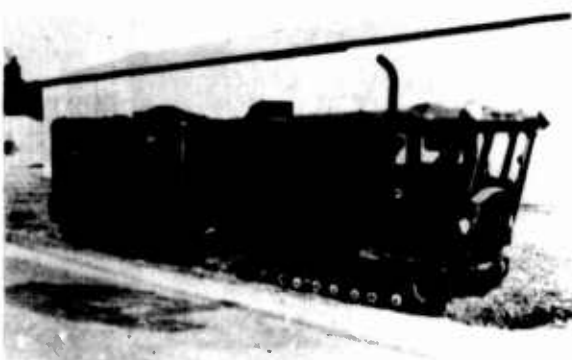


Fig. 18. Polecat Model 941 articulated personnel carrier.



Fig. 22. M56 self-propelled gun.



Fig. 19. M4 high-speed tractor.

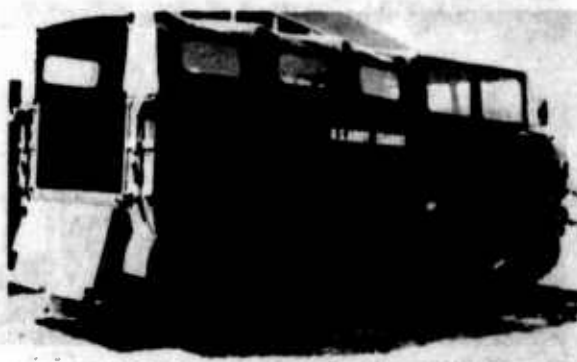


Fig. 23. M116 cargo carrier.



Fig. 24. M114 personnel carrier.



Fig. 25. M59 personnel carrier.



Fig. 26. M48A1 medium tank.



Fig. 27. M274 with 7.50-10 tires. Immobilized on 1st pass.



Fig. 28. M274 with 16.00-15 Terra-Tires. Immobilized on 1st pass.



Fig. 29. M151 with 9.00-14 smooth tires. Immobilized on 1st pass.



Fig. 30. M151 with 36.00-20 Terra-Tires. Immobilized on 1st pass.



Fig. 31. M37 with 9.00-16 tires. Immobilized on 1st pass.



Fig. 32. M37 with 46.00-18 Terra-Tires. Immobilized on 4th pass.



Fig. 36. D4 with 24" tracks. Immobilized on 3rd pass



Fig. 33. M29C with 20" tracks. Immobilized on 18th pass.



Fig. 37. M5A4. Immobilized on 1st pass.



Fig. 34. "Dinah." Immobilized on 6th pass.



Fig. 38. M116. Immobilized on 6th pass.



Fig. 35. D4 with 13" tracks. Immobilized on 4th pass.

TEST SOILS

Major test areas were in two natural terrains having, respectively:

- 1) a heavy clay soil (CH) (Lake Centennial area), and
- 2) clayey silt (ML) and silty clay (CL) soils (Grenada Lake, Mississippi).

Gradation curves of these soils, and of those at Fort

Stewart and Camp Shelby as well, are given in Figures III-1 to III-4 of Appendix III.

Within each area and soil type, soils having a wide range of soil strengths as measured by cone indices (with and without various degrees of remolding corrections) were utilized. This range was the result primarily of differences in natural moisture content at the time and/or precise place of the tests. Suitable test areas having still other soil types could not be located in the Mississippi area during this program. The tests accordingly were limited to only the two fine-grained soils areas.

TEST PROCEDURES

Field Soil Tests

Procedures and techniques developed in earlier WES investigations [9] were used in measuring soil properties and in collecting samples for laboratory analysis (Figs. 39-42). In addition, the Cohron shear-graph was used to measure surface shear strength of the soils. The manner of its use is given in Reference 5 (Fig. 43).

Self-Propelled Traffic Tests

Self-propelled tests were also conducted in the same general manner as in previous WES 50-pass



Fig. 39. After-traffic soil measurements in low strength (3-9 layer RCI=5) soil. Note use of "duck" boards.



Fig. 40. Measurement of soil strength profile (along test lane) with cone penetrometer.

trafficability programs, except that it was, of course, necessary to select lower soil strength levels in order to obtain one-to-ten-pass immobilizations.

Drawbar Pull Tests

Drawbar tests were run by connecting the test vehicle to a drag vehicle by means of a tow cable and load cell (Fig. 44). Drawbar load was adjusted by adjusting the speed of the drag vehicle (and hence test vehicle slip) while maintaining a constant, nominal test vehicle track or wheel speed of approximately 2 miles per hour. Drawbar pull and, in those vehicles equipped with torquemeters, driveline torque were measured.



Fig. 41. Field party measuring remolding index and collecting moisture/density samples.

During the first program at Lake Centennial, drawbar tests were run by regulating the drag load so that a continuous record of pull was made between no load and the load that caused a test vehicle to slip approximately 100 percent. The drawbar pull record was then examined for maximum pull, and soil data were obtained in the area of occurrence of maximum pull. For these tests slip was not measured. While these first tests were underway, instrumentation to measure slip was assembled and a subsequent series of drawbar tests covered the slip range from 0 to 70 or 80 percent. In these latter tests, both drawbar pull and slip were measured, and it was determined from these that maximum pull in all of the tests occurred at approximately 20 percent slip for wheeled vehicles and 40 percent for tracked vehicles (see Figs. 45 and 46). Subsequent drawbar tests of each vehicle accordingly were run at constant slips of 20 and 40 percent only. This provided approximate maximum pulls for either tracked or wheeled vehicles as well as data for each at the same slip, for direct comparison if desired.

In order to obtain a maximum range of soil strengths at Lake Centennial, test lanes were arranged perpendicular to the water's edge. Constant



Fig. 42. Measuring after-traffic soil strength in rut created by vehicle.

slip tests toward the water thus provided a record of drawbar pull versus more-or-less continuously decreasing soil strength. This procedure greatly expedited testing, but the vehicle at any instant was, in effect, operating on soil of varying strength throughout its running gear length. Average soil strength values paired with each drawbar measurement thus have a slightly greater uncertainty than might have been attained by tests in more nearly constant conditions. It was considered that the increase in the number of valid data points available more than compensated, statistically, for the probable slight degradation of accuracy of individual points. Moreover, had the tests been run parallel to the water, somewhat the same uncertainty as to soil strength would have existed from one side of the vehicle to the other.

Surface Traction Tests

Two diked test lanes were prepared on WES grounds,



Fig. 43. Sheargraph being used to measure surface shear strength.

one of a clayey silt and the other of a heavy clay. Preparation consisted of blading and rolling. Both courses were compacted to provide a 0-6-inch CI of 300-plus in order to minimize rutting when trafficked. The surface strength of the two test courses was varied by sprinkling and/or flooding. Surface sheargraph measurements and moisture content samples were taken along each course just before use.

Drawbar tests were conducted with three vehicles: the M29C, the M37 4x4 with 9.00-16 tires, and the M38A1 4x4 with 6.00-16 tires. Tests consisted of measuring drawbar pull and torque in each case at 20 and 40 percent slip, to conform to the drawbar determinations made in other parts of the program.

The heavy clay traction course, partly due to the necessity of using fill material and partly due to frequent, heavy rains, was never really uniform in strength in the surface layer, and consistently pro-



Fig. 44. M29C equipped for drawbar test. Note 5th wheel, load cell, and instrument cluster for driver.

duced erratic test results. Tests in the clayey silt traction course produced results of somewhat better quality, but alternate periods of heavy rain and high ambient temperatures (and high drying rate) caused rapid changes in the surface moisture content, and consequently in surface shear strength which, as could be expected, also made for poor control over test conditions.

Speed Tests

Full-throttle speed tests were run on selected vehicles in several soil strengths. Care was taken to

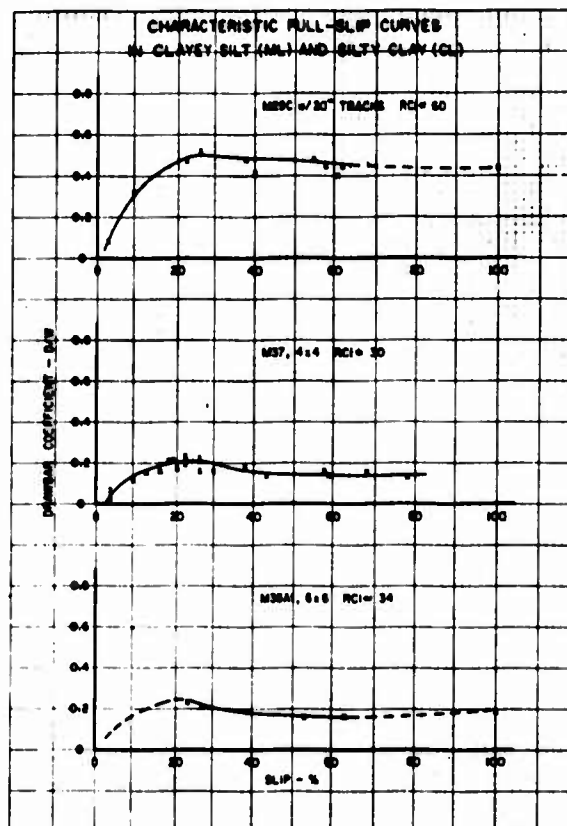


Fig. 46

insure a long enough run to reach equilibrium. In each test the procedure was to operate the vehicle in a gear which caused the full throttle engine speed (read on a tachometer) to stabilize at a level below the maximum allowable (or the governed speed). Upon reaching a stable speed, a marker was thrown from the vehicle and a stop watch was started. At the end of a fixed time period (5 or 10 seconds) a second marker was thrown and the gear position, engine speed, distance traveled, and elapsed time were recorded. Insofar as possible, these tests were made along a test lane selected to have a reasonably uniform strength throughout its length. The results

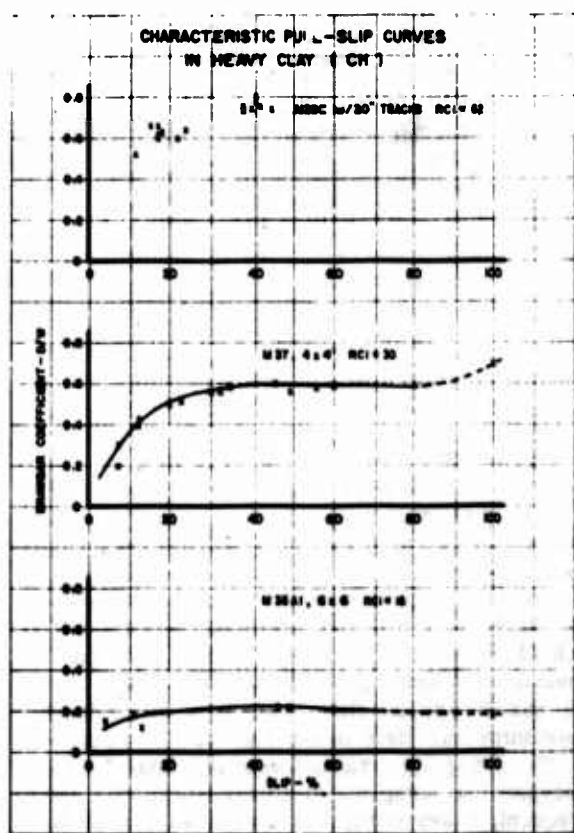


Fig. 45

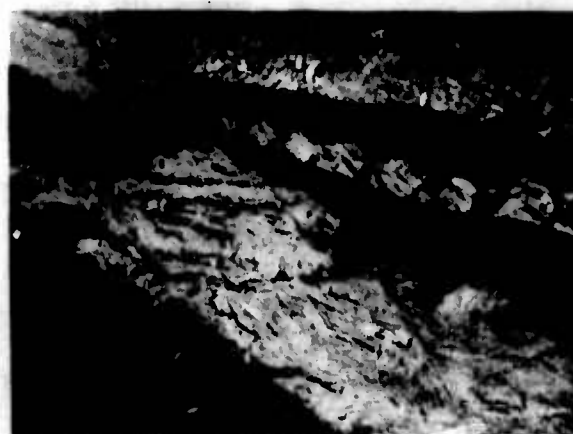


Fig. 47. Accumulation of soil in running gear of M29C.



Fig. 48. Accumulation of soil on articulated steering mechanism of Dlnah.

were markedly influenced by the amount of soil accumulated in the running gear of the vehicle before and/or during the course of the run (Figs. 47-48).

Maneuver Tests

For each of the basic vehicles, torque was measured via propeller shaft torquemeters while operating in soils of various strength when proceeding in a straight line; on one or more fixed radii less than minimum; and on the minimum radius of which each is capable (Fig. 49). The tests were con-



Fig. 49. Polecat undergoing maneuver tests. M29C on left is instrumentation vehicle.

ducted in lanes of various radii established to provide, again insofar as possible, uniform soil strength. The test vehicle was operated in its lowest gear at an engine speed giving a nominal forward speed of 2 miles per hour. Torque, engine speed, slip, rut width, rut depth, and soil strength were measured and recorded. As in the speed tests, problems of soil uniformity and soil accumulation in the running gear were encountered. Both problems were exaggerated by the curved path.

INSTRUMENTATION

Electronic transducers and event markers were used to obtain continuous measurements of engine speed, wheel or track speed and slip, driveline torque, drawbar pull, distance traveled, and elapsed time. These were recorded on a vehicle-mounted 10-channel oscillographic recorder with associated amplifiers (Fig. 50). The 110-volt, a. c. voltage required was obtained from an engine-driven generator mounted on the instrumentation vehicle.

Drawbar pull was measured by a commercial strain-gaged load cell connected, via tow cable, between the test and the drag vehicles (Fig. 51).

Engine/driveline rotations were counted by a cam-actuated microswitch attached to the speedometer take-off on the vehicle transmission and were recorded on the oscillograph as a series of event marks. A second cam-actuated microswitch mounted on a trailing fifth wheel gave a similar record of distance traveled by the fifth wheel. Pretest calibration on a hard surface provided values of distance traveled per "pip" for each of these event marks. Comparison of event marks with each other and with the timing lines, recorded continuously on the chart,



Fig. 50. View inside instrumentation vehicle showing arrangement of recorders, amplifiers, etc.

permitted ready calculation of slip and various speeds in the system.

The fifth wheel was also equipped with a d.c. generator whose voltage output was linearly proportional to speed. This drove a meter calibrated, for each of the test vehicles, directly in percent slip. The meter was used by the drag vehicle operator



Fig. 51. M29C undergoing drawbar pull tests at Grenada Lake test site.

in regulating his throttle to provide the approximate desired slip during a test.

Each test vehicle was equipped with an electric tachometer by means of which the driver was able to adjust the engine speed to produce a traction element speed (relative to the vehicle) of approximately 2 miles per hour.

Several of the test vehicles were equipped with commercial driveline torquemeters, with which drive shaft torque was continuously measured and recorded during maneuver and drawbar tests (Fig. 52).



Fig. 52. M29C drive shaft torquemeter.

A manually operated switch, connected to an event marker in the recorder, was used to indicate on the oscillograph, for later coordination with other logged data, occurrences such as passing a test lane marker, crossing an obstacle or old ruts in the test lane, or other observable conditions likely to produce erratic results.

A major component of the instrumentation package was the intercommunication system, by means of which the drivers of the test and drag vehicles, the instrument operator, and the test engineer maintained constant voice contact. The system used was one in which all stations were "open" in order that the personnel involved might have free use of both hands during the test operation.

TEST RESULTS

The complete data from all vehicle field test programs and supporting field soil tests are tabulated in Appendix III in Tables III-3 to III-50. Tables III-3 through III-48 are print-outs of the data as concurrently reduced to punched-card form by

WES for their own future reference. The coding used is fully explained in Tables III-1 and III-2, immediately preceding. The test location code is given in the location maps, Figures III-5 and III-6 of Appendix III.

ANALYSES

Because of their semi-empiric nature, the analyses, as they developed, did not follow the original outline in detail. The emerging data altered the order of precedence of some factors originally proposed. In other cases the data did not have the precision needed to treat some of the secondary effects contemplated in the original program. In still others, complex factors which were not amenable to treatment within the present time frame, such as the soil/vehicle relationships governing the loading-up of suspension in sticky soils, proved to have effects upon measurements, such as speed, which tended to mask the effects of the basic mass soil-strength variable. Continuing exposure to the on-going, related work on soil/vehicle relationships of other persons and/or organizations also provided new insights.

Problem 1. Basic First-Pass Trafficability Criteria

The crux of the study lay in unraveling from the data a rational, workable soil strength index. The pattern and progress of such a semi-empiric process is often orderly only in retrospect. This is a retrospective account.

The data available for the determination of a first-pass trafficability criterion consist of:

- 1) Measured drawbar pull maxima for 14 vehicles and/or load conditions in two soil types, each at several strengths characterized by measured cone penetrometer profiles and standard remolding index determinations;* and
- 2) number of passes completed in the same ruts (traffic tests) for 45 vehicle configurations (36 from present tests, nine from past) in several soils, again of various strengths as recorded by standard WES cone penetrometer procedures.

The basic approach in analyzing these data was to treat the two performance parameters for all vehicles (maximum drawbar pull in the pull-slip tests, passes completed in the self-propelled traffic tests) as independent, single-valued monotonic functions of a given soil strength index. Several different soil strength

indices, all derived by manipulation of the corresponding cone penetrometer and remolding measurements, were tried. A curve of visual best-fit was drawn and extended as necessary to obtain an intercept at zero drawbar pull or one-pass completed, as appropriate. The intercept value from a given exercise was taken as the estimate of VCI_1 for the vehicle, type of test (drawbar or traffic), and structure of soil strength index involved. Where both drawbar and traffic test data were available on a vehicle, the two plots (maximum drawbar pull and passes completed) were made on a common soil strength index base, and the assumption made in fitting the two curves that they should have the same intercept; i.e., that when the soil strength is just sufficient to support one pass of a vehicle there is no excess of drawbar pull, and vice versa* (see Figure 84, for example). The exercise was repeated for various reasonable configurations of the strength index in terms of

- 1) averages of measured cone indices in soil layers of several thicknesses, at several depths in the soil (6-12", 0-18", etc.), each modified by
- 2) the application of various percentages of the total reduction in strength due to remolding determined by the standard WES method.

A computerized manipulation of the data was set up and conducted under a subcontract by the Davidson Laboratory, Stevens Institute of Technology [7]. In this program the many computations for various forms of index were carried out, a least-mean squares best-fit made for each form, the corresponding intercepts obtained, and several simple statistical measures of "goodness of fit" calculated. The form of the curve fit to the drawbar data, selected after a review of available theoretical and laboratory results [6], was

$$D/W = K_1 - K_2/CI'$$

where D/W = drawbar pull/gross vehicle weight

and CI' = the soil strength index

*During the spring of 1964, WES altered their standard cone penetrometer from one having a 5/8-inch diameter shaft to one having a 3/8-inch diameter shaft. It was desired to express the results of this study in terms of measurements of the new standard instruments. It was therefore necessary to "correct" some of the earlier data. For this purpose, simple approximate relationships were developed experimentally during the remainder of the program (Appendix V).

*Note that a vehicle operating in fine-grained soil of the absolute minimum strength in which it will continue to function will, in general, be proceeding with considerable slip. The zero-pull point will, accordingly, be a true member of the 20-40 percent slip -- or maximum DBP -- data family in this case, even though this is not necessarily so in the case of multipass trafficability.

In the absence of any theoretical considerations, a linear relationship between passes completed (P) and strength was arbitrarily used, as follows:

$$(P) = K(CI' - CI_0'),$$

The thought was implicit in the overall treatment that that configuration of the basic cone penetrometer data which most reduced "scatter" in the performance/strength relationships would probably be the most useful and "correct." However, despite its arithmetic and logical complexity when reduced to a rigorous, objective, decision-making procedure, the program proved too naive. It did not provide for elements of selection and judgment actually utilized in less-formalized, subjective handling of the data. Its results showed no useful consistency, and proved to confuse rather than clarify the picture. No doubt a more sophisticated program could be developed which would perform better. However, neither time nor funds nor experience encouraged further work along these lines at this time.

A rapid, manual reassessment of a broader range of possibilities in handling the data than encompassed in the computer approach, and using more complex judgment bases, was subsequently undertaken. During this period the WES laboratory test work on tires in sand and clay, which had been underway for several years, matured and was consolidated by Freitag [2]. His synthesis, taken with trends which were emerging in the on-going treatment of the field data and with considerable general background on vehicle-soils relationships, suggested a rational and potentially more general approach to the critical problem of selecting an appropriate layer within the soil mass over which to average the measured cone indices (with or without some degree of remolding correction). The reasoning involved is detailed in Appendix II. From this it was decided to try layer rules for tires and tracks as follows:

tires--surface to a depth = $\sqrt{b\Delta}$

tracks--surface to depth = b_t

where b = undeflected tire section width

d = undeflected tire outside diameter

Δ = tire deflection ratio
= δ/h

δ = radial deflection of tire on a hard surface, under test load and at test inflation

h = section height over rim flange
= $0.5(d - d_{rf})$

d_{rf} = wheel diameter over rim flange

and b_t = track width.

The computer results demonstrated that selection of a proper remolding adjustment required simultaneous consideration of soil types of significantly

different sensitivity. The Lake Centennial (CH) and Grenada Lake (CL and ML) data were used for the purpose.*

Finally, a review was made of the abundant, simple, but largely unsubstantiated theoretical treatments of vehicle/soil relationships published over the past 20 years, to establish a general form of the relationship to be expected between the minimum soil strength at which a given vehicle may operate (on a steady, straight, level course) and the basic characteristics of that vehicle. (In cone index -- RCI_1 -- terms, this minimum strength defines the vehicle cone index, VCI_1 .) The result, as developed in Appendix I, is, unremarkably, that for either wheeled or tracked vehicles

$$VCI_1 = Kq_n \quad (1)$$

where q_n = nominal unit ground pressure of the vehicle.

For tracked vehicles

$$q_n = W_1/b_t L \quad (2)$$

and for wheeled vehicles

$$q_n = W_1/br \quad (3)$$

where W_1 = the gross load on a single tire or track, lb

L = nominal contact length of a track on hard ground, in.

and r = undeflected tire outside radius, in.

This consideration was incorporated as part of the value judgment in assessing the probable validity of various layer-rule/remolding treatments of the soil data.

The major results applicable to one-pass soil trafficability criteria are as follows:

1. RCI_1 : Based upon analyses of the data in CH and CL and ML soils, along the lines discussed, the following definition for RCI_1 is proposed:

$$RCI_1 = \frac{1}{z_0} \int_0^{z_0} (CI \times RI_1) dz \quad (4)$$

where CI = cone index measured at depth z

RI_1 = the remolding correction
= $0.5(1+RI)$

*Vehicle immobilizations during tests at Camp Shelby and Fort Stewart in silty sands upon perched water tables appeared to be qualitatively different from those in the fine-grained soils, suggesting that pore water behavior may play a significant role in this situation. In any event, the data from the Camp Shelby and Fort Stewart tests did not lend themselves to the above analysis and accordingly were not pooled with the fine-grained soil tests in these analyses. The soil type involved is important and deserves further study, however.

RI = the standard WES remolding index [3]
 and $z_0 = \sqrt{5da}$ for wheeled vehicles
 or $z_0 = b_c$ for tracked vehicles

i.e., RCI_1 is the average cone index, corrected for remolding effects, from the surface to the depth, z_0 , defined. z_0 is taken to the nearest 3-inch increment, consistent with current WES 50-pass trafficability measurement procedures, and RI is measured for each 6-inch layer and applied to the corresponding measured cone indices.

Since remolding indices were usually measured for 6-inch layers only, the following equations, which assume a linear relationship between soil strength and depth, were used to compute RCI for depths which were not multiples of 6 inches.

$$RCI_1(0-9) = 3/4 RCI_1(0-6) + 1/4 RCI_1(6-12)$$

$$RCI_1(0-15) = 1/4 RCI_1(0-6) + 3/4 RCI_1(6-12)$$

Based upon 50-pass trafficability experience, cone index profiles were in many cases taken to a depth of only 18 inches. Where this occurred, and an average to a deeper depth was called for, the following equations were used to extrapolate the measured data (again linearly):

$$RCI_1(0-21) = 3/4 RCI_1(6-12) + 1/4 RCI_1(12-18)$$

$$RCI_1(0-24) = 1/2 RCI_1(6-12) + 1/2 RCI_1(12-18)$$

2. VCI_1 : Plots of the total fine-grained vehicle/soil test data treated in this manner are shown in Appendix IV, Figures IV-1-IV-6 for wheeled vehicles and Figures IV-7-IV-10 for tracked vehicles tested under this program. Those past WES tests for which adequate data for this new analysis were available are plotted in Figures IV-11-IV-13 of Appendix IV. The intercepts from these plots which define VCI_1 on a passes-completed basis and, where available, also on a drawbar pull basis, are tabulated in Tables 3 and 4, and the VCI_1 's from pass data only are plotted in Figures 53 and 54.

From Figures 53 and 54,

$$VCI_1 \approx 3 q_n \quad \text{for tires} \quad (5)$$

$$\text{and } VCI_1 \approx 2.5 q_n + 4 \quad \text{for tracks.} \quad (6)$$

A conservative upper bound for each case, as shown, might be

$$VCI_1 = 3 q_n + 3 \quad \text{for tires} \quad (7)$$

$$VCI_1 = 3 q_n + 6 \quad \text{for tracks.} \quad (8)$$

As shown in Table 3, the agreement between VCI_1 as estimated from passes-completed data and as estimated from drawbar tests, is good except for the tracked M116 at 8435 pounds, and the wheeled M35A1 6x6 at 13 psi tire inflation. As will be discussed in the next section, first-pass performance is

far more sensitive to departures in surface soil shear strength from a norm associated with the mass shear strength which provides bearing capacity than is 50-pass trafficability. It is possible that this accounts for such discrepancies, as well as for much of the scatter apparent in Figures 53 and 54. No attempt was made to "correct" the data for such effects, although means of accounting for them are suggested by the next section. Any further program should be designed to attempt this, however.

3. An alternate "layer rule" (not recommended): During the search for synthesis, numerous other reasonable appearing layer/remolding rules were tried. Among these the following produced the most consistent results:

$$RCI_1' = \frac{1}{6} \int_{z_1}^{z_2} (C \pm RCI_1) dz \quad (9)$$

where RCI_1 is defined as before and the layer ($z_1 - z_2$) is a function of nominal unit ground pressure (q_n) as given below:

q_n	Layer
0-3 psi	0-6"
3-6	3-9"
6-9	6-12"
9-12	9-15"
12-15	12-18"

The current data, treated as before, produced the VCI_1 estimates given in Table 5, and plotted versus q_n in Figure 55. From Figure 55, for both wheeled and tracked vehicles,

$$VCI_1 \approx 2.3 q_n + 2 \quad (10)$$

and a conservative upper bound might be

$$VCI_1' = 2.3 q_n + 5 \quad (11)$$

As will be seen in Table 5, with this treatment of the cone data there are no serious discrepancies for any of the vehicles between VCI_1 as determined by pass data and drawbar tests. The fact that wheeled and tracked vehicle results fall into the same, reasonably narrow, scatter band is also suggestive. However, the use of a pressure to estimate the depth to which the soil mass may be actively involved in the continuous failure which is rutting is unacceptable on fundamental grounds. Hence the generality of the demonstrated relationship is more questionable than those, such as developed in the paragraph just preceding, which depend upon a layer rule related to the geometry of the loading system. The first proposal is thus to be preferred.

Problem 2a. Prediction of Drawbar Pull and Gradeability

The maximum drawbar pull (D) of a vehicle in a given soil bed is generally treated as the difference between maximum traction (T) developable by its running gear in the soil it is engaging, and the sum of the external motion resistances (R_e) offered by the soil body as the vehicle passes over and through it. Reduced to dimensionless form, this becomes

TABLE 3
VCI₁ FROM NEW DATA USING (0-Z₀) LAYER

Wheeled Vehicles	GVW	Tires	Infl. Press.	q _n	Key	VCI ₁	
	lb		psi			Pass Data	BP Data
					Fig. 53		
<u>M151</u>	3,560	36.00-20 TT	3	2.3	1	8	
			15	2.3	2	7	
<u>M274</u>	1,325	16.00-15 TT	3	2.5	3	7	
			15	2.5	4	8	
	1,190	7.50-10	5	3.1	5	7	
			10	3.1	6	10	
			30	3.1	7	11	
			3	3.7	8	11	
	1,940	16.00-15 TT	15	3.7	9	11	
<u>M37</u>	7,240	46.00-18 TT	3	3.8	10	11	
			15	3.8	11	13	13
<u>M274</u>	1,940	7.50-10	5	5.1	12	15	
			10	5.1	13	17	
			30	5.1	14	15	
<u>M151</u>	3,560	9.00-14	20	7.9	15	27	
			30	7.9	16	22	
	3,560	7.00-16	15	8.8	17	25	
			30	8.8	18	27	
<u>M37</u>	7,240	9.00-16	6.5	10.8	19	25	20
				10.8	20	33	33
				10.8	21	30	30
<u>M35A1</u>	19,410	11.00-20	13	13.3	22	37	25
			35.5	13.3	23	40	

<u>Tracked Vehicles</u>		<u>Track Width, in.</u>		<u>Fig. 54</u>		
<u>Dinah</u>	4,095	20	1.3	1	6	
	4,975	20	1.6	2	7	
<u>Wassel</u>	4,960	20	1.6	3	8	4
	5,960	20	1.9	4	8	12
<u>M116</u>	8,435	20	2.0	5	10	20
<u>Polecat</u>	12,580	20	2.0	6	10	9
<u>M116</u>	10,610	20	2.6	7	12	12
<u>Wassel</u>	5,960	12	3.2	8	8	10
<u>D-4</u>	13,585	24	4.6	9	16	16
<u>M56</u>	15,995	20	4.7	10	20	
<u>D-4</u>	12,420	13	7.8	11	17	
<u>D-4</u>	14,870	13	9.2	12	25	
<u>M-5A4</u>	28,350	17.1	7.1	13	26	

TABLE 4

VCI₁ FROM PREVIOUS DATA USING (0-Z₀) LAYER

Wheeled Vehicles	GVW lb	Tires	Infl. Press. psi	q _n	Key	VCI ₁ (from Pass Data)
<u>Fig. 53</u>						
<u>M151</u>	3,430	36.00-20 TT	5	2.2	A	24
<u>M274</u>	1,260	7.50-10	10	3.3	B	12
<u>CV-8, 1T Truck</u>	8,890	46.00-24 TT	10	4.0	C	30
<u>Jeep Utility Wagon</u>	3,650	7.00-15	30	8.0	D	25
<u>M37</u>	5,925	9.00-16	30	8.9	E	25
<u>Michigan Payloader</u>	13,815	14.00-24	30	9.5	F	32
<u>M37</u>	7,425	9.00-16	30	11.1	G	35
<u>XM-438EZ, Goer</u>	38,310	29.50-20	15	12.1	H	40
<u>WWII 2-1/2T Truck</u>	16,300	10.50-18	5	15.0	J	43

Tracked VehiclesTrack Width, in.Fig. 54

<u>M24, Lt. Tank</u>	36,800	16	11.30	A	34
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$$D/W = T/W - R_s/W \quad (12)$$

where W = gross vehicle weight.

Thus drawbar pull is a composite response. The two more fundamental performance factors which make it up do not necessarily have the same form of relationship to measured soil strength. Moreover, traction generally will involve soil only in close proximity to the running gear, while many components of the resistance force are generated in the process of mobilizing the bearing capacity which supports the vehicle weight, and hence reflect soil behavior and properties throughout the soil body up to considerable distances from the mechanical soil-vehicle interface.

Use of a simple soil strength index in this situation, and hence in any limiting one-pass performance prediction, thus implies that that index reflects the soil strength both in terms of direct shear, and in terms of bearing capacity. It also implies expectation of a high degree of simple regularity in normal strength profiles throughout the soil depth involved in the total system. These are two independent problems.

Treating the question of profile regularity first, it is evident that, except under controlled conditions, as in the laboratory, any more than a crude similarity in profiles cannot be expected. Even the gross lineari-

zation of the profile suggested in Figures II-4 and II-5 of Appendix II requires two independent parameters to define it properly. Replacing these by an average throughout a depth related to the size of the system, as in the "critical layer" rule just proposed, is conceptually adequate to approximate the response of the soil body to bearing loads. It can only serve the same function for tractive loads if the strength of surface layers is some fixed proportion of the average. Even in the same soil body, this proportion can not be entirely fixed for averages taken to various depths except when the surface strength is effectively zero, or the strength is essentially invariant with depth over the range of depths of interest. Thus, for drawbar pull prediction*

*Strictly speaking, of course, the minimum supporting soil strength required for a single self-propelled pass -- VCI₁ -- is also affected by surface shear strength, for it is simply the zero drawbar-pull case. Much of the scatter in the test results as presented in the preceding section is probably due to variations in surface strength from the chance norm in which the tests were run. The methods developed in this section, applied to these other data, would presumably refine the results to a useful degree. Unfortunately, exhaustion of project time and funds prevented this third cycle of analysis at this time.

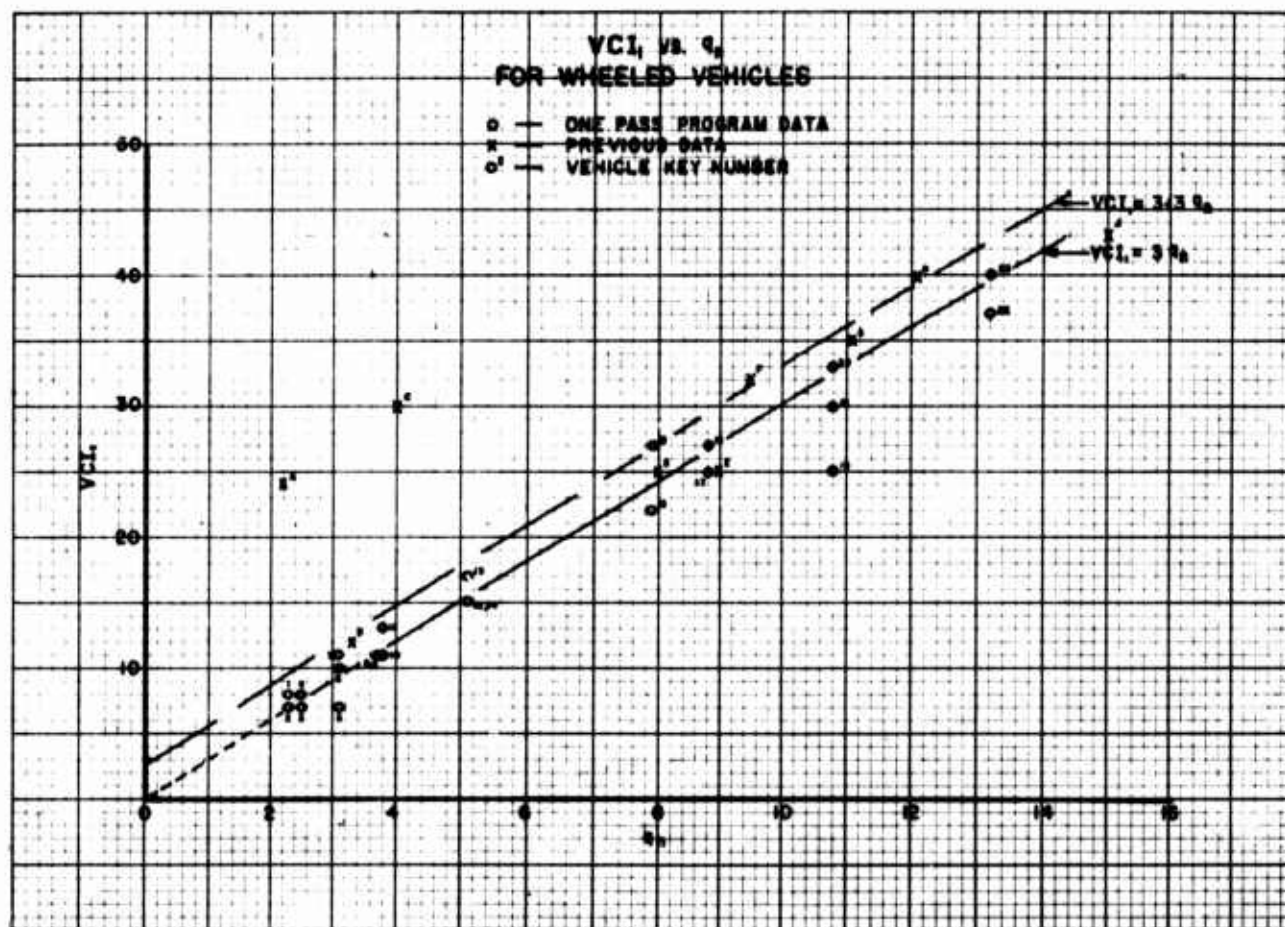


Fig. 53

a second strength parameter is necessary in addition to that reflecting bearing capacity.

Beginning with Micklethwait [10] and Nichols [11] it has been generally accepted that maximum traction may be approximated essentially by the simple application of Coulomb's equation

$$\tau = c + \sigma \tan \phi \quad (13)$$

where τ = soil unit shear strength

c = apparent soil cohesion

ϕ = apparent soil angle of internal friction

and σ = unit normal loading,

by selecting the appropriate contact area (and corresponding nominal normal pressure). The requisite value of t , or of c and ϕ , conceptually may be obtained by means of *in situ* direct shear measurements. The Cohron sheargraph [5], a small, manual torsion shear device, compatible in its portability with the standard WES soil trafficability equipment [12], was used in this program in an attempt to obtain these values in the field.

The outcome is discussed in Appendix VI. In general, the sheargraph gave results which showed the proper trends, but detailed correlation with measured vehicle performance, in accordance with equation [13], proved elusive. In this circumstance, a

cruder approach was taken in which the sheargraph measurements were reduced to an index

$$(\tau/\sigma)_{10}$$

where τ was evaluated from the records at a nominal σ of 10 psi. This index appeared to correlate reasonably well with results from tests (the "slipperiness" tests) in which measured vehicle pull could be presumed to be traction only; i.e., in tests where the main soil body was so strong ($RCI_1 \geq 300$) that external motion resistance was nil.

This index was next correlated approximately with cone index, using field data from this program, and data from two WES laboratory programs [Smith 13, Meyer 14] which became available as this study concluded (Appendix VI). The relationship for nine different fine-grained soils appeared to be given to a useful accuracy by the exponential decay expression.

$$(\tau/\sigma)_{10} = 1 - e^{-K_2 \cdot CI} \quad (14)$$

where K_2 was a soil constant varying between about 0.01 and 0.03, and having the dimensions $(\text{psi})^{-1}$. This suggested that the sheargraph, or any similar second instrument, might be eliminated from future field soil test procedures.

Equation (14) made it evident that, conceptually, at least, the cone index of the surface layer (say

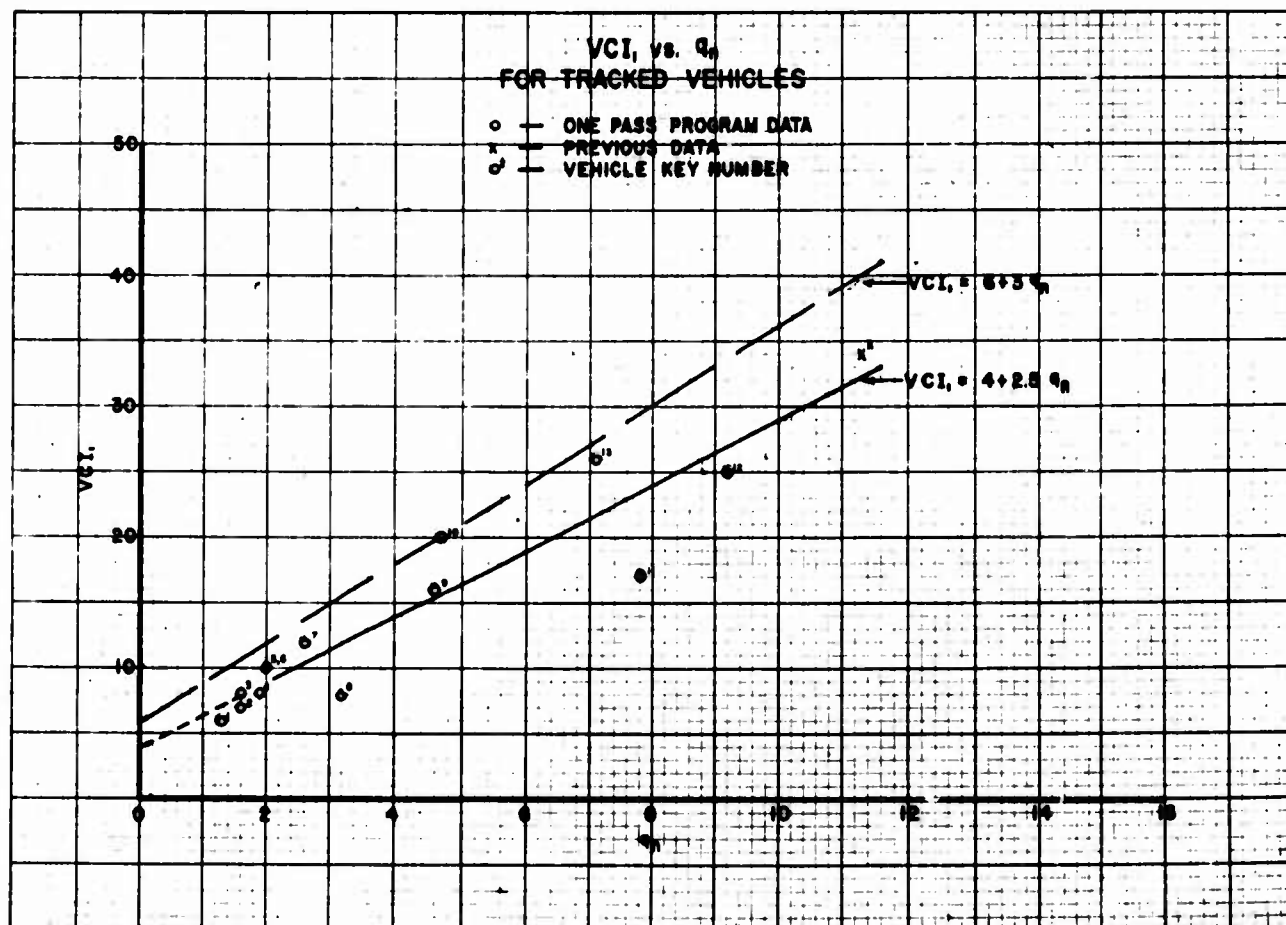


Fig. 54

0-1-inch average)* could be used as the second parameter needed to specify soil strength for drawbar pull prediction. Upon further consideration of the entire problem, including the range of soil strengths of practical interest to reasonably mobile military vehicles, and the quantity and quality of available data, it was decided to use a simple linear assumption in place of equation (14), as follows:

$$(\tau/\sigma)_{10} = K_4(CI) \quad (15)$$

truncated conservatively at

$$(\tau/\sigma)_{10} = 0.8 \quad (16)$$

In order to relate this index specifically to traction (T/W) and to vehicle characteristics, it was assumed that, for the weak, fine-grained soils of interest, the surface shear strength it represented was essentially cohesive. In this case

$$T/W = c/q_n \quad (17)$$

By equations (5) and (6)

*As a result of concurrent WES laboratory tests to study soil "slipperiness," Smith [14] also suggested use of the 0-1-inch cone index to characterize surface shear strength.

$$q_n \approx 1/3 VCI_1 \quad (18)$$

and from plasticity theory (cf. Drucker [15]) and from laboratory investigations by Evans [16] and Smith [17]:

$$c \approx K' (CI) \quad (19)$$

Combining equations (15), (17), (18), (19), and a grain of salt,

$$T/W \approx K (RCI_1/VCI_1) \quad (20)$$

Having thus temporarily established a crude but convenient handle on the traction part of the basic equation (12), attention was turned to the motion resistance term, R_g/W . Consideration of several theoretical approaches (see Appendix I), of Freitag's consolidation of WES laboratory data on tires [2], and of driveline torque measurements made as part of the present program, led to the study of the following, compatible general form for this term:

$$R_g/W = K_R (VCI_1/RCI_1)^m \quad (21)$$

By definition, a vehicle operating in soil such that

$$RCI_1 = VCI_1$$

has no margin for drawbar pull; i.e.,

$$D/W = 0.$$

TABLE 5

VCI₁ FROM NEW DATA USING (Z₁-Z₂) LAYER

Wheeled Vehicles	GVW lb	Tires	Infl. Press. psi	q _n	VCI ₁	
					Pass Data	DBP Data
<u>M151</u>	3,560	36.00-20 TT	3 15	2.3 2.3	9 8	
<u>M274</u>	1,325	16.00-15 TT	3 15	2.5 2.5	8 8	
	1,190	7.50-10	5 10 30	3.1 3.1 3.1	5 5 6	
	1,940	16.00-15 TT	3 15	3.7 3.7	8 8	
<u>M37</u>	7,240	46.00-18 TT	3 15	3.8 3.8	9 11	9 12
<u>M274</u>	1,940	7.50-10	5 10 30	5.1 5.1 5.1	9 11 9	
<u>M151</u>	3,560	9.00-14	20 30	7.9 7.9	17 17	
	3,560	7.00-16	15 30	8.8 8.8	28 23	
<u>M37</u>	7,240	9.00-16	6.5 15 30	10.8 10.8 10.8	25 26 25	26
<u>M35A1</u>	19,410	11.00-20	13 35.5	13.3 13.3	33 34	33
<u>Tracked Vehicles</u>		<u>Track Width, in.</u>				
<u>Dinah</u>	4,095 4,975	20 20		1.3 1.6	7 8	
<u>Weasel</u>	4,960 5,960	20 20		1.6 1.9	6 6	6 8
<u>M116</u>	8,435	20		2.0	8	13
<u>Polecat</u>	12,580	20		2.0	7	7
<u>M116</u>	10,610	20		2.6	9	9
<u>Weasel</u>	5,960	12		3.2	9	10
<u>D-4</u>	13,585	24		4.6	13	11
<u>M56</u>	15,995	20		4.7	13	
<u>D-4</u>	12,420	13		7.8	16	
<u>D-4</u>	14,870	13		9.2	25	
<u>M-5A4</u>	28,350	17.1		7.1	20	

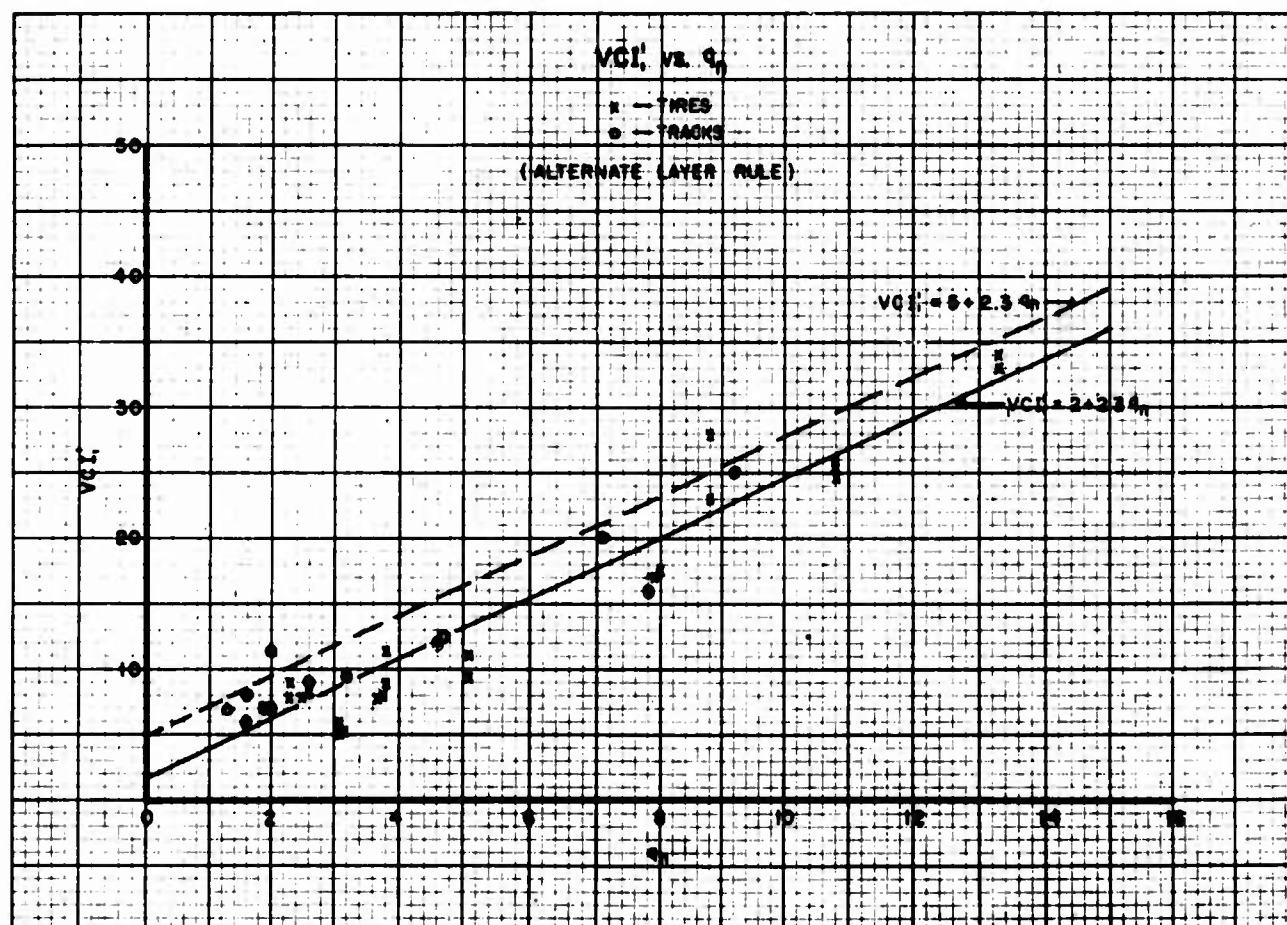


Fig. 55

By equation (12), then, when $RCI_1 = VCI_1$

$$T/W = R_s/W \quad (22)$$

and, therefore, from equations (20) and (21),

$$K_R = K \quad (23)$$

Equation (12) may thus be written

$$D/W = K \left[\frac{RCI_1}{VCI_1} - \left(\frac{VCI_1}{RCI_1} \right)^m \right] \quad (24)$$

Note that in utilizing equation (20) in this development, the truncation suggested in equation (16) is implied. Thus in strong soils where $R/W \approx 0$ (i.e., where $RCI_1/VCI_1 \leq 0.8/K$)

$$D/W = 0.8 \quad (25)$$

It is implicit in equation (24) that soil strength is essentially constant from the surface to a considerable depth, so that RCI_1 characterizes both bearing capacity and surface shear strength. In order to generalize to the case where this is not true, the factor

$$K_T = \frac{RCI_{1,s}}{RCI_1} \quad (26)$$

where $RCI_{1,s}$ = the one-pass re-molded cone index for a surface layer of s inches

may be introduced, as follows:

$$D/W = K \left[K_T \frac{RCI_1}{VCI_1} - \left(\frac{VCI_1}{RCI_1} \right)^m \right] \quad (27)$$

Data from field tests of two wheeled and three tracked vehicles, in which maximum drawbar pull, driveline torque, and soil strength were concurrently obtained, were analyzed to develop estimates for K and m . Measured torques during tests in field soil conditions were converted to equivalent hard surface drawbar pulls, using an experimental curve for each vehicle developed for this purpose. The difference between measured drawbar pull in the soil and the expected hard surface pull was taken as the gross motion resistance due to operating in the soil. This figure includes both external motion resistance, R_p , and a pseudo resistance force from internal losses, such as arise from sticking soil clogging suspension, increasing sprocket losses, etc. The latter component requires extra engine torque (and hence is sensed by a driveline torquemeter), but not extra traction, and is a function of a number of design features largely unrelated to either vehicle traction or flotation characteristics.

Values for gross resistance (R/W) are plotted versus (VCI_1/RCI_1) , for wheeled vehicles in Figure 56, and for tracked vehicles in Figure 57. Using these data plots and a little imagination, values for K and m in equation (21) were selected, giving for

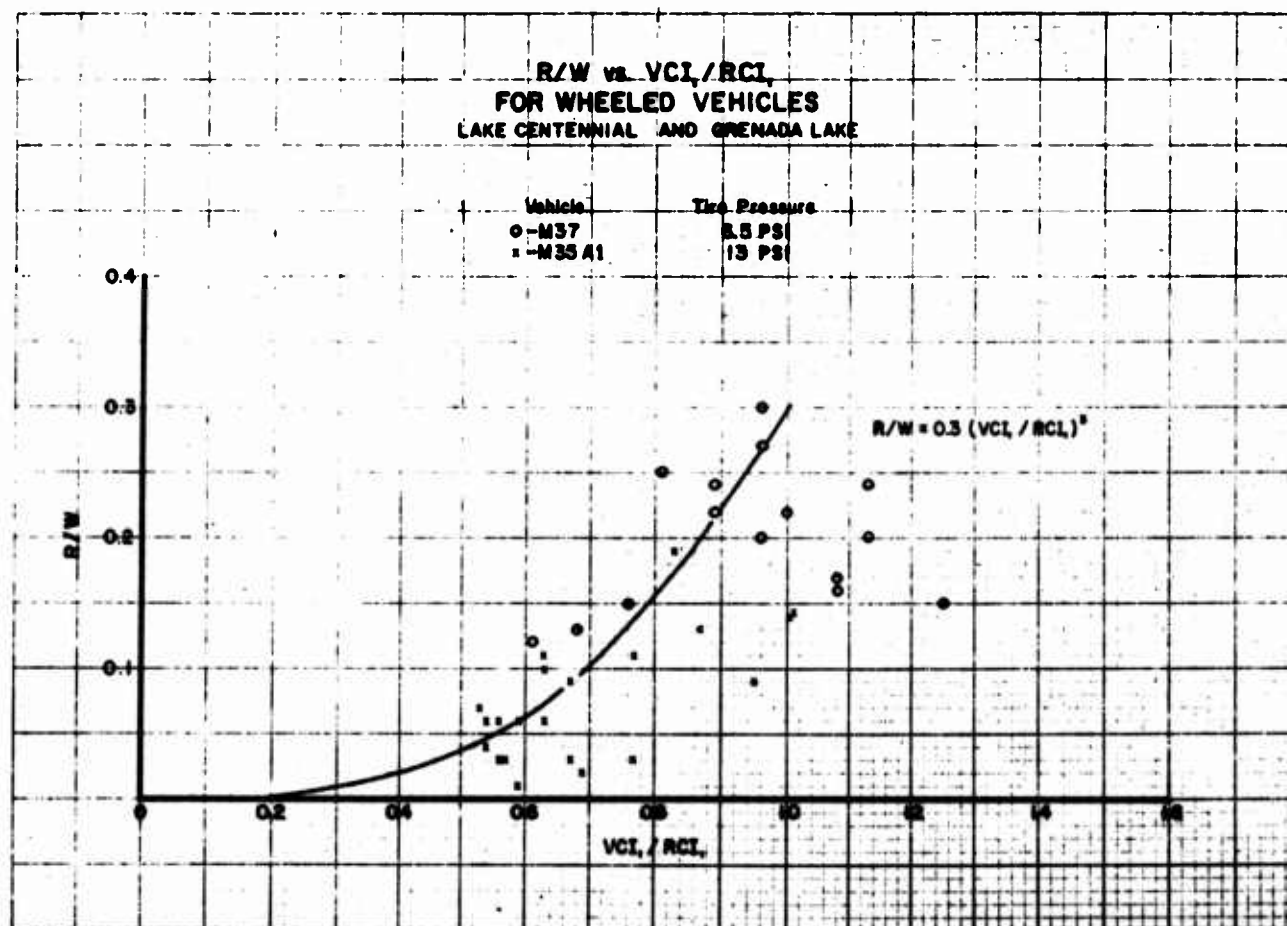


Fig. 56

both wheeled and tracked vehicles

$$R_g/W = 0.3(VCI_1/RCI_1)^3 \quad (28)$$

This expression is also plotted in both figures. It appears as an approximate upper bound to the measured data for wheeled vehicles. It is at best a poor approximation to tracked vehicle gross resistance measurements at soil strengths between 2 and 10 times VCI_1 . In this region the data follows, rather, the complex curve shown. It is believed that this increase to a maximum when RCI_1 is between 4 and 5 times VCI_1 is due to suspension clogging. The Lake Centennial soil is at moisture contents producing decided "stickiness" in this soil strength range.* Stickiness effects will clearly vary with soil properties and with detailed vehicle design. There is too little information available for even the present authors to attempt any generalization at this time.

From equation (28), equation (27) may now be written in its proposed final form,

*Note that the "stickiness range" of a given soil is related to moisture content and hence to cone index. When test results are plotted on the basis of (VCI_1/RCI_1) , effects at a given cone index will appear at low values for very mobile vehicles (low VCI_1) and higher values for less mobile vehicles.

$$D/W = 0.3 \left[K_r \left(\frac{RCI_1}{VCI_1} \right) - \left(\frac{VCI_1}{RCI_1} \right)^3 \right] \quad (29)$$

All of the maximum drawbar pull (D/W) results developed during this program, on all vehicles, from both test areas, are plotted in Figure 58, as functions of the parameter (VCI_1/RCI_1) . Each test is keyed according to which of three ranges of K_r (0-0.375, 0.376-0.750, > 0.750) it fell into according to the field measurements. Also shown is equation (29), evaluated for $K_r = 0.25, 0.50$, and 1.00 . From this, it is considered that equation (29) expresses a useful approximate relationship between soil strength (RCI_1, K_r), vehicle design (VCI_1), and drawbar pull performance for most first-order estimating and prediction purposes. It may also be taken to express gradeability (G_r), which, to a like precision, may be taken as

$$G_r = D/W \quad (30)$$

As footnoted on page 21, surface traction affects the actual minimum RCI_1 required for one successful pass of a vehicle. Equation (29) clearly shows that (VCI_1) actually refers only to the condition where $K_r = 1.0$. In other cases, the RCI_1 required for one, straight, level pass is given by

$$RCI_1' = VCI_1' = (VCI_1)(1/K_r)^{1/3} \quad (31)$$

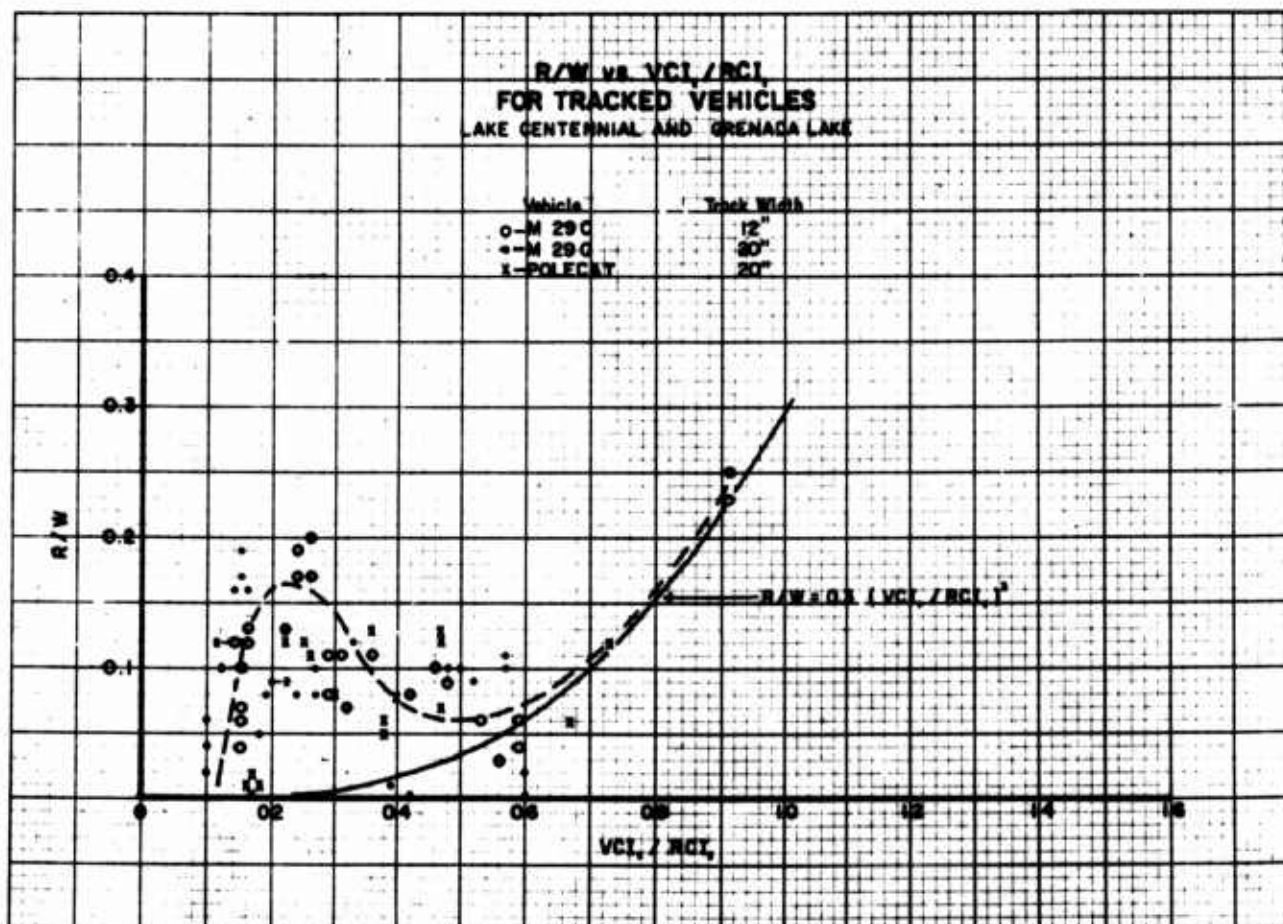


Fig. 57

so that for $K_T = 0.5$

$$VCI_1' = 1.19(VCI_1)$$

and, for $K_T = 0.25$

$$VCI_1' = 1.41(VCI_1).$$

Variations of K_T of this order were regularly recorded, and scatter of a corresponding order is observed in the self-propelled test data.

Problem 2b. Prediction of Soil Strength Increment Required to Permit Free Maneuvering

Estimates of the minimum excess of RCI_1 over VCI_1 necessary to permit a given vehicle to maneuver freely in a level, weak-soil terrain are based upon three rude but not unreasonable assumptions.

- 1) The soil strength which will allow a given vehicle to execute continuously a slow-speed, 180-degree turn of approximately 25-foot radius may be considered sufficient to permit that vehicle to "maneuver freely"; i.e., to proceed continuously along a circuitous path in level terrain.
- 2) The requirement for additional soil strength during such a turn results from
 - a) increased motion resistance, which imposes increased tractive loads on the soil/vehicle interface, and

b) in skid-steered vehicles, the increased traction required from the running gear at the outside of the turn to produce a net turning moment sufficient to overcome the resisting moment of the ground contact areas.

- 3) The increment in soil strength necessary to support the increased traction requirements will be essentially the same as that required to produce a drawbar pull of the same magnitude as the resistance increment.

Estimates of relative motion resistance of a given test vehicle in a soil of given strength (RCI_1) were obtained directly from drive-line torque measurements made while running at several radii and straight ahead (radius = ∞). Such tests were run with six vehicle configurations, each in several soil strengths.

The results are illustrated in Figures 59 through 60, in which measured torques in each of several soil strengths are plotted versus the inverse of the turn radius ($1/r$). As an index of soil strength conditions, the remolded cone index for the 0-6-inch layer as measured for each test is shown. It may be seen that for each vehicle configuration, the effects of turning radius (expressed as the inverse) in a given soil strength are essentially linear, and that, with only a few exceptions associated with special grass conditions, the slope of the lines may reasonably be taken to be the same. Thus the increment in motion

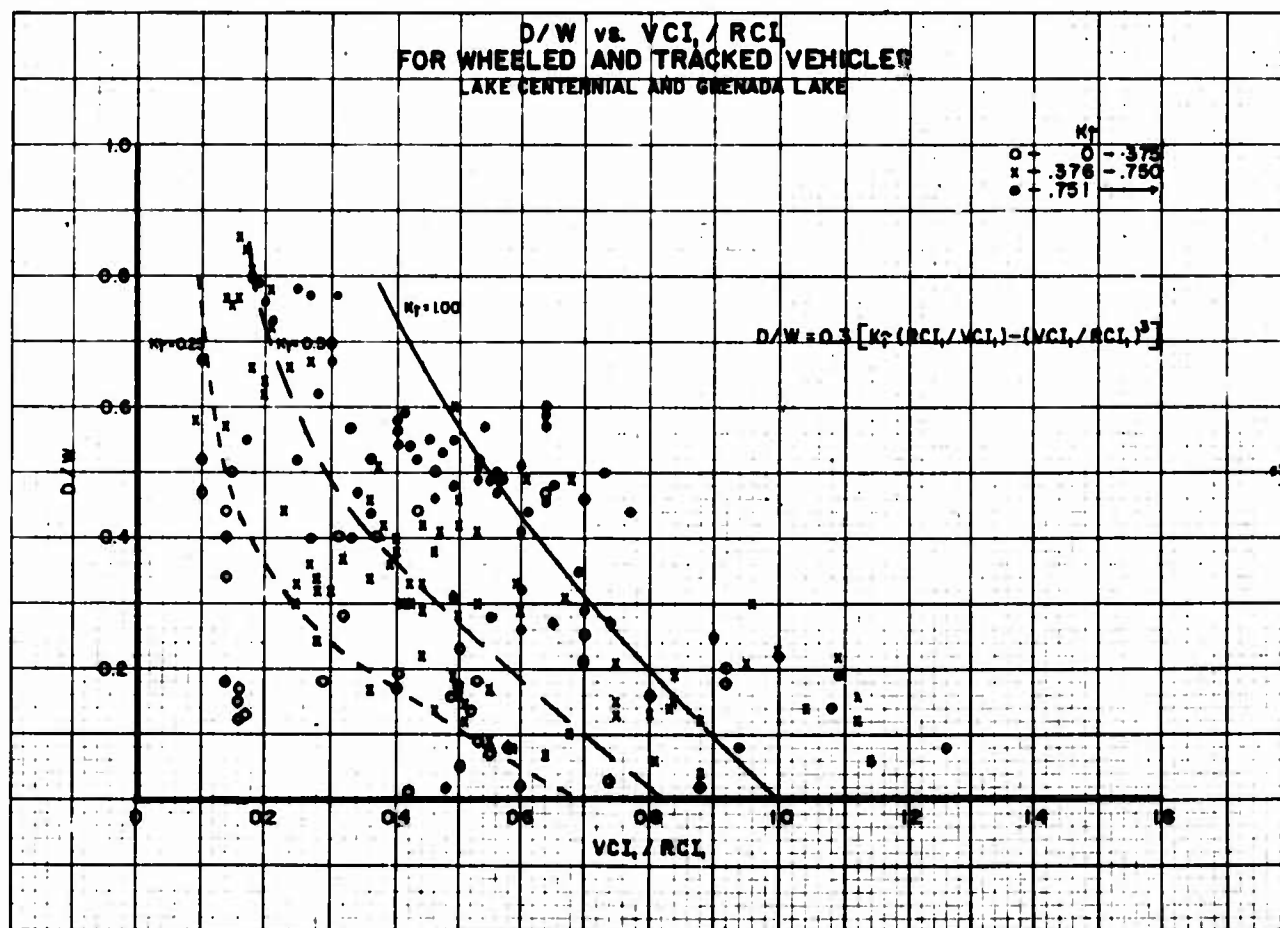


Fig. 58

resistance due to turning may be taken to be a function of turn radius and vehicle configuration, and essentially independent of soil strength.

Measured torques were converted to equivalent track or tire thrusts simply by multiplying by gear ratio between the torquemeter and the tire or sprocket, and dividing by the rolling radius of the tire or the pitch radius of the sprocket. The resulting increments in thrust (ΔR) due to turning were fit by an equation of the form

$$\frac{\Delta R}{W} = \frac{K_T}{r_t} \quad (32)$$

where K_T = a constant for the given vehicle configuration

and r_t = turning radius in feet.

Resulting values of K_T are tabulated in Table 6.

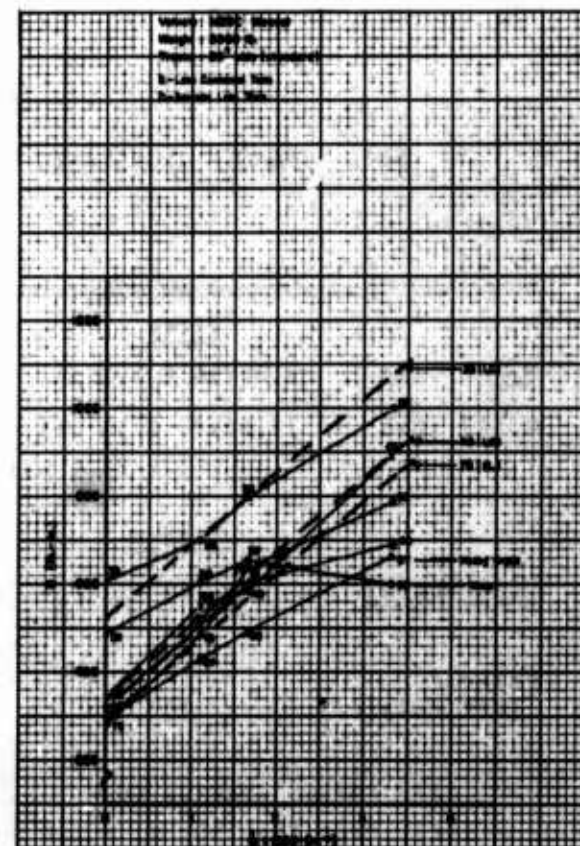
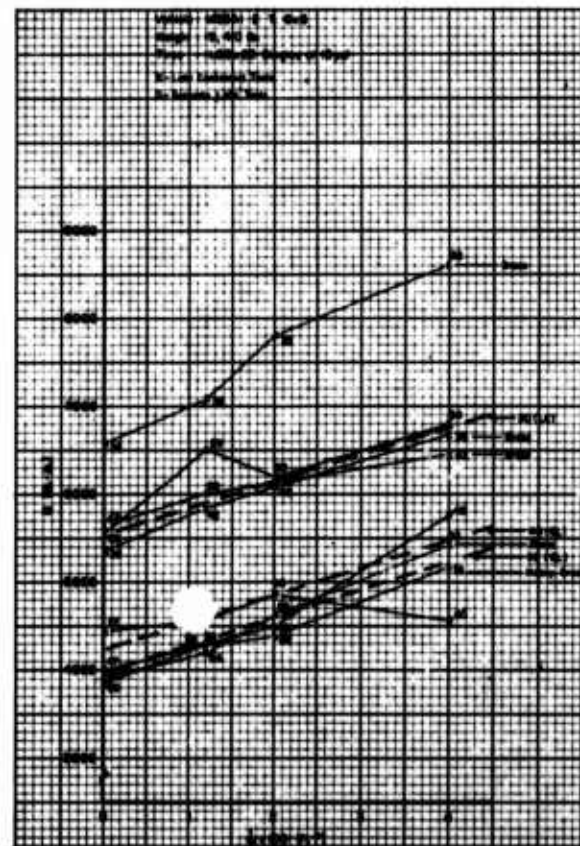
In order to reach a conclusion as to the increment of soil strength required to permit free maneuvering, the increment $\Delta R/W$ was calculated for a turning radius of 25 feet, and the value of (RCI_1 / VCI_1) needed to develop this much extra traction was read from Figure 58 assuming $K_T = 1.0$. Finally, for the skid-steered vehicle (the WEASEL), a further increment of 2 per cent was added, in accordance with the approximate analysis given in Appendix VII. The final estimated value, $(RCI_1 / VCI_1)_T$, for all six vehicle configurations is tabulated in Table 6.

These values show a reasonable progression from 1-5 per cent in strength required for the wheeled vehicles to 15-25 per cent for the tracked WEASEL, with the articulated POLECAT requiring an increment of approximately 10 per cent. Both the trends and the order of magnitude shown appear qualitatively correct. Until further work can be done on this problem and the dependence of values of K_T upon vehicle parameters studies, it is suggested that the increment in soil strength required to permit free maneuvering in a weak soil situation be taken as follows:

for wheeled vehicles	5%
for tracked vehicles	25%
for articulated tracked vehicles	15%.

Problem 2c. Estimation of Maximum Vehicle Speed

The maximum speed of a vehicle in a level terrain with weak soil is influenced by the motion resistance offered by that soil. Accordingly, the appropriate procedure for calculating maximum speed is simply an extension of standard automotive engineering methods [of. 18] to include the soil resistance with the other possible resistances. It was assumed that soil resistance was adequately given by



29

TURNING TEST RESULTS

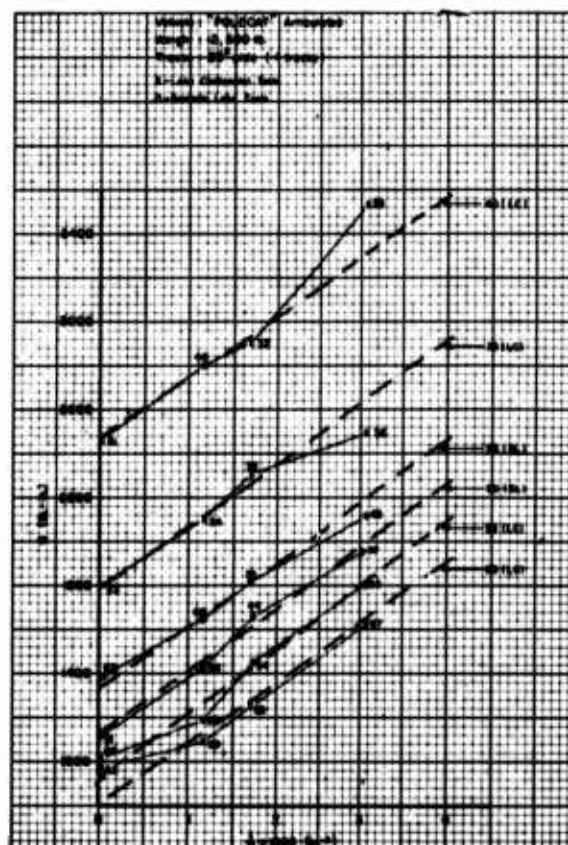
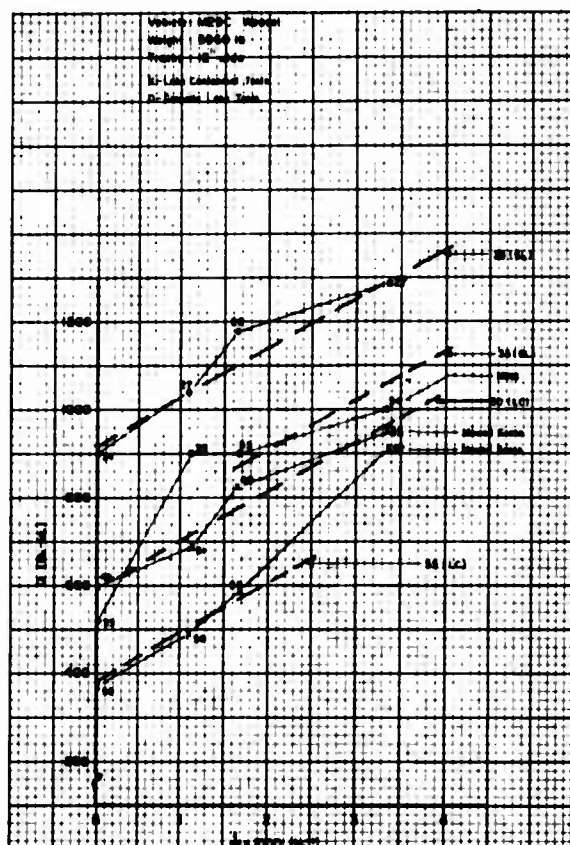


Fig. 60

TABLE 6

SOIL STRENGTH INCREMENTS REQUIRED FOR "FREE MANEUVERING"

Vehicle		"K _r "	$\frac{\Delta R}{W}^{(1)}$	$\frac{RCI_1}{VCI_1}^{(2)}$	$\left(\frac{RCI_1}{VCI_1}\right)_T^{(3)}$
	<u>Tires</u>				
<u>M37</u>	4x4	9.00x16 @ 6.5 psi	0.26	0.01	1.01
<u>M35A1</u>	6x6	11.00x20 @ 13 psi	0.57	0.02	1.02
		@ 35.5 psi	1.14	0.05	1.05
	<u>Tracks</u>				
<u>M29C Weasel</u>	20"	4.74	0.19	1.23	1.25
	12"	3.21	0.13	1.15	1.17
<u>Polecat</u> (Articulated)	20"	1.94	0.08	1.09	1.09

- (1) For 25' radius turn
- (2) From Fig. 58, $K_r = 1.0$
- (3) Corrected for skid steering as necessary

equation (28), and that it was not speed dependent. Then maximum speed in miles per hour (V) is

$$V \approx \frac{HP_A}{ER} \times 375. \quad (33)$$

To estimate HP_A = horsepower available at wheel or sprocket,

$$HP_A = BHP \times n \quad (34)$$

where BHP = brake horsepower
 n = overall efficiency
 (treating accessory loads as an efficiency type of loss)
 ≈ 0.75 for wheeled vehicles
 ≈ 0.65 for tracked vehicles.

To estimate ER = total resistance

$$ER = R_A + R_T + R_s + G_T W \quad (35)$$

where R_A = air resistance
 $\approx 0.004 AV^2$
 A = frontal area, sq. ft.
 R_T = track or tire losses
 $\approx 0.015 W$ for tires
 $\approx (0.05 + 0.002 V) W$ for tracks
 $G_T W$ = grade resistance
 and R_s = soil resistance (eq. 28).

As noted, there may be a substantial loss (up to 0.15 W) due to track and suspension clogging on tracked vehicles (see Fig. 57), and an increment due to maneuver. Neglecting the latter two effects, and considering only level ground, equation (33) may be written

$$V \approx \frac{0.47(BHP/W_T)}{\left(\frac{VCI_1}{RCI_1}\right)^3 + 0.013 \left(\frac{AV^2}{W}\right) + 0.05} \quad (36)$$

for wheeled vehicles, and

$$V \approx \frac{0.40(BHP/W_T)}{\left(\frac{VCI_1}{RCI_1}\right)^3 + 0.013 \left(\frac{AV^2}{W}\right) + 0.067V + 0.167} \quad (37)$$

for tracked vehicles, where W_T = gross vehicle weight in short tons.

It is evident that allowances for slope, maneuver, and suspension clogging could readily be included as necessary or desirable.

In Figure 65, measured speeds in various soil strengths, as tabulated in Appendix III, Table III-49, are compared to predictions via equations (36) and (37) for four test vehicles. Considering the many test variables which could not be controlled, and the long series of gross approximations used to reach this point, the agreement is considered acceptable, except in the case of the POLECAT, which appears to have been "sick" during these tests. Field experience with other POLECATS does not confirm such low figures for operation on what, for it, is excellent footing.

SPEED vs. RCI_1 / VCI_1

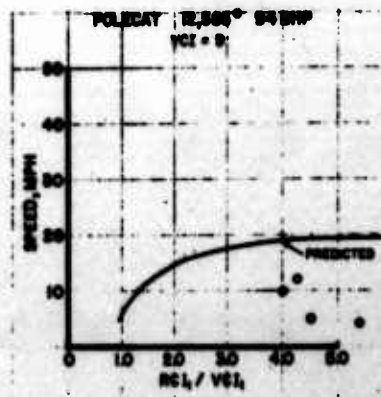
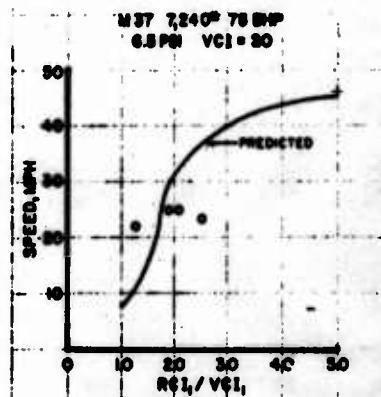
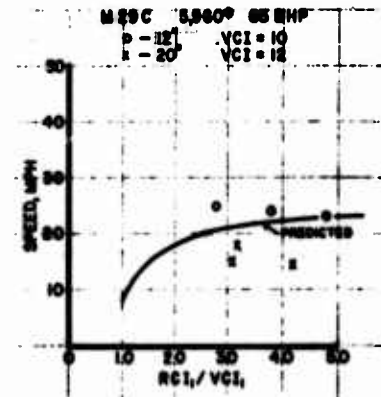
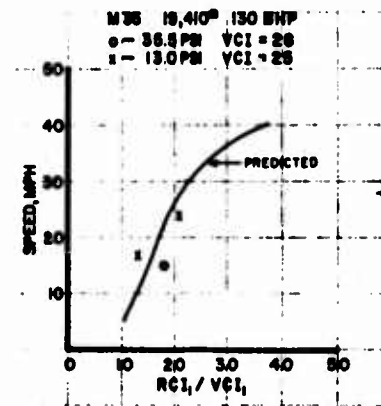


Fig. 61

ASSESSMENT OF RESULTS

The stated goals of the investigation, usable, first-order answers within a limited time frame, have been achieved. The results, like the methods and the analyses, are rough and contain nothing essentially new except perhaps actual, usable numbers. Probable precision is low (± 20 -30 percent), but with these results available it is no longer possible to talk complete nonsense about one-pass vehicle performance.

Much more can, and should, be done, however, both in the way of developing more and better data, and even in analyzing the present data. While it is evidently useful to know the orders of magnitude of the several effects upon performance of varia-

tions in soil strength, the scatter of the VCI_1 versus q_n results shown in Figures 53 and 54 (for instance) leaves much to be desired, particularly from the viewpoint of improved vehicle design. It does, of course, make considerable difference whether VCI_1 for a given vehicle is 20 or 30. If, through a fuller understanding of all factors, new designs at the same ground pressure (for example) could be made to follow the lower limit, this would be a major improvement. Thus, while it is believed that the present study has roughed in the outlines of the full and proper answers ultimately required, it is clear that it can only be considered as an exploratory first-pass at the problem.

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APPENDIX I

THE FORM OF THE RELATIONSHIP OF LIMITING CONE INDICES FOR TRACKED AND WHEELED VEHICLES TO BASIC VEHICLE CHARACTERISTICS

TRACKED VEHICLES

Some twelve years ago, just before emigrating to a more productive line of endeavor, Evans concluded that the performance of tracked vehicles in effectively frictionless soils could be summarized satisfactorily by the following four semi-empiric equations [1,19]*

$$\frac{q_1 - q}{q_1 - q_n} = 1 - e^{-\frac{5z}{b_t}} \quad (1)$$

$$\frac{R_p}{W_1} = \frac{z}{L} \cdot \frac{q}{q_n} \quad (2)$$

$$\frac{T}{W_1} = \frac{c}{q_n} \quad (3)$$

and

$$\frac{D}{W_1} = \frac{T}{W_1} - \frac{R_p}{W_1} \quad (4)$$

where q = bearing capacity of the soil

$$q_1 = \sqrt{\frac{W_1 E}{n_b b_t d_b}} \quad (5)$$

$$\text{or } = \frac{W_1}{n_b b_t y} \quad (6)$$

whichever is smaller,

q_n = nominal unit ground pressure

$$= \frac{W_1}{b_t L} \quad (7)$$

b_t = track width

W_1 = weight on one track

E = Young's modulus for soil (taken as 1000 lb/in²)

n_b = number of bogie wheel stations per track

d_b = bogie wheel diameter

y = track pitch

L = length of track on (hard, level) ground

R_p = external motion resistance due to plastic flow

T = tractive effort

D = drawbar pull

c = soil cohesion

all in consistent units. Equation (1) may be solved explicitly for sinkage:

$$z = \frac{b_t}{5} \log_e \left[\frac{q_1/q_n - 1}{q/q_n - 1} \right] \quad (8)$$

Substituting in (4)

$$\frac{D}{W} = \frac{c}{q_n} \left[1 - \frac{q}{q_n} \cdot \frac{b_t}{5c} \log_e \frac{q_1/q_n - 1}{q/q_n - 1} \right] \quad (9)$$

At the point where $\frac{D}{W} = 0$, the required soil bearing capacity, q_{crit} , is given by

$$q_{crit} = q \left[1 + \frac{q_1/q_n - 1}{q/q_n - 1} \right] \quad (10)$$

Examination of the quantity in brackets as it applies to two widely different vehicles, the M29C Weasel and the M60 Battle Tank, gives values of 1.024 and 1.008, respectively. That is, it may reasonably be taken as 1, thus yielding in the limit the simple and useful but not very remarkable result,

$$q_{crit} \approx q_n \quad (11)$$

PNEUMATIC-TIRED VEHICLES

According to a simple concept, described in 1960 by Bekker and Janosi [20], a pneumatic tire operating in a plastic material will not deflect significantly unless its total effective inflation pressure is less than the yield pressure for the material. It is reasonable to assume that, in the limiting case where the soil is so weak that the tire sinks considerably on its first pass and can just self-propel itself with no margin for drawbar or slope loading, there will, in fact, be little deflection of the tire in the soil.

The test data on single tires in clay soils, developed by WES over the past several years in the AMRB soil bins, have recently been reported in summary form by Freitag [2]. Freitag shows that, for a wide range of drawbar performance, soil strengths, and tire sizes, shapes, and loadings, the data over a wide

*See References, p. 33 in main body of report.

range of soil strengths collapse quite well on the basis of the load numeric

$$\frac{W_1}{CI \cdot b \cdot d \cdot \Delta^{1/2}} \quad (12)$$

where W_1 = the load on the single tire, lb.

CI = the average cone index of the test soil bed, uniform with depth, psi

b = undeflected tire section width, in.

d = undeflected tire diameter, in.

$\Delta = \frac{\delta}{h}$ = deflection on a hard surface, at test inflation and under test load, divided by tire section height from rim flange, in./in.

This may be rewritten as

$$\left(\frac{q_n}{CI}\right) \left(\frac{1}{2 \Delta^{1/2}}\right) \quad (13)$$

where $q_n = \frac{W_1}{b \cdot r}$

and r = undeflected tire radius, in.

Close examination of the data near the loading point where drawbar pull vanishes ($D/W=0$) (Figures 1-1 to 1-3), however shows that in this limited region the critical load numeric (in similar form) is as well given for all deflections as

$$\frac{q_n}{CI} (= 0.4) \quad (14)$$

This indicates that, near the failure point, pneumatic tires may be considered as essentially rigid. Accordingly, Uffellmann's work with rigid wheels may be germane [21].

Uffellmann considered that the results of his several years of tests on large rigid wheels in laboratory clay pits was adequately expressed by Drücker's 1955 proposals derived for small sinkages from simple plasticity considerations [15], as follows:

$$\frac{R_P}{W_1} = \frac{W_1}{q \cdot b \cdot d} \quad (15)$$

$$\text{and } \frac{z}{d} = \left(\frac{W_1}{q \cdot b \cdot d}\right)^2 \quad (16)$$

For traction, Uffellmann assumed

$$\frac{T}{W_1} = \frac{c \cdot b \cdot \ell}{W_1} \quad (17)$$

where ℓ = effective contact length

$$\approx d \sqrt{\frac{z}{d}} \quad \text{for small sinkages.} \quad (18)$$

From equations (15-18), at the critical point where drawbar pull vanishes,

$$c = \frac{W_1}{b \cdot d} = \frac{q_n}{2} \quad (19)$$

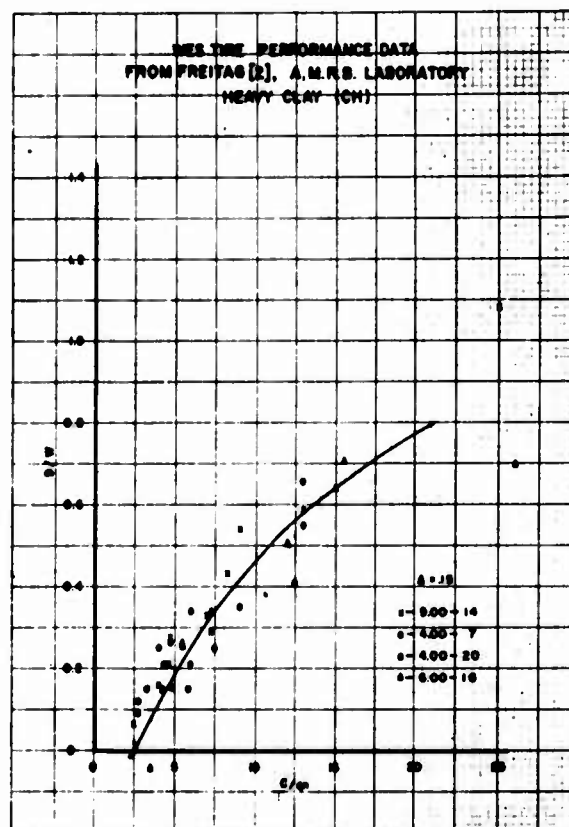


Fig. 1-1

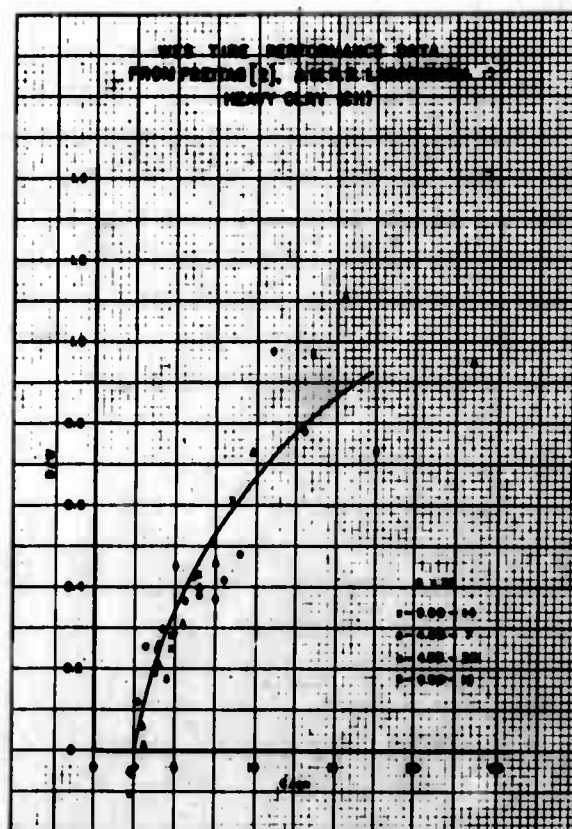


Fig. 1-2

or, taking from plasticity theory the classical relationship between bearing capacity at the surface and cohesion [see, for example, Reference 15]; i.e.,

$$q = 5.7 c ; \quad (20)$$

then

$$q_{crit} = 2.85 q_n. \quad (21)$$

Note that while Drücker's published derivation of his equations, and Uffelmann's extension to include traction, are based upon some conventional approximations to simplify the geometry and algebra involved, the final result (eq. 19) may be shown to be

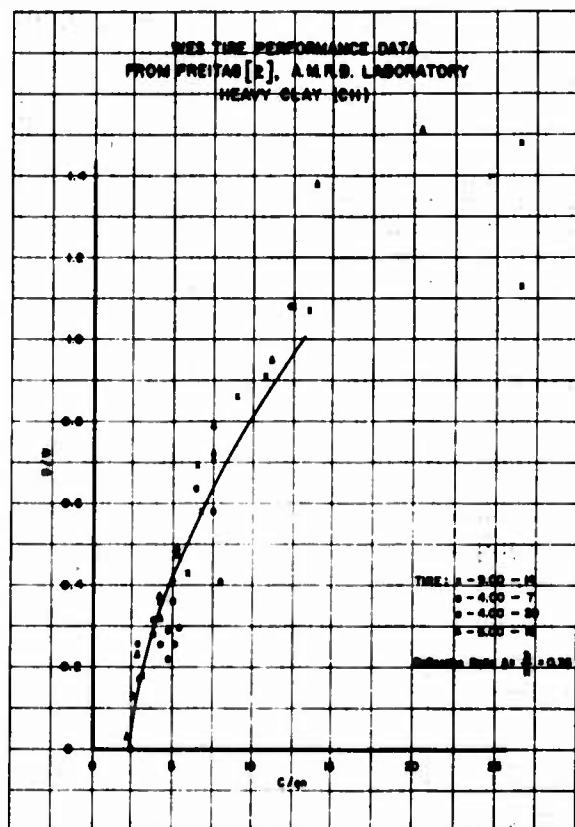


Fig. 1-3

as valid as the basic assumptions up to sinkages of the order of a full radius.

Also, the same results would be achieved by the Bernstein approach [see, for instance, Reference 22], which relates wheel behavior to that of small plates expressed by

$$p = k z^n \quad (22)$$

where p = resisting pressure on the plate

z = sinkage

and k and n are curve-fitting parameters.

For a uniform clay soil bed, $n = 0$, and the Bernstein expressions for sinkage and resistance become identical to Drücker's equations, (15) and (16), above.

From the literature [cf. 16, 17] it is evident that in frictionless soils the cone index may be taken as a direct measure of bearing capacity, i. e.,

$$q \approx k' C I$$

and that $k' \approx 1.5$

so that $q_{crit} \approx 1.5 VCI_1$.

Equations (11), (14), and (21) may then be summarized in consistent cone index form as follows:

Evans for tracks,

$$VCI_1 \approx 0.67 q_n \quad (23)$$

Uffelmann/Drücker/Bernstein for rigid wheels,

$$VCI_1 \approx 1.9 q_n \quad (24)$$

WES/Freitag for pneumatic tires,

$$VCI_1 \approx 2.5 q_n. \quad (25)$$

For present purposes the significant point is that, on the basis of several theoretical approaches, the basic form of relationship to be expected in the field data is simply

$$VCI_1 = k q_n. \quad (26)$$

APPENDIX II

AN APPROACH TO A "CRITICAL LAYER" RULE FOR ONE-PASS OPERATIONS OF TIRES IN WEAK SOILS

In the development of 50-pass prediction methods using the cone penetrometer, WES established a rule whereby, barring significant anomalies, the strength of a fine-grained soil in which a vehicle was operating was taken to be the average cone index (corrected for remolding) measured in a 6-inch thick "critical layer." The critical layer was specified essentially as a function of gross vehicle weight [3].* In sands, however, it was generally found that the cone index increased linearly with depth, and the gradient of the cone index versus depth curve was adopted as the controlling soil strength parameter [23,24].

The physical meaning of the "critical layer" has not been clearly developed. Upon consideration, however, it appears to represent a convenient averaging procedure, rather than truly a "critical" section of the soil profile. A typical cone index versus penetration curve for a field soil situation will look about as shown in Figure II-4. It can usually be approximated reasonably by means of a straight line having an intercept and a slope or gradient. A "critical layer" average can thus be interpreted as an index of the average strength over the range of the profile within the layer, or equally, as the average strength for still larger segments of the profile centered in the designated layer. In the limit, it could be considered as the average strength for the entire profile from the surface to a depth twice the depth of the "critical layer" center. So interpreted, lowering or raising the "critical layer" reflects that, in consonance with general soil mechanics theory, various vehicles are influenced by the soil strength profile to greater or lesser depths, according to their size and/or nominal loading.

The recently published synthesis by Freitag [2] of tests on single tires in sand and clay, performed over several years in the WES/AMRB laboratory soil bins, was examined in this context. Freitag shows that drawbar pull, sinkage, driving torque, and free-rolling motion resistance of tires of several sizes and proportions, operating under a range of wheel loads and inflations, and in a full range of soil strengths, collapse well on the basis of the following simple load numerics:

*See References, p. 33 in main body of report.

$$\text{For Clays -- } \frac{W_1}{C b d \Delta^{1/2}} \quad (1)$$

$$\text{For Sands -- } \frac{W_1}{G (bd)^{3/2} \Delta} \quad (2)$$

where W_1 = load on a single tire, lb

b = undeflected tire section width, in.

d = undeflected tire diameter, in.

$\Delta = \frac{\delta}{h}$ = deflection on a hard surface, at test inflation and under test load, divided by tire section height from rim flange, in./in.

C = average cone index, psi

and G = average cone index vs. depth gradient, psi/in.

Closer examination of the data in the immediate vicinity of the loading at which drawbar pull vanishes, however, (see Figs. I-1 to I-3, App. I, for clay results and Figs. II-1-3, this appendix, for sand) shows that in this limited region both the sand and clay load numerics are less dependent upon tire deflections than indicated by equations (1) and (2), and may be better approximated by:

$$\text{For Clays -- } \frac{W_1}{C b d} \quad (3)$$

$$\text{For Sands -- } \frac{W_1}{G (bd)^{3/2} \Delta^{1/2}} \quad (4)$$

Because the clay tests were run in prepared bins such that the cone index was essentially constant with depth, "C" may be interpreted either as an average cone index over some depth, or as the intercept of a straight line approximation to the profile (Fig. II-5a). G , consistent with the latter interpretation, is already taken as the slope (Fig. II-5b). Thus the general case may be as in Figure II-5c:

$$CI = C + G z. \quad (5)$$

In this case the average for the layer (0- z_0) would be:

$$\overline{CI}_{(0-z_0)} = C + 1/2 G z_0. \quad (6)$$

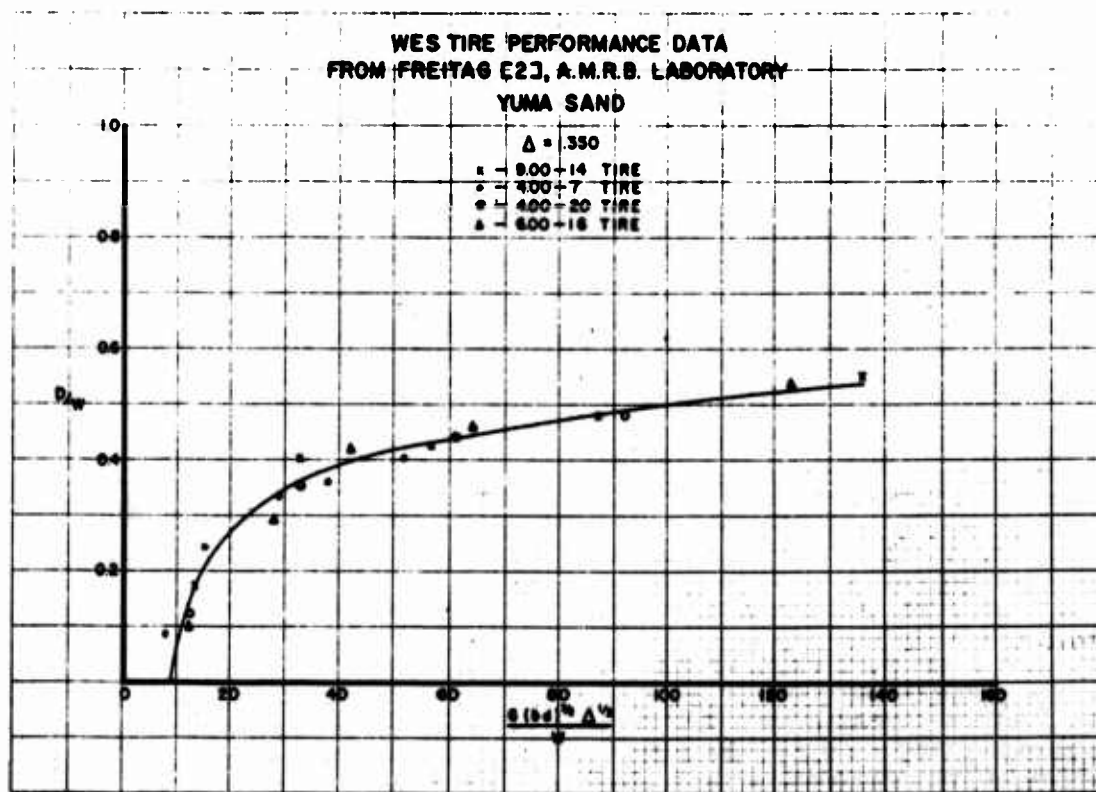


Fig. 11-1

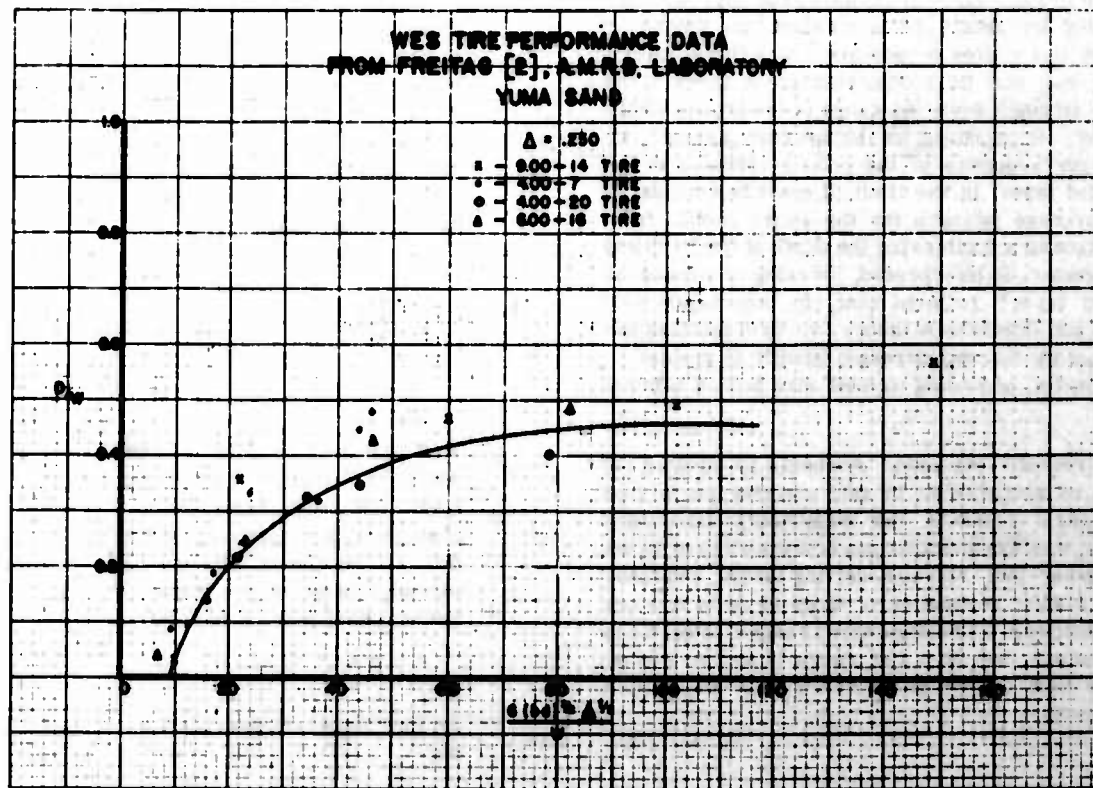


Fig. 11-2

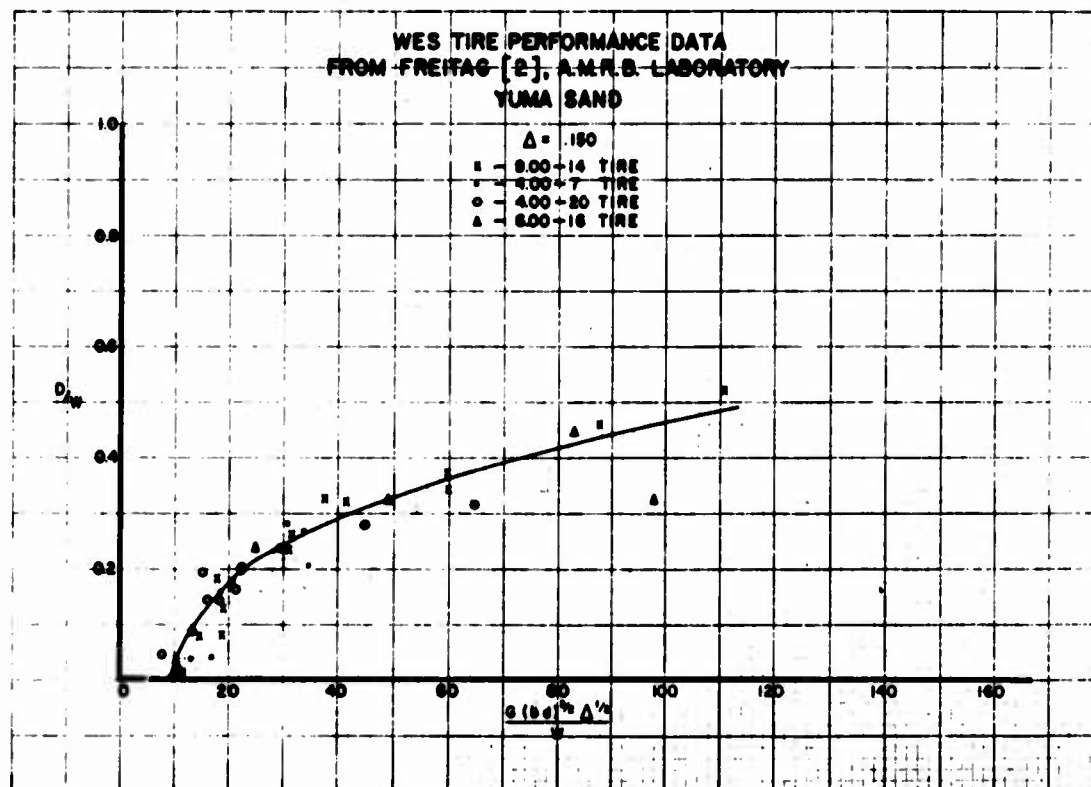


Fig. 11-3

It may now readily be shown that the separate clay and sand numerics (3) and (4) might be considered as end points of a single numeric of the form

$$\frac{W_1}{CI(0-z_0) b d} \quad (7)$$

By substituting (6) and taking

$$z_0 = \sqrt{b d \Delta} \quad (8)$$

(7) becomes

$$\frac{W_1}{C b d + 1/2G (bd)^{3/2} \Delta^{1/2}} \quad (9)$$

which plainly reduces to the clay numeric (3) when $G=0$, and to the sand numeric (4) when $C=0$.

Condition (8) becomes a "critical layer" rule for tires in either sand or clay, and perhaps for the myriad soils between, as well. To explore its reasonableness in this role, (8) may be rewritten

$$\sqrt{b d \Delta} = \sqrt{b d \cdot \frac{\delta}{h}} \quad (10)$$

or, since for the normal form of tire with which the major portion of the tests were run

$$h \approx b, \quad (11)$$

*It is interesting to note that a similar form for the controlling numeric was proposed by Nuttall in 1951 on the basis of dimensional reasoning applied to the equations for rolling resistance of wheels in soils derived from the Bernstein assumptions [22].

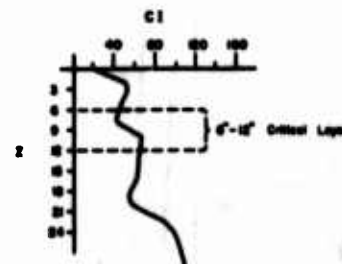


Fig. 11-4

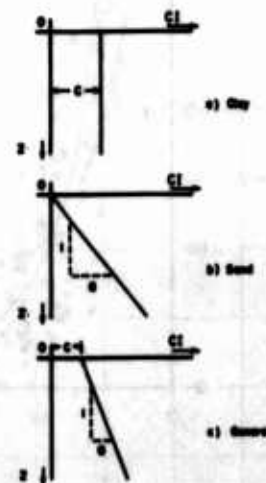


Fig. 11-5

then

$$\sqrt{b d \Delta} \approx \sqrt{d \delta} \quad (12)$$

$$\approx l/2 \quad (13)$$

where l = the hard surface contact length of the deflected tire.

Again for conventionally proportioned tires over the full practical range of deflections,

$$0.6 b < l/2 < 1.2 b. \quad (14)$$

Thus condition (8), interpreted as a layer rule, suggests that the proper depth to be averaged is of the order of the minimum planar dimension of the hard surface contact area, which is reasonable.

As a necessary (but clearly not sufficient) check on the validity of the combined numeric (9), the towing resistance data tabulated by Freitag (with the sand values reduced by a constant $R/W = 0.04$, to eliminate -- quite arbitrarily -- this thus far unexplained anomaly in the sand data) were consolidated on that basis. The results, shown in Figure II-6

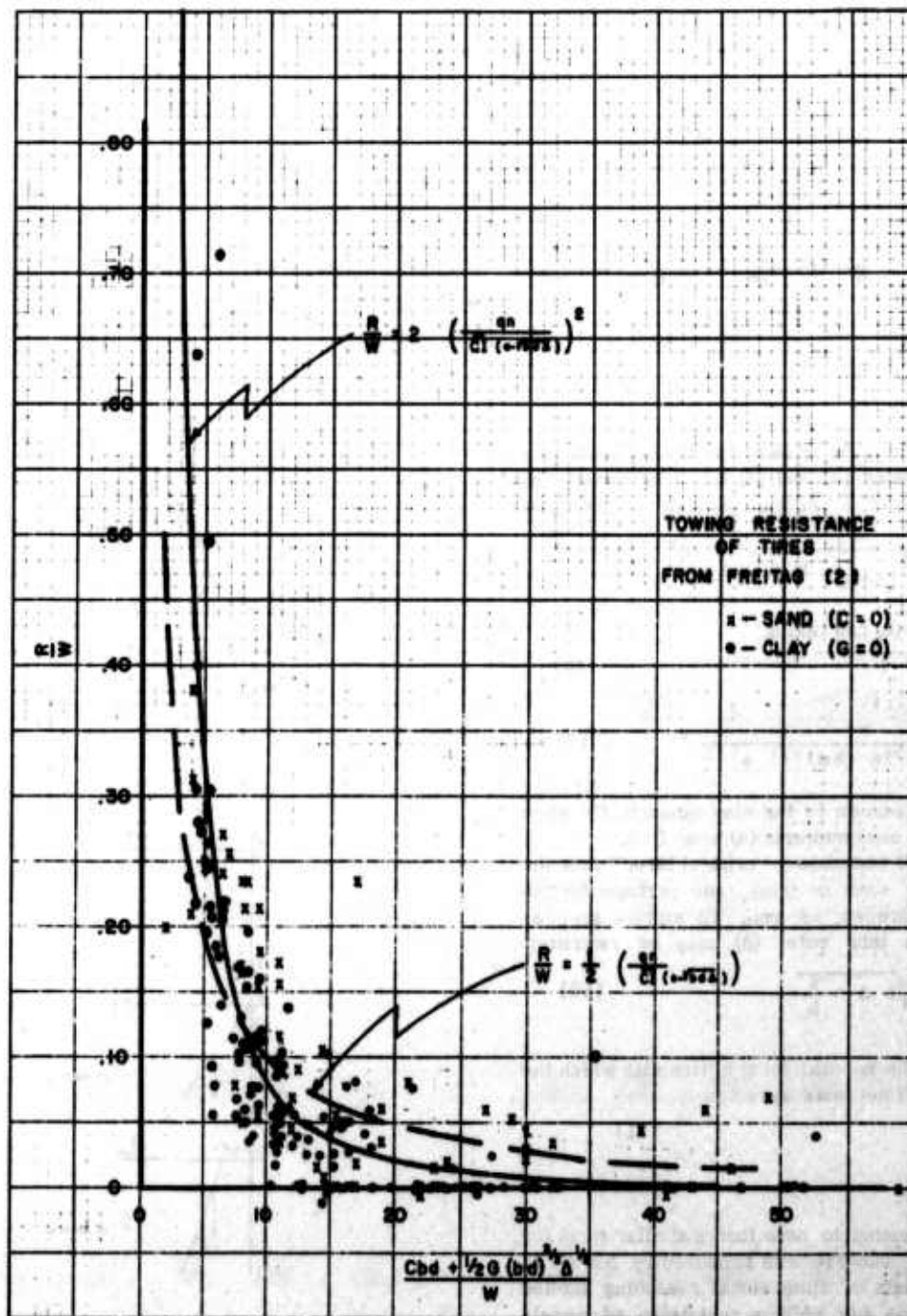


Fig. II-6

are presentable. The fact that the multiplier (1/2) applied to the 'G' term in the denominator (eq. 9) appears appropriate is particularly encouraging. The pooled data are reasonably well fit by the equation

$$\frac{R_S}{W_1} = 2 \left[\frac{q_n}{CI_{(0 - \sqrt{b d \Delta})}} \right]^2 \quad (15)$$

where $q_n = \frac{W_1}{b r}$ = the nominal unit ground pressure for a wheel,

and r = undeflected tire radius.

The theoretical value proposed by Drucker and others for rigid wheels in plastic clays Appendix I, eq. (15) reduced to cone index terms by using Appendix I, eq. (29) is

$$\frac{R_S}{W_1} = \frac{1}{2} \frac{q_n}{CI_{(0 - \sqrt{b d \Delta})}} \quad (16)$$

This is also shown. While not as good a fit to the data as equation (15), it does quite well, especially for the sand results.

APPENDIX III

BASIC TEST DATA

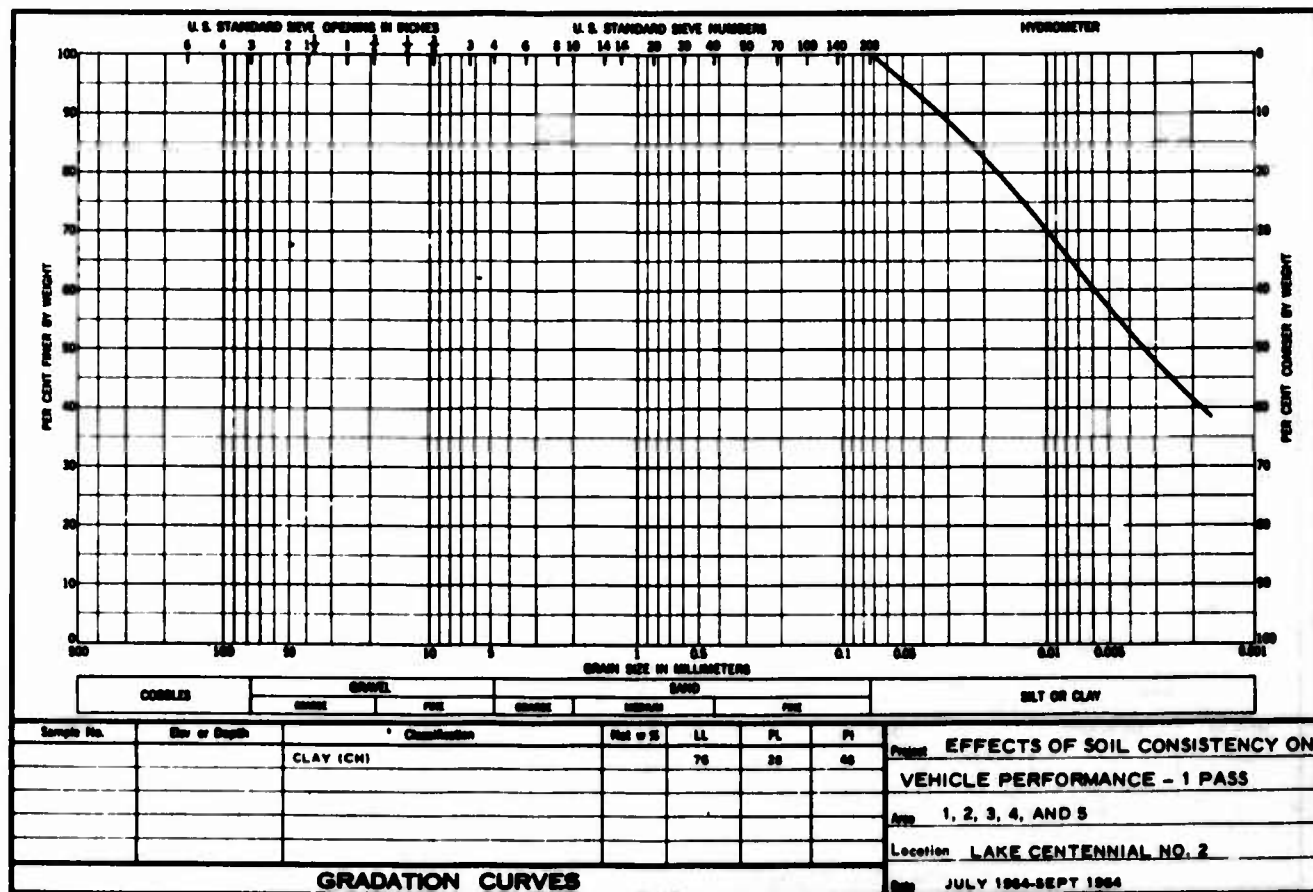
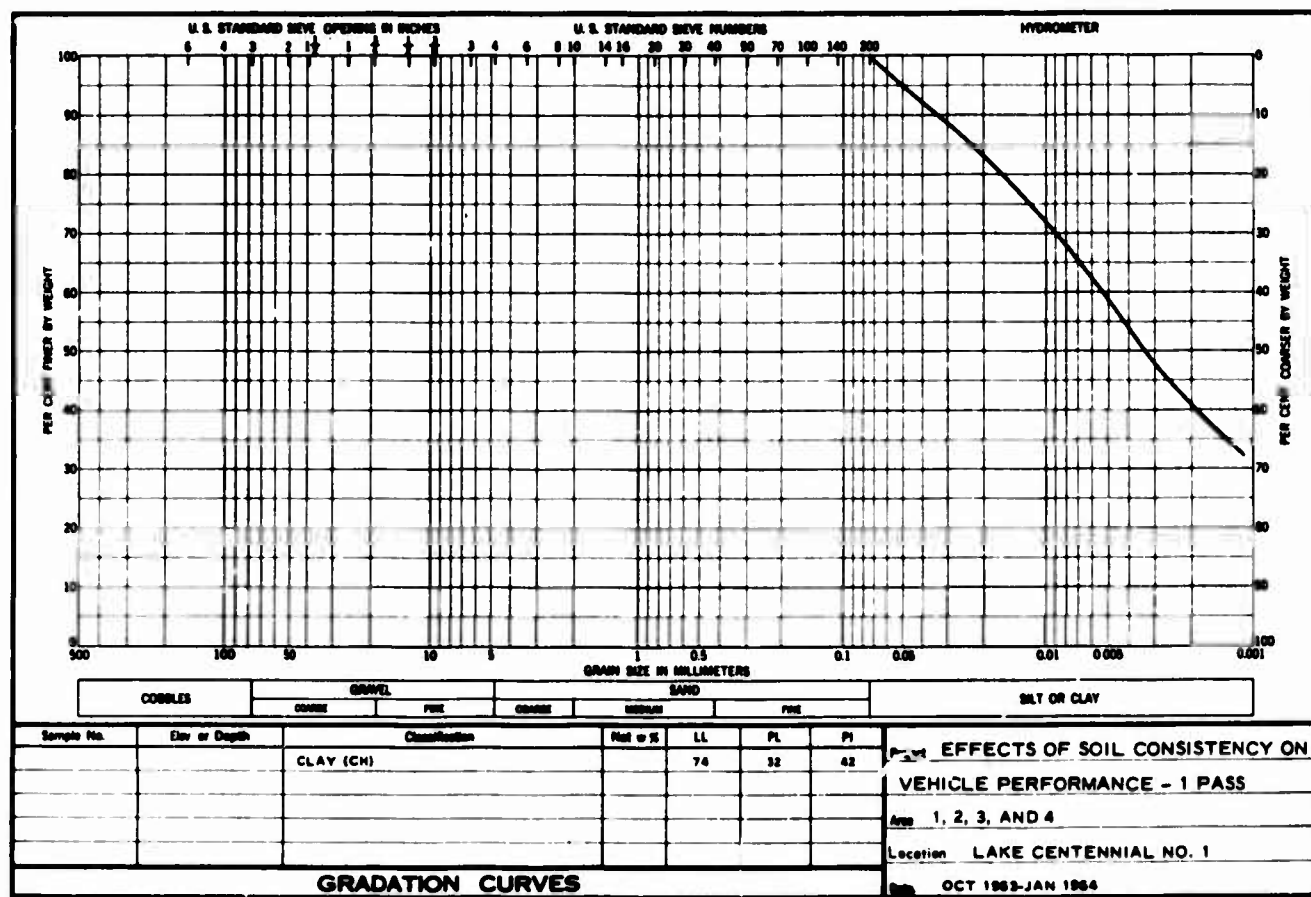


Fig. III-1

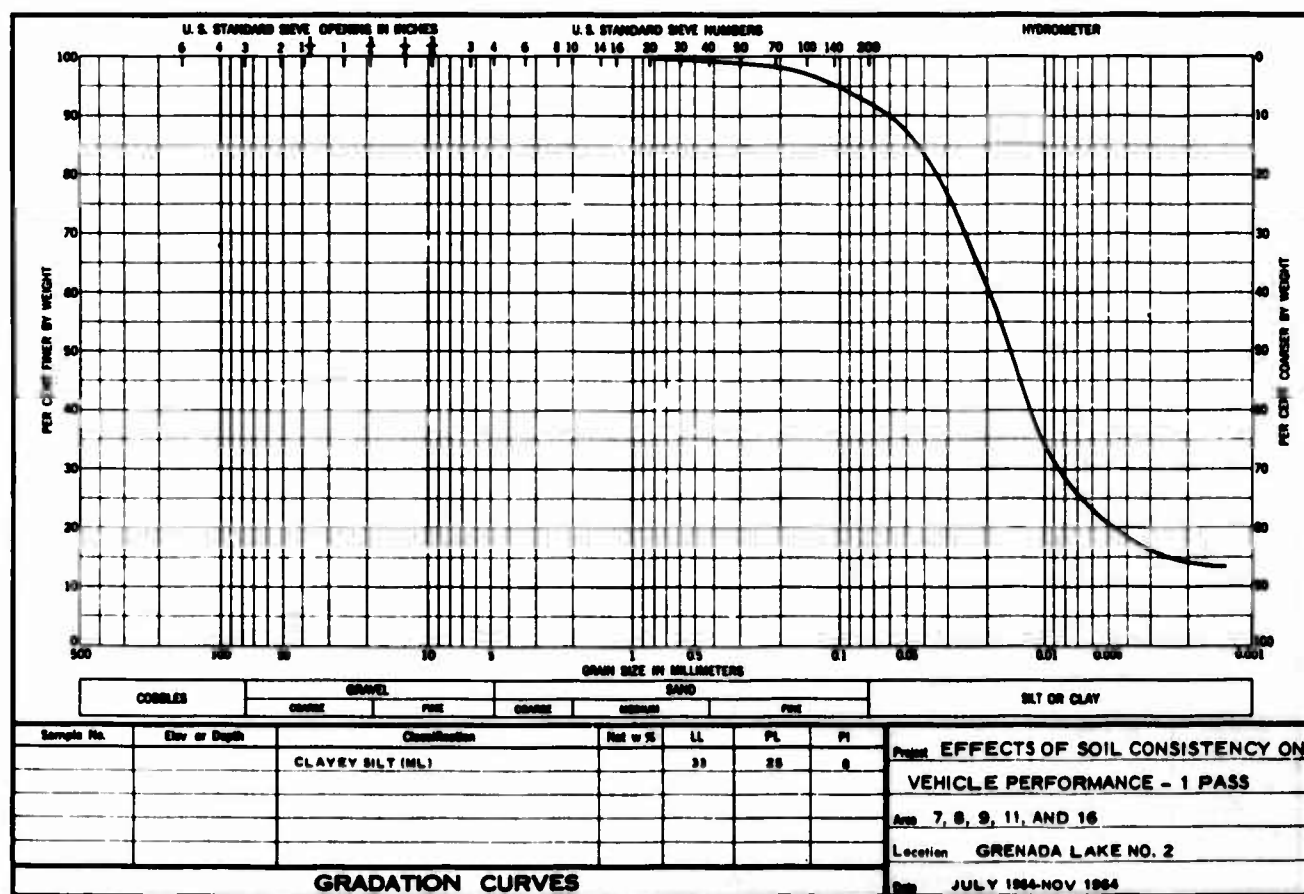
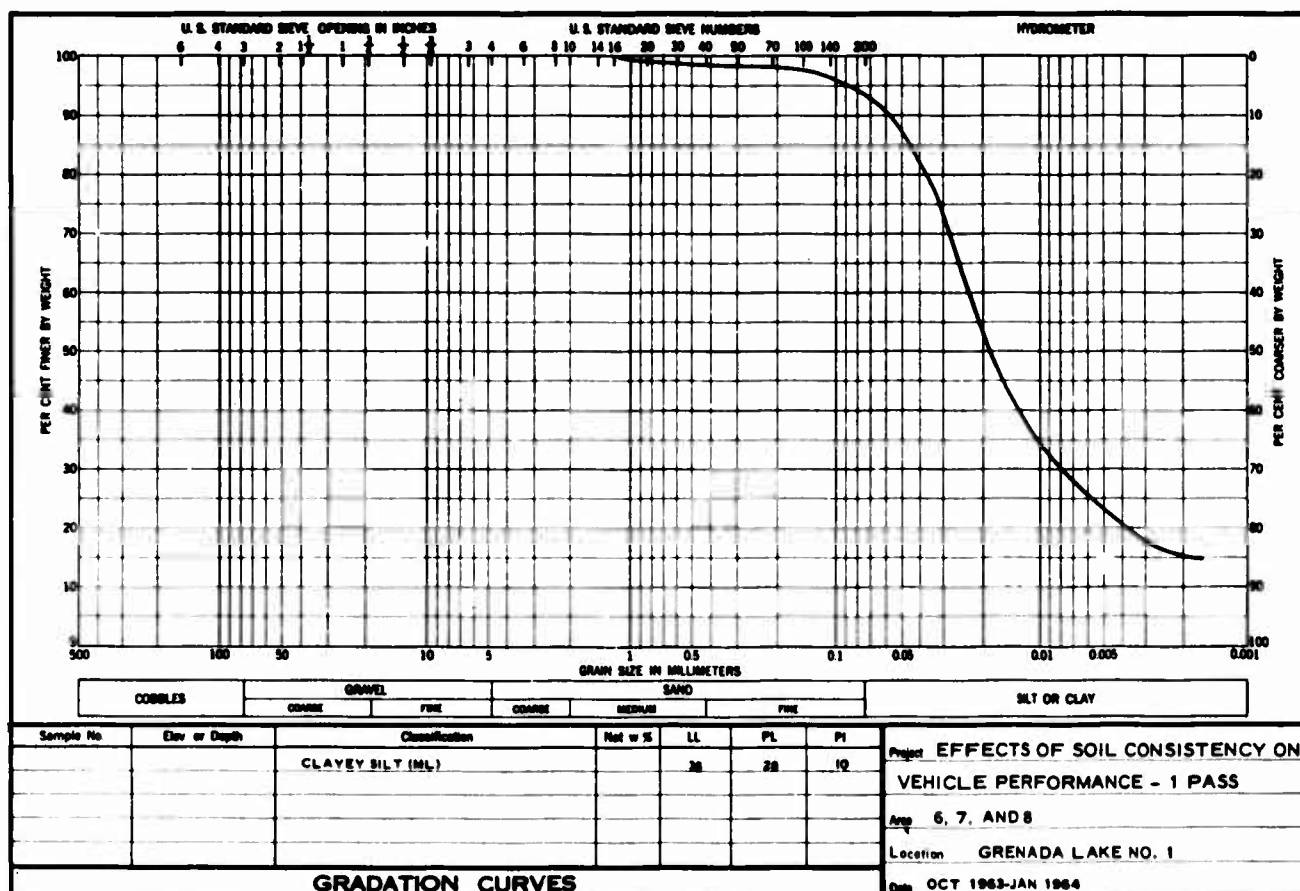


Fig. III-2

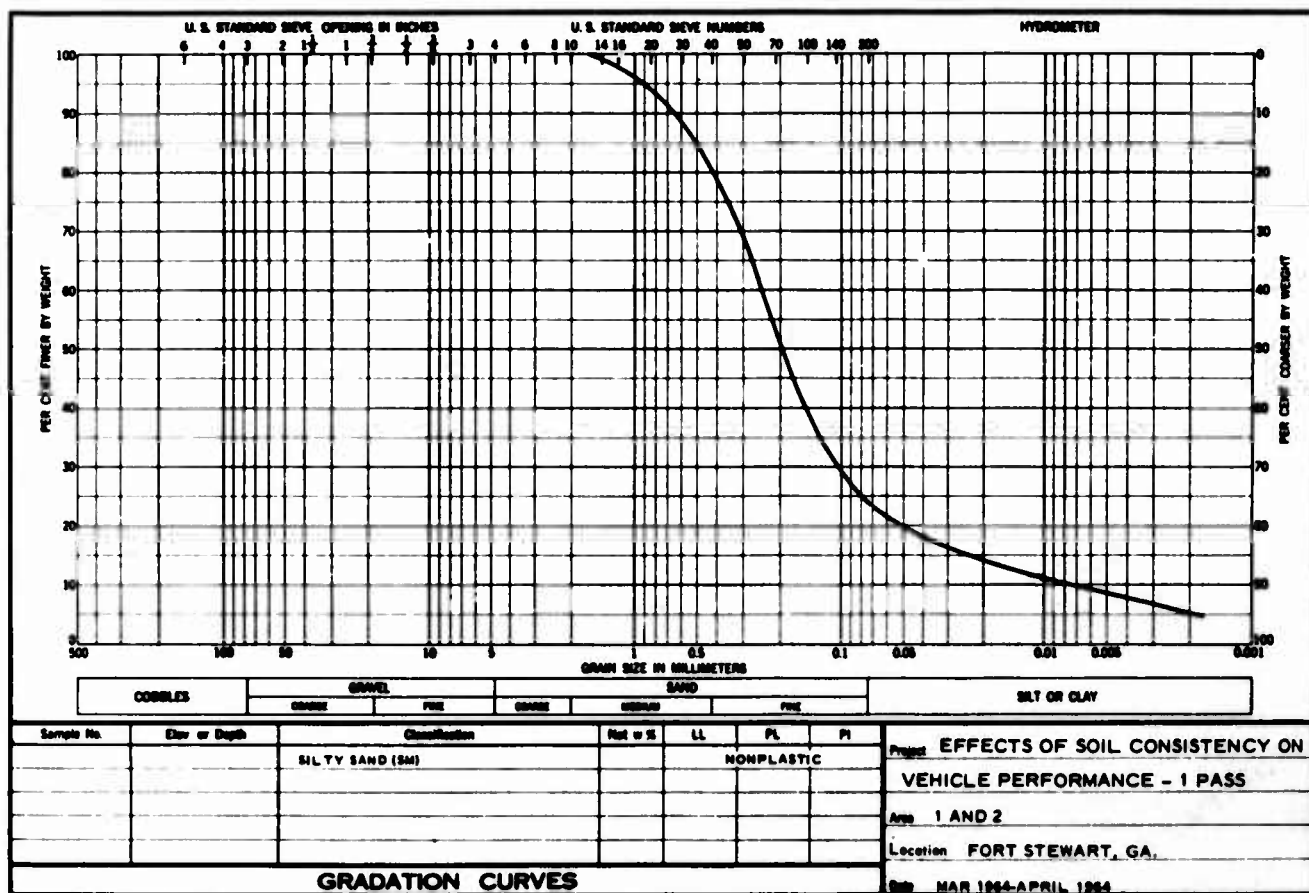
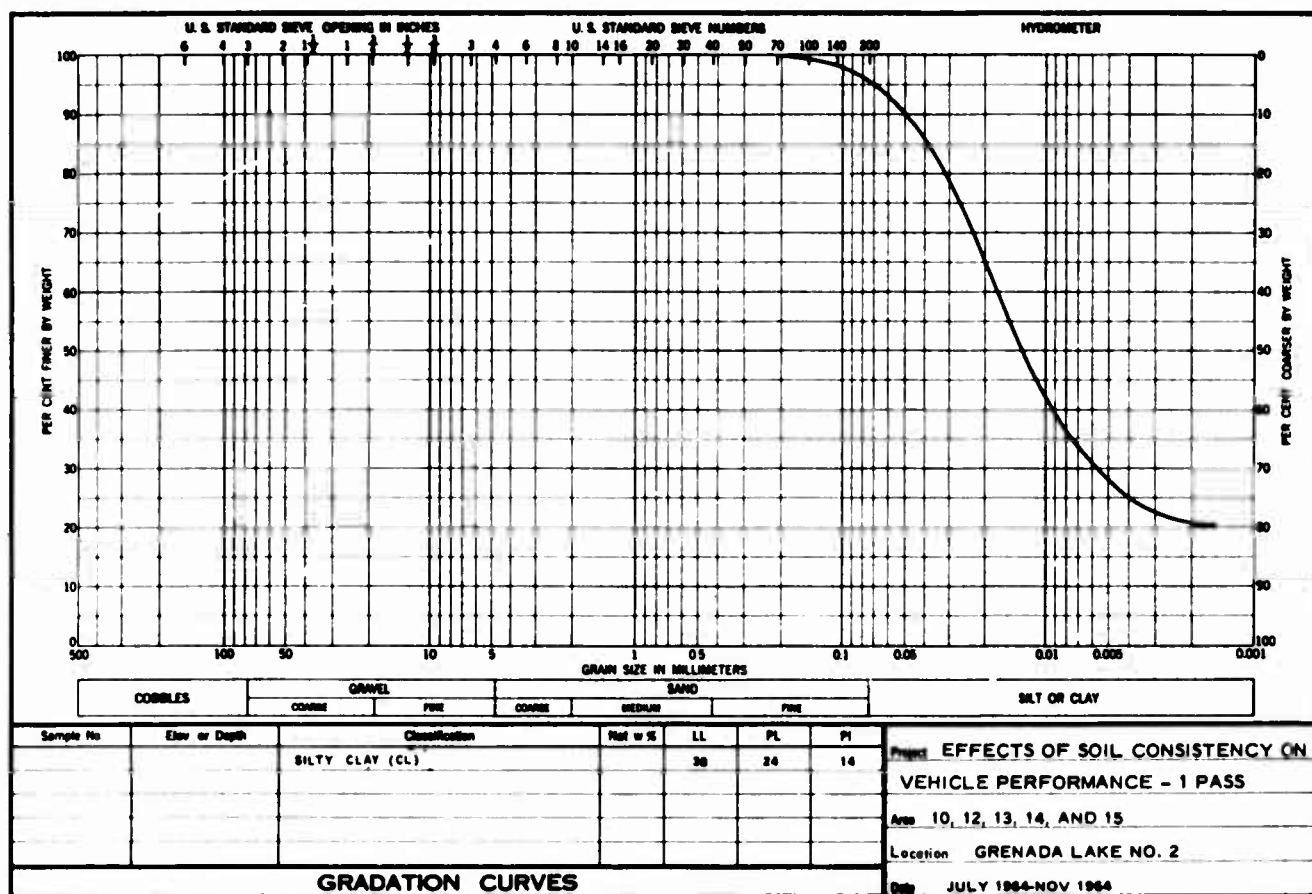


Fig. III-3

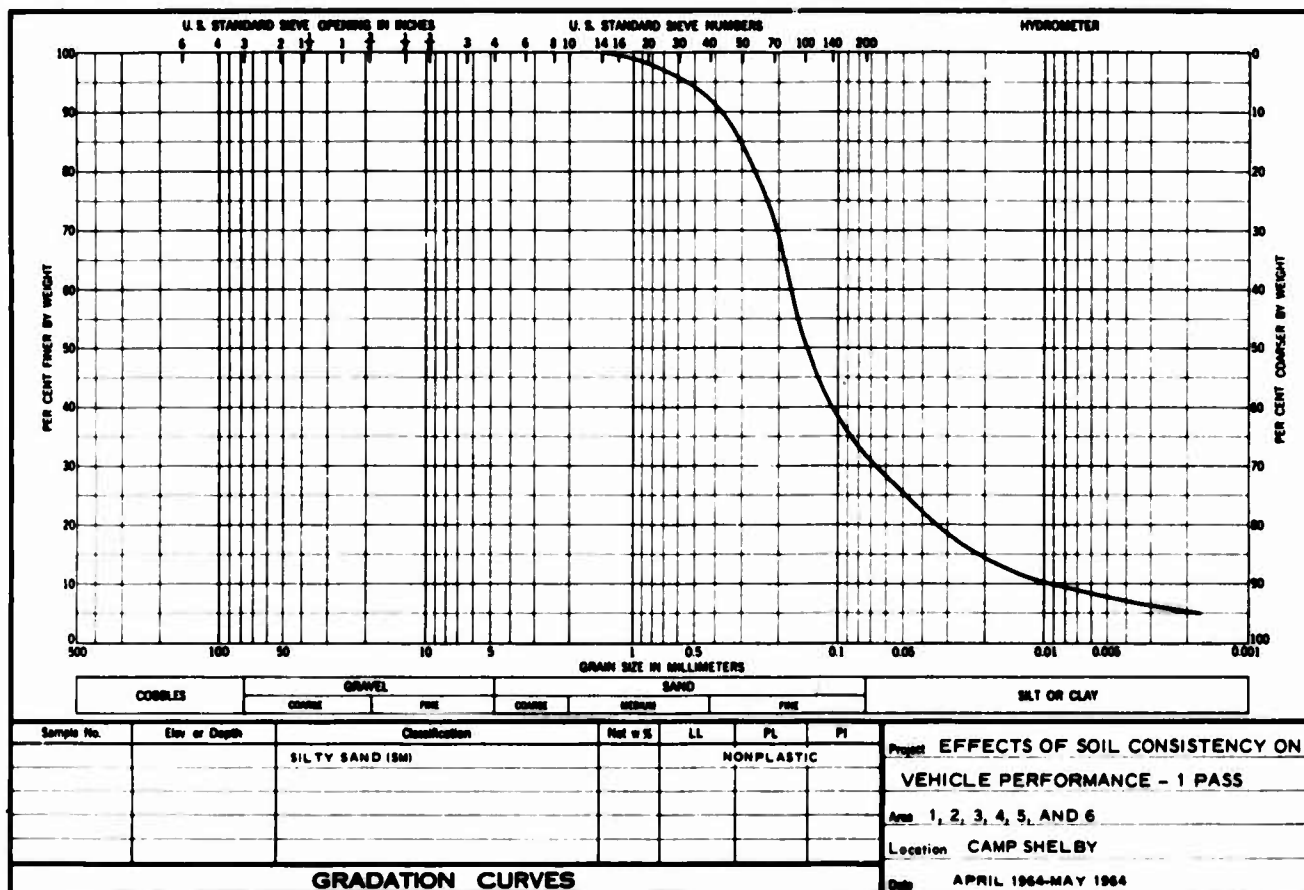


Fig. III-4

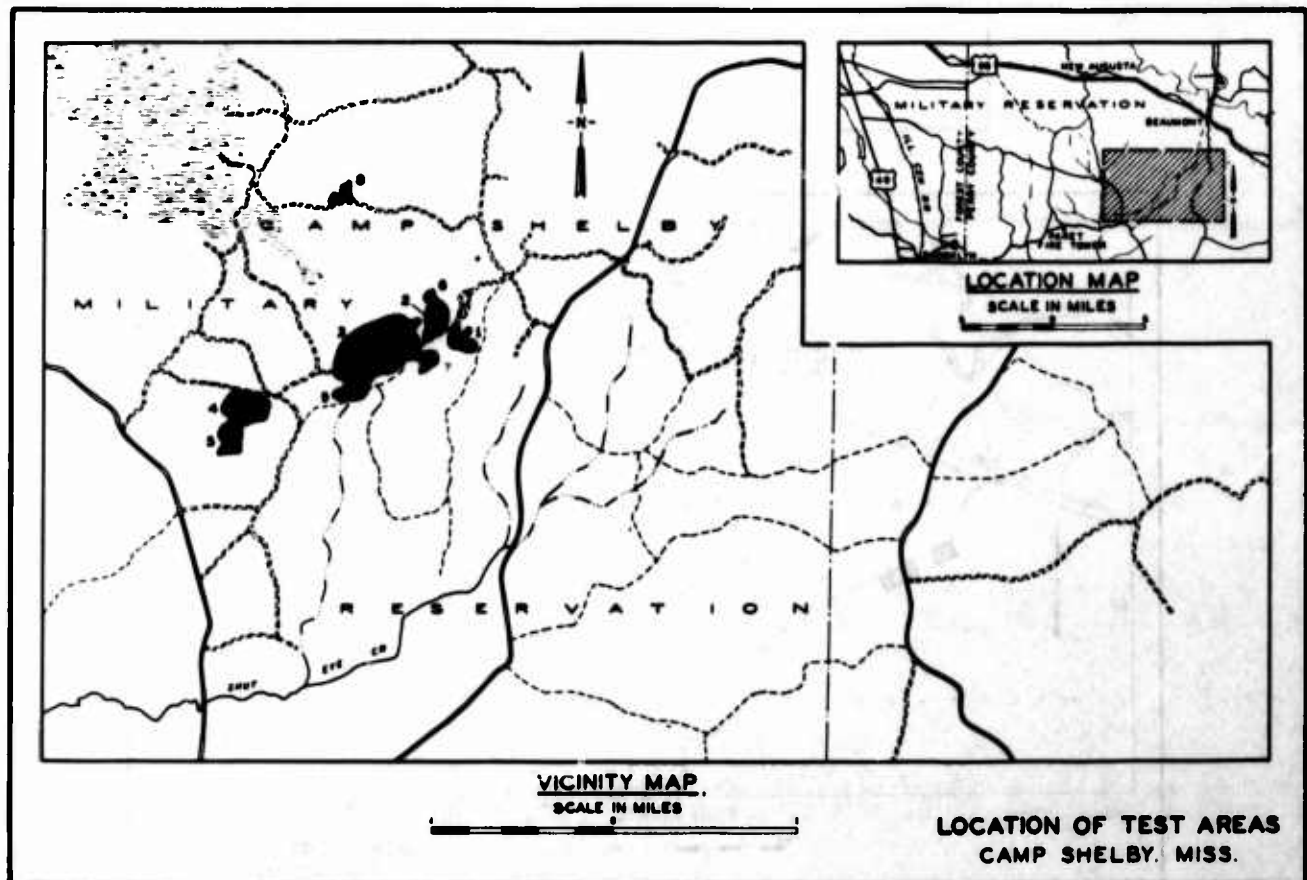
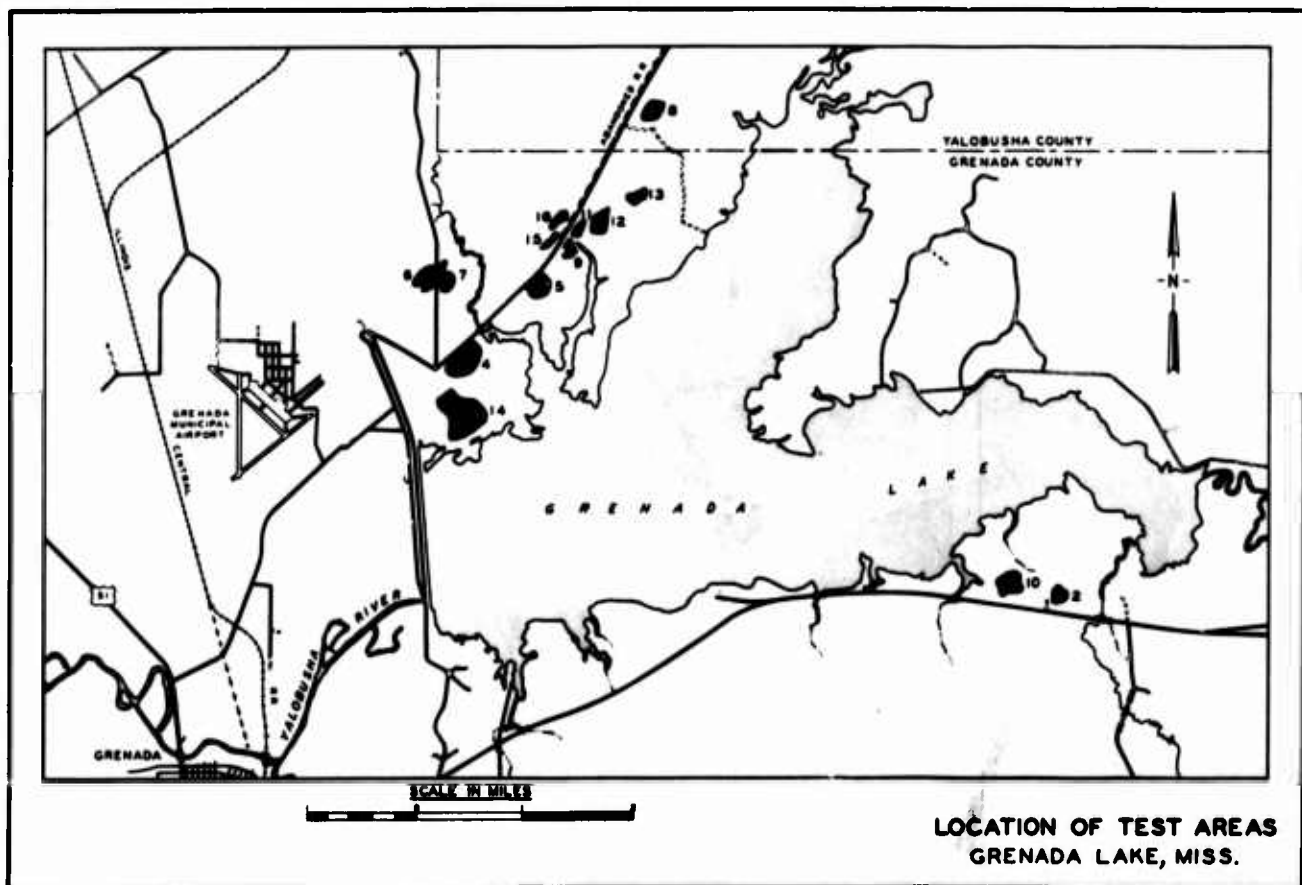


Fig. III-5

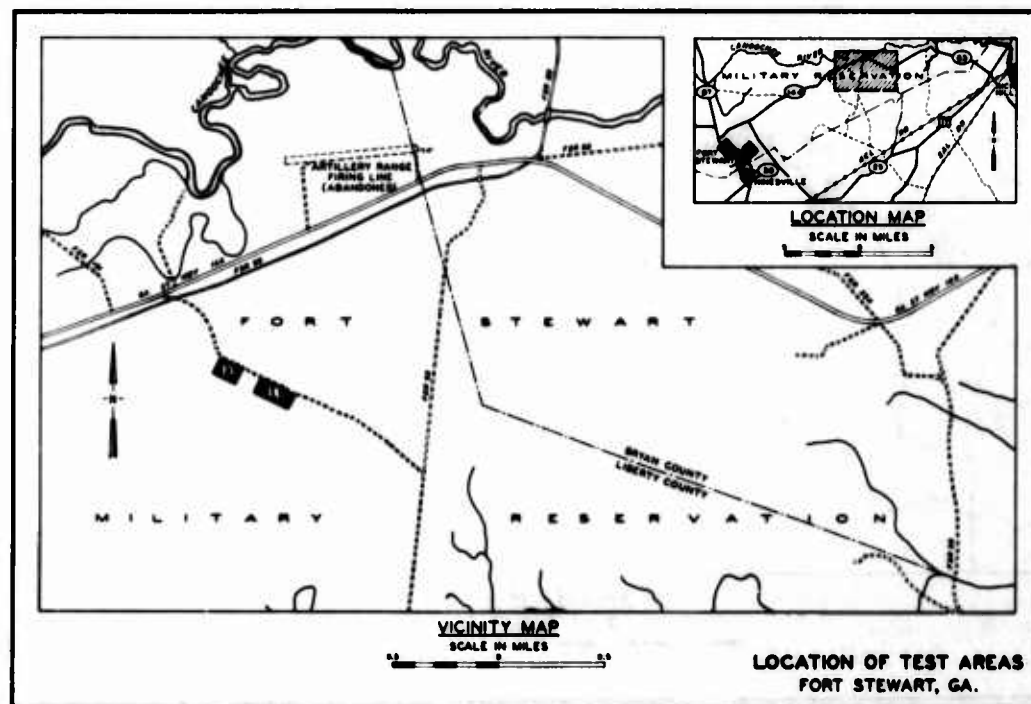


Fig. III-6

Table III-1
CODE SHEET FOR TABLES III-3--III-48

<u>Location</u>	<u>Test</u>	<u>Area</u>	<u>Explanation of Code</u>	<u>Soil Type (USCS)</u>	<u>Explanation of Code</u>
1	1 thru 127	01 thru 16	Grenada Lake, Miss.	1 2 3 4	CH CL SM ML
2	1 thru 170	01 thru 09	Camp Shelby, Miss.	<u>Vehicle Code</u> <u>No.</u> <u>Explanation of Code</u> 1 See Table III-2 thru 101	
3	1 thru 487	01 thru 05	Centennial Lake, Miss.		
4	1 thru 40	01 thru 03	Fort Stewart, Ga.	<u>Pass</u> <u>No.</u> <u>Explanation of Code</u> 0 All pass numbers above thru zero indicate immobi- 51 lized pass except pass No. 51 which indicates vehicle was not immo- bilized.	
	<u>Test Type</u>		<u>Explanation of Code</u>		
	1		Self-propelled	When the water table of a test area is at the ground level, it is recorded as 000. All water table measurements are in inches. When three or more nines appear in any column it is understood that the soil data given for that test were collected in undisturbed soil, and that the vehicle data were collected during the first pass. Usually in a uniform test area one set of soil measurements was made and used in conjunction with several vehicle tests conducted in the area. For this reason soil measurements are repeated for more than one test in the data summary tables.	
	2		Drawbar pull		
	3		Turn		
	4		Speed		

TABLE III-2
VEHICLE CODE NO. IDENTIFICATION

Vehicle Code No.	Vehicle	Empty Weight lb	Gross Weight lb	Tire Description					Track Size			
				Overall Diam in.	Nominal Width in.	Rim Diam in.	Ply Rating	Tire Pressure psi	Defl	Contact Length in.	Contact Width in.	Total Contact Area, sq in.
Wheeled Vehicles												
1	1/2-ton carrier, M274, 4x4	1,190	1,190	16	7.50	10	2	30	6			
2								10	12			
3								5	15			
7	1/2-ton carrier, M274, 4x4	1,190	1,940	16	7.50	10	2	30	10			
9								10	21			
11								5	35			
13	1/2-ton carrier, M274, 4x4	1,325	1,325	16	15.00	6	2	15	10			
15								3	22			
19	1/2-ton carrier, M274, 4x4	1,325	1,940	16	15.00	6	2	15	15			
22								3	39			
24	1/4-ton utility truck, M151, 4x4	2,275	3,560	16	7.00	16	6	30	12			
27								7.5	35			
29	1/4-ton utility truck, M151, 4x4 (mod)	2,405	3,560	16	7.00	16	6	30	12			
31								15	20			
35	1/4-ton utility truck, M151, 4x4 (mod)	2,420	3,560	20	9.00	14	2	30	15			
36								20	19			
40	1/4-ton utility truck, M151, 4x4 (mod)	2,950	3,560	36	20.00	14	4	15	6			
41								3	15			
45	3/4-ton cargo truck, M37, 4x4	6,175	7,240	20	9.00	16	8	30	13			
46								20	15			
47								15	20			
49								15	20			
51	3/4-ton cargo truck, M37, 4x4 (mod)	6,150	7,240	46	18.00	16	4	15	35			
53								3	25			
56	2-1/2-ton cargo truck, M35A1, 6x6	13,475	19,410	20	11.00	20	12	35.5	15			
58								13	35			
101	1/4-ton utility truck, M38A1, 4x4	2,720	3,560	16	6.00	16	4	11.6	35			
Tracked Vehicles												
60	Dinah II, 1/2-ton floater	4,095	4,095							80	20	3200
62	Dinah II, 1/2-ton floater	4,095	4,975							80	20	3200
64	Amphibious cargo carrier, M29C	4,960	4,960							78	20	3120
66	Amphibious cargo carrier, M29C	4,960	5,960							78	20	3120
70	Amphibious cargo carrier, M29C	4,960	5,960							78	12	1872
72	Std D4 engineer tractor without blade	--	12,420							62	13	1612
73	Std D4 engineer tractor with blade	--	14,070							62	13	1612
74	Std D4 engineer tractor without blade	--	13,580							62	24	2576
76	Pelocat, model 941	10,555	12,580							156	20	6240
77	Pelocat, model 941	10,555	13,140							156	20	6240
83	Mi-speed tractor, M5A4	24,800	28,350							117-1/2	17	3978
85	90-mm self-propelled gun, M56	13,760	15,500							93	20	3720
88	Armored personnel carrier, M113	22,900	22,900							105	15	3150
90	Armored personnel carrier, M114	14,750	14,750							102	16-1/2	3365
92	Amphibious cargo carrier, M116	8,435	8,435							98	20	3920
94	Amphibious cargo carrier, M116	8,435	10,610							98	20	3920
96	Combat tank, M41	45,000	45,000							128	21	5376
98	Armored personnel carrier, M59	42,870	42,870							143	21	6006
100	Combat tank, M48A1	98,400	98,400							157-1/2	28	8820

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Table III-4

[illegible]

Table III-5

LOC. TEST AND AREA	TEST TYPE	VEH TYPE	NO. SIZE	PERCENTAGE	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH	DEPTH
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DATE 4544445

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PLEASE RETURN TO

[illegible]

Table III-3

[illegible]

Table III-10

[illegible]

NO.	DATE	PAGE	REMARKS
1	10/10/50	1	...
2	10/10/50	2	...
3	10/10/50	3	...
4	10/10/50	4	...
5	10/10/50	5	...
6	10/10/50	6	...
7	10/10/50	7	...
8	10/10/50	8	...
9	10/10/50	9	...
10	10/10/50	10	...
11	10/10/50	11	...
12	10/10/50	12	...
13	10/10/50	13	...
14	10/10/50	14	...
15	10/10/50	15	...
16	10/10/50	16	...
17	10/10/50	17	...
18	10/10/50	18	...
19	10/10/50	19	...
20	10/10/50	20	...
21	10/10/50	21	...
22	10/10/50	22	...
23	10/10/50	23	...
24	10/10/50	24	...
25	10/10/50	25	...
26	10/10/50	26	...
27	10/10/50	27	...
28	10/10/50	28	...
29	10/10/50	29	...
30	10/10/50	30	...
31	10/10/50	31	...
32	10/10/50	32	...
33	10/10/50	33	...
34	10/10/50	34	...
35	10/10/50	35	...
36	10/10/50	36	...
37	10/10/50	37	...
38	10/10/50	38	...
39	10/10/50	39	...
40	10/10/50	40	...
41	10/10/50	41	...
42	10/10/50	42	...
43	10/10/50	43	...
44	10/10/50	44	...
45	10/10/50	45	...
46	10/10/50	46	...
47	10/10/50	47	...
48	10/10/50	48	...
49	10/10/50	49	...
50	10/10/50	50	...
51	10/10/50	51	...
52	10/10/50	52	...
53	10/10/50	53	...
54	10/10/50	54	...
55	10/10/50	55	...
56	10/10/50	56	...
57	10/10/50	57	...
58	10/10/50	58	...
59	10/10/50	59	...
60	10/10/50	60	...
61	10/10/50	61	...
62	10/10/50	62	...
63	10/10/50	63	...
64	10/10/50	64	...
65	10/10/50	65	...
66	10/10/50	66	...
67	10/10/50	67	...
68	10/10/50	68	...
69	10/10/50	69	...
70	10/10/50	70	...
71	10/10/50	71	...
72	10/10/50	72	...
73	10/10/50	73	...
74	10/10/50	74	...
75	10/10/50	75	...
76	10/10/50	76	...
77	10/10/50	77	...
78	10/10/50	78	...
79	10/10/50	79	...
80	10/10/50	80	...
81	10/10/50	81	...
82	10/10/50	82	...
83	10/10/50	83	...
84	10/10/50	84	...
85	10/10/50	85	...
86	10/10/50	86	...
87	10/10/50	87	...
88	10/10/50	88	...
89	10/10/50	89	...
90	10/10/50	90	...
91	10/10/50	91	...
92	10/10/50	92	...
93	10/10/50	93	...
94	10/10/50	94	...
95	10/10/		

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TYPE=000000

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Table III-12

[illegible]

[illegible][illegible]

100

LOC:	TEST SOIL	VEN	TYPE----	PENETROMETER
TEST	TYPE	CODE	STAFF CODE	
AND		NO.	DATE	
AREA				

LOC:	1-1	1-2	2-1	2-2	3-1	3-2
YES:						
NO:						

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LAST	TEST	YR	YR
TEST	9014	CODE	STAFF CODE
NAME	TYPE	TYPE	NO.
AREA			SIZE SIZE

[illegible][illegible]

Table III-13

[illegible]

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RECEIVED

[illegible]

Table III-22

Table III-22																
LOC. TEST AND AREA	TEST TYPE	SCIL TYPE	VCM TYPE	CORE TYPE	CORE SIZE	PERCENTAGE										LOC. TEST AND AREA
						0-1	0-2	0-3	0-4	0-5	0-6	0-7	0-8	0-9	0-10	
3 4002	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4002
3 4003	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4003
3 4004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4004
3 4005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4005
3 4006	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4006
3 4007	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4007
3 4008	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4008
3 4009	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4009
3 4010	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4010
3 4011	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4011
3 4012	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4012
3 4013	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4013
3 4014	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4014
3 4015	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4015
3 4016	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4016
3 4017	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4017
3 4018	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4018
3 4019	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4019
3 4020	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4020
3 4021	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4021
3 4022	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4022
3 4023	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4023
3 4024	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4024
3 4025	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4025
3 4026	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4026
3 4027	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4027
3 4028	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4028
3 4029	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4029
3 4030	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4030
3 4031	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4031
3 4032	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4032
3 4033	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4033
3 4034	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4034
3 4035	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4035
3 4036	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4036
3 4037	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4037
3 4038	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4038
3 4039	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4039
3 4040	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4040
3 4041	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4041
3 4042	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4042
3 4043	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4043
3 4044	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4044
3 4045	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4045
3 4046	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4046
3 4047	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4047
3 4048	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4048
3 4049	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4049
3 4050	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4050
3 4051	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4051
3 4052	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4052
3 4053	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4053
3 4054	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4054
3 4055	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4055
3 4056	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4056
3 4057	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4057
3 4058	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4058
3 4059	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4059
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3 4061	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4061
3 4062	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4062
3 4063	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4063
3 4064	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4064
3 4065	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4065
3 4066	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4066
3 4067	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4067
3 4068	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4068
3 4069	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4069
3 4070	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4070
3 4071	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4071
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3 4073	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4073
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3 4077	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4077
3 4078	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4078
3 4079	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4079
3 4080	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4080
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3 4083	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4083
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3 4089	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4089
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3 4096	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4096
3 4097	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4097
3 4098	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4098
3 4099	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4099
3 4100	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3 4100

Table 111-23

[illegible]

Table III-24

LOC TEST AND AREA	TEST DATE	TEST TIME	TEST TYPE	TEST CODE	TEST STAFF	TEST SIZE	CLAS												DENSITY	SHEAROGRAPH				DEPTH				WATER	TABLE	SLIP	SLIP																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
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Table III-25

[illegible]

WALSH-CURTIS, N.

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Table III-20

Table III-2

TEST	TEST NO.	TEST TYPE	TEST NO.	TEST NO.	TEST NO.	TEST NO.	TEST NO.	TEST NO.	TEST NO.	RESULTS	RESULTS NO.	RESULTS NO.	RESULTS NO.	RESULTS NO.	RESULTS NO.	RESULTS NO.	RESULTS NO.	RESULTS NO.	RESULTS NO.	REMARKS	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.	REMARKS NO.
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Table III-30

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Table III-31

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Table III-32

[illegible]

Table III-33

LOC TEST LOC TEST	SCIL V4-1	V4-2	V4-3	V4-4	V4-5	V4-6	V4-7	V4-8	V4-9	V4-10	V4-11	V4-12	V4-13	V4-14	V4-15	V4-16	V4-17	V4-18	V4-19	V4-20	V4-21	V4-22	V4-23	V4-24	V4-25	V4-26	V4-27	V4-28	V4-29	V4-30	V4-31	V4-32	V4-33	V4-34	V4-35	V4-36	V4-37	V4-38	V4-39	V4-40	V4-41	V4-42	V4-43	V4-44	V4-45	V4-46	V4-47	V4-48	V4-49	V4-50	V4-51	V4-52	V4-53	V4-54	V4-55	V4-56	V4-57	V4-58	V4-59	V4-60	V4-61	V4-62	V4-63	V4-64	V4-65	V4-66	V4-67	V4-68	V4-69	V4-70	V4-71	V4-72	V4-73	V4-74	V4-75	V4-76	V4-77	V4-78	V4-79	V4-80	V4-81	V4-82	V4-83	V4-84	V4-85	V4-86	V4-87	V4-88	V4-89	V4-90	V4-91	V4-92	V4-93	V4-94	V4-95	V4-96	V4-97	V4-98	V4-99	V4-100	V4-101	V4-102	V4-103	V4-104	V4-105	V4-106	V4-107	V4-108	V4-109	V4-110	V4-111	V4-112	V4-113	V4-114	V4-115	V4-116	V4-117	V4-118	V4-119	V4-120	V4-121	V4-122	V4-123	V4-124	V4-125	V4-126	V4-127	V4-128	V4-129	V4-130	V4-131	V4-132	V4-133	V4-134	V4-135	V4-136	V4-137	V4-138	V4-139	V4-140	V4-141	V4-142	V4-143	V4-144	V4-145	V4-146	V4-147	V4-148	V4-149	V4-150	V4-151	V4-152	V4-153	V4-154	V4-155	V4-156	V4-157	V4-158	V4-159	V4-160	V4-161	V4-162	V4-163	V4-164	V4-165	V4-166	V4-167	V4-168	V4-169	V4-170	V4-171	V4-172	V4-173	V4-174	V4-175	V4-176	V4-177	V4-178	V4-179	V4-180	V4-181	V4-182	V4-183	V4-184	V4-185	V4-186	V4-187	V4-188	V4-189	V4-190	V4-191	V4-192	V4-193	V4-194	V4-195	V4-196	V4-197	V4-198	V4-199	V4-200	V4-201	V4-202	V4-203	V4-204	V4-205	V4-206	V4-207	V4-208	V4-209	V4-210	V4-211	V4-212	V4-213	V4-214	V4-215	V4-216	V4-217	V4-218	V4-219	V4-220	V4-221	V4-222	V4-223	V4-224	V4-225	V4-226	V4-227	V4-228	V4-229	V4-230	V4-231	V4-232	V4-233	V4-234	V4-235	V4-236	V4-237	V4-238	V4-239	V4-240	V4-241	V4-242	V4-243	V4-244	V4-245	V4-246	V4-247	V4-248	V4-249	V4-250	V4-251	V4-252	V4-253	V4-254	V4-255	V4-256	V4-257	V4-258	V4-259	V4-260	V4-261	V4-262	V4-263	V4-264	V4-265	V4-266	V4-267	V4-268	V4-269	V4-270	V4-271	V4-272	V4-273	V4-274	V4-275	V4-276	V4-277	V4-278	V4-279	V4-280	V4-281	V4-282	V4-283	V4-284	V4-285	V4-286	V4-287	V4-288	V4-289	V4-290	V4-291	V4-292	V4-293	V4-294	V4-295	V4-296	V4-297	V4-298	V4-299	V4-300	V4-301	V4-302	V4-303	V4-304	V4-305	V4-306	V4-307	V4-308	V4-309	V4-310	V4-311	V4-312	V4-313	V4-314	V4-315	V4-316	V4-317	V4-318	V4-319	V4-320	V4-321	V4-322	V4-323	V4-324	V4-325	V4-326	V4-327	V4-328	V4-329	V4-330	V4-331	V4-332	V4-333	V4-334	V4-335	V4-336	V4-337	V4-338	V4-339	V4-340	V4-341	V4-342	V4-343	V4-344	V4-345	V4-346	V4-347	V4-348	V4-349	V4-350	V4-351	V4-352	V4-353	V4-354	V4-355	V4-356	V4-357	V4-358	V4-359	V4-360	V4-361	V4-362	V4-363	V4-364	V4-365	V4-366	V4-367	V4-368	V4-369	V4-370	V4-371	V4-372	V4-373	V4-374	V4-375	V4-376	V4-377	V4-378	V4-379	V4-380	V4-381	V4-382	V4-383	V4-384	V4-385	V4-386	V4-387	V4-388	V4-389	V4-390	V4-391	V4-392	V4-393	V4-394	V4-395	V4-396	V4-397	V4-398	V4-399	V4-400	V4-401	V4-402	V4-403	V4-404	V4-405	V4-406	V4-407	V4-408	V4-409	V4-410	V4-411	V4-412	V4-413	V4-414	V4-415	V4-416	V4-417	V4-418	V4-419	V4-420	V4-421	V4-422	V4-423	V4-424	V4-425	V4-426	V4-427	V4-428	V4-429	V4-430	V4-431	V4-432	V4-433	V4-434	V4-435	V4-436	V4-437	V4-438	V4-439	V4-440	V4-441	V4-442	V4-443	V4-444	V4-445	V4-446	V4-447	V4-448	V4-449	V4-450	V4-451	V4-452	V4-453	V4-454	V4-455	V4-456	V4-457	V4-458	V4-459	V4-460	V4-461	V4-462	V4-463	V4-464	V4-465	V4-466	V4-467	V4-468	V4-469	V4-470	V4-471	V4-472	V4-473	V4-474	V4-475	V4-476	V4-477	V4-478	V4-479	V4-480	V4-481	V4-482	V4-483	V4-484	V4-485	V4-486	V4-487	V4-488	V4-489	V4-490	V4-491	V4-492	V4-493	V4-494	V4-495	V4-496	V4-497	V4-498	V4-499	V4-500	V4-501	V4-502	V4-503	V4-504	V4-505	V4-506	V4-507	V4-508	V4-509	V4-510	V4-511	V4-512	V4-513	V4-514	V4-515	V4-516	V4-517	V4-518	V4-519	V4-520	V4-521	V4-522	V4-523	V4-524	V4-525	V4-526	V4-527	V4-528	V4-529	V4-530	V4-531	V4-532	V4-533	V4-534	V4-535	V4-536	V4-537	V4-538	V4-539	V4-540	V4-541	V4-542	V4-543	V4-544	V4-545	V4-546	V4-547	V4-548	V4-549	V4-550	V4-551	V4-552	V4-553	V4-554	V4-555	V4-556	V4-557	V4-558	V4-559	V4-560	V4-561	V4-562	V4-563	V4-564	V4-565	V4-566	V4-567	V4-568	V4-569	V4-570	V4-571	V4-572	V4-573	V4-574	V4-575	V4-576	V4-577	V4-578	V4-579	V4-580	V4-581	V4-582	V4-583	V4-584	V4-585	V4-586	V4-587	V4-588	V4-589	V4-590	V4-591	V4-592	V4-593	V4-594	V4-595	V4-596	V4-597	V4-598	V4-599	V4-600	V4-601	V4-602	V4-603	V4-604	V4-605	V4-606	V4-607	V4-608	V4-609	V4-610	V4-611	V4-612	V4-613	V4-614	V4-615	V4-616	V4-617	V4-618	V4-619	V4-620	V4-621	V4-622	V4-623	V4-624	V4-625	V4-626	V4-627	V4-628	V4-629	V4-630	V4-631	V4-632	V4-633	V4-634	V4-635	V4-636	V4-637	V4-638	V4-639	V4-640	V4-641	V4-642	V4-643	V4-644	V4-645	V4-646	V4-647	V4-648	V4-649	V4-650	V4-651	V4-652	V4-653	V4-654	V4-655	V4-656	V4-657	V4-658	V4-659	V4-660	V4-661	V4-662	V4-663	V4-664	V4-665	V4-666	V4-667	V4-668	V4-669	V4-670	V4-671	V4-672	V4-673	V4-674	V4-675	V4-676	V4-677	V4-678	V4-679	V4-680	V4-681	V4-682	V4-683	V4-684	V4-685	V4-686	V4-687	V4-688	V4-689	V4-690	V4-691	V4-692	V4-693	V4-694	V4-695	V4-696	V4-697	V4-698	V4-699	V4-700	V4-701	V4-702	V4-703	V4-704	V4-705	V4-706	V4-707	V4-708	V4-709	V4-710	V4-711	V4-712	V4-713	V4-714	V4-715	V4-716	V4-717	V4-718	V4-719	V4-720	V4-721	V4-722	V4-723	V4-724	V4-725	V4-726	V4-727	V4-728	V4-729	V4-730	V4-731	V4-732	V4-733	V4-734	V4-735	V4-736	V4-737	V4-738	V4-739	V4-740	V4-741	V4-742	V4-743	V4-744	V4-745	V4-746	V4-747	V4-748	V4-749	V4-750	V4-751	V4-752	V4-753	V4-754	V4-755	V4-756	V4-757	V4-758	V4-759	V4-760	V4-761	V4-762	V4-763	V4-764	V4-765	V4-766	V4-767	V4-768	V4-769	V4-770	V4-771	V4-772	V4-773	V4-774	V4-775	V4-776	V4-777	V4-778	V4-779	V4-780	V4-781	V4-782	V4-783	V4-784	V4-785	V4-786	V4-787	V4-788	V4-789	V4-790	V4-791	V4-792	V4-793	V4-794	V4-795	V4-796	V4-797	V4-798	V4-799	V4-800	V4-801	V4-802	V4-803	V4-804	V4-805	V4-806	V4-807	V4-808	V4-809	V4-810	V4-811	V4-812	V4-813	V4-814	V4-815	V4-816	V4-817	V4-818	V4-819	V4-820	V4-821	V4-822	V4-823	V4-824	V4-825	V4-826	V4-827	V4-828	V4-829	V4-830	V4-831	V4-832	V4-833	V4-834	V4-835	V4-836	V4-837	V4-838	V4-839	V4-840	V4-841	V4-842	V4-843	V4-844	V4-845	V4-846	V4-847	V4-848	V4-849	V4-850	V4-851	V4-852	V4-853	V4-854	V4-855	V4-856	V4-857	V4-858	V4-859	V4-860	V4-861	V4-862	V4-863	V4-864	V4-865	V4-866	V4-867	V4-868	V4-869	V4-870	V4-871	V4-872	V4-873	V4-874	V4-875	V4-876	V4-877	V4-878	V4-879	V4-880	V4-881	V4-882	V4-883	V4-884	V4-885	V4-886	V4-887	V4-888	V4-889	V4-890	V
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Table III-34

LUC		TEST		SCAL		VEM		TYPE		STAFF		CODE		AREA		SIZE		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA		CONE		AREA	
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Table 111-35

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Table III-36

LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN	TYPE	STAFF	DATE	LOC.	TEST	SOIL	VEN
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[illegible]

LOC.

PENETROMETER

STATION	DATE	MOISTURE CONTENT, PERCENT, DRY WT				DENSITY, LB/CU FT				SHEARGRAPH				RUT		RUT		DEPTH		D/W
		0-3	3-6	6-9	9-12	0-3	3-6	6-9	9-12	CU	PHI	AU	ALPHA	LT	RT	LT	RT	WATER	TABLE	
20-2	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	4478	0.75
20-3	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	4280	0.74
20-4	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3888	0.64
20-5	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-6	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-7	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-8	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-9	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-10	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-11	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-12	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-13	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-14	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-15	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-16	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-17	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-18	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-19	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-20	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-21	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-22	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-23	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-24	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-25	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-26	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-27	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-28	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-29	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-30	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-31	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-32	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-33	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-34	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-35	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-36	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-37	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-38	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-39	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-40	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-41	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-42	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-43	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-44	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-45	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-46	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-47	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-48	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-49	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-50	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-51	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-52	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-53	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-54	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-55	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-56	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-57	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-58	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-59	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-60	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-61	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-62	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99.0	99.0	3718	0.62
20-63	10-10	35.2	39.8	40.0	41.5	44.1	49.0	50.0	78.0	72.4	99.0	99.0	99.0	99.0	99.0	99.0	99			

[illegible]

Table III-42

[illegible][illegible]

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[illegible]

PERFORMANCE

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Table III-45

[illegible][illegible]

Table III-46

LOC	TIME	LAT	LONG	ELEVATION	WIND	TEMP	PRESS	HUMID	VIS	CLOUDS	SEA	WAVE	ICE	SUN	MOON	STAR	PLANET	COMET	METEOR	AURORA	OTHER	REMARKS	PAGE	REMARKS
2000000	1	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000001	2	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000002	3	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000003	4	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000004	5	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000005	6	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000006	7	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000007	8	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000008	9	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000009	10	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000010	11	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000011	12	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000012	13	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000013	14	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000014	15	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000015	16	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000016	17	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000017	18	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000018	19	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000019	20	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000020	21	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000021	22	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000022	23	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000023	24	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000024	25	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000025	26	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000026	27	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000027	28	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000028	29	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000029	30	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000030	31	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000031	32	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000032	33	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000033	34	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000034	35	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000035	36	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000036	37	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000037	38	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000038	39	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000039	40	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000040	41	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000041	42	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000042	43	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000043	44	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000044	45	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000045	46	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000046	47	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000047	48	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000048	49	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000049	50	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000050	51	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000051	52	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000052	53	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000053	54	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000054	55	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000055	56	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000056	57	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000057	58	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000058	59	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000059	60	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000060	61	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
2000061	62	04	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	0	

Table III-47

TEST SOIL VEH TYPE-----										PENETROMETER										DEPTH, INCHES										DEPTH, FEET										DEPTH, METERS										DEPTH, METERS																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
LOC	TEST	TYPE	VEH	TYPE	NO.	SIZE	NO.	SIZE	NO.	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	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215

Table XIX-48

[illegible]

TABLE III-49
SPEED TEST VEHICLE PERFORMANCE

Location Test No. Area	Gear	RPM	Feet per sec	RCI Depth, in.		
				0 to 6	3 to 9	6 to 12
Vehicle Code No. 76						
329301	4 TR	1st 2000	2.5	26	32	36
		2nd 1550	3.3			
		2nd 1650	3.5			
	2 TR	1st 2350	2.9	31	35	31
		2nd 2000	4.4			
		3rd 1300	5.9			
329401	4 TR	1st 2300	2.8	31	35	31
		2nd 2000	4.4			
		2nd 2150	4.7			
	2 TR	1st 2350	3.1	24	22	25
		2nd 2000	4.5			
		3rd 1750	7.4			
341202	2 TR	3rd 1750	8.0	51	59	60
		3rd 2400	10.3			
		3rd 2450	10.3			
	4th	1800	14.5	24	22	25
		4th 1900	15.2			
		5th 1700	16.1			
343102	2 TR	5th 1700	16.5	24	22	25
		4th 2300	15.6			
		4th 2300	15.3			
	5th	1950	15.9	24	22	25
		5th 1950	17.4			
		5th 2000	17.1			
Vehicle Code No. 66						
329501	H-3	1900	23.4	31	35	31
		1800	26.8			
		1800	25.9			
330502	H-2	2400	22.4	20	27	31
330602	H-2	1400	12.4	20	27	31
330702	H-2	1700	13.0	20	27	31
330802	H-1	3300	16.7	20	27	31
340602	H-1	4300	20.2	38	38	40
		4300	21.4			
		4300	21.0			
Vehicle Code No. 49						
341302	H-3	2300	33.1	36	28	32
		2450	36.7			
		1000	25.2			
	H-4	1000	25.5	40	30	37
		2200	34.7			
		2200	36.7			
341402	H-3	900	18.8	41	42	44
		900	18.8			
		2100	29.5			
341706	H-3	2400	34.5	19	20	21
		2400	34.6			
		2200	30.4			
341802	H-3	2200	32.7	19	20	21
		2200	32.7			
		850	17.0			
Vehicle Code No. 70						
344302	H-2	3600	31.1	55	60	64
		4000	36.2			
		4050	35.5			
	H-3	2400	37.8	47	37	40
		2400	35.0			
		2500	33.8			
344402	H-2	3800	33.6	21	14	18
		4000	31.4			
		4000	32.9			
	H-3	2100	29.8	29	31	30
		2200	28.6			
		2300	32.4			
344502	H-2	4000	35.5	21	14	18
		4000	35.6			
		2500	34.3			
	H-3	2500	36.8	29	31	30
		2500	34.1			
		4000	31.0			
344602	H-2	4000	33.1	29	31	30
		4000	35.1			
		2600	34.2			
	H-3	2600	33.8	29	31	30
		2600	33.8			
		2600	33.8			
Vehicle Code No. 56						
332902	L-2	2750	12.5	41	43	34
333002	L-3	2600	20.6	40	47	38
333102	H-2	2200	20.0	39	42	35
Vehicle Code No. 58						
341502	H-2	2700	23.7	23	26	24
		2700	23.9			
		2700	25.2			
	H-3	1700	24.8	56	42	41
		1700	24.8			
		2700	24.7			
341606	H-2	2700	26.2	56	42	41
		2700	26.2			
		1900	35.3			

TABLE III-50

SURFACE TRACTION TESTS IN CLAY

		Sheargraph Data						M37, 4x4 W=7240 LB. 30 PSI D/W	M38A1, 4x4 W=3560 LB. 18.5 PSI D/W	M29C W=5960 LB. D/W
0-1"		Vane		Rubber		V	R			
Date	M.C.-%	c	tanφ	a	tana	τ/σ_{10}	τ/σ_{10}			
July 15	23.0	0.2	0.73	0.5	0.45	0.84	0.50	0.66	----	0.77
July 15	27.0	0.4	0.65	0.2	0.14	0.66	0.20	0.20	----	0.37
July 21	15.0	0.2	1.07	0	0.65	1.02	0.71	0.57	----	0.76
July 23	23.0	2.2	0.42	2.8	0.16	0.71	0.43	0.23	----	0.62
July 23	38.0	1.8	0.16	1.0	0.21	0.36	0.32	0.14	----	0.32
July 24	31.0	1.0	0.16	1.0	0.09	0.29	0.28	0.14	0.18	0.25
July 24	27.0	1.0	0.23	1.0	0.21	0.35	0.32	0.20	0.20	0.30
Nov. 6	15.0	0.0	0.81	0.3	0.36	0.90	0.32	----	----	0.77
Nov. 7	27.0	2.0	0.10	1.5	0.05	0.28	0.20	----	0.22	0.68
Nov. 10	21.0	2.0	0.60	2.0	0.60	0.75	0.70	0.85	----	0.84
Nov. 12	19.0	---	----	0.5	0.68	----	0.74	0.72	0.61	0.83

SURFACE TRACTION TESTS IN SILT

June 23	----	0.9	0.33	1.3	0.16	0.35	0.26	0.18	0.22	0.26
June 24	----	0.0	0.65	0.0	0.25	0.70	0.28	----	----	0.26
June 26	42.0	1.5	0.23	1.0	0.14	0.41	0.24	0.13	----	0.23
June 26	42.0	0.9	0.21	0.9	0.19	0.26	0.25	0.13	0.14	----
June 30	38.0	0.7	0.25	0.9	0.21	0.30	0.25	0.13	0.13	0.22
July 1	27.8	1.3	0.33	1.7	0.33	0.44	0.42	0.16	----	----
July 1	27.8	1.3	0.33	1.9	0.25	0.44	0.37	----	----	0.35
July 1	28.0	1.3	0.33	0.5	0.42	0.44	0.50	----	0.19	----
July 2	11.6	0.0	0.84	0.3	0.73	0.83	0.75	0.61	----	0.68
July 6	45.0	0.6	0.25	1.0	0.25	0.34	0.33	0.16	----	----
July 6	45.0	0.6	0.25	0.2	0.29	0.34	0.32	----	----	0.28
July 6	45.0	0.6	0.25	0.7	0.25	0.34	0.30	----	0.20	----
July 10	21.0	1.0	0.60	0.8	0.51	0.70	0.76	0.28	----	----
July 10	21.0	1.0	0.60	0.3	0.62	0.70	0.73	----	----	0.48
July 10	21.0	1.0	0.60	1.0	0.36	0.70	0.45	----	0.26	----
July 23	31.0	0.9	0.19	0.5	0.19	0.23	0.34	0.17	----	0.15
July 24	17.0	2.0	0.53	1.7	0.42	1.05	0.78	0.22	0.40	0.29
Nov. 6	20.0	0.0	0.78	0.0	0.27	0.87	0.26	----	----	0.75
Nov. 7	28.0	1.3	0.18	1.4	0.18	0.33	0.24	----	0.47	0.65
Nov. 9	12.0	1.5	0.93	1.0	0.55	1.06	0.60	0.69	----	0.73
Nov. 10	16.5	0.5	0.58	0.2	0.51	0.62	0.55	0.67	0.57	0.66
Nov. 10	16.5	0.5	0.58	0.2	0.51	0.62	0.55	0.47	----	----
Nov. 10	16.5	0.5	0.58	0.2	0.51	0.62	0.55	0.67	0.57	0.66
Nov. 10	16.5	0.5	0.58	0.2	0.51	0.62	0.55	0.47	----	----

APPENDIX IV

PLOTS OF COMPOSITE VEHICLE PERFORMANCE VERSUS RCI_1

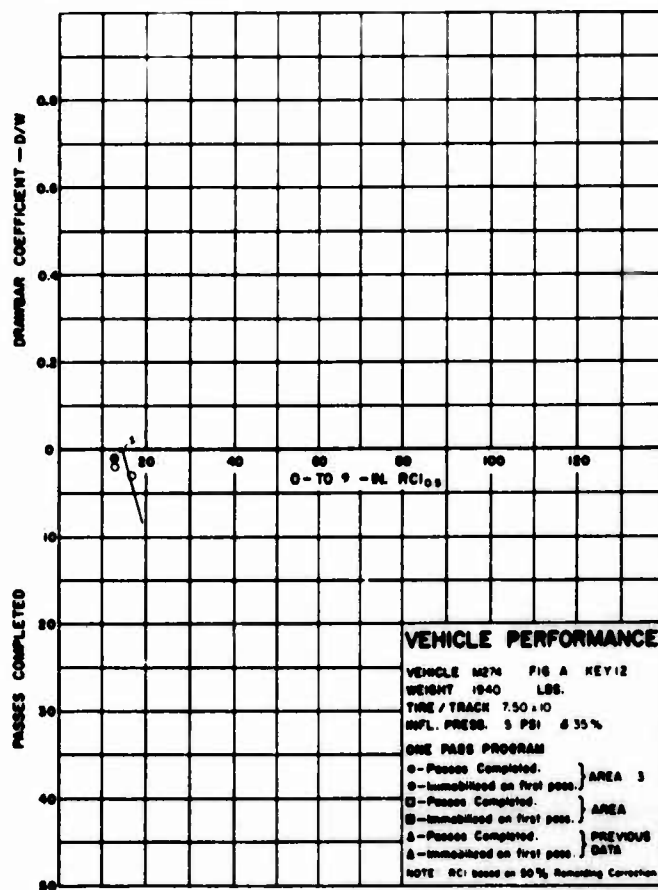
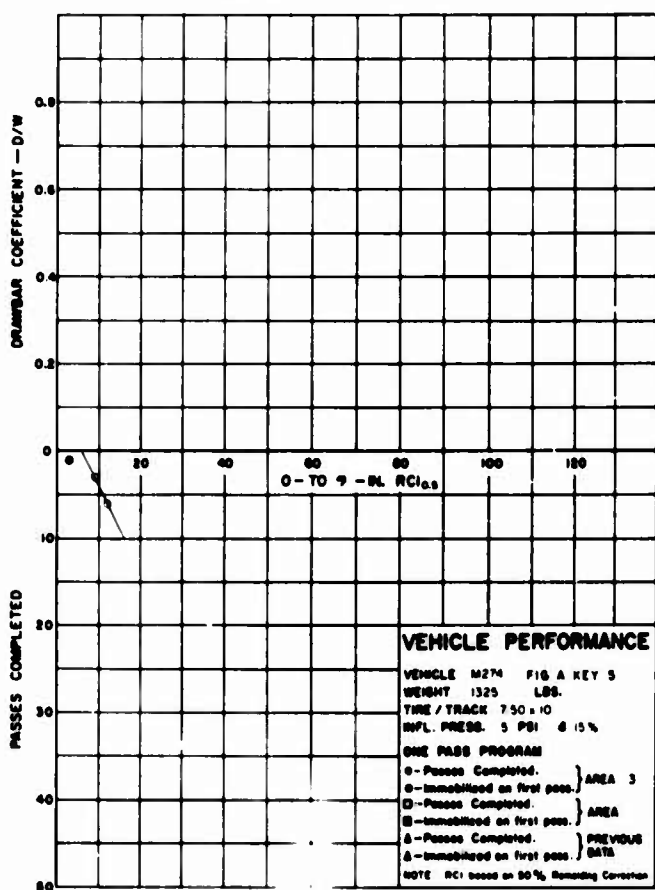
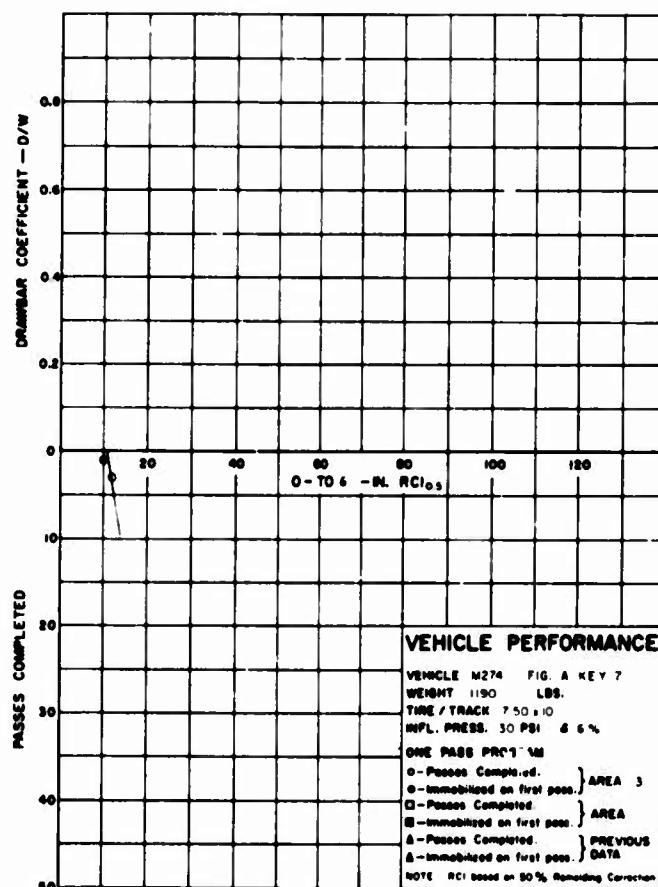
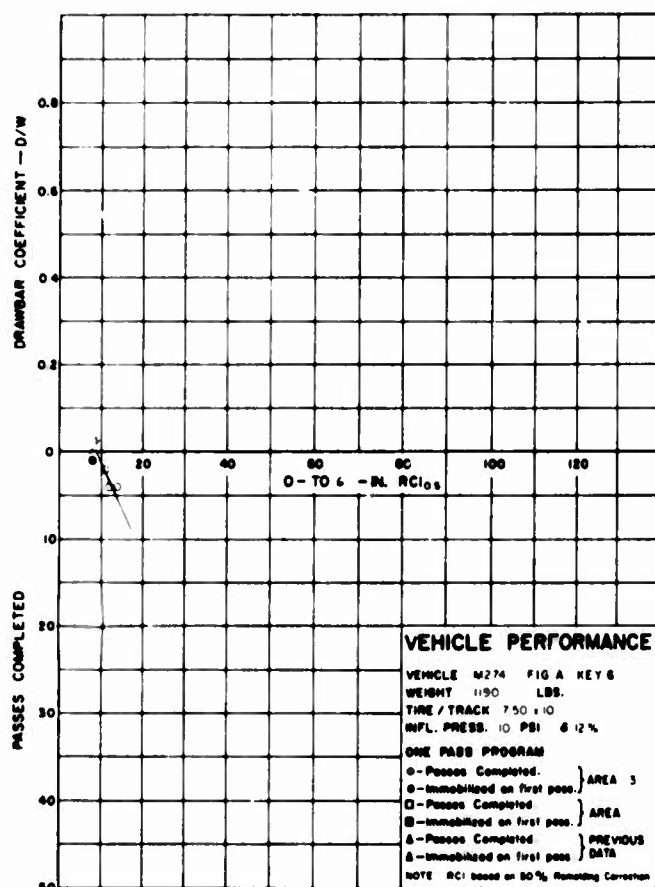


Fig. IV-1

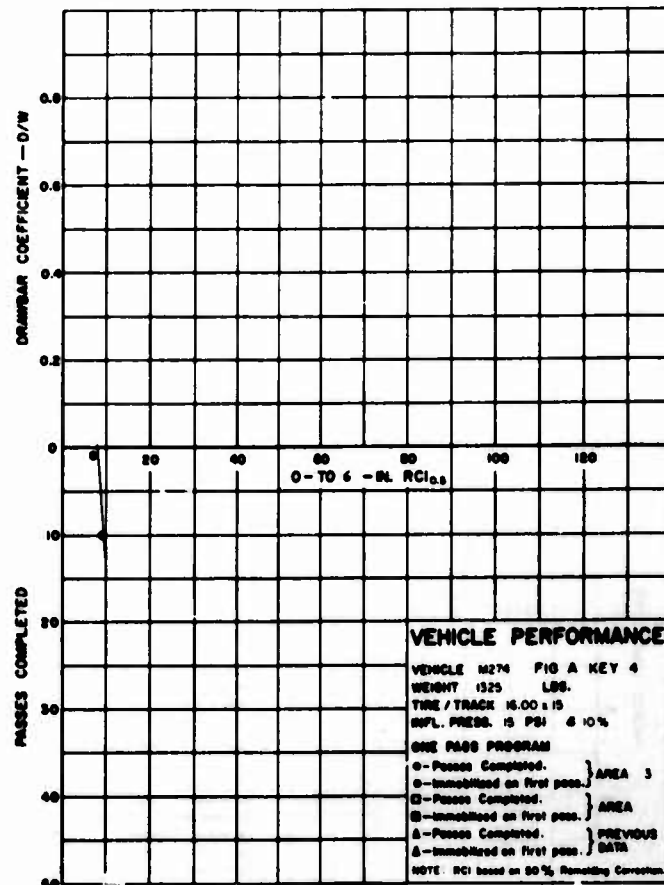
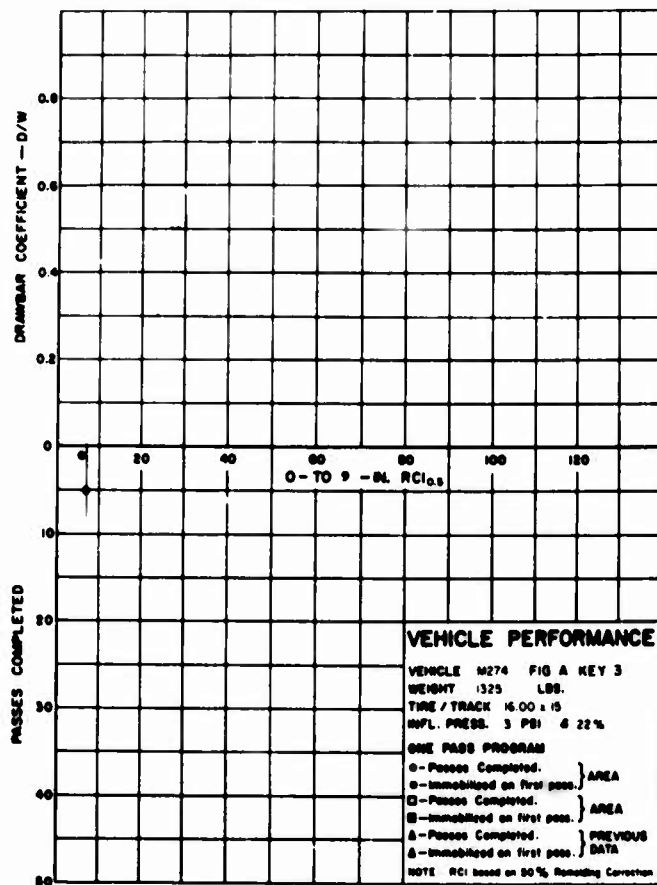
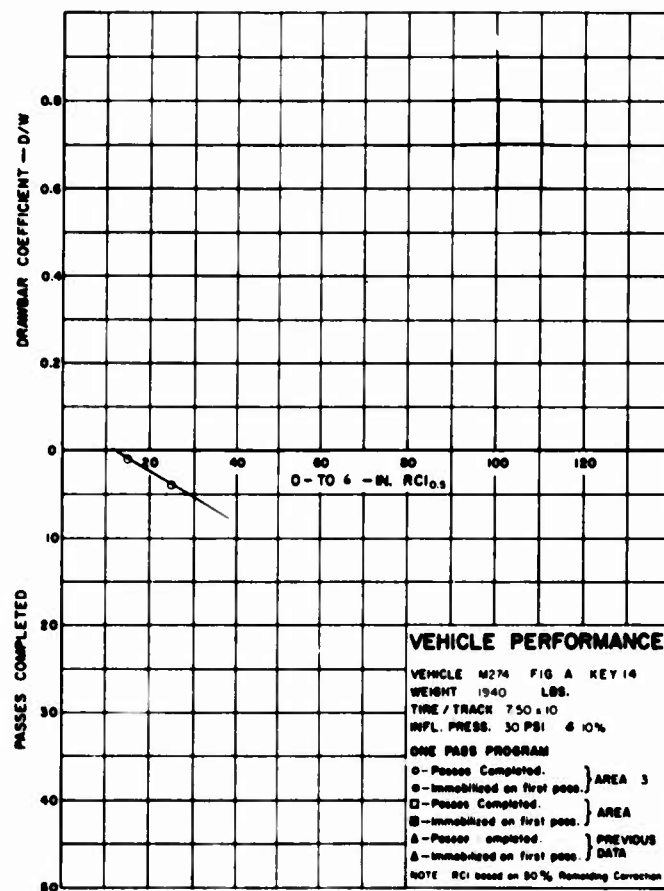
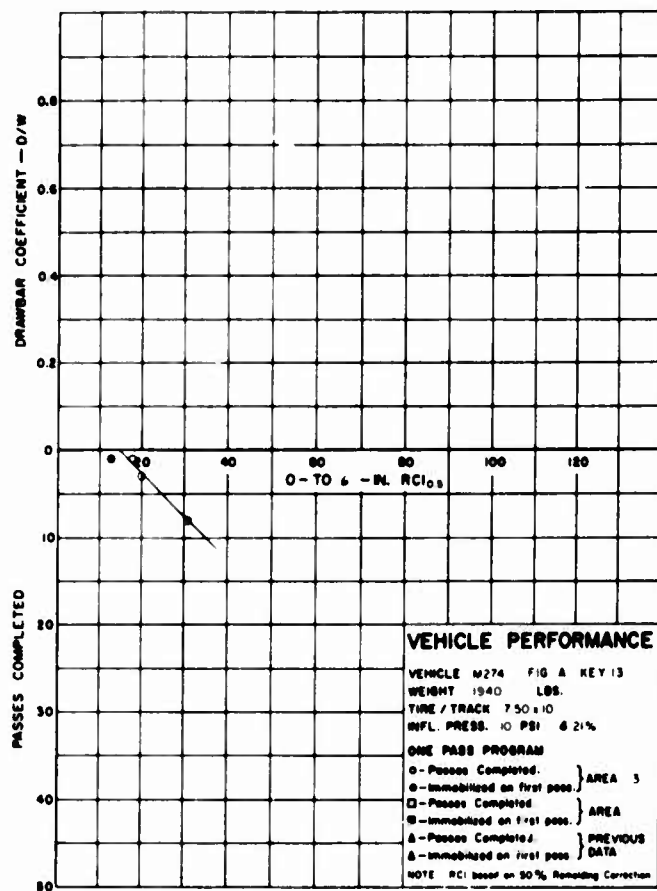


Fig. IV-2

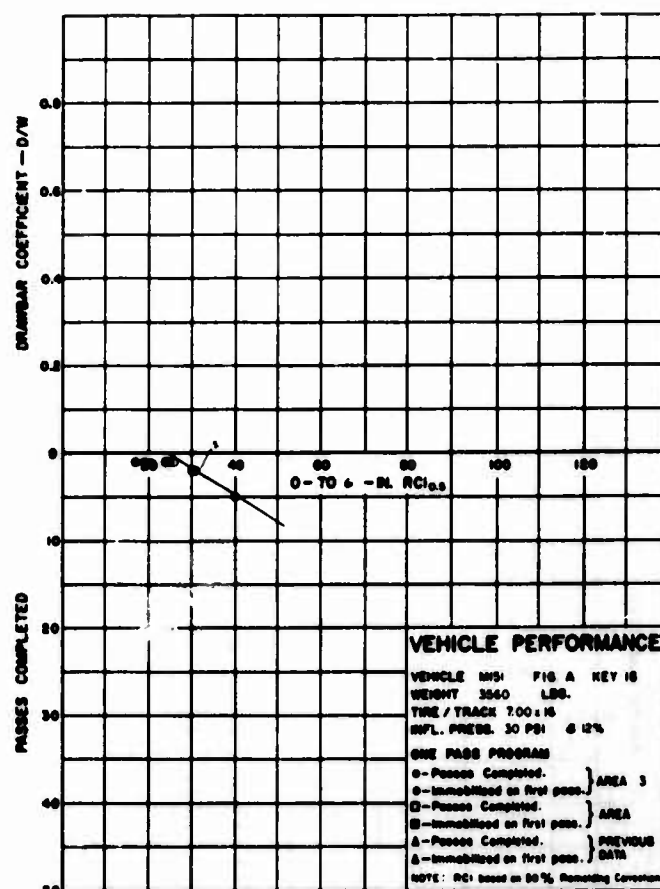
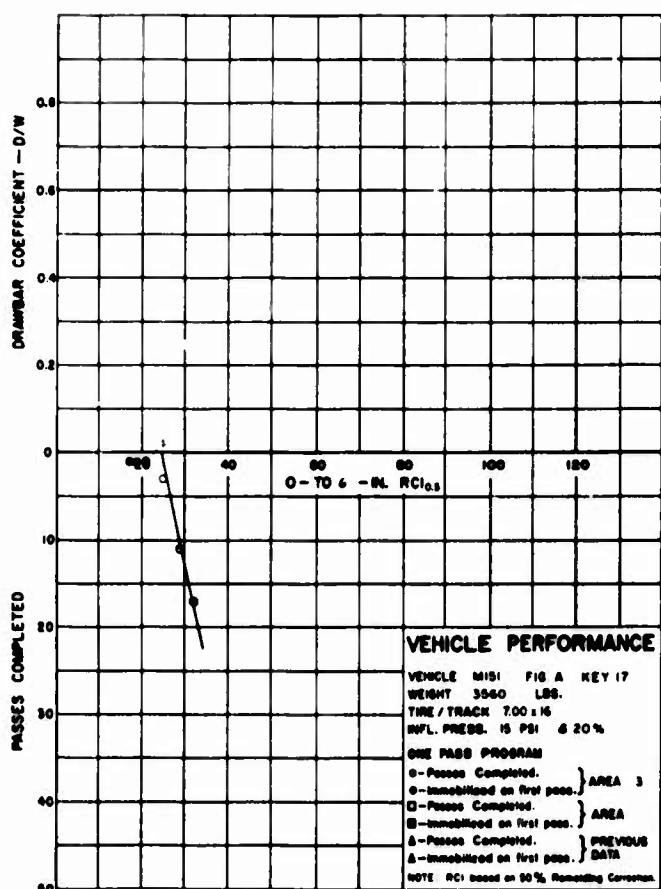
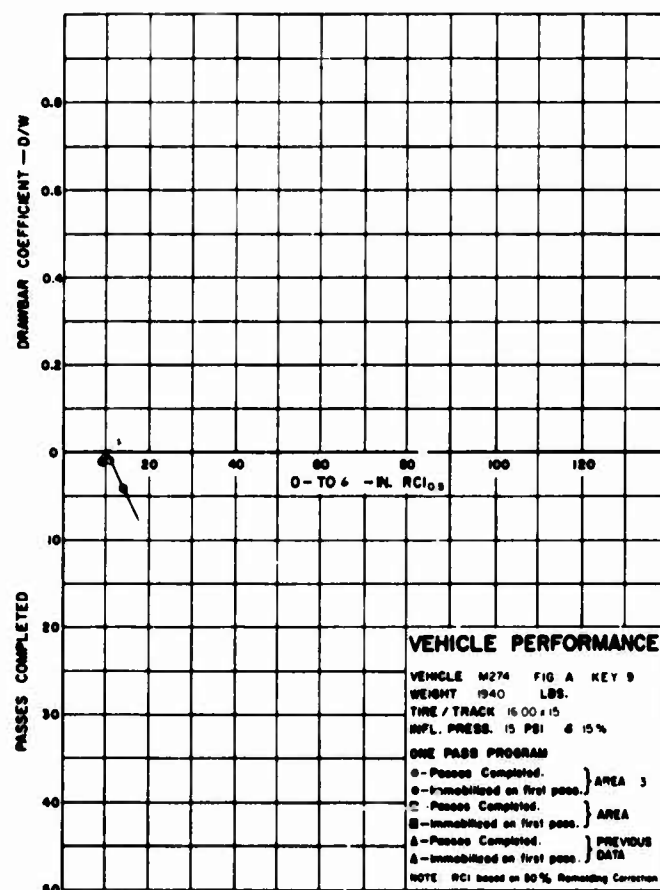
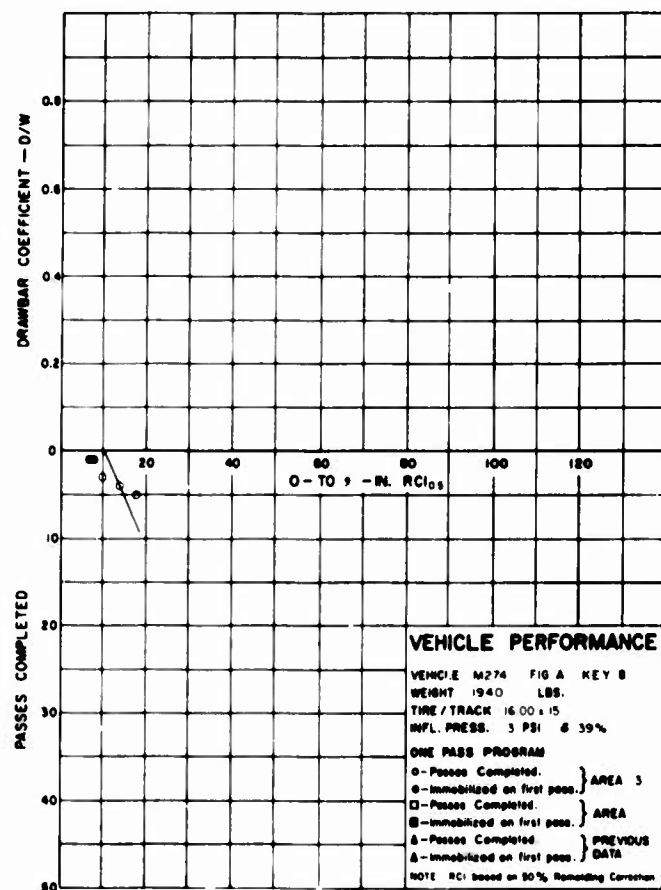


Fig. IV-3

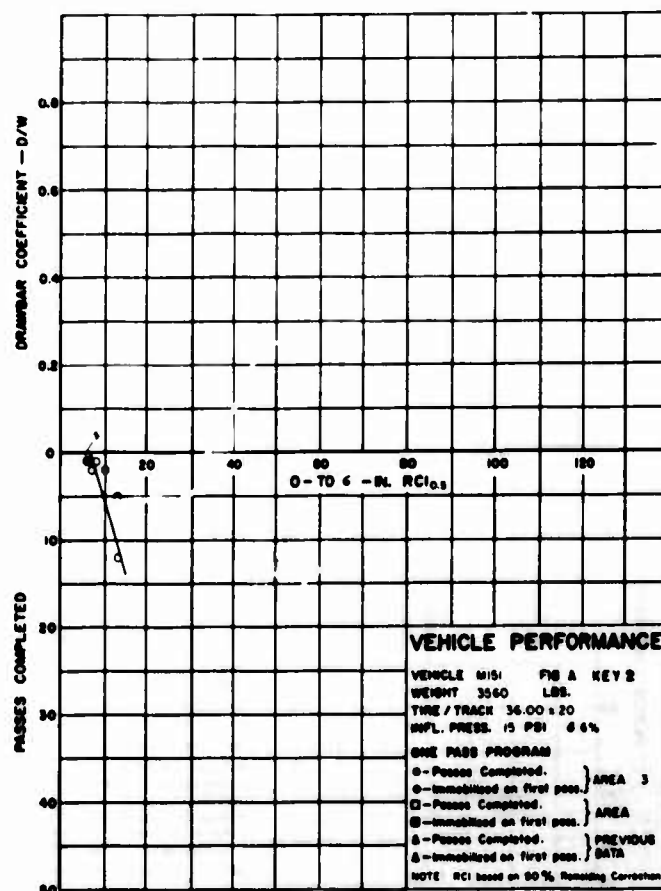
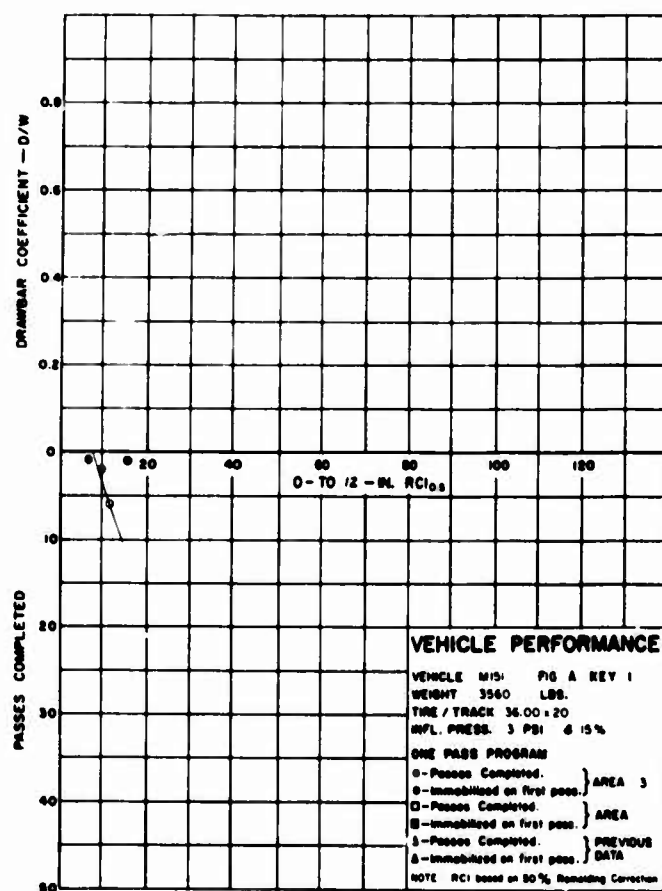
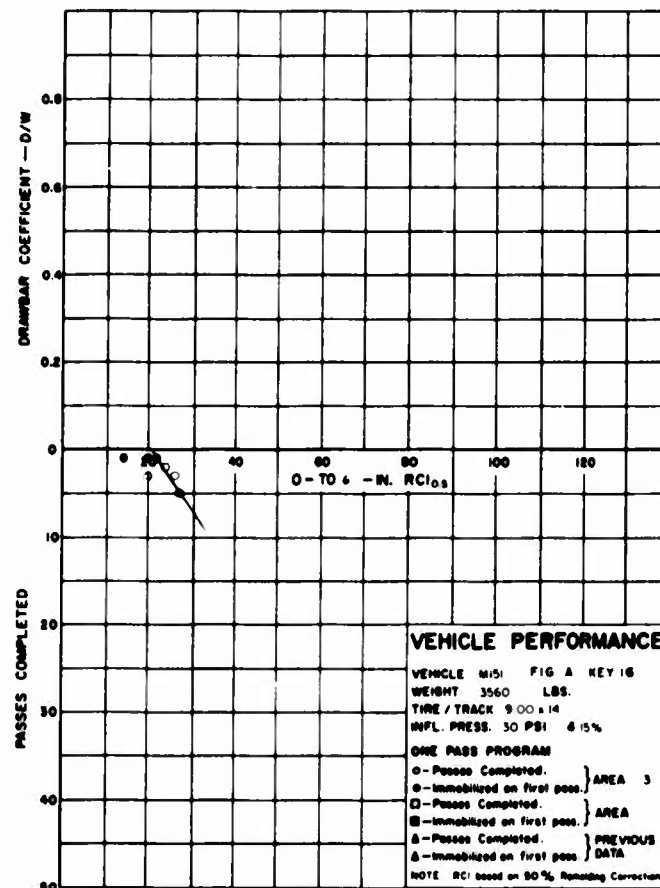
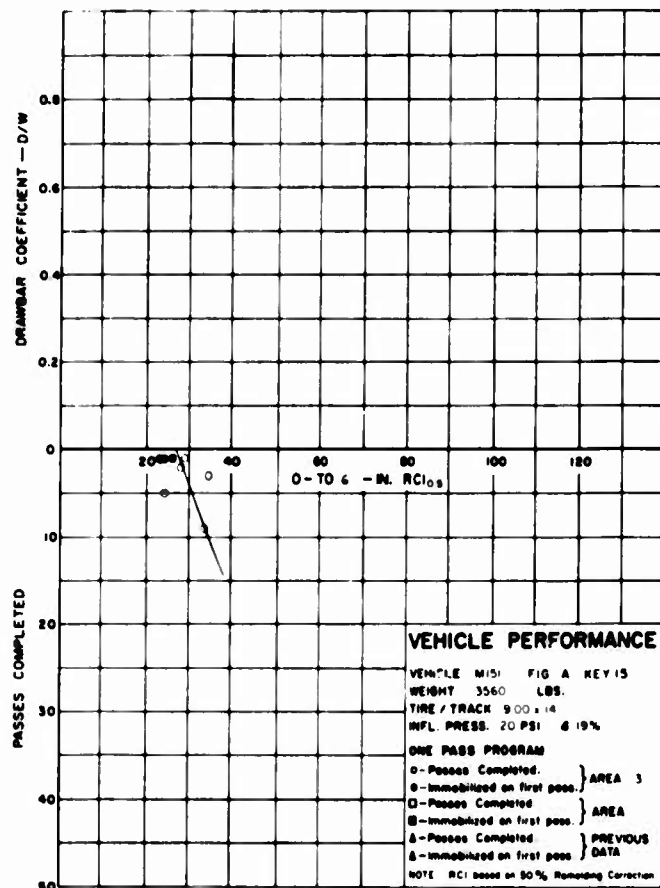


Fig. IV-4

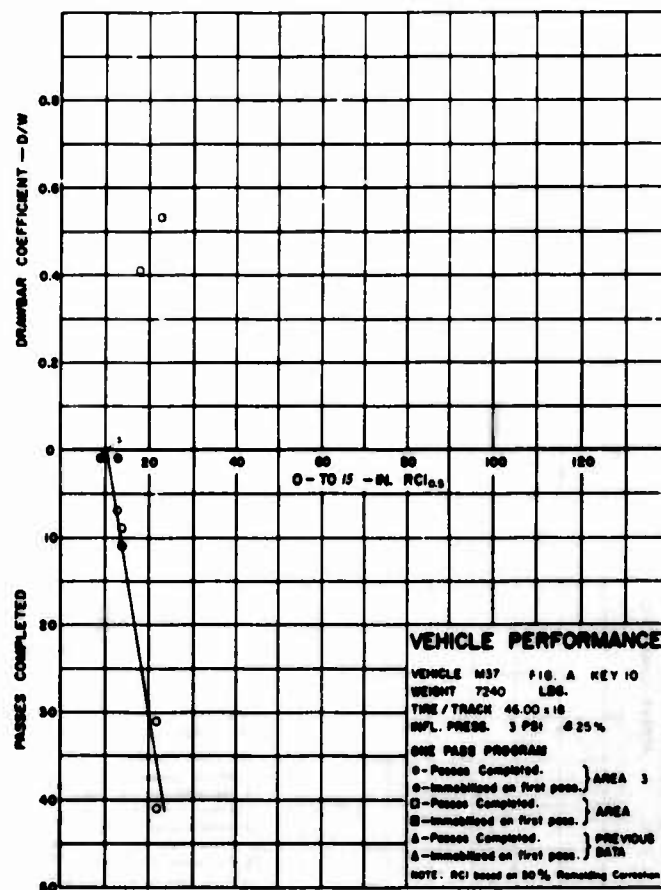
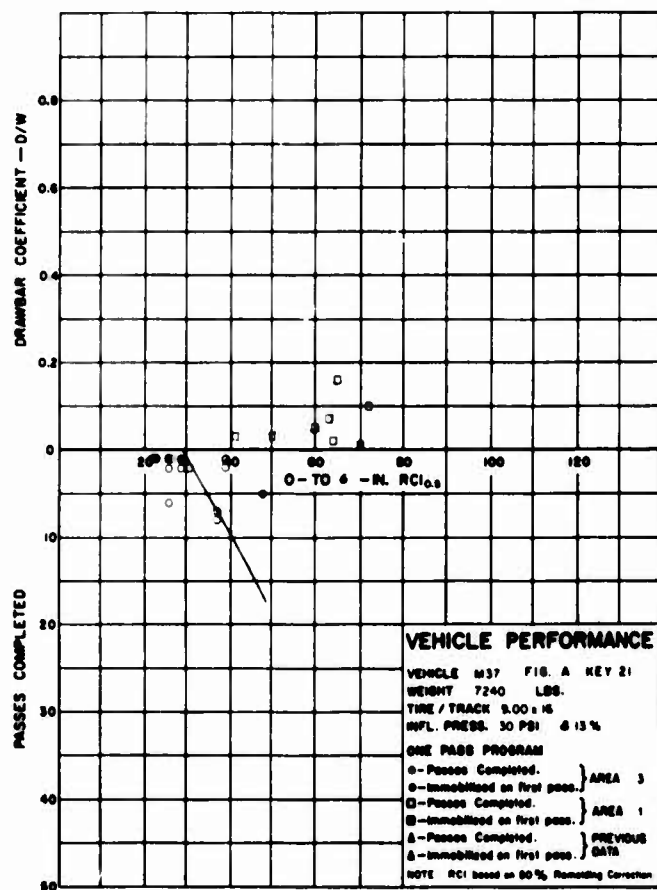
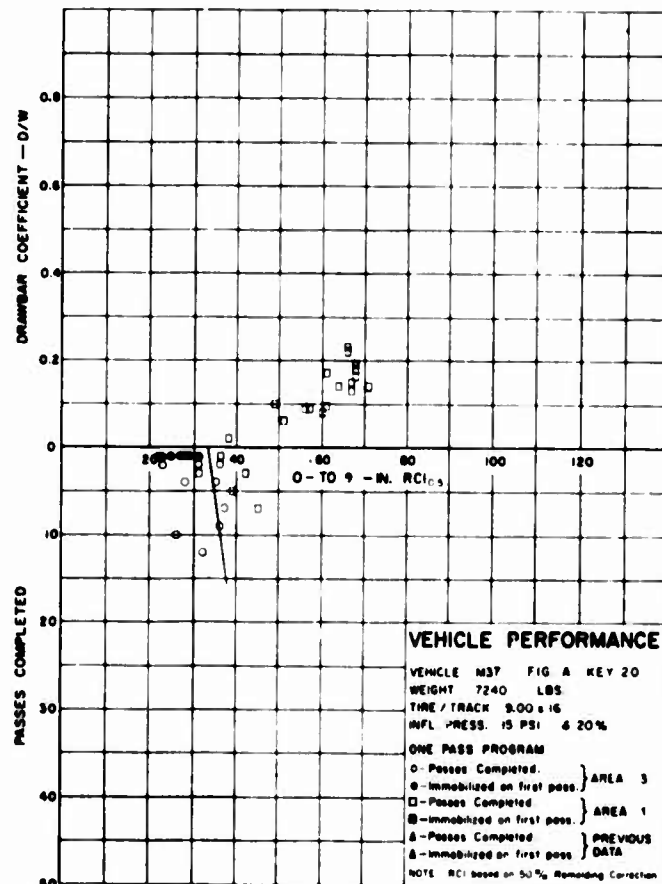
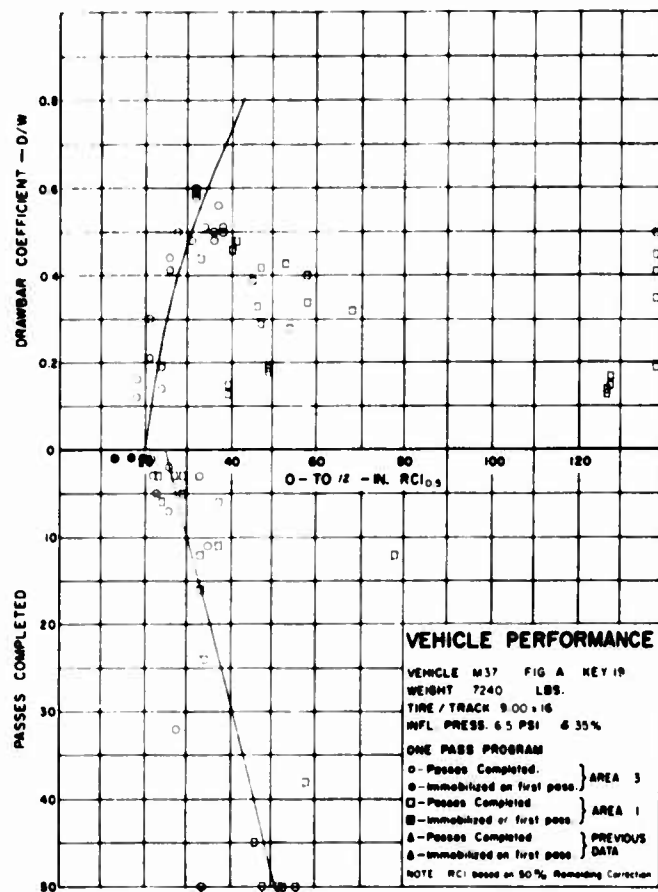


Fig. IV-5

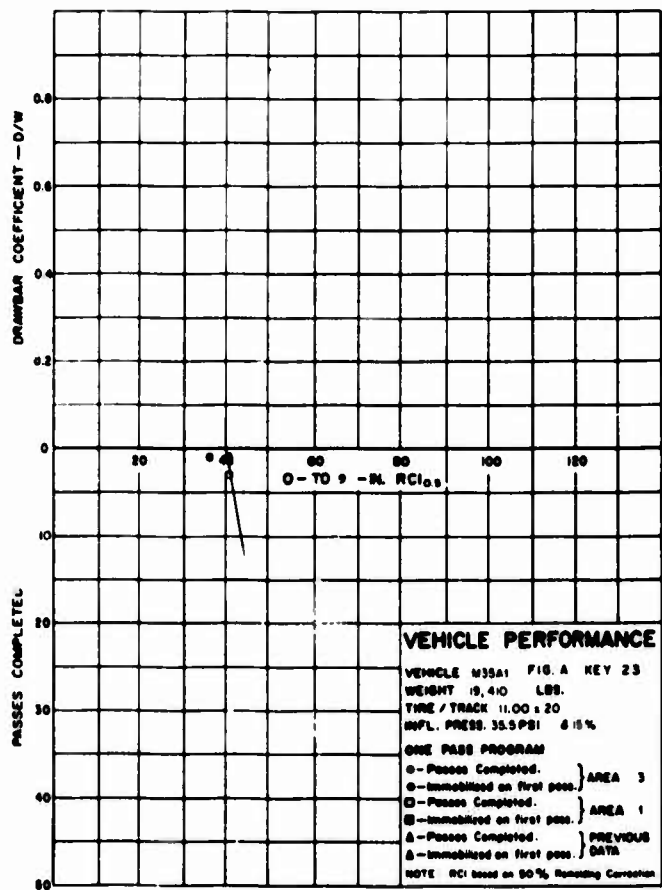
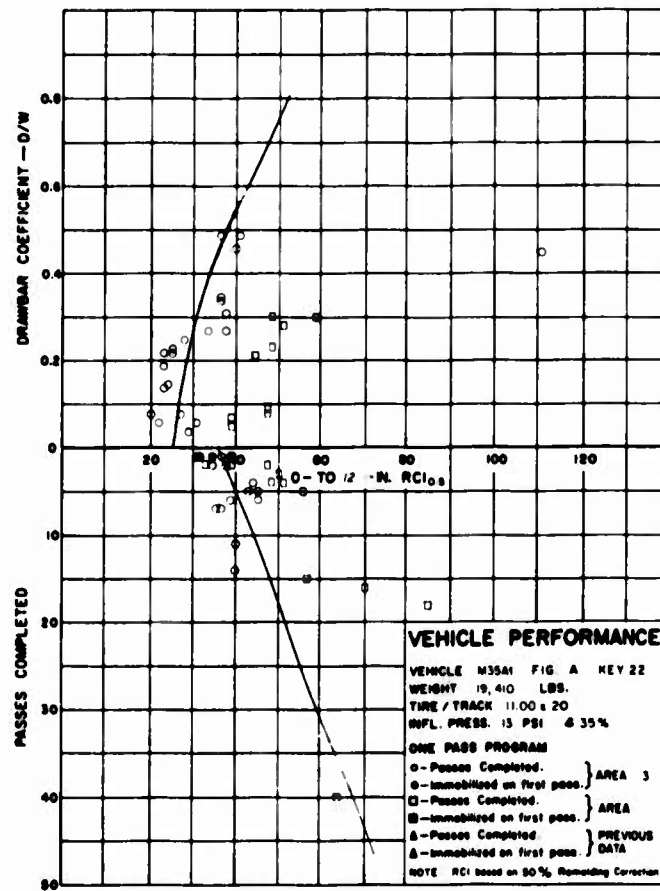
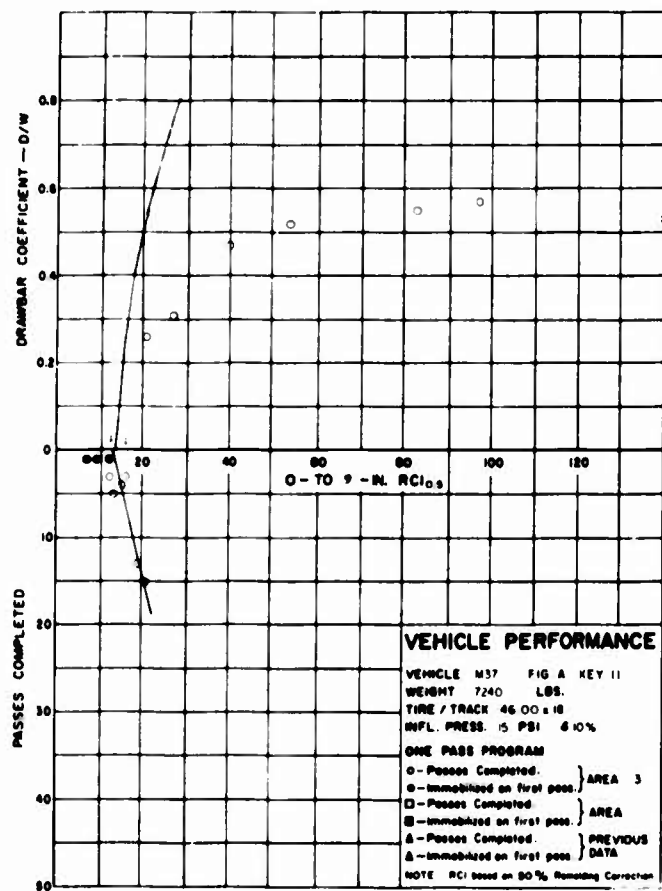


Fig. IV-4

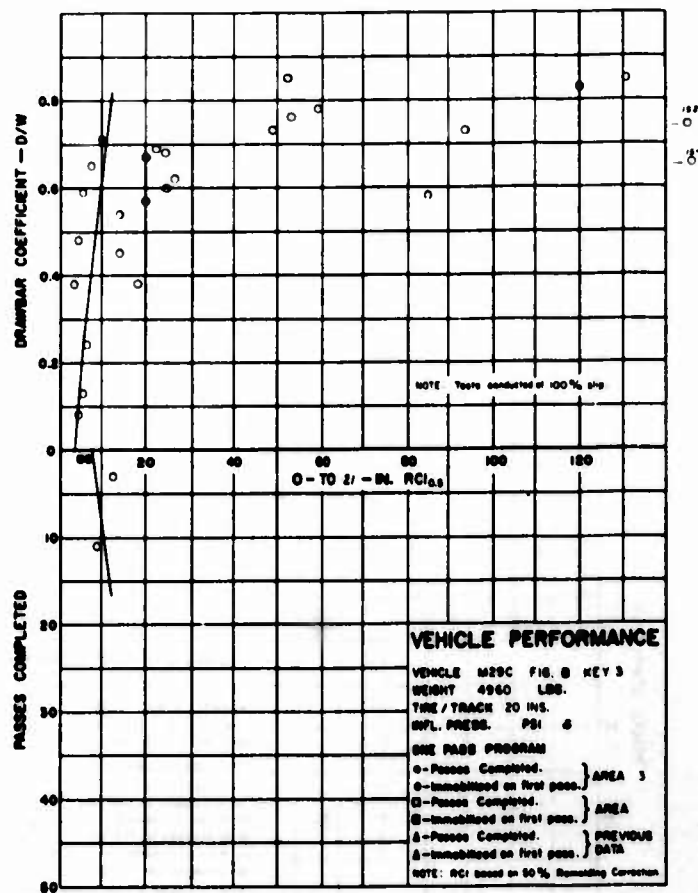
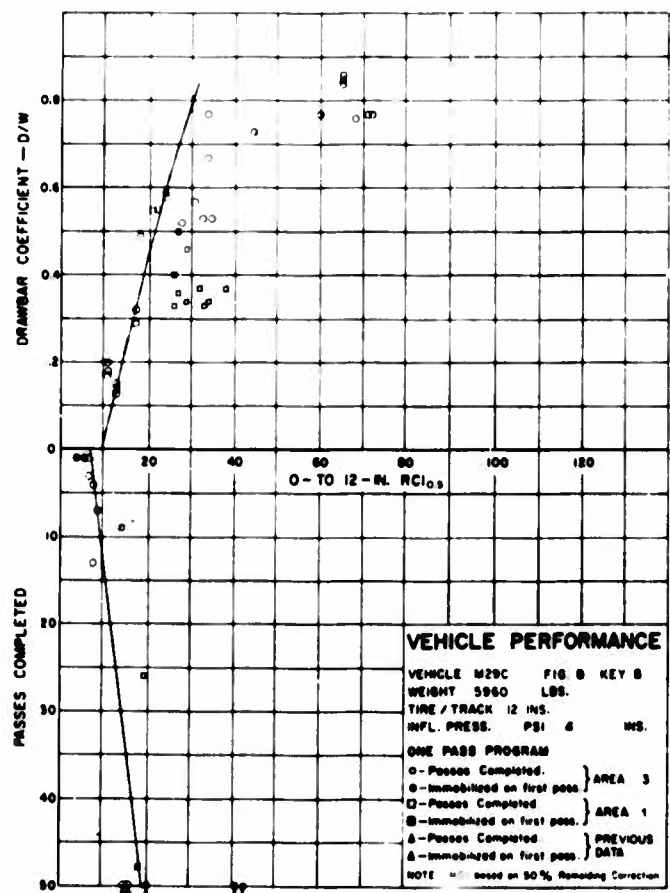
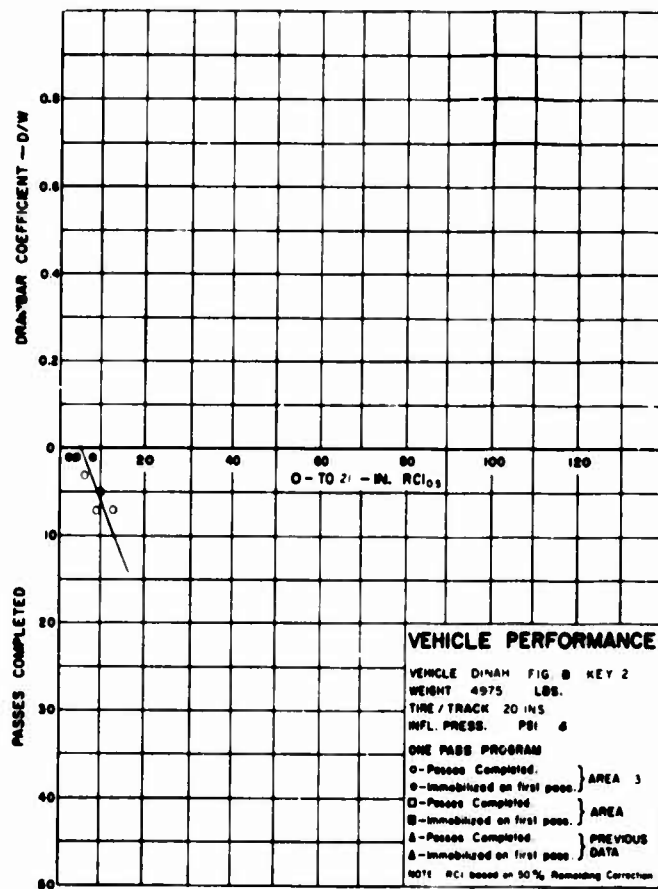
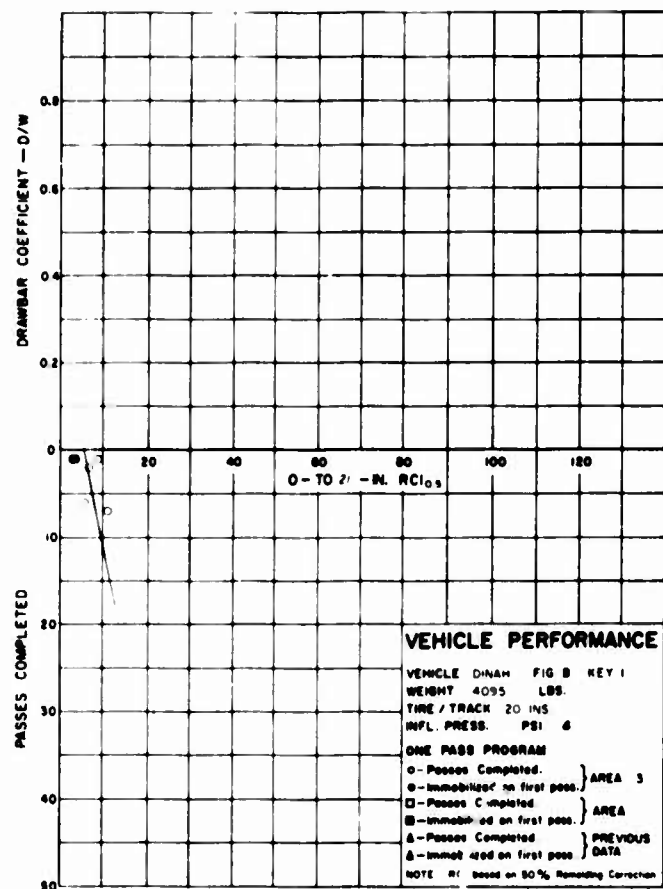


Fig. IV-7

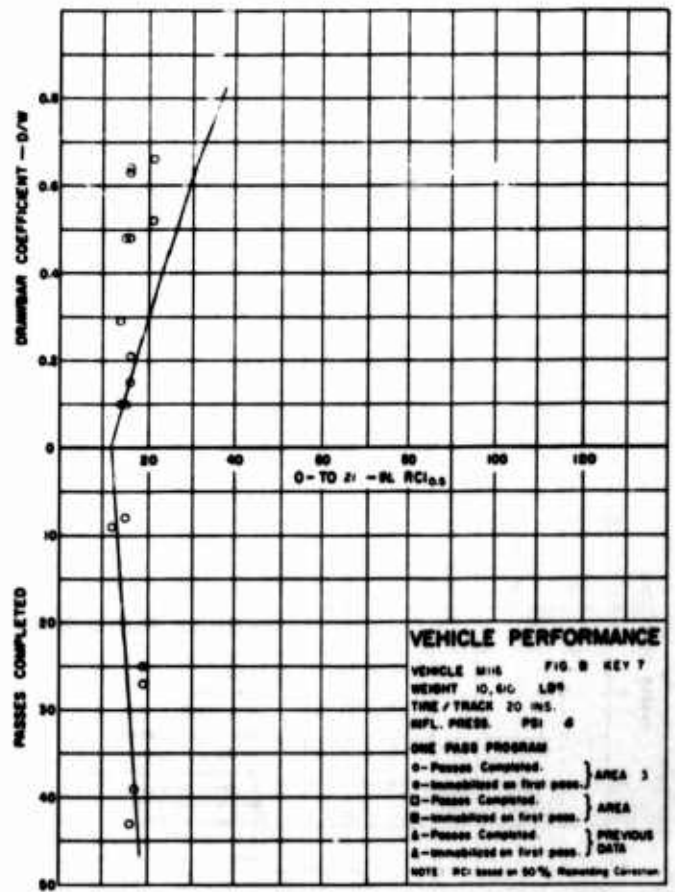
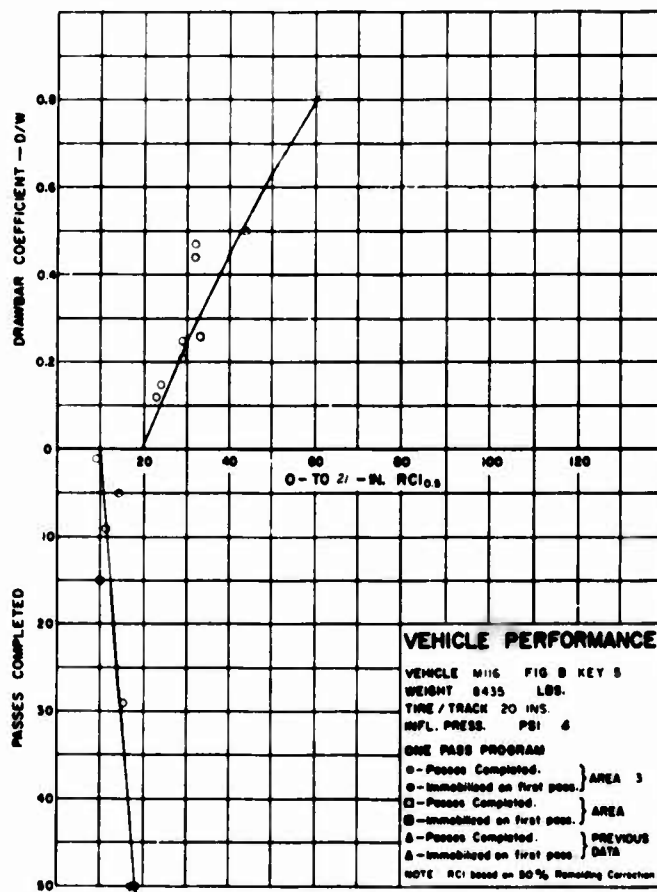
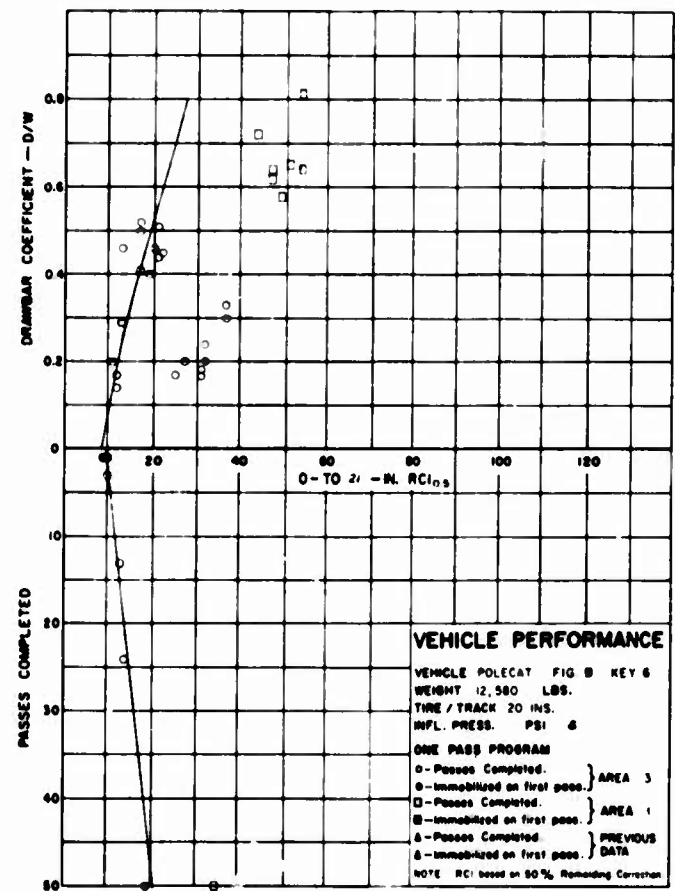
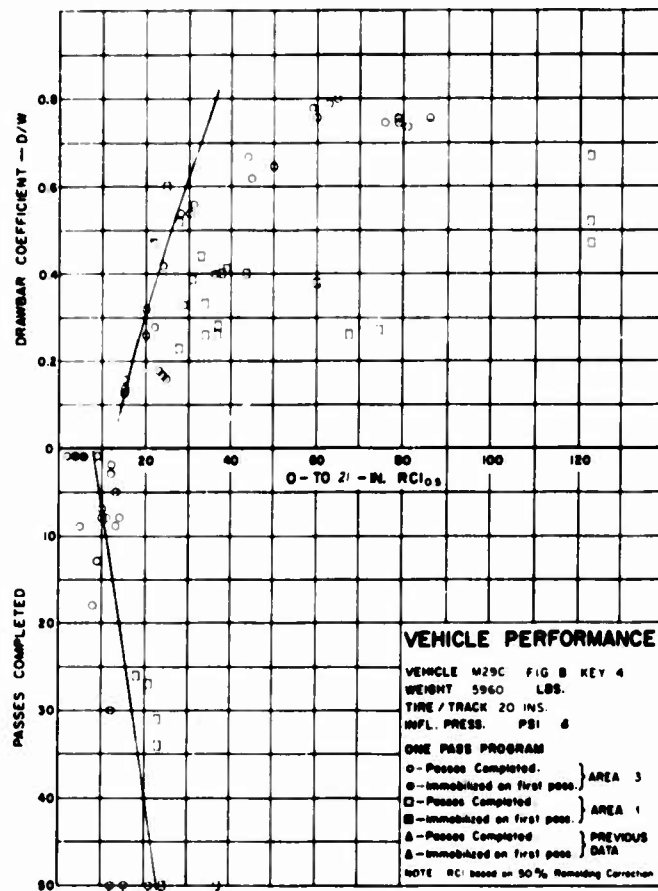


Fig. IV-6

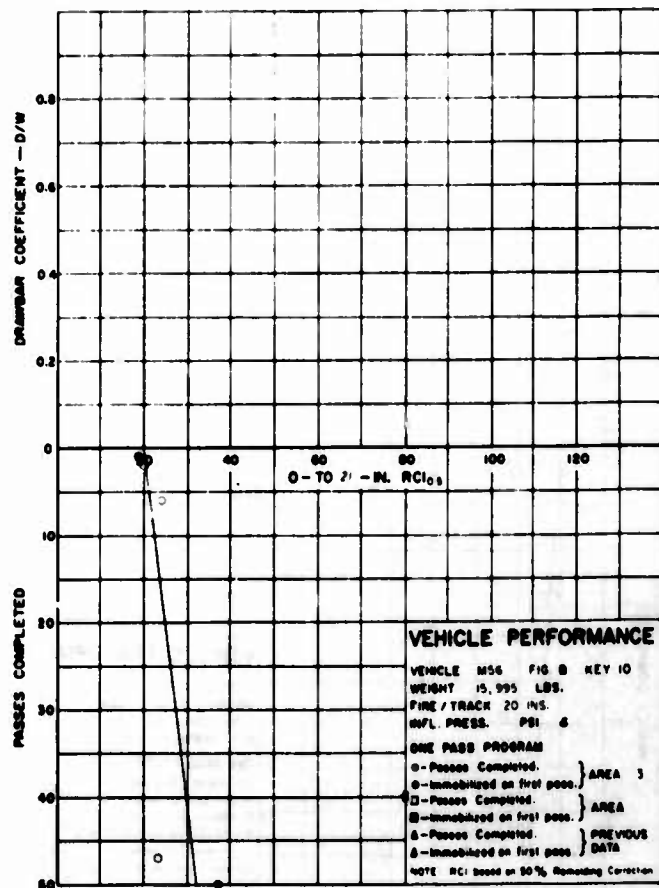
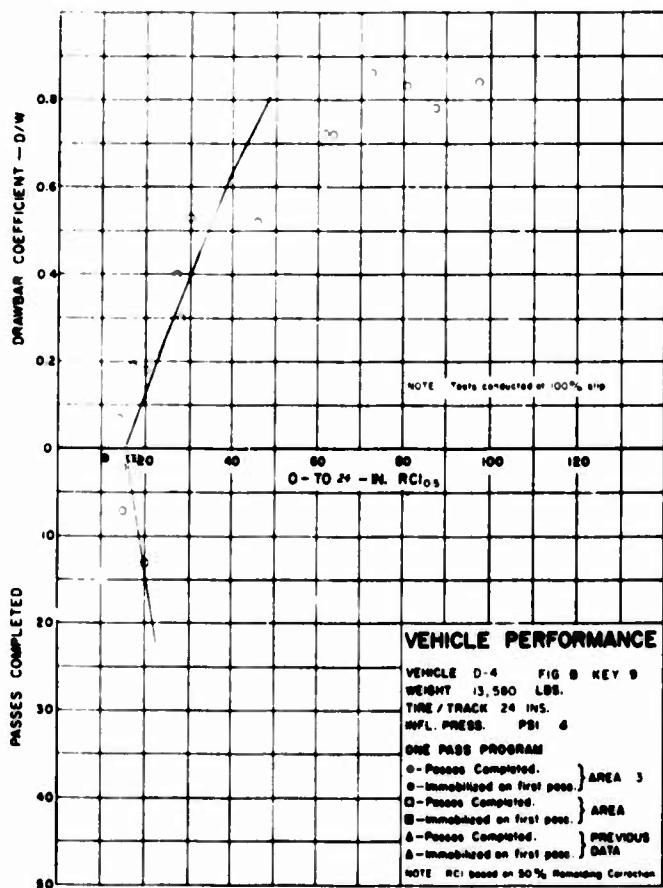
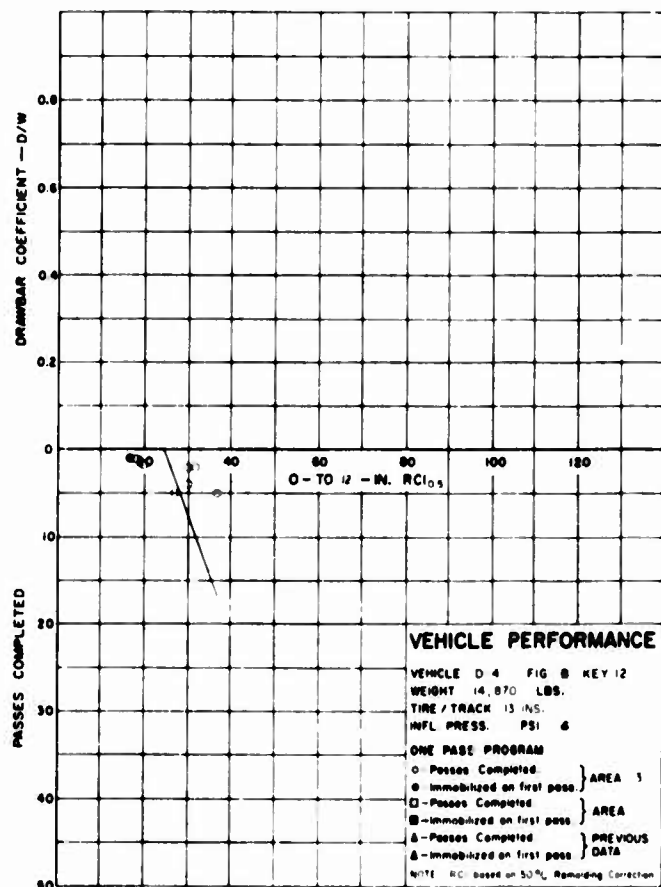
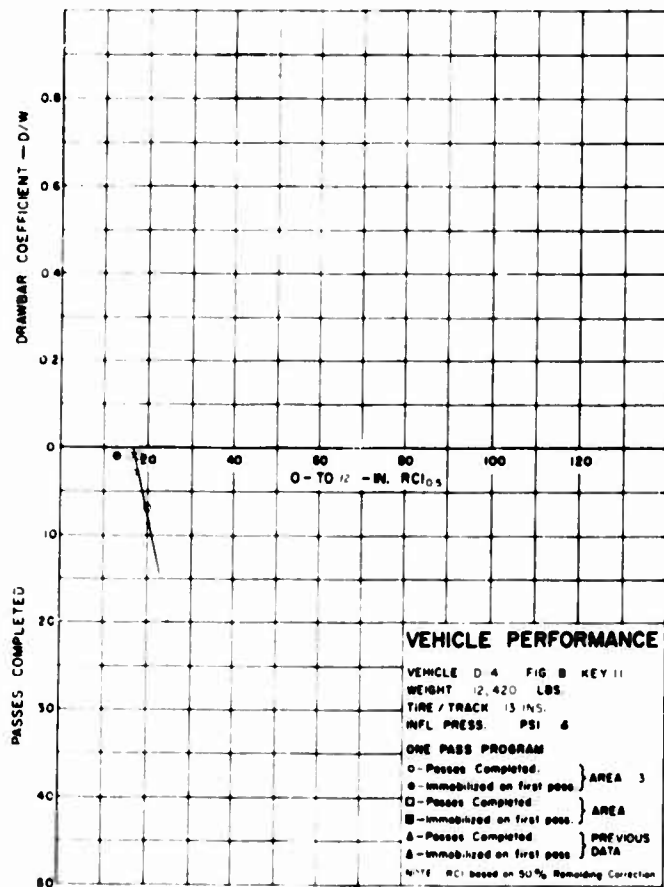


Fig. IV-9

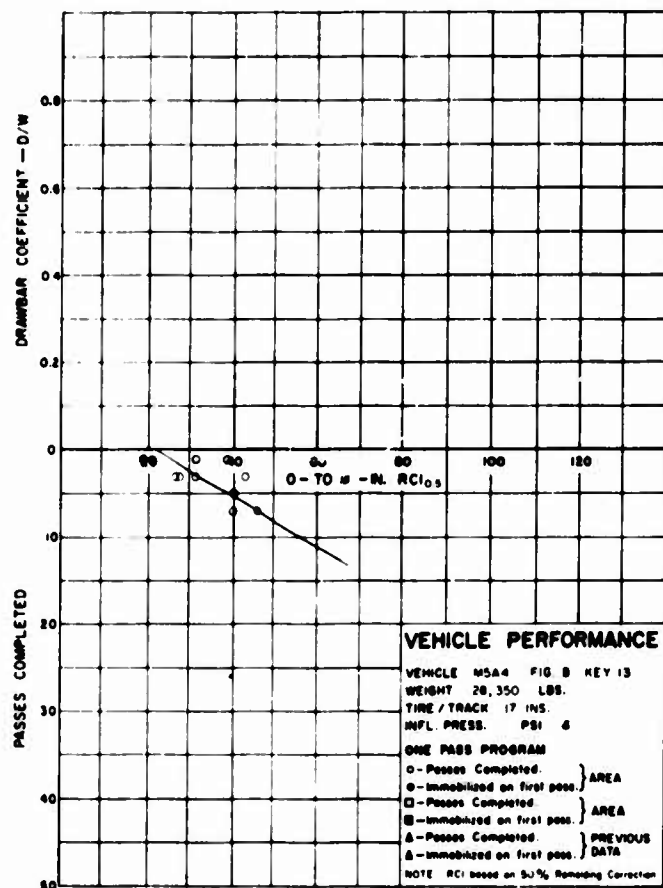


Fig. IV-10

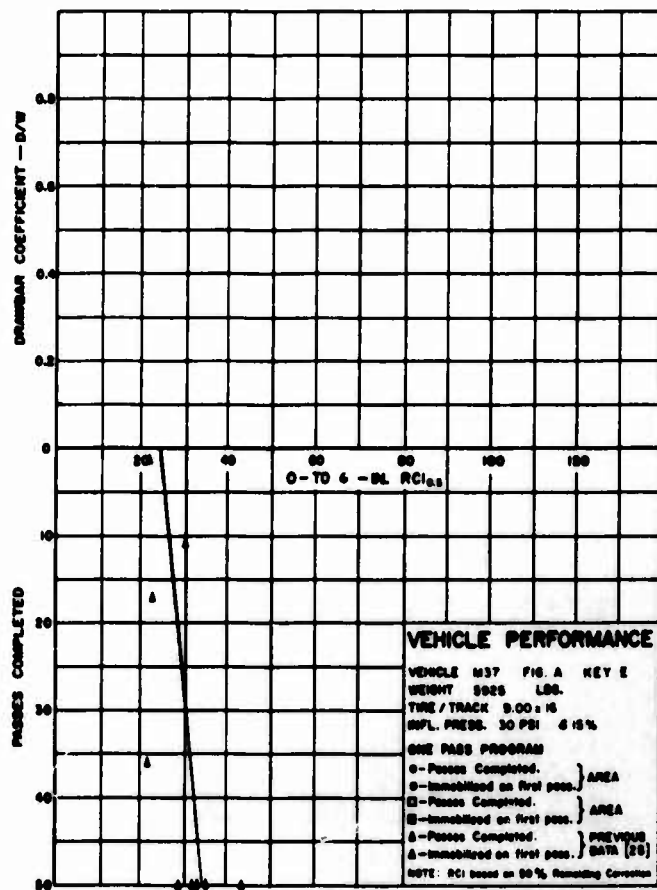
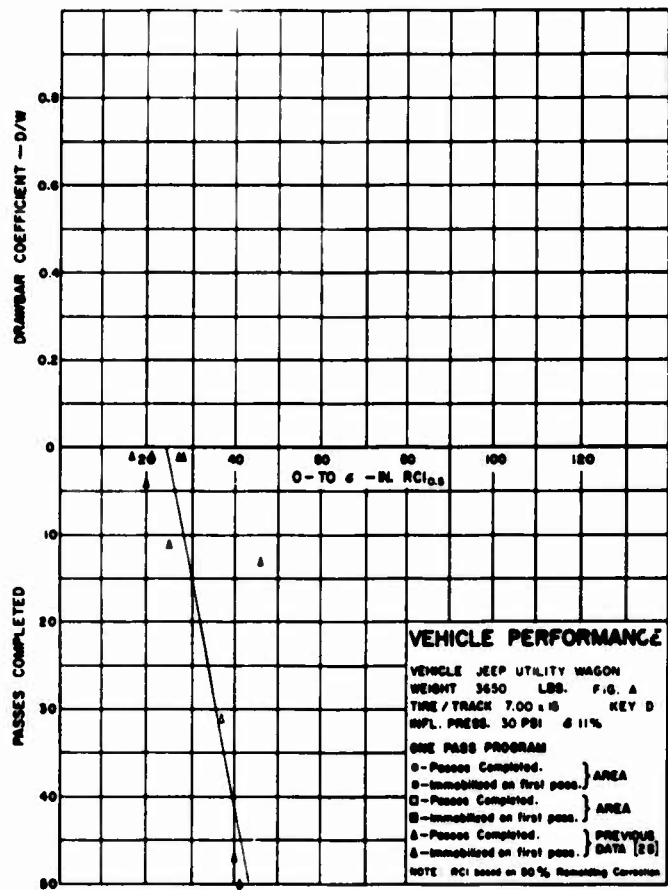
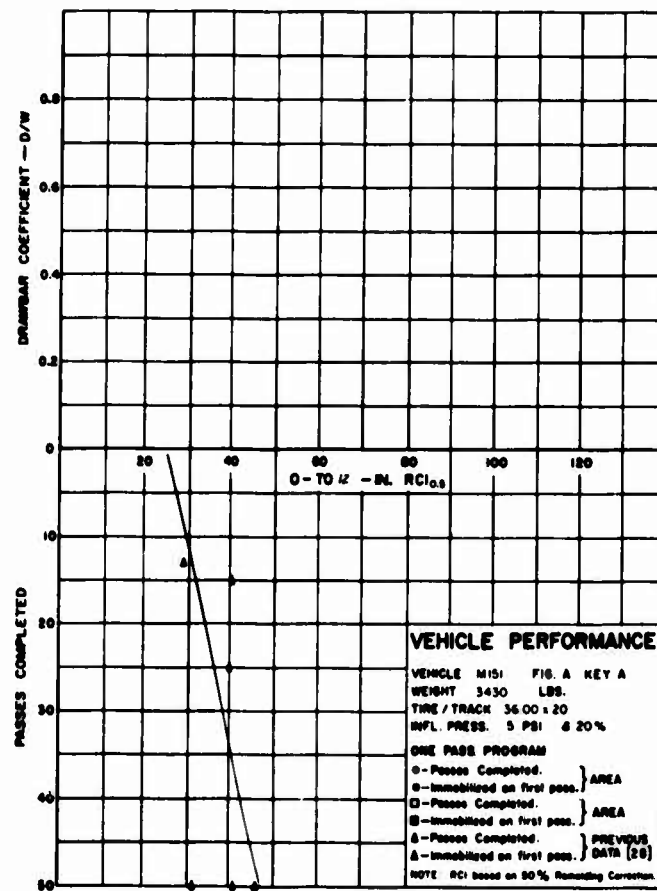
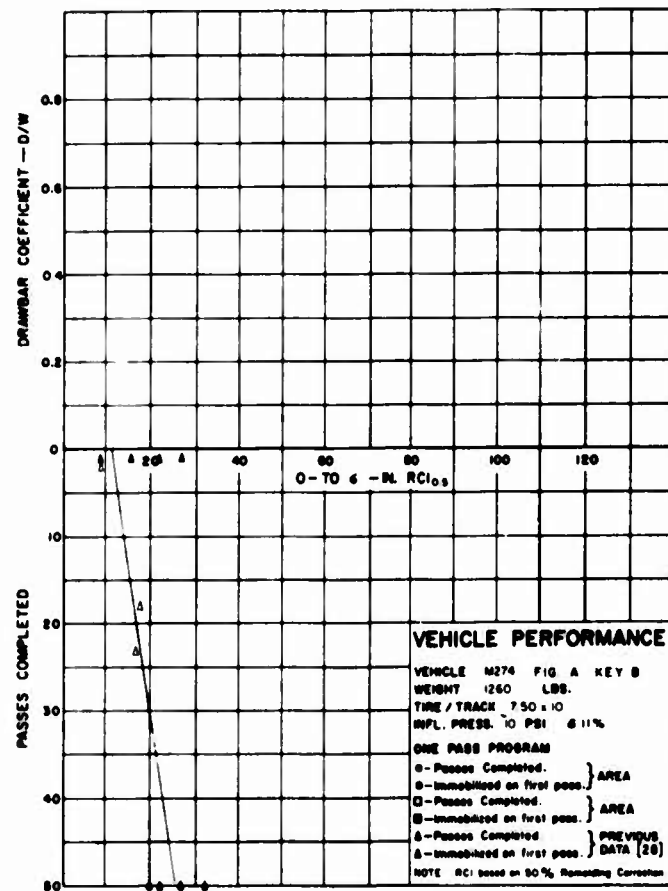


Fig. IV-11

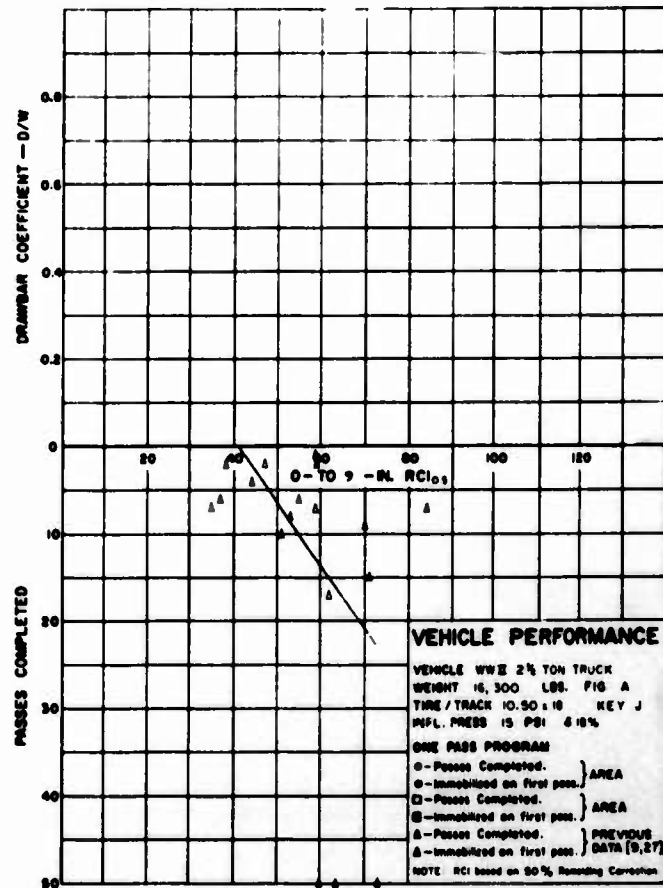
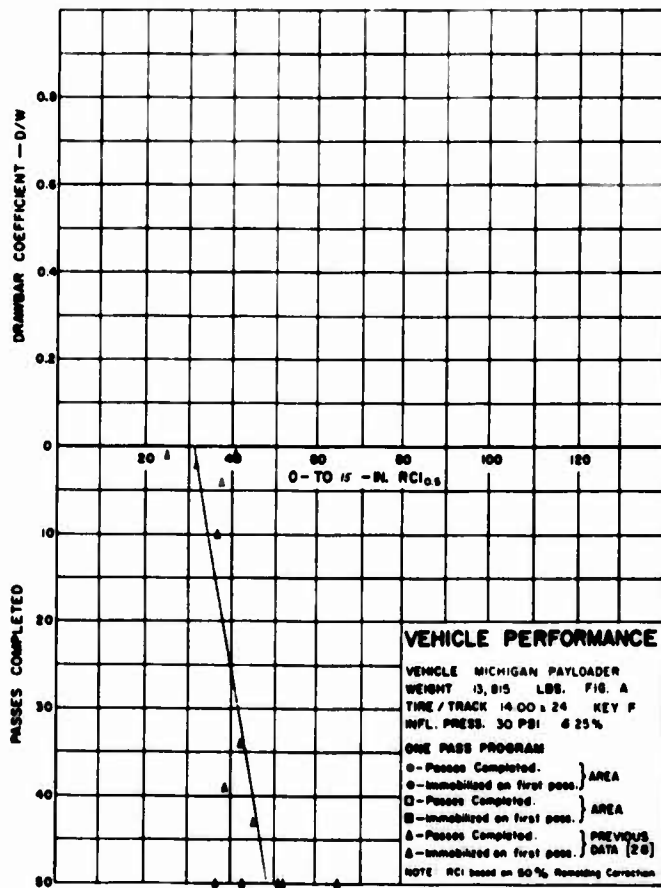
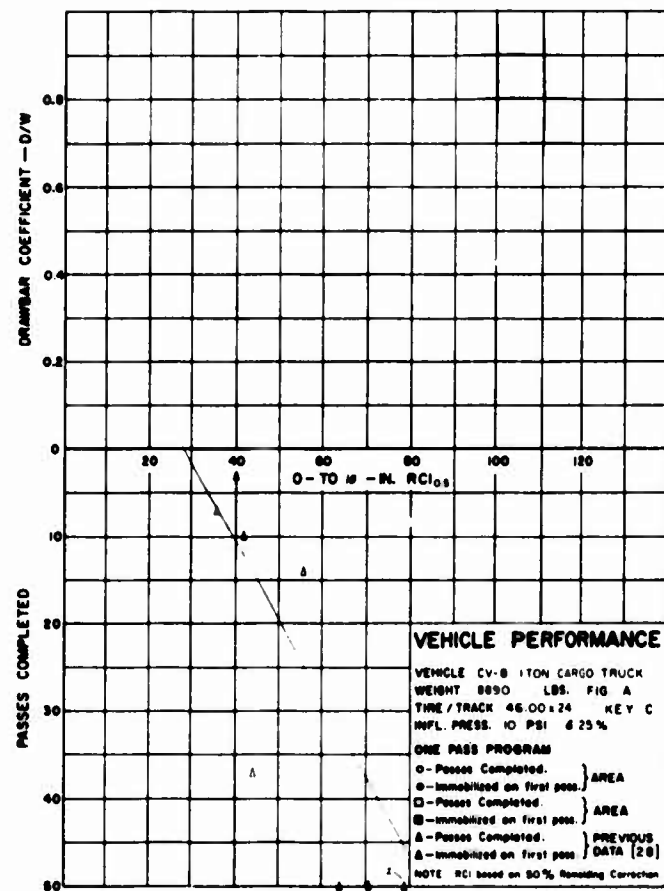
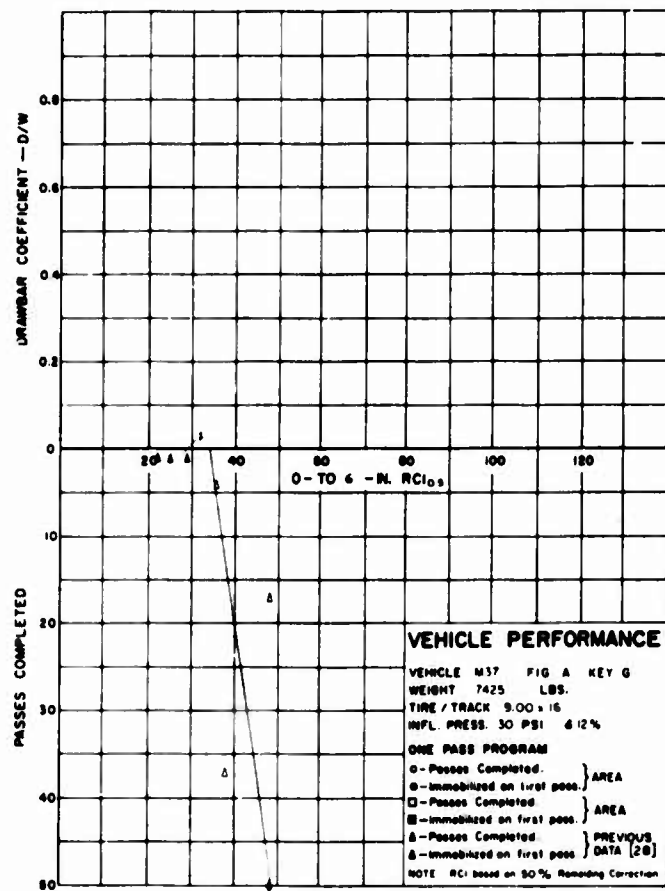


Fig. IV-12

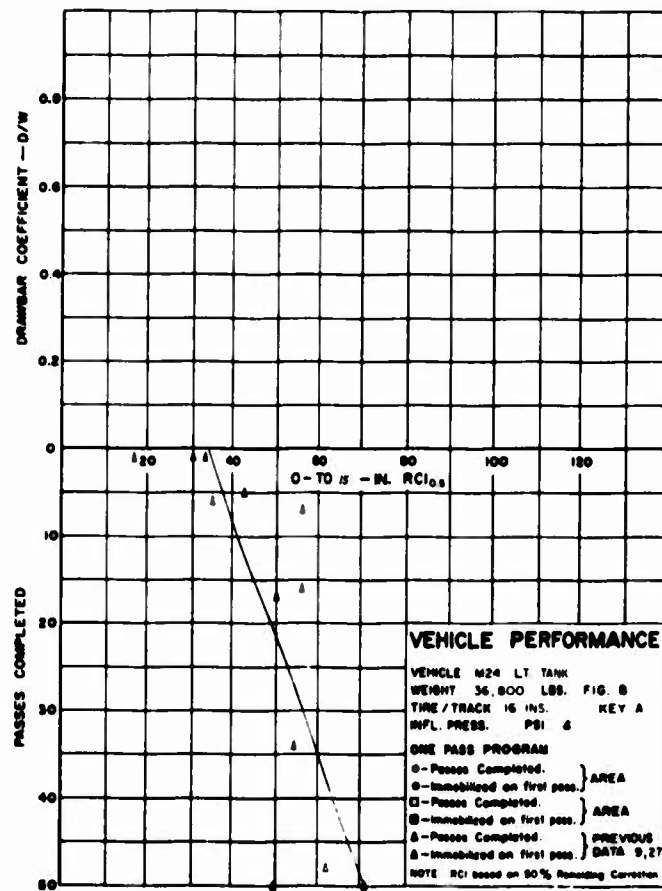
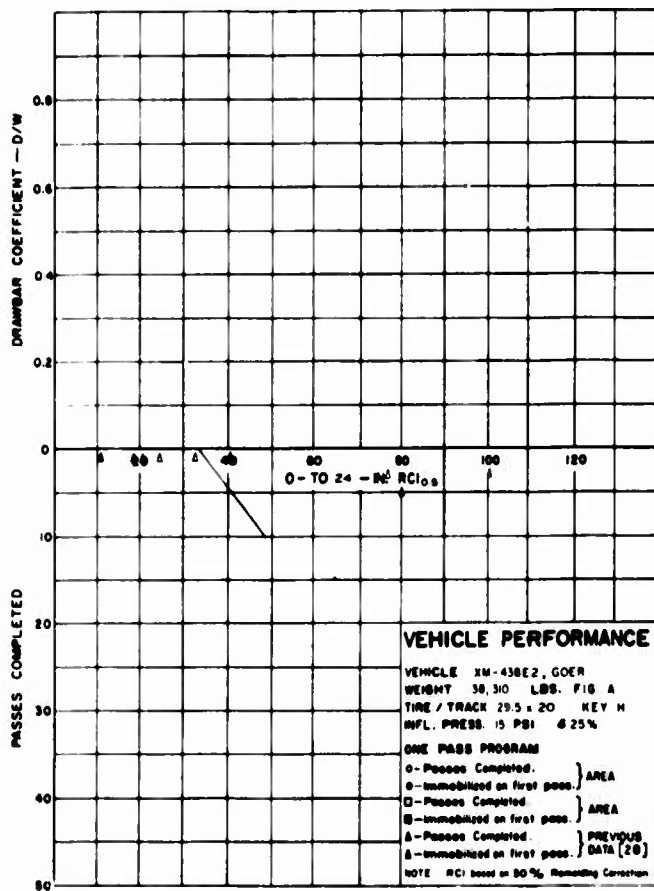


Fig. IV-13

APPENDIX V

AN APPROXIMATION FOR THE EFFECT OF SHAFT SIZE UPON CONE INDEX MEASUREMENTS

Approximately half way through the test program, it was decided by WES to modify the shaft diameter of the standard WES cone penetrometer. The instrument in use until this time had a 5/8" diameter shaft, and it was strongly suspected that shaft drag during deep penetration in weak soils was contributing significantly to the resistance to penetration being measured (at the top of the shaft), and previously presumed to be cone resistance. Accordingly, shaft diameter was reduced to 3/8". It was desired to express the results of this study in terms of measurements of the new standard instrument. In order to do so, both instruments were used side-by-side for the remainder of the program.

The results of these simultaneous tests are shown

in Figures V-1-5, in which the indications at both Lake Centennial and Grenada Lake of the instrument with the 5/8" diameter shaft are plotted as functions of measurements with the new standard instrument for the 0-6", 3-9", 6-12", 9-15", and 12-18" layers, respectively. While there is considerable scatter, the following approximate relationships, plotted in the appropriate figures, appear reasonable:

for layer 0-6"	$CI_{3/8} = CI_{5/8} - 0$
3-9"	$CI_{3/8} = CI_{5/8} - 3$
6-12"	$CI_{3/8} = CI_{5/8} - 6$
9-15"	$CI_{3/8} = CI_{5/8} - 9$
12-18"	$CI_{3/8} = CI_{5/8} - 12$

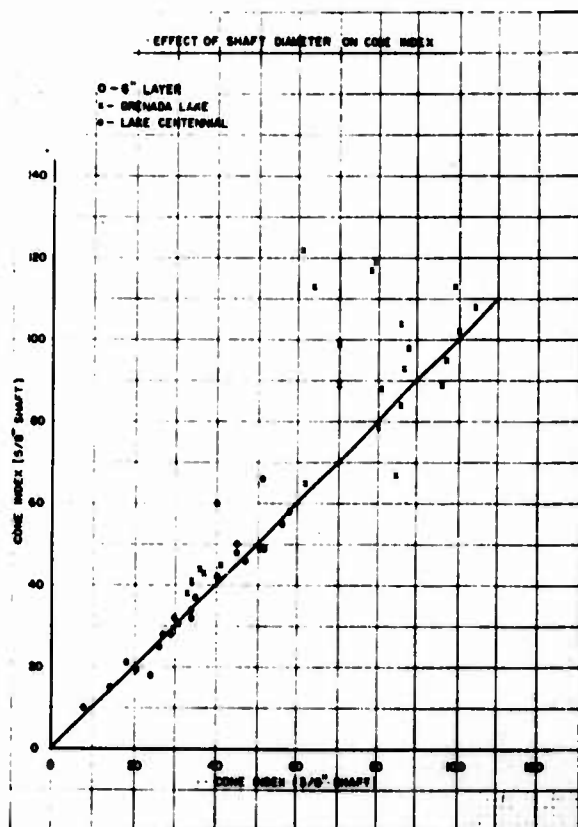


Fig. V-1

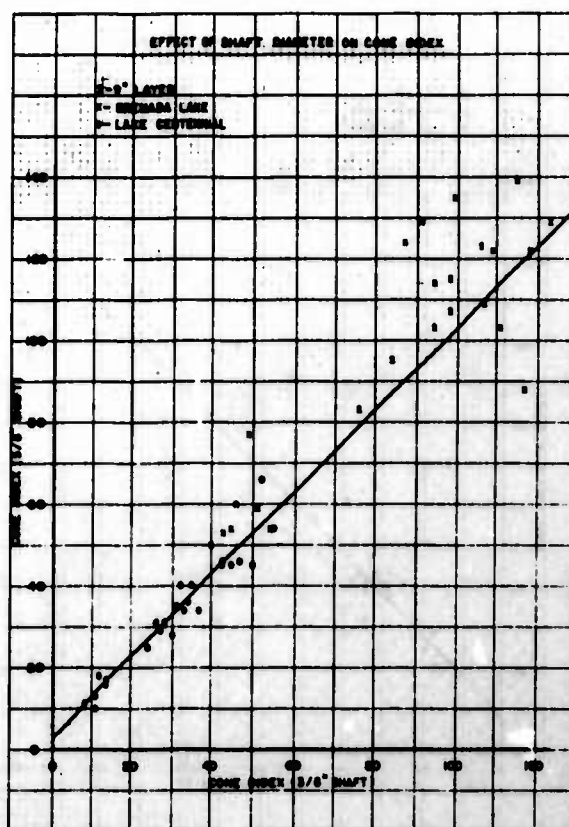


Fig. V-2

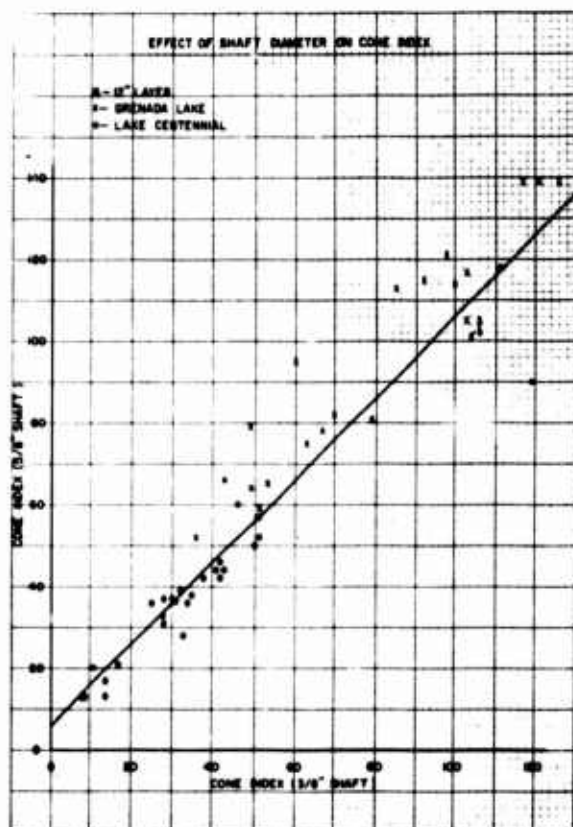


Fig. V-3

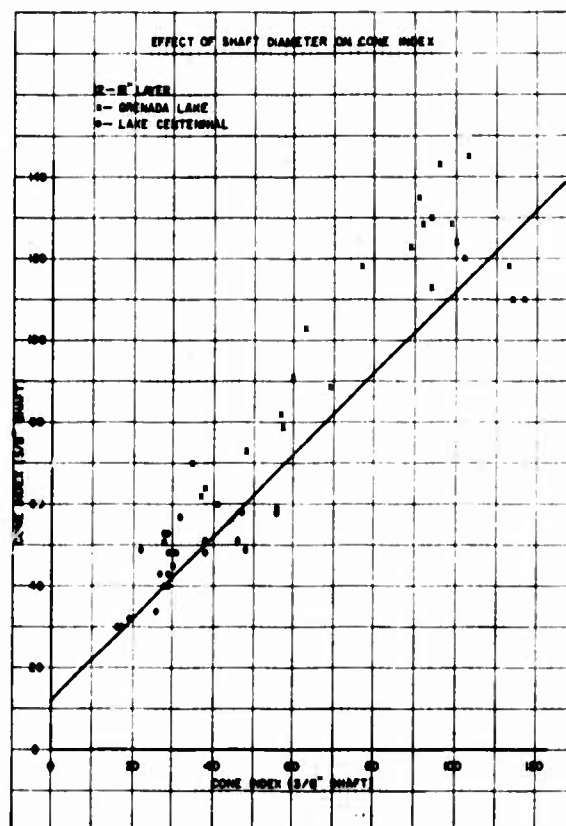


Fig. V-5

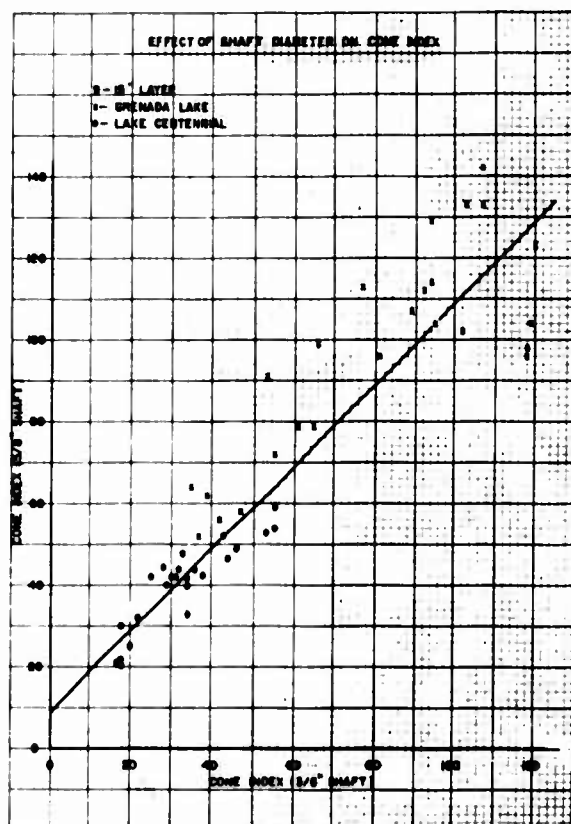


Fig. V-4

All test data obtained prior to the introduction of the 3/8" shaft instrument were "corrected" as indicated before being used in the analyses conducted as part of this program.

APPENDIX VI

THE RELATIONSHIP OF CONE INDEX TO SOIL DIRECT SHEAR STRENGTH

It is recognized that a vehicle develops traction in soils through direct shearing action of the soil at the mechanical vehicle/soil interface and/or through friction and/or adhesion between the vehicle running gear and the soil. Accordingly, a relationship between soil direct shear properties and cone indices is useful in the context of this study.

Traction (T) is conventionally treated in terms of Micklethwait's [10]* adaptation of Coulomb's equation

$$T = S [c + q_n \tan \phi] \quad (1)$$

where S = contact area

q_n = nominal unit ground pressure

c = effective soil cohesion

and ϕ = effective soil angle of internal friction

or, where, because of the running gear design, shear failure occurs at the soil/gear interface rather than within the soil, by

$$T = S [a + q_n \cdot f] \quad (2)$$

where a = soil to gear material adhesion

and f = soil to gear material friction.

An aggressive track will develop traction according to eq. (1); a smooth track or tire, according to eq. (2). A normally aggressive off-road tire, or a track with substantial road pads, will develop part of its traction via eq. (1), part by eq. (2), in accordance with the distribution of its total effective contact area between soil trapping and smooth elements.

On the usual assumption that the cone index expresses directly the bearing capacity of a frictionless, weightless, plastic soil, the relationship between cone index and soil direct shear strength becomes, for flat plate and at the surface, according to plasticity theory [af. 15]

$$CI \approx 5.7 c$$

where c = soil cohesion (psi)

Evans [16] has published results from tests in heavy plastic clays indicating that

$$CI \approx 5 c,$$

and Smith's [17] data, from tests in a wider range of fine-grained soils, suggests that

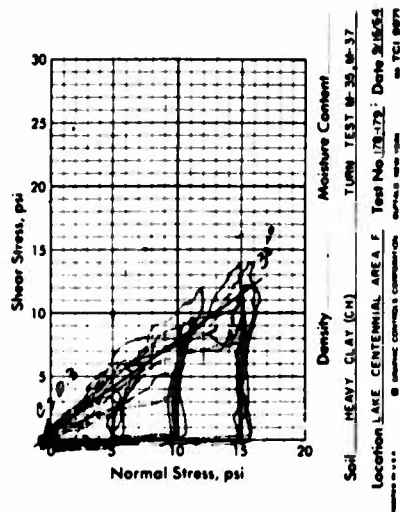
$$CI \approx 12.5 c.$$

Throughout the present study a Cohron shear-graph [5] was used to obtain direct shear parameters on surface soils encountered in the field program, and during a special series of "slipperiness" tests. Sheargraphs were also used in concurrent WES laboratory studies by Meyer [14] and by Smith [13]. In addition, Haley, of the ATAC Land Locomotion Laboratory, ran some side-by-side field tests with a bevameter [25] in the areas where some of the vehicle tests were run [26]. Comparative values from the bevameter and the sheargraph, obtained in prepared lanes used in the "slipperiness" tests, are given in Table VI-1. Except for the 10 July data, agreement between the two instruments on $\tan \phi$ and f_r is good.

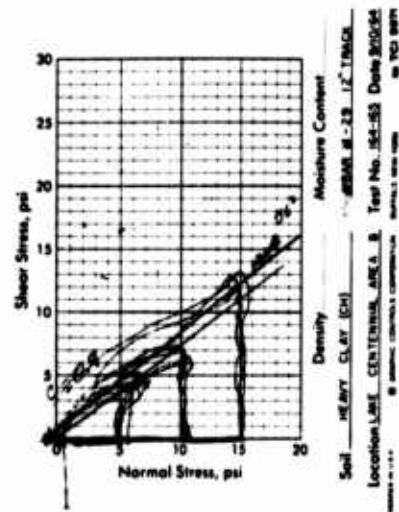
However, the most striking feature of these, and indeed all of the *in situ*, torsional shear measurements cited, is the clear dependence in "frictionless" soils of shearing resistance upon normal loading up to moisture contents of the order of the Atterberg liquid limit. Figure VI-1 shows a number of sheargraph records in the heavy Vicksburg buckshot clay (CH) at various moisture contents. Moreover, as illustrated in Table VI-1, the zero normal load intercepts were generally small in the sheargraph records (interpretable as apparent cohesion values of seldom more than 1 psi) and almost nonexistent in those of the LLL bevameter, which uses a larger, annular shear head.

A series of surface traction tests were undertaken to determine the degree to which the sheargraph could be used to predict drawbar pull performance. The tests were deliberately run under conditions where a thin layer of surface soil was made wet and weak, and the underlying soil body was kept sufficiently strong to permit the assumption that external motion resistance was nil, and hence that measured pull equaled traction. The procedure is described in the body of the report on page 13 and 14; the data are summarized in Table III-50

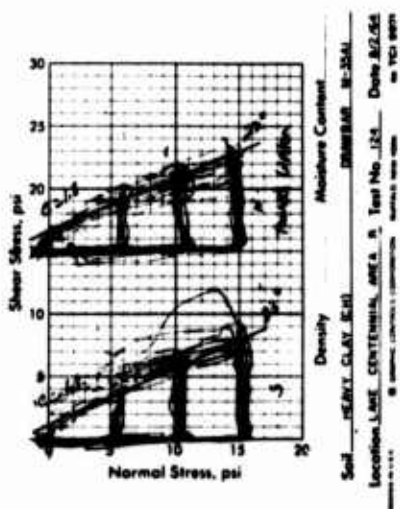
*See References, p. 33 in main body of report.



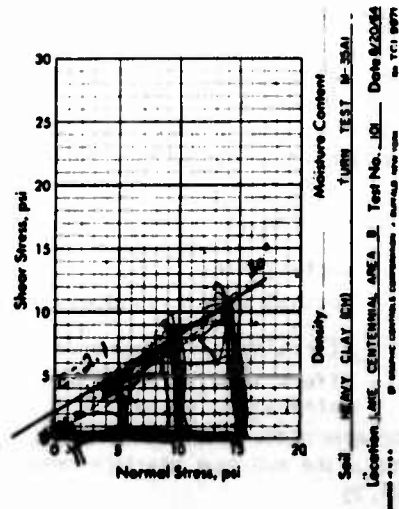
a. Moisture Content (0-3) = 31.3%



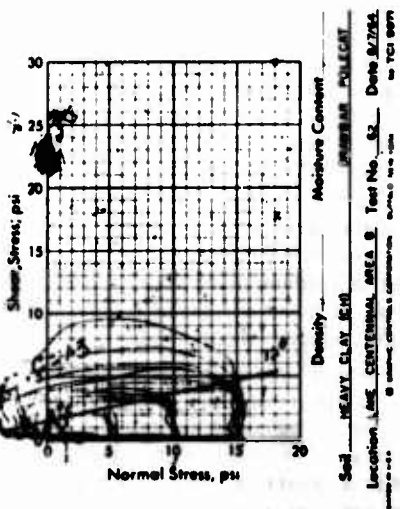
b. Moisture Content (0-3) = 36.7%



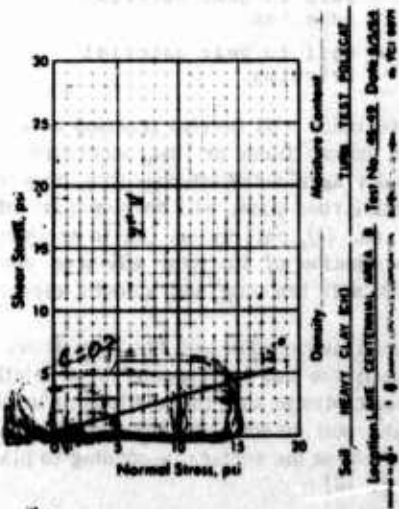
c. Moisture Content (0-3) = 44.6%



d. Moisture Content (0-3) = 50.6%



e. Moisture Content (0-3) = 56.8%



f. Moisture Content (0-3) = 61.4%

Cohron Sheargraph Records (2" grousered vane shearhead) In Heavy Clay (CH)

Fig. VI-1

TABLE VI-1
Surface Direct Shear Parameters as Measured by the
LLI Bevameter and the Cohren Sheargraph in Prepared Lanes

Date 1964	Course*	Condition**	Bevameter (26)			Sheargraph		
			tan ϕ	c psi	f _r ***	tan ϕ	c psi	f _r ***
6/23-25	1	F			0.22			0.16
6/26	2	F	0.27	0	0.22	0.23	1.5	0.19
6/30		D-1 hr.						
		D-12 hr.	0.25	0		0.21	0.8	
		D-16 hr.			0.33			0.25
7/1		D-48 hr.			0.25			0.33
7/6		D-2 hr.	0.25	0	0.25	0.25	0.8	0.25
7/10		D-24 hr.	0.36	0.11	0.31	0.60	0.9	0.51

*1 - Clayey Silt (ML) **F = Flood

2 - Heavy Clay (CH) D = Drained for x hrs.

***f_r = coefficient
of friction
of rubber
on soil

The results showed the expected trends, but had considerable scatter, due to a number of factors:

- 1) the test courses were not ideally uniform;
- 2) the sheargraph shear head only sampled -- and averaged -- a very small area at one time;
- 3) the action of both the vehicle and the sheargraph when the surface layer was very weak and thin was not clearly in either the surface layer or in the hardpan;
- 4) in situations where the weak layer was somewhat thicker, the sheargraph appeared to operate more nearly in the indeterminate region between layers than did some of the vehicles; and
- 5) each of the vehicles had running gear which had both grousered and relatively smooth areas (which, of course, is common).

In the absence of sharper correlation with the proposed equations, it was decided to treat the sheargraph measurements simply as an *index* of surface soil shear strength. For this purpose, the measured shear strength (τ) at 10 psi average normal loading (σ), divided by the loading, was used; i.e.,

$$(\tau/\sigma)_{10}$$

where the subscript indicates the value of σ at which the ratio was evaluated.

This index showed a strong correlation with soil moisture content in the sampled layer, as would be expected. It also still had considerable scatter. In Figures VI-2-5, measured vehicle drawbar performance (D/W) and values of this index (for the grousered vane shear head or for the smooth rubber shear head, as appeared appropriate) are jointly plotted to the same scale as functions of moisture content of the surface soil. The results, while not exciting, indicate that the proposed index is related in useful degree to vehicle traction. They also clearly demonstrate that a weak or "slippery" surface layer can reduce performance as much as 80 percent from what would be expected from deep measurements made to determine the strength of the soil mass which supports the vehicle's weight.

As this study drew to a close, preliminary results from a concurrent WES study of the "slipperiness" problem, conducted with tires in the AMRB laboratory soil bins by Smith, became available [13]. Smith's findings were generally similar to those

from the field tests. In Figure VI-6, $(\tau/\sigma)_{10}$ from Smith's tests is plotted as a function of moisture content in the surface soil layer, and in Figure VI-7, his measured (D/W) values with one, normal tire are plotted on the same basis. Once again the scatter in sheargraph results is large, but does not totally obscure what appears to be a usefully strong and direct correlation between the sheargraph index and measured traction.

On the strength of these demonstrations, a general correlation was sought between the index $(\tau/\sigma)_{10}$ as determined by sheargraph measurements, and cone index. Both extensive field data, in which cone penetrometer, sheargraph, and moisture content data were concurrently taken, and preliminary results of still another WES laboratory study by Meyer [14] were available for this.

Meyer's data showed, for carefully prepared, uniform, fully remolded samples of a large number of fine-grained soils, variations in cone index, in c and tan ϕ as determined by the sheargraph (and in several other properties) as functions of moisture content. From these, the index $(\tau/\sigma)_{10}$ was calculated and correlated via moisture content to cone index. Figures VI-8 and VI-9 illustrate cone index and $(\tau/\sigma)_{10}$ respectively as functions of moisture content for one CH soil, as developed from Meyer's report. Figure VI-10 illustrates the resulting $(\tau/\sigma)_{10}$ versus CI relationship.

All of the curves developed in this way were similarly shaped, suggesting that a simple exponential decay curve of the form

$$(\tau/\sigma)_{10} = K_1 (1 - e^{-K_2 CI}) \quad (3)$$

where K_1 and K_2 are curve fitting parameters, might usefully be fit to them. One such is shown in Figure VI-9. In order to investigate the possible importance of the deviation between the algebraic expression fitted and the original relationship, arbitrarily adjusted curves of $(\tau/\sigma)_{10}$ and (CI) were backplotted to the original data, with the results illustrated by the dotted lines in Figures VI-8 and VI-9. It was judged that such deviations were generally within the data scatter band.

Six additional fine-grained soils from Meyer's data were selected and similarly treated. The designation of each and its USCS classification, Atterberg limits, and the value of " K_2 " [in eq. (3)] assigned, are tabulated in Table VI-2. Note that the constant " K_1 " in eq. (3) was assigned the value of 1.0 in the course of these analyses. All of the soils did not approach this single value asymptotically. How-

TABLE VI-2
Soils from Meyer [14]
to Which Curve $(\tau/\sigma)_{10} = (1 - e^{-K_2 CI})$ Was Fit.

Soil Site	USCS Classification	Atterberg Limits		" K_2 "
		PL	LL	
U.S. 7	CL	22	39	.022
U.S. 11	CH	36	71	.035
U.S. 9	CH	31	73	.019
U.S. 1	CH	36	66	.016
U.S. 2A	ML	27	45	.030
P.R. 1	MH	38	58	.023
U.S. 3	MH	77	89	.016

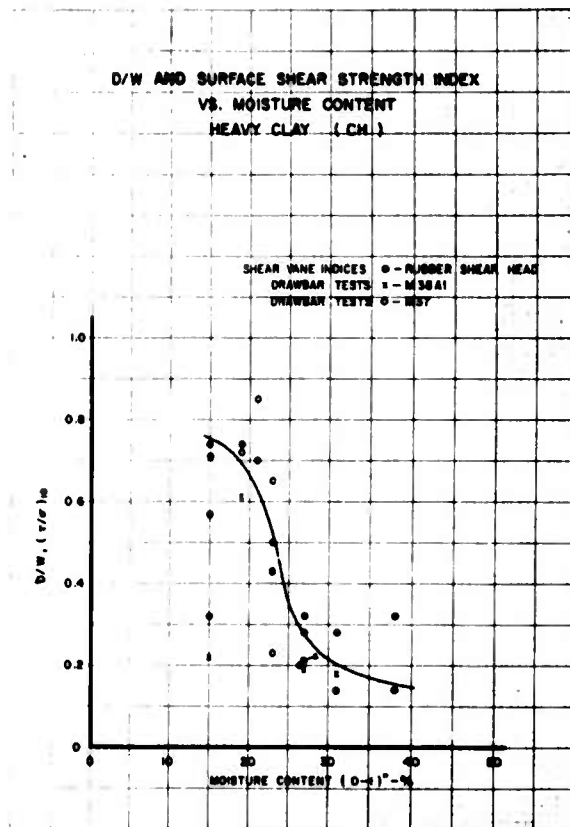


Fig. VI-2

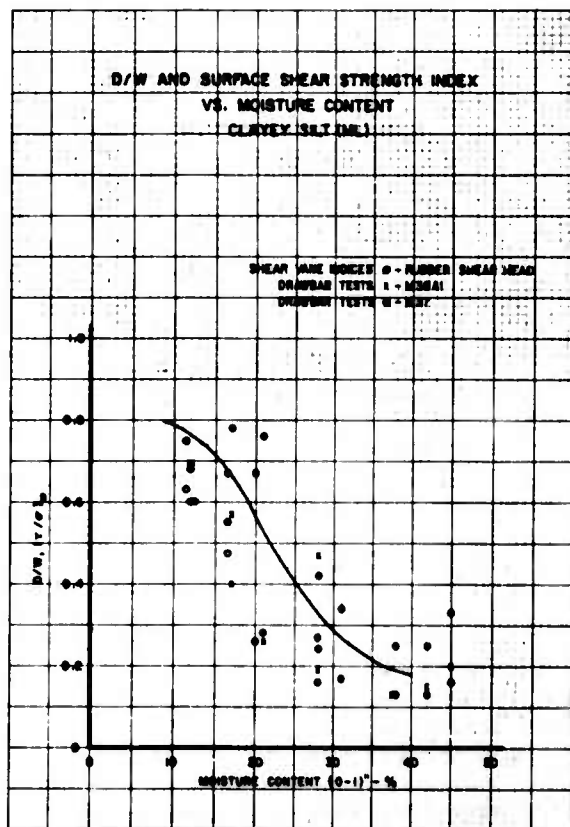


Fig. VI-4

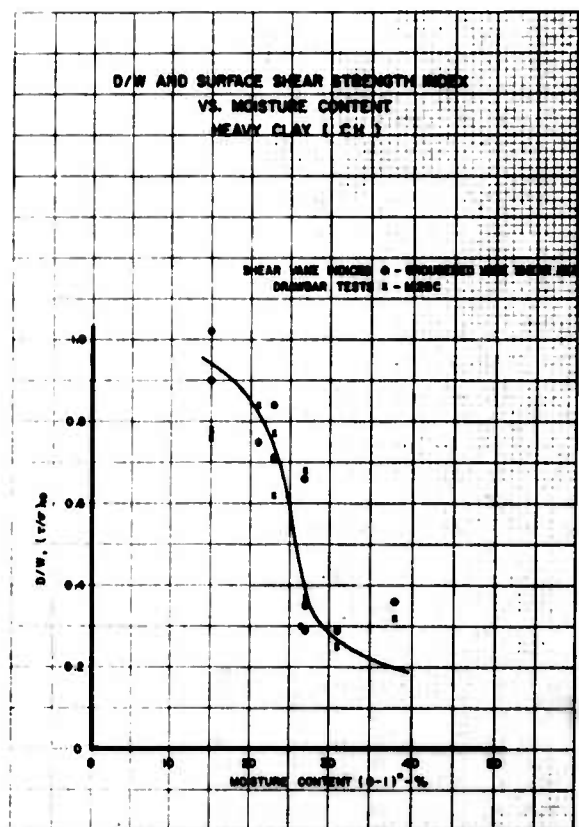


Fig. VI-3

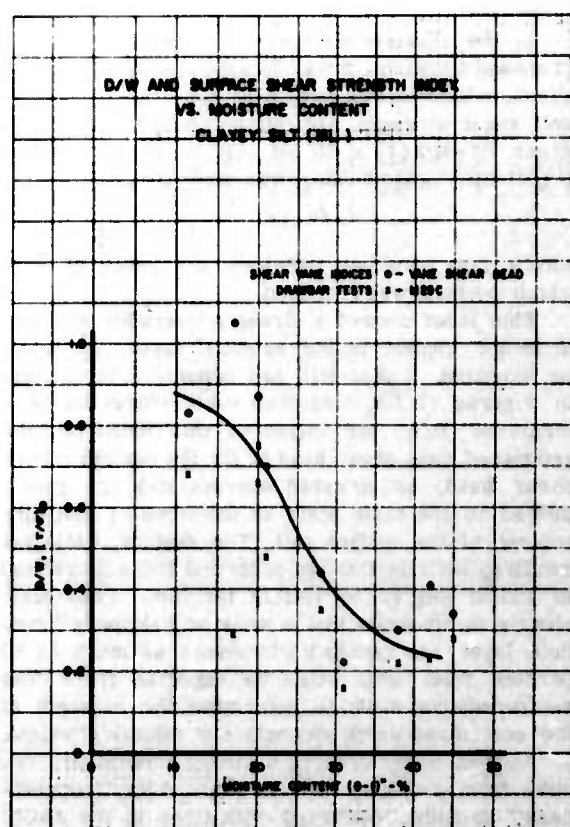


Fig. VI-5

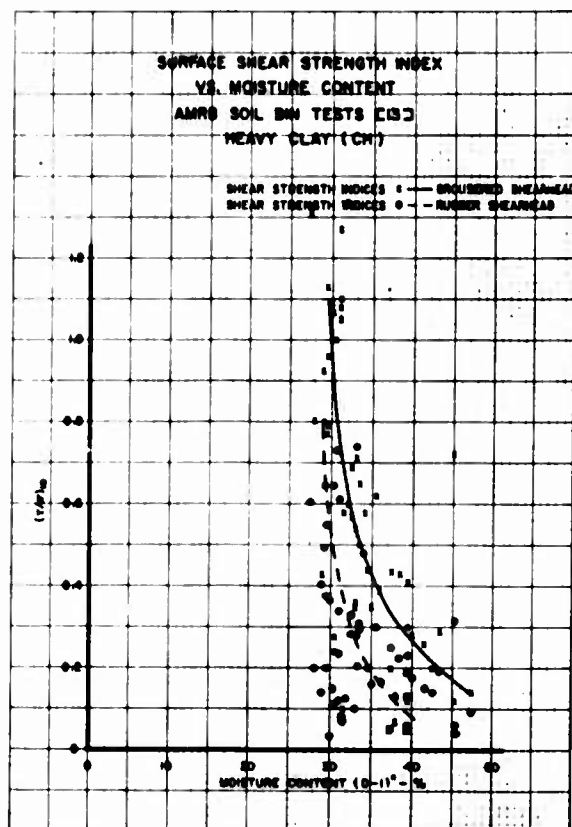


Fig. VI-6

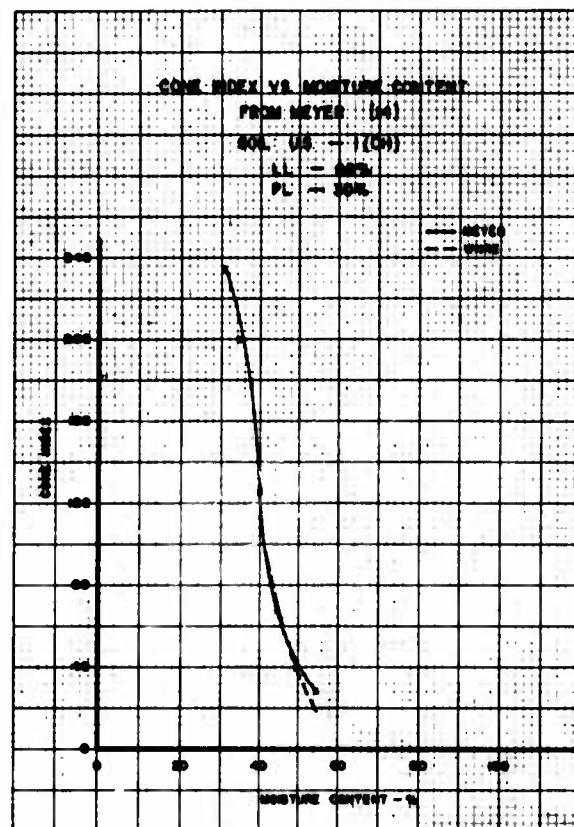


Fig. VI-8

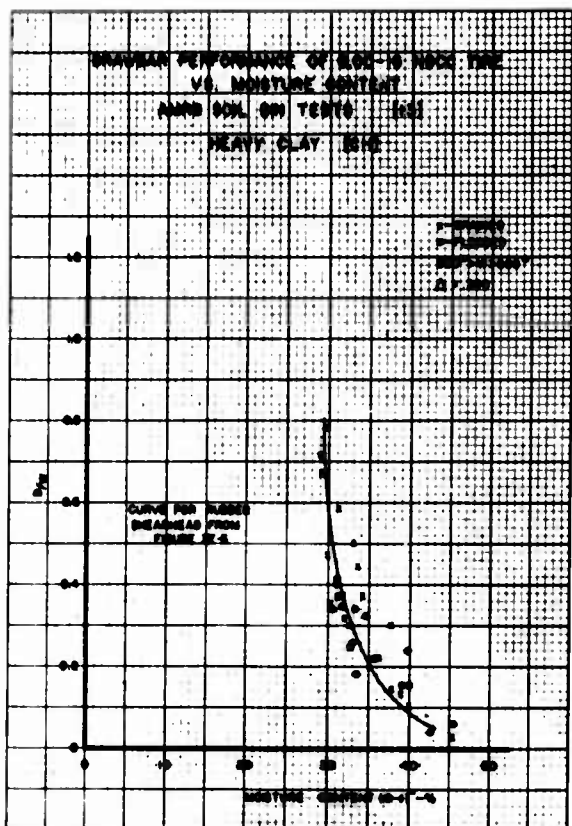


Fig. VI-7

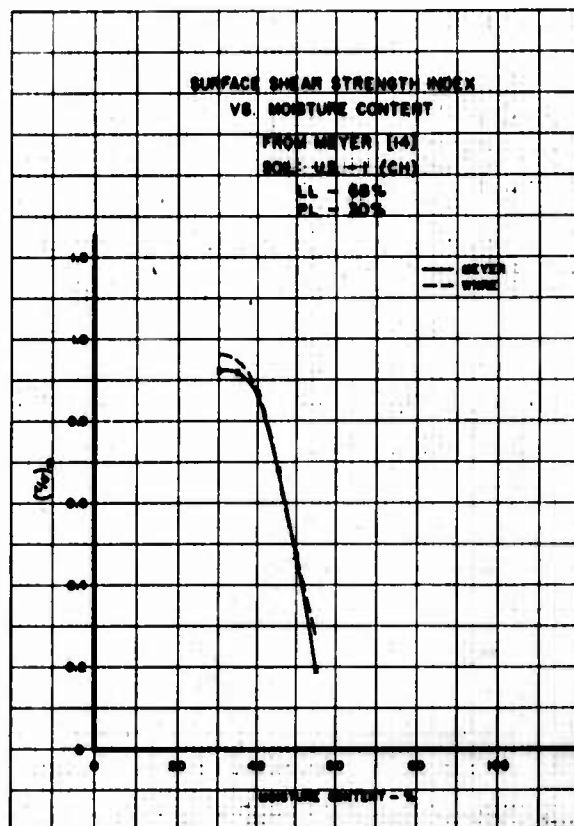


Fig. VI-9

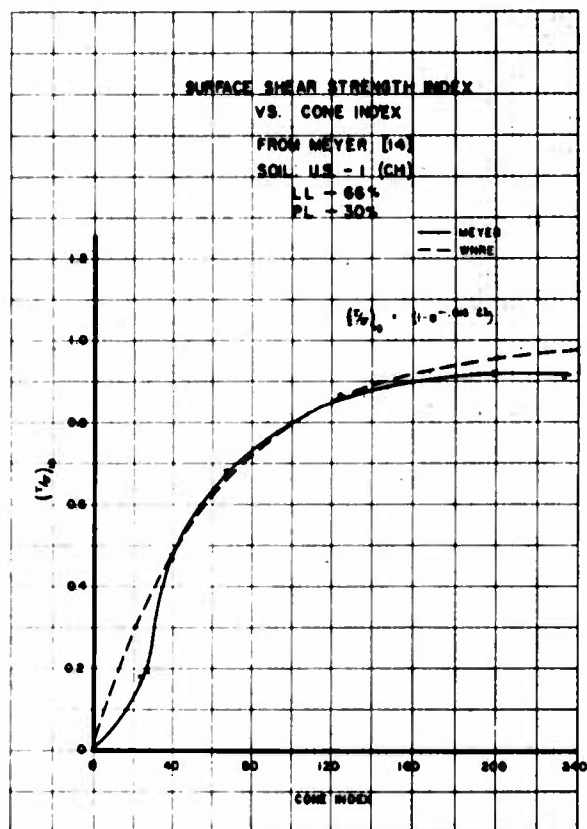


Fig. VI-10

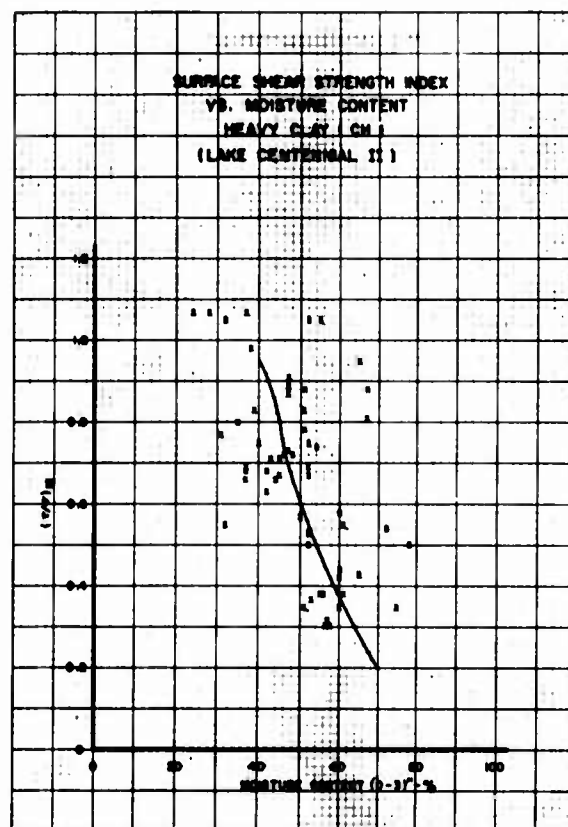


Fig. VI-12

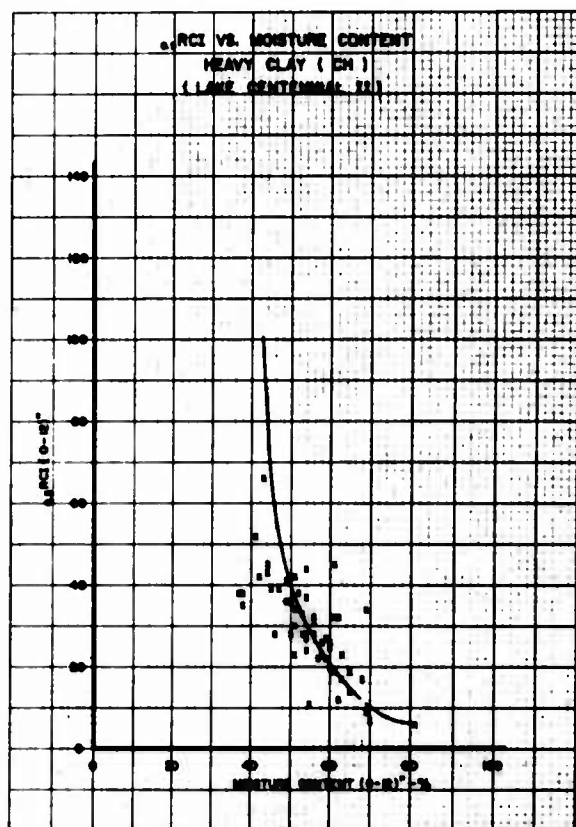


Fig. VI-11

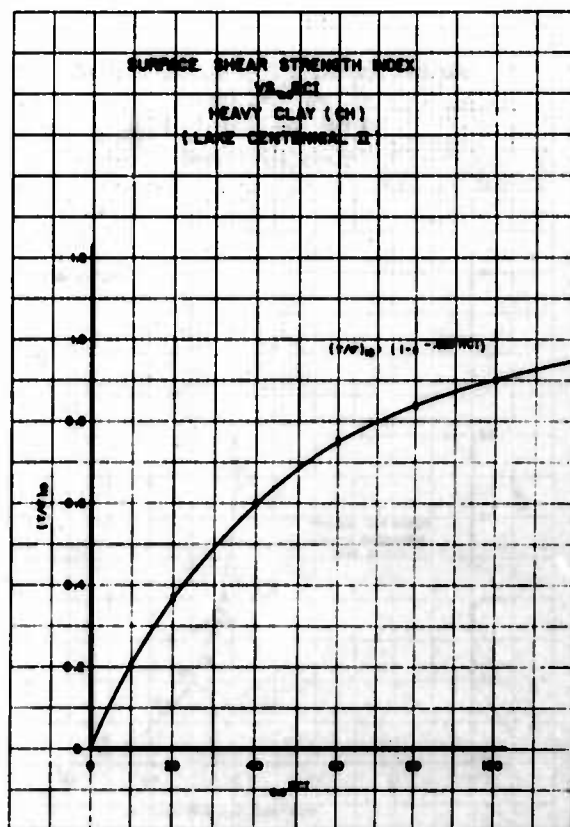
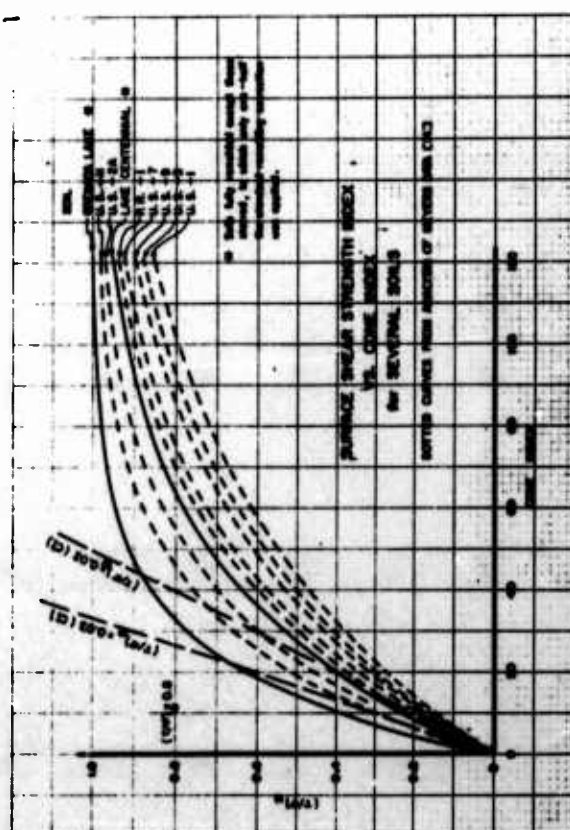
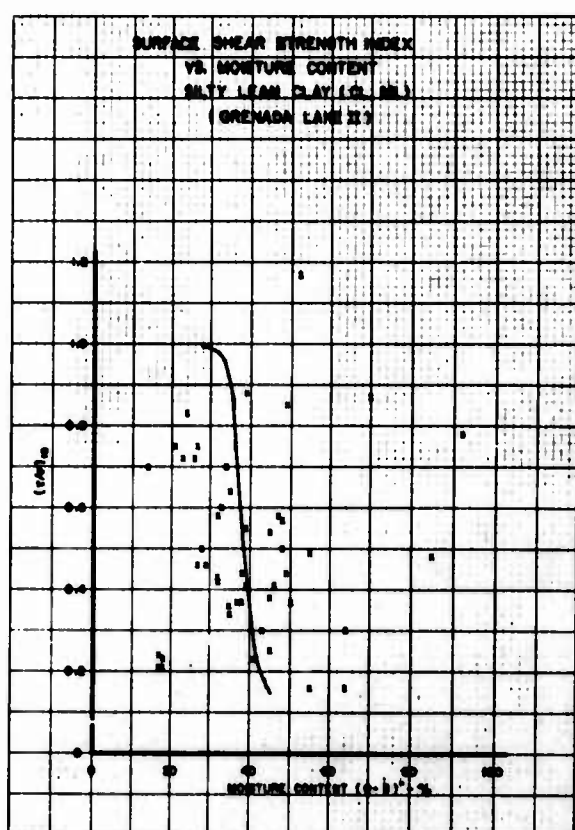
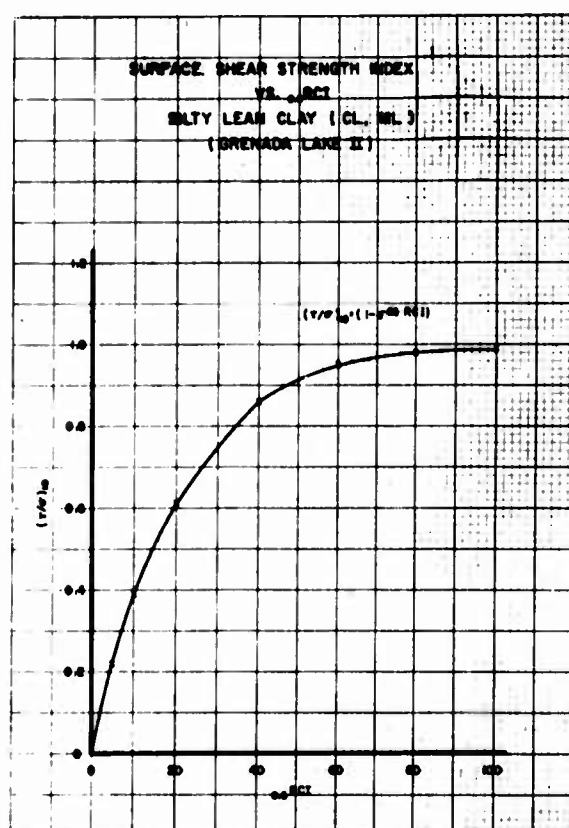
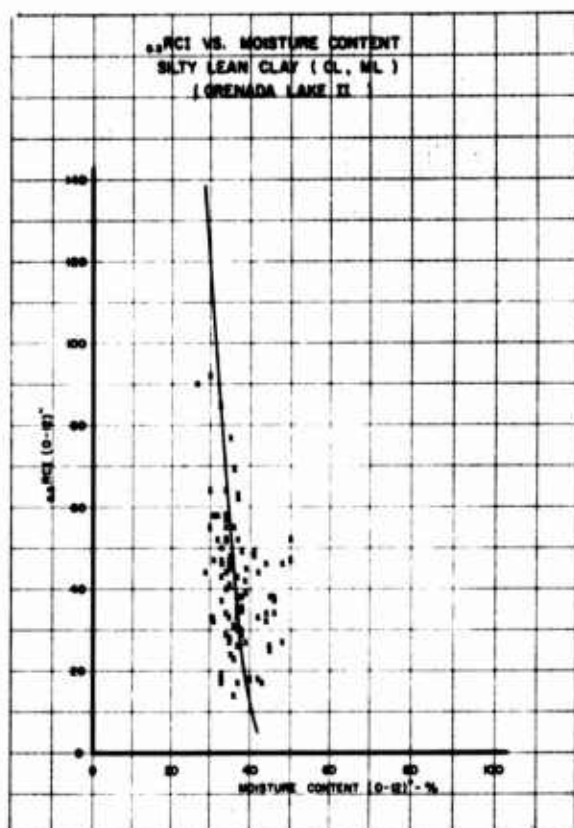


Fig. VI-13



ever, the range was not large (0.8 to 1.2) and it was considered that for present purposes the gain in simplicity of reducing the parameters to one far offset any loss in apparent precision.

Available field data were similarly treated. On the assumption that the soil body was uniform with depth to 12 inches, except in moisture content, recorded 0-12-inch average cone indices (with the 50 percent remolding correction thought appropriate to the one-pass problem applied) and concurrently taken moisture contents over the same depth were used to establish the $0.5RCI$ versus MC curves, while the $(\tau/\sigma)_{10}$ versus MC curves were developed from 0-3-inch layer moisture content and concurrent sheargraph data taken in the same area. The results for the CH soil are shown in Figures VI-11-13, and for the (CL, ML) soil in Figures VI-14-16.

The final curves from the several analyses are consolidated in Figure 17. In the range of cone index values of prime interest in predicting the first-pass performance of reasonably mobile vehicles, say from

0-40, each of the curves shown could readily be replaced by a simple straight line function

$$(\tau/\sigma)_{10} = K_3(CI) \quad (4)$$

where K_3 lies between about 0.01 and 0.03 and has the dimensions $(\text{psi})^{-1}$.

In order to make a crude judgment on the relationship of this expression to those quoted at the outset of this discussion, it may be assumed (in the face of all the evidence) that τ is entirely cohesive. In this case

$$(\tau/\sigma)_{10} = c/10$$

and from (4)

$$CI = c/10K_3$$

which, for the range of values of K_3 suggested, indicates that

$$CI = 3.3 \text{ c to } 10 \text{ c,}$$

which is familiar, at least.

APPENDIX VII

AN APPROXIMATION CONCERNING THE SKID STEERING OF TRACKED VEHICLES IN WEAK SOILS

Normal two-tracked vehicles are steered by "skid-steering," in which the moment required to change the vehicle heading, against the resistance principally of forces developed within the ground/vehicle contact surface, is generated by increasing the thrust developed by the outside track over that developed by the track on the inside of the turn. This is normally done by changing the speed ratio between the two tracks, and in more sophisticated vehicles involves but little power loss due to the use of various "geared-steer" or regenerative track speed control systems. If the vehicle is to maintain headway, however, total forward thrust must be maintained, which implies that the outer track must develop more traction in a turn than in straight-ahead operation. Thus

$$T_o + T_i = R_s \quad (1)$$

$$\text{and } (T_o - T_i)t = M_r \quad (2)$$

where T_o = traction developed by the outside track

T_i = traction developed by the inside track

R_s = external motion resistance

M_r = moment resisting rotation of the vehicle, which at slow speeds is developed largely in the vehicle/ground contact

and t = the tread of the tracks, center to center.

Eliminating T_i between (1) and (2)

$$T_o = 1/2 \left(\frac{M_r}{t} + R_s \right) \quad (3)$$

When a vehicle is operating in limiting soil conditions ($RCI_1 = VCI_1$), the maximum traction which the soil will support is already being developed at each track, so that the added increment at the outside track required to steer ($M_r/2t$) may be expected to bring on immobilization. Alternatively, if the vehicle is to remain free to maneuver, RCI_1 must be somewhat more than VCI_1 .

This problem has not been adequately treated, but a first-order estimate of this effect, based upon grossly simplified statics of the situation, has suggested that it is large, particularly in marginal conditions [29]. This treatment neglected the ef-

fects of track slip, both radially and tangentially. A vehicle operating in marginally weak soils, however, will be operating with considerable longitudinal slip.

In order to examine the order of performance change when track slip is considered, the model employed some years ago by Steeds [30] may be employed. In its simplest form, this model assumes that ground contact forces behave in the manner of dry friction; i.e., are of constant magnitude for any given incremental track area, regardless of their ultimate direction, and act in a direction opposite to that of the net velocity vector of that incremental area in relation to the ground. Although it is obvious that such a simple "friction circle" can be no more than a crude approximation to the true behavior of an actual track in a real situation involving such elements as sinkage and rutting, directional grouzers, and non-uniform pressure and traction distributions over the contact area, it may be used for present exploratory purposes.

Figure VII-1 illustrates a single track contact patch rotating at a forward (tangential) speed, V , about a center "O" on a radius " r_t " and proceeding with slippage

$$V_s = V_t - V$$

where V_s = tangential slip speed

and V_t = track speed

Assume for simplicity that elements along the track centerline are adequately representative of the entire track width, and that maximum traction (T) is developed uniformly along the track length. At any section at a distance x from the normal through "O,"

$$\tan \alpha = \frac{x}{r_t}$$

$$\text{and } V_1 = \frac{V}{\cos \alpha}$$

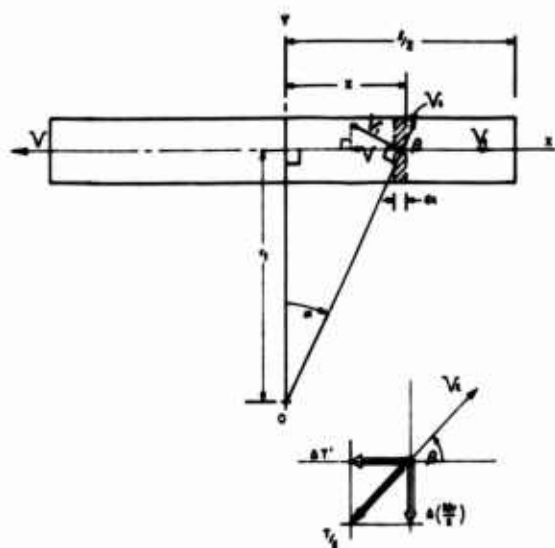
The net longitudinal speed (rearward) is

$$V_x = V_t - V$$

and the net lateral speed (outward in this quadrant)

$$V_y = V_1 \sin \alpha = V \tan \alpha$$

Accordingly



SIMPLIFIED DIAGRAM OF SLIP RELATIONSHIPS
UNDER A TRACK TURNING ABOUT CENTER "O".

Fig. VII-1

$$\tan s = \frac{V_y}{V_x} = \frac{V}{V_t - V} \tan a$$

$$\text{or } \tan s = \frac{x}{r} \left(\frac{1-s_j}{s_j} \right)$$

Where s_j is the normally defined slip ratio

$$s_j = 1 - \frac{V}{V_t}$$

Net traction (T') available over the track length

(l) is then (letting $\frac{s_j r}{1-s_j} = m$)

$$T' = 2 \int_0^{\frac{l}{2}} \frac{T}{l} \cos s \, dx = \frac{2mT}{l} \int_0^{\frac{l}{2}} \frac{x^2 dx}{\sqrt{x^2 + m^2}}$$

or

$$\frac{T'}{T} = N \sinh^{-1} \left(\frac{1}{N} \right) \quad (4)$$

where T = maximum traction available in straight running.

Corresponding total resisting moment is

$$M_r = 2 \int_0^{\frac{l}{2}} x \cdot \frac{T}{l} \sin s \, dx = \frac{2T}{l} \int_0^{\frac{l}{2}} \frac{x^2 dx}{\sqrt{x^2 + m^2}}$$

$$\text{or } \frac{M_r}{\frac{l}{2} \cdot T} = \sqrt{1+N^2} - N \sinh^{-1} \left(\frac{1}{N} \right) \quad (5)$$

where the joint radius-ratio/slip parameter

$$N = \left(\frac{2r_t}{l} \cdot \frac{s_j}{1-s_j} \right) \quad (6)$$

Equations (4) and (5) are plotted as functions of N in Figure VII-2. To obtain an idea of the normal range of values found in practice, consider the M29C Weasel in a tight turn, for which $2r_t/l=8$. (The slight difference, + 10%, in ratio value between inner and outer tracks is neglected.) Then,

for $s_j = 0.05$	$N = 0.42$	$\frac{T'}{T} = 0.67$	$\frac{M_r}{\frac{l}{2} \cdot T} = 0.80$
0.10	0.89	0.86	0.57
0.20	2.00	0.96	0.31
0.30	3.43	0.99	0.20
0.40	5.33	1.00	0.11
0.50	8.00	1.00	0.06

Thus, when operating at 20% slip, traction available is a full 96% of the nominal static value, but the moment resisting turning is only 31% of its static value. This is far from a negligible effect. Equation (3) may now be evaluated. From the preceding

$$T_o = T_{\max} \left(\frac{T'}{T} \right)$$

and

$$\frac{M_r}{t} = \frac{1}{t} \cdot T_{\max} \cdot \frac{l}{4} \left(\frac{M_r}{\frac{l}{2} \cdot T} \right)$$

$$\text{thus } 2T_{\max} \left(\frac{T'}{T} \right) = \frac{l}{4t} \cdot T_{\max} \left(\frac{M_r}{\frac{l}{2} \cdot T} \right) + R$$

$$\text{or } T_{\max} \left[\left(\frac{T'}{T} \right) - \frac{l}{8t} \left(\frac{M_r}{\frac{l}{2} \cdot T} \right) \right] = \frac{R}{2} \quad (7)$$

From the report proper

$$R_o = 0.3 \left(\frac{VCI_1}{RCI_1} \right)^3 W \quad (\text{eq. 28})$$

and, for one track,

$$T_{\max} = \frac{1}{2} \left[0.3 K_r \left(\frac{RCI_1}{VCI_1} \right) \right] \quad (\text{eq. 28 and 29})$$

Substituting these in equation (7), and assuming the case of a vehicle proceeding in decidedly marginal conditions for which slip may reasonably be taken to be about 30%

$$\left(\frac{T'}{T} \right) = 0.99, \quad \left(\frac{M_r}{\frac{l}{2} \cdot T} \right) = 0.20$$

gives the controlling soil strength, in terms of VCI_1 , as

$$\left(\frac{RCI_1}{VCI_1} \right) \approx \left(\frac{40}{K_r (40 - \frac{l}{2})} \right)^{1/4} \quad (8)$$

From this it appears that, contrary to what has usually been assumed, the steering ratio (l/t) has but little influence upon the low limit of soil strength (RCI_1) required. Furthermore, taking $l/t=2$ (normally an absolute maximum) and $K_r=1$

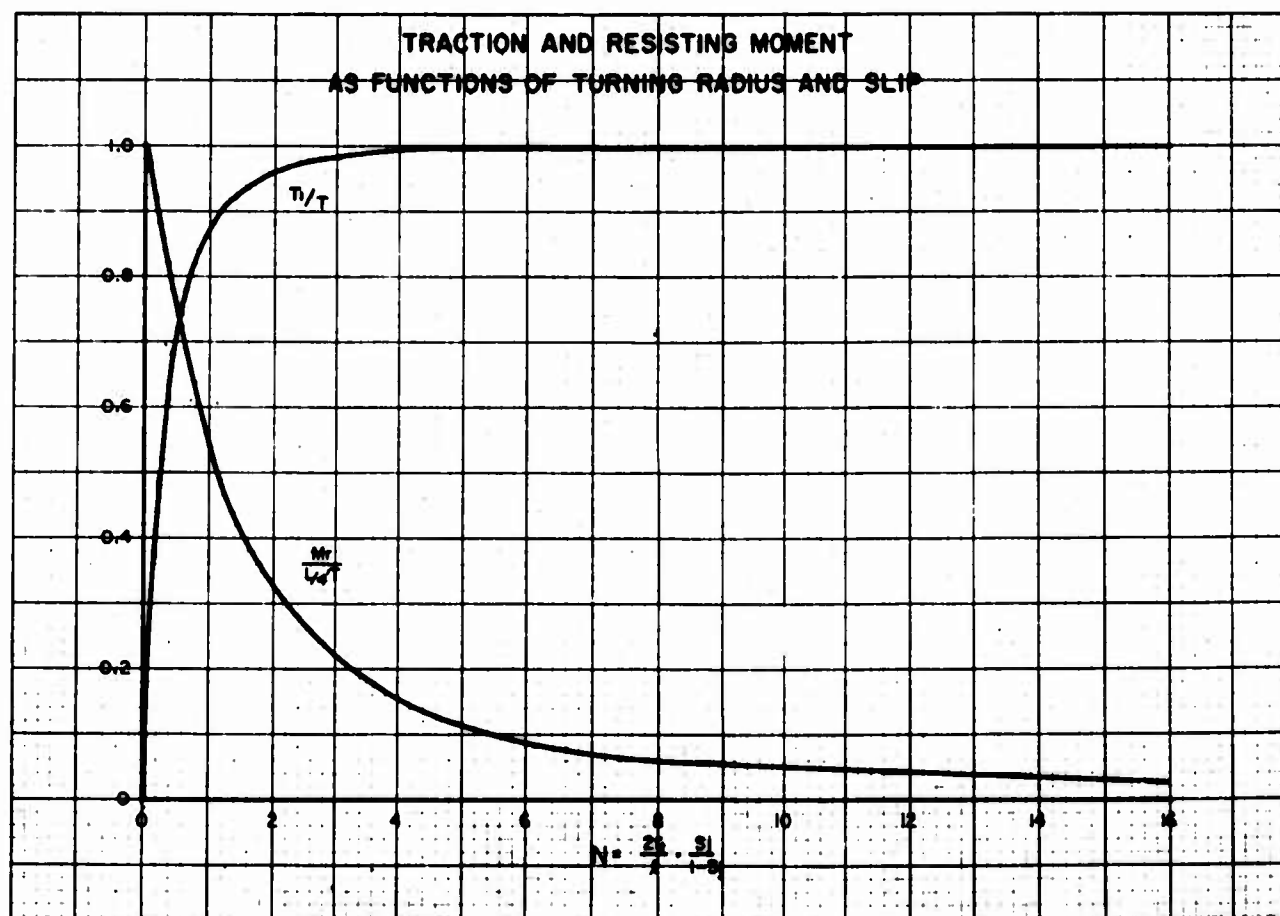


Fig. VII-2

$$\frac{RCI_1}{VCI_1} \approx 1.013$$

It thus also appears that the fact of skid steering
per se (at reasonable minimum radii - say $2r_t > 8$)
 $\frac{r}{L}$

does not materially change the limiting lowest soil
strength requirement.

These conclusions, of course, are dependent upon
the adequacy of the simple model used, and must
be treated with caution pending some direct experi-
mental verification.

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13. ABSTRACT <i>are presented</i> This report presents results of an investigation of the one-pass performance of self-propelled vehicles in natural, weak, fine-grained soils for the following purposes: (1) to develop (a) a reliable strength index for fine-grained soils with which predictions may be made of the performance of a vehicle on its first pass on a straight, level course, and (b) a nominal vehicle load index to be used with the soil strength index to establish whether or not a vehicle will go; and (2) to provide means to predict (a) one-pass drawbar pull and slope performance in soils having strengths in excess of the minimum required for one vehicle pass on level terrain, (b) the increment of soil strength index necessary to permit a vehicle to maneuver freely, and (c) the probable maximum speed of a vehicle operating in a terrain situation where the soil strength index exceeds the net vehicle load index. First-order answers are proposed to the five basic questions utilizing minor adaptations of techniques and concepts developed by ~~WES~~ in their 50-pass trafficability work, and defining modified "vehicle cone indices" (VCI_1) and soil "rating cone index" (RCI_1) procedures appropriate to the one-pass problem. The ratio (VCI_1/RCI_1) is used as the basic soil loading numeric in simple approximate calculations of drawbar pull, grade performance, soil strength increments necessary to permit free maneuvering, and probable maximum speeds, all as influenced by soil strengths.		

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