ADVANCED RESEARCH PROJECTS AGENCY
WASHINGTON, D.C. 20301

In reply refer to:
11-30/65(11.11)

JUN 9 1965

MEMORANDUM FOR THE DIRECTOR, U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION, VICKSBURG, MISS.

SUBJECT: Advisory Committee Report on Mobility Environmental Research Studies (Project MERS)

References: a. ARPA Memorandum III-175 dated 13 October 1964, subject as above.

b. WESFM Memorandum dated 14 May 1965, subject: "Request for Advisory Committee Report on Project MERS," with attachments.

Reference a. gave specific instructions for distribution of subject report because it contained internal ARPA planning and funding information.

Since the time period to which these plans and funding information pertained is now past, the "FOR OFFICIAL USE ONLY" designation should be removed and this report distributed in accordance with appropriate procedures for an unclassified report.

MP 4-670

R. H. Wienecke
R. H. Wienecke
Major General, USA
Director for Remote Area Conflict

cc: CG, AMC

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REPORT OF SECOND MEETING OF ARPA ADVISORY COMMITTEE ON MOBILITY ENVIRONMENTAL RESEARCH STUDY

(24-26 FEBRUARY 1964, VICKSBURG, MISSISSIPPI)

MISCELLANEOUS PAPER NO. 4-670

August 1964

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

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PREFACE

At the request of the Advanced Research Projects Agency (ARPA), the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, accepted the responsibility for arranging and implementing the second Advisory Committee meeting on Mobility Environmental Research Study (Project MERS), sponsored by ARPA, and for the preparation and publication of the conference proceedings. The meeting was held at WES on 24-26 February 1964.

This report consists of 18 papers presented at the Advisory Committee meeting, summaries of important discussions and questions relative to the various papers, the Committee's conclusions and recommendations, and a report of an Ad Hoc Working Group recommended by the Committee to examine the applicability of an airborne profilometer to obtain terrain profiles. The papers included reports on WES studies related to Project MERS, review of project history, conclusions and recommendations of the first Advisory Committee meeting held at Bethesda, Maryland, on 7-9 November 1962, accomplishments on Project MERS tasks since the first committee meeting, Marsh Screw Amphibian tests conducted by WES, Project MERS plans for the next 12 months, and funding status and requirements for Fiscal Year 1965.

The meeting attendants included 7 members of the Advisory Committee and 28 observers and visitors. Col. William J. Lynch, U. S. Army, ARPA Project Manager for Mobility and Logistics, was the meeting chairman, assisted by Mr. W. G. Shockley, Chief, Mobility and Environmental Division, WES, as cochairman. Professor K. B. Woods, Head, School of Civil Engineering, Purdue University, was chairman of the Advisory Committee and was assigned the responsibility for the committee report.

The papers presented at the meeting are arranged in this report in

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the same order in which they were presented. The authors of the various papers presented are identified in the text.

Project MERS is under the direct supervision of Mr. A. A. Rula, Chief, Mobility Environmental Research Studies (MERS) Branch, and under the general supervision of Mr. W. G. Shockley, Chief, Mobility and Environmental Division, WES.

During the conduct of the phase of the work reported herein, Col. Alex G. Sutton, Jr., CE, was Director of the Waterways Experiment Station, and Mr. J. B. Tiffany was Technical Director.

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ATTENDANTS, SECOND ARPA ADVISORY COMMITTEE MEETING

ON

MOBILITY ENVIRONMENTAL RESEARCH STUDY (PROJECT MERS)

Advisory Committee Members Present

Col. William J. Lynch, U. S. Army	OSD/ARPA Project Manager Mobility and Logistics Room 3E163 Pentagon Building Washington, D. C. 20301
Dr. Emil H. Jebe	Operations Research Department Institute of Science and Technology The University of Michigan Box 618 Ann Arbor, Michigan 48107
Prof. Kenneth B. Woods	Head, School of Civil Engineering Purdue University Lafayette, Indiana
Mr. Ronald A. Liston	Director, Land Locomotion Laboratory U. S. Army Tank-Automotive Center Warren, Michigan 48090
Mr. Robert R. Philippe	Chief, Environmental Sciences Branch Research Division Research and Development Directorate U. S. Army Materiel Command Washington, D. C. 20315
Mr. Herman P. Simon	Surface Mobility Division Transportation Research and Engineering Command Ft. Eustis, Virginia
Mr. Willard J. Turnbull	Chief, Soils Division U. S. Army Engineer Waterways Experiment Station Vicksburg, Mississippi 39181
Dr. Hoyt Lemons*	Office, Chief of Research and Development Department of the Army Washington, D. C. 20310

* Replaced Dr. Leonard S. Wilson.

Committee Leadership

Col. William J. Lynch, U. S. Army, and Mr. W. G. Shockley, WES, cochaired the meetings and guided the procedure.

Prof. Kenneth B. Woods, Chairman of Committee, marshaled the synthesis of conclusions and recommendations.

Advisory Committee Members Absent

Dr. Daniel C. Drucker	Physical Sciences Council Brown University Providence, Rhode Island
Prof. Robert Horonjeff	Institute of Transportation and Traffic Engineering The University of California 1301 South 46th Street Richmond, California 94804
Dr. Ralph E. Fadum	Dean, School of Engineering North Carolina State College of the University of North Carolina Raleigh, North Carolina
Col. Rex H. White, Jr.	Director, Research and Development HQ, U. S. Army Mobility Command Warren, Michigan 48090
Dr. Leonard S. Wilson	Chief, Environmental Sciences Division Office, Chief of Research and Development Department of the Army Washington, D. C. 20310

Visitors and Observers

Maj. Gen. R. H. Wienecke*	Advanced Research Projects Agency
Lt. Col. J. L. Jones	Advanced Research Projects Agency
Mr. Al Tedesco	Advanced Research Projects Agency
Mr. R. F. Jackson	U. S. Army Materiel Command
Mr. R. C. Kerr	U. S. Army Materiel Command
Dr. G. J. Zissis	Institute of Defense Analysis
Lt. Col. N. Prentice	U. S. Army Polar Research and Development Center

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* Part-time attendance.

Visitors and Observers (Continued)

Col. K. Eklund	White Sands Missile Range
Mr. C. J. Nuttall, Jr.	Wilson, Nuttall, Raimond, Engineers, Inc.
Mr. G. T. Cohron	Wilson, Nuttall, Raimond, Engineers, Inc.

WES Personnel

Col. Alex G. Sutton, Jr.	Director
Mr. J. B. Tiffany	Technical Director
Mr. W. G. Shockley	Chief, Mobility and Environmental Division
Mr. A. A. Rula	Chief, MERS Branch
Mr. S. J. Knight	Chief, Army Mobility Research Branch
Mr. W. E. Grabau	Chief, Area Evaluation Branch
Mr. R. R. Friesz	MERS Branch
Mr. R. D. Wismer	MERS Branch
Mr. E. S. Rush	Army Mobility Research Branch
Mr. B. R. Davis	Army Mobility Research Branch
Mr. J. G. Kennedy	Army Mobility Research Branch
Mr. D. R. Freitag*	Army Mobility Research Branch
Mr. M. P. Meyer*	Army Mobility Research Branch
Mr. E. E. Addor	Area Evaluation Branch
Mr. J. H. Shamburger	Geology Branch
Mr. W. K. Dornbusch, Jr.	Geology Branch
Mr. R. G. Ahlvin*	Soils Division

* Part-time attendance.

PROGRAM

PROJECT MERS ADVISORY COMMITTEE MEETING

U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION

Vicksburg, Miss.

24-26 February 1964

Col. W. J. Lynch, Chairman
Mr. W. G. Shockley, Cochairman

<u>24 February</u>

0830	Registration and Travel Arrangements	
0900	Welcome	Col. Alex G. Sutton, Jr.
0910	Sponsor's Remarks	Maj. Gen. R. H. Wienecke
0920	Introductory Remarks	Col. W. J. Lynch
0925	Introductory Remarks	Mr. W. G. Shockley
0930	<u>Environmental and Ground Mobility Research Studies Related to the MERS Program</u>	
	WES MEGA Studies	Mr. W. E. Grabau
	WES Trafficability, Terrain Analyzer, and Mobility Studies	Mr. S. J. Knight
1030	Coffee Break	
1100	Tour, WES Facilities	
1245	Lunch	
1330	Review of Background and History of Project MERS	Mr. R. R. Friesz
1345	Review of First Advisory Committee Meeting Recommendations	Mr. R. R. Friesz
1400	General Status Report on Project MERS Activities	Mr. A. A. Rula
1445	Coffee Break	
1515	Marsh Screw Amphibian	Mr. E. S. Rush
1535	Committee Discussion, Questions, and Recommendations	
1600	Adjourn	

25 February

Progress Report on MERS Tasks Initiated

0830	Conceptual Approach to the Development of Terrain-Vehicle Relations	Mr. R. D. Wismer
	Field Tests	
0900	Compilation of Existing Trafficability Data	Mr. G. T. Cohron
0920	One-Pass Soil Trafficability Studies	Mr. C. J. Nuttall, Jr.
0950	Mobility in Rice Fields	Mr. J. G. Kennedy
1005	Committee Discussion and Questions	
1015	Coffee Break	
	Classification Systems	
1045	Handbook of Instructions for Collecting Environmental Data	Mr. E. E. Addor
1115	Review of Published Environmental Data of Southeast Asia	Mr. J. H. Shamburger
1135	Committee Discussion and Questions	
	Measurements	
1145	Prediction of Terrain Characteristics in Thailand by Airphoto Interpretation	Mr. W. K. Dornbusch, Jr.
1205	Radar Studies for Detection of Surface and Groundwater	Mr. B. R. Davis
1220	Design and Acquisition of Instruments and Test Vehicles	Mr. R. D. Wismer
1230	Committee Discussion and Questions	
1245	Lunch	
	Data Collection and Environmental Analysis	
1345	Classification of Terrain Types of Southeast Asia	Mr. W. E. Grabau
	Vehicle Design and Analysis	
1400	State-of-the-Art of Off-Road Vehicle Design	Mr. C. J. Nuttall, Jr.
1430	Plans for Next Twelve Months	Mr. A. A. Rula
1445	Committee Discussion and Questions	
1455	Coffee Break	

25 February (Continued)

1525 Advisory Committee Time for Report Preparation

1630 Adjourn

26 February

0830 Advisory Committee Time for Report Preparation

1130 Adjourn

REPORT OF SECOND MEETING OF ARPA ADVISORY COMMITTEE ON MOBILITY ENVIRONMENTAL RESEARCH STUDY

Waterways Experiment Station
Vicksburg, Miss.
24-26 February 1964

INTRODUCTION

A second meeting of the Advisory Committee on Mobility Environmental Research Study (Project MERS) was held at the Waterways Experiment Station (WES), Vicksburg, Miss., on 24-26 February 1964. The purpose of this meeting was to review the progress to date and the work planned for the coming year, to discuss the effectiveness of the Marsh Screw vehicle, and to make recommendations as to further development and testing of the Marsh Screw vehicle. A list of the Advisory Committee members, observers, and visitors is given on pages vii-ix. The program agenda is presented on pages xi-xiii.

Col. Sutton opened the meeting at 9:00 a.m. on 24 February by welcoming the attendants. He then briefly outlined the scope of the meeting and concluded with an introduction of those persons in attendance. Maj. Gen. Wienecke, representing the sponsor, followed with an emphasis on the need for Project MERS to find some solutions to the off-road mobility problem by 1 July 1966. Col. Lynch, chairman of the meeting, next announced that he would soon be reassigned and that his place in ARPA would be taken by Mr. Tedesco. Col. Lynch further announced that Prof. Woods had been assigned as chairman of the Advisory Committee for this meeting. Finally, the meeting was turned over to the cochairman, Mr. Shockley, who briefly outlined the purpose and scope of the meeting and then initiated the formal presentation of papers.

All papers presented at this meeting are published in full herein. Where significant, the papers are followed by a summary of pertinent discussion and questions.

WES MEGA STUDIES

by

W. E. Grabau*

The "Military Evaluation of Geographic Areas" project, which we tend to call "MEGA" for short, was first organized some 12 years ago, more or less as a direct response to the fact that our World War II armies were all too frequently surprised by environmental conditions with which they were not equipped to cope. The initial activating documents are delightful examples of that class of papers of which the Constitution is the outstanding sample, consisting of beautifully broad statements which one can interpret to mean almost anything. Reduced to essentials, they say that the MEGA study is to seek ways of improving the performance of U. S. Army anywhere in the world, through improved understanding of the relations between environments and military men, materiel, and operations. Of course there were some riders tacked on, mostly concerned with specific tasks, but that is the essence of the idea.

As might be expected, in the beginning we had trouble bringing the project into focus; it was too inclusive to be comprehensible. However, it rather quickly became apparent that there were some areas in which substantial gains could be achieved relatively quickly, so the project narrowed down to studies aimed at three basic problems.

First, the evidence of our recent wars suggested that our terrain intelligence could be improved; we needed better ways of <u>describing</u> environmental situations for military purposes.

Second, it was obvious that we were often surprised because we were ignorant of what environmental factors <u>caused</u> our many discomfitures.

Third, even when we had some insight into causative factors, we were unable to anticipate effects properly because we were unable to estimate the <u>magnitude</u> of the effects.

The MEGA project, then, has addressed itself to these three problems.

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* Chief, Area Evaluation Branch, Mobility and Environmental Division, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

In this context it should be noted that the MEGA project is concerned with <u>all</u> military activities, and in this sense it is extremely unspecialized. We are interested in the problem of a rifleman trying to peer through a screen of foliage in a tropical forest, at the same time that we are interested in the effects of varying kinds of snow on the effective burst radius of a fragmentation round, while at the same time being concerned with the problem faced by an off-road logistical cargo carrier trying to cross a desert arroyo.

From this, it is obvious that a major effort would need to go into the development of methods of describing and measuring all the multitudinous environmental factors which are either known, or which can be hypothesized to effect some military activity. Existing systems, derived from geology, geography, botany, ecology, zoology, and others proved inadequate, so we have been forced to try to develop our own. This, of course, led into the development of special methods of measuring environmental conditions in the field, and storing and manipulating this information in several ways. This effort continues at the present time. Current projects in this field are:

<u>a</u>. Marshall University is engaged in a basic study to refine and debug a quantitative system for describing what might be called the "military properties" of vegetation. Over the past two years they have studied the vegetation of southern Florida and central Wisconsin. The areas were deliberately picked to be as unlike as possible, so as to give the system as thorough a wringing out as possible. We have also provided them with vegetation data collected by our own teams in Puerto Rico and elsewhere. In the course of this study, we have reduced the high art of vegetation sampling to a relatively simple and rapid routine that can be accomplished by any reasonably intelligent three-man team after a few hours of instruction. The system includes measures of plant spacing, plant sizes, branching characteristics, leaf characteristics, thorniness, and many other properties known to affect one or many military activities. Tests of the system have been conducted in widely different environmental regimes, including Alaska, Arizona, Missouri, Wisconsin, Mississippi, Georgia, Florida, Puerto Rico, Panama, Colombia, and Southeast Asia.

<u>b</u>. The University of Southern California has just completed a report on a technique to describe microgeometry for military purposes. It is the culmination of a long series of efforts, which included studies of microgeometry in many parts of the U. S., and, recently, Southeast Asia. Briefly, it defines surface roughness--that is, the small irregularities of the surface that so

strongly affect the movement of men and machines, the effectiveness of artillery fire, and the cover of infantrymen--in terms of the coefficients of a special adaptation of Fourier series. This system has by no means been adequately tested, either in terms of its own internal consistency, or in terms of its utility. Obviously, if it is to be useful, its terms must be amenable to correlation with specific effects on military activities. This we will test in the near future.

In this context, it is of interest to note that the Land Locomotion Laboratory has been conducting a study involving the mathematical description of microgeometry, but using an application of power spectral density in a form specifically, and perhaps uniquely, capable of revealing relations between surfaces and the vehicles operating thereon. Needless to say, we are keenly interested in the products of their investigations.

c. Vanderbilt University is conducting a study of stream morphology for us, the objective of which is the development of a quantitative system for describing the array of related factors which we call hydrologic geometry. This subject has proven to be extremely troublesome. We have been making attempts at this problem for some time, but the results thus far have been unsatisfactory. This is probably because we have not yet learned how to state the problem. For example, when a stream is considered from the point of view of the cross-country mobility analyst, one finds that the problem is normally not the stream itself, but rather, the question of getting into the stream, and getting out of the stream. That is, the area of greatest importance is the narrow zone where water, land, and air come together. We have come to call this the "water-land interface," and have designed a special study to examine the properties of such systems without regard to whether they are associated with streams, canals, lakes, or whatever. Thus, it may be that we do not have a "hydrologic geometry" problem; instead, we have an interface problem of a special kind.

Actually, we are not precisely starting from scratch on this. A short time ago one of our contractors, Drexel Institute of Technology, investigated the possibility of describing and classifying the shapes of channel cross sections by means of Chebyshev polynomials. Classification could be accomplished by grouping similar coefficients of the terms of the appropriate polynomial. While this approach was interesting and certainly ingenious, it failed in its primary purpose for reasons which we need not discuss here. This method of describing channel shape will probably not be wasted; it appears to be a much more accurate and convenient method of storing channel configuration information for hydrological purposes (that is, estimation of discharge, etc.) than any previously known method. We understand that Drexel is continuing their studies in this direction.

Most of the work in soil mechanics in which MEGA is interested is being funded primarily by other projects; we simply try to keep up with the times. However, we have contributed modest sums to these projects for special investigations of particular interest to us. It should be remembered that our interests are catholic; soils, from our point of view, are materials to build roads and airfields with, to dig foxholes in, to receive the impact of shells or bombs, to support vehicles, and so on. The existing descriptive and classification systems appear to be inadequate for all these purposes, so we are continually seeking new approaches. To this end, for example, we contribute to a project being conducted by the Massachusetts Institute of Technology, the overall objective of which is to develop suitable methods for stabilizing tropical soils. Our interest in this is the revelation of chemical and physical properties of such soils, which MIT measures in pursuit of a larger goal. We also contribute to a study of the mineralogy of tropical clays, being conducted by the WES Concrete Division. Here, our interest is in the relation between clay minerals and physical properties, hoping that we will discover a way to identify clay types in the field, and thus permit rapid evaluation of certain engineering properties. Soils have been collected for study from Costa Rica, Puerto Rico, and Thailand.

One long-standing handicap to the MEGA project is the lack of detailed environmental information in quantitative terms. For example, we do not know, nor can we obtain from existing literature, accurate information on the range of tree spacings and trunk diameters, which is a matter of military concern for several reasons. How big and how far apart do trees become in various types of forests around the world? We don't know. Everybody knows that rice fields have dikes between the fields. How big are they, and how are they shaped, and how far apart are they in various places? We don't know, nor will the existing literature tell us. Nor can one detect these from air photographs, because the scale of photography is usually too small to permit actual measurement. And so on, through almost every significant environmental factor one can name. Furthermore, it usually comes as something of a surprise to find out that our ignorance is not confined to the exotic parts of the world. In most cases, we don't know what the conditions are in our own country. What measurements do ravines in Mississippi exhibit? We know very little.

As a result, we have been forced into relatively elaborate programs to collect our own information. To this end, we have conducted, or are conducting, basic environmental data-collection programs in many places: Arizona, California, Missouri, Wisconsin, Kentucky, Georgia, Florida, Mississippi, Puerto Rico, Panama, Colombia, Costa Rica, Alaska, and Manitoba, to name the most important. And, of course, under ARPA's auspices, in Thailand.

The effort in Puerto Rico has been especially fruitful. Not only have we gathered very large amounts of information on tropical environments, which was the primary purpose in establishing the team there, but our team has developed into a sort of independent research agency. When we, or one of our contractors, has a bright idea about sampling procedures or the like, we send it to Mr. Benn in San Juan. He sends his people out, and they give it a thorough field test. Usually it comes back all full of red marks, so that the next time around it works much better.

As an example, the field procedures which we plan to use in Thailand have all been field-checked by our Puerto Rico detachment. This doesn't cost ARPA anything, but it will certainly save some blood, sweat, and probably tears, in Thailand.

The last remaining major problem is to measure the kind and magnitude of effects imposed by specific environments on military activities of various kinds. Our program in this area is new, but we plan to expand it as rapidly as possible. For example, a major current effort is to determine the effects of vegetation on visibility. We have developed an internally consistent method of measuring visibility, and we believe that we can correlate those measurements with considerable precision to actual field situations. This will contribute directly and immediately to MERS, since other tests have demonstrated that inhibition to driver vision is a vital factor in cross-country mobility through vegetation. Incidentally, this procedure is now being run through our Puerto Rico detachment for evaluation.

We have also recently conducted some tests, using standard vehicles operating in very carefully described environments, in Arizona and

Mississippi, primarily to provide us with some insight into the proper design of valid cross-country mobility tests. In addition to refining our design of experiments, the tests have given us, as a sort of fringe benefit, some valuable data on the effects of certain combinations of environmental factors on vehicle mobility. As a matter of fact, for example, our present concern over the importance of microgeometry stems in large part from our experience during these tests. Of course, our observers at such exercises as Swamp Fox I and II tended to reinforce our concepts.

We have also learned considerable about the effects of such things as tree spacing on both vehicles, visibility, and small arms fire. All of this is directly pertinent to MERS objectives, and will, of course, be exploited to the greatest extent possible.

This, I think summarizes the more important of the activities of MEGA. We think that you will agree that large portions of our present and previous research are of direct use to the MERS object.

WES TRAFFICABILITY, TERRAIN ANALYZER, AND MOBILITY STUDIES

by

S. J. Knight*

Introduction

WES has been conducting research in trafficability for 18 years, in mobility for 6 years, and in the terrain analyzer field for 4 years. In a half hour I cannot, of course, do justice to this combined total of 28 years of research. I will have to hit the high spots and skip the details to give you the most for your money. My talk will be mainly about trafficability because it is a little more pertinent to MERS than the other two subjects, and also because the other two subjects will come up again on the tour scheduled for later today.

Trafficability

The objective of the trafficability research is to develop tools and techniques for measuring or estimating the ability of level and sloping soils to permit the traffic of a military vehicle. The measurement phase usually is referred to as the contact phase; the estimation phase usually is called the noncontact or remote phase.

Vehicle performance-cone index relations

Perhaps the principal accomplishment of the contact phase has been the development of empirical relations between vehicle performance and soil strength. Vehicle performance has been mainly in terms of go or no-go on a 50-pass basis, the maximum slope a vehicle could climb, or the maximum drawbar load it could continuously tow. Soil strength is in terms of cone index with the familiar cone penetrometer.

Along with the vehicle performance-cone index relations, there have been developed empirical formulas which permit the computation of the minimum cone index required to support a vehicle from data on the vehicle's physical characteristics. Fig. 1 illustrates the kind of accuracy that

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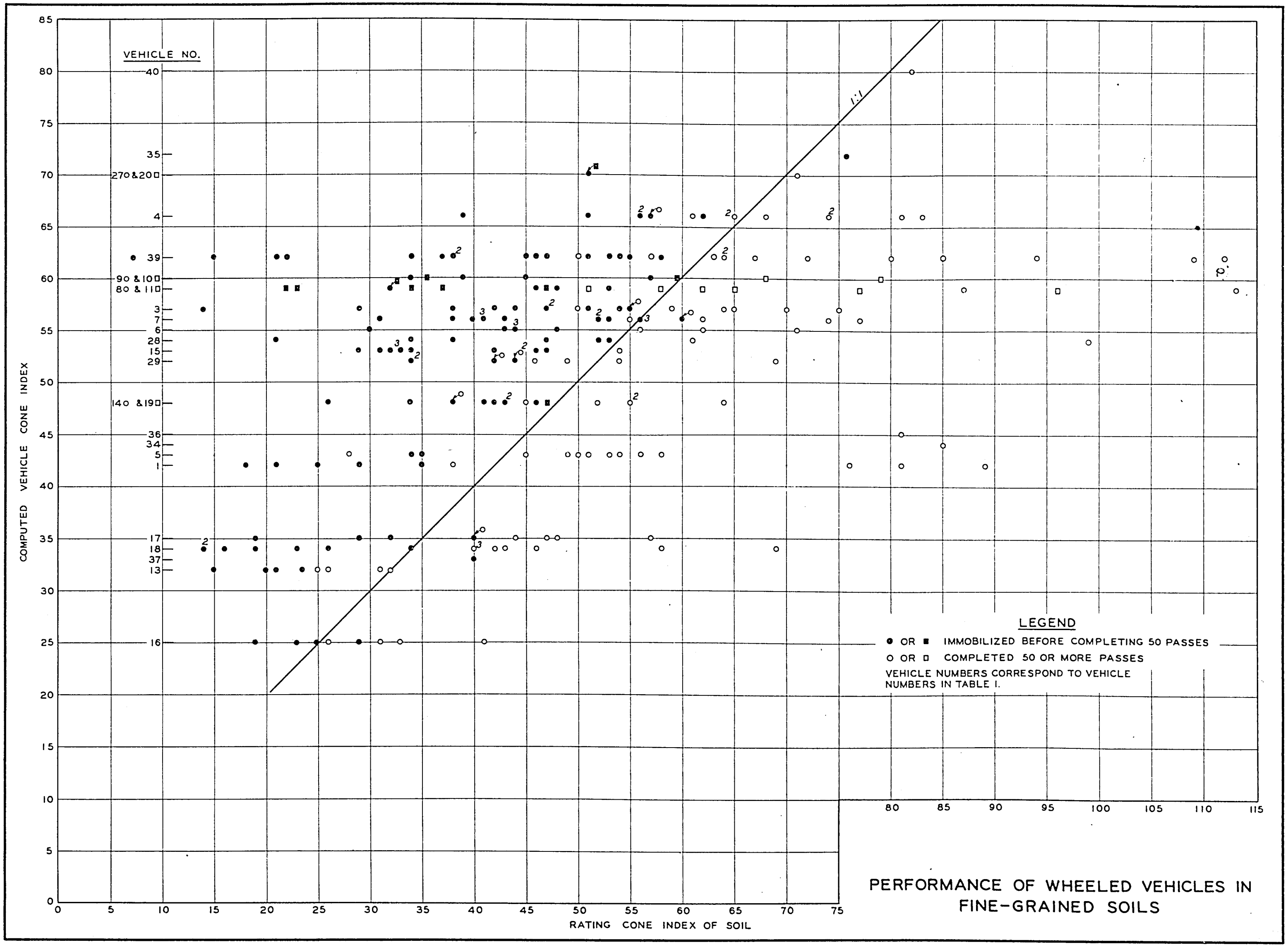
* Chief, Army Mobility Research Branch, Mobility and Environmental Division, Waterways Experiment Station, Vicksburg, Miss.



PERFORMANCE OF WHEELED VEHICLES IN FINE-GRAINED SOILS

Fig. 1.

Table 1

Vehicle Data

Fine-Grained Soils

Vehicle No.	Vehicle	Tire Size	No. of Wheels	Weight lb	Vehicle Cone Index	Nominal Contact Pressure psi*	Projected Contact Pressure psi
			Wheeled Vehicles				
1	16-ton GOER XM437E1 (empty)	29.5-25	4	39,300	42	17	4.5
2	16-ton GOER XM437E1 (loaded)	29.5-25	4	71,070	79	--	8.1
3	5-ton GOER XM520	18.00-26	4	26,667	57	17	6.0
4	5-ton GOER XM520	15.00-34	4	26,667	66	19	6.9
5	6x6 Meili Flex-Trac	10.00-20	6	9,100	43	26	3.8
6	4x4 Meili Flex-Trac	10.00-20	4	9,100	55	27	5.7
7	Tournadozer	21.00-25	4	31,209	56	21	6.0
8	2-1/2-ton M135	11.00-20	6	17,700	59	31	6.4
9	2-1/2-ton M34	11.00-20	6	17,500	60	31	6.3
10	3/4-ton M37	9.00-16	4	7,475	60	24	6.1
11	4-ton, 6x6 truck	14.00-20	6	25,100	59	27	6.2
12	6-ton, 6x6 truck	14.00-20	6	34,800	81	35	8.6
13	1/2-ton M274 (mule)	7.50-10	4	1,100	32	15	1.5
14	Bucket loader	14.00-24	4	13,815	48	19	4.7
15	1/4-ton Willys station wagon	7.00-15	4	3,665	53	--	4.5
16	1/4-ton M151 (jeep)	36x20-14	4	3,450	25	15	1.3
17	1-1/2-ton Powerwagon	46x18-16	4	9,500	35	15	2.9
18	Gama Goat	12.4/11-16	6	5,770	34	--	2.4
19	2-1/2-ton M49	9.00-20	10	13,490	48	28	3.9
20	XM409E1 truck	16.00-20	8	46,450	70	--	7.0
21	Rough terrain forklift	16.00-24	4	30,625	77	--	8.5
22	BARC	36.00-41	4	197,000	174	22	12.0
23	5-ton LARC	18.00-25	4	28,000	56	--	6.4
24	15-ton LARC	24.00-29	4	65,060	87	--	8.8
25	2-1/2-ton DUKW	11.00-18	6	20,055	74	27	7.6
26	1/4-ton M38 (jeep)	7.00-16	4	3,250	50	21	4.1
27	5-ton M41	14.00-20	6	30,185	70	27	7.5
28	4x4 Jumbo truck	18.00-26	4	20,100**	54	21	6.3
29	3/4-ton M37 (empty)	9.00-16	4	5,925	52	23	4.8
30	Marsh buggy	33.5-66	4	11,990	22	--	0.7
31	Marsh buggy	18.00-25	4	11,745	35	--	2.7
32	Marsh buggy (model)	9.00-14	4	180	9	19	0.2
33	Marsh buggy (model)	6.00-16	4	210	16	15	0.3
34	3/4-ton XM408	7.00-16	6	4,562	44	21	3.7
35	8-ton XM520E1	18.00-33	4	43,410	72	--	7.6
36	3/4-ton FC-170	9.00-16	4	6,920	45	23	4.3
37	2-1/2-ton XM410	16.00-20	8	15,050	33	--	2.3
38	Saracen APC	11.00-20	6	22,400	79	32	8.8
39	2-1/2-ton, 6x6 truck	10.50-18	6	16,300	62	25	6.6
40	GOER, 5000 gal, XM438E2	29.5-25	4	72,000	80	--	8.2

* Nominal contact pressures are for tire inflation pressure of 15 psi.
** Weight of 14,000 lb used to obtain vehicle cone index.

has been achieved in these two areas. The figure shows a plot for wheeled vehicles on level, fine-grained soils. The X-axis is rating cone index, which is the measured in-situ strength of a soil modified by a factor called remolding index. This modification is necessary since practically all soft field soils become even softer under a moving vehicle. The rating cone index is thus the effective strength of the soil under a vehicle. The Y-axis is vehicle cone index. This is the minimum rating cone index required by the vehicle, computed from the formulas I mentioned. The various vehicles which have been tested are represented by numbers along the Y-axis. Vehicle names corresponding to these numbers may be found in the table following fig. 1. Each point on the plot represents an actual test with a vehicle. There are some 226 tests on 27 vehicles represented. The open symbols indicate that the vehicle was able to complete 50 passes; the closed symbols show that the vehicle was immobilized before completing 50 passes because of inadequate soil strength. Thus, if there is any merit in the idea that cone index measures soil strength from a vehicle standpoint, all the open symbols should fall to the right of all the closed symbols; and if the vehicle cone index formula is valid, the 1:1 line should exactly divide the two kinds of symbols. In fact, the separation is not perfect, as you can see for yourself. A count will reveal that 22 tests were on the "wrong" side of the line, or, in other words, the accuracy is a little better than 90 percent.

This accuracy of about 90 percent also is maintained for tracked vehicles on fine-grained soils and for all vehicles on coarse-grained soils. We have also investigated the trafficability of snow and muskeg, and while this work is not yet quite complete, the available data show that an accuracy of about 75 to 80 percent can be expected at present. We hope to improve this somewhat with further testing.

You will remember that I stated that the ability to travel 50 passes is the "go" criterion for a vehicle. Tests designed on this basis do not, of course, always lend themselves to analysis on a one-pass basis. However, some of them did, and a study shows that 75 percent of the minimum strength required for 50 passes is more than adequate for one pass. Field studies are being made to shed additional light on the one-pass problem, and Mr. Nuttall will discuss these tomorrow.

Soil classification

Another important accomplishment in the contact phase has been the development of a scheme for classifying soils from a trafficability standpoint. This has consisted of a statistical analysis of 1300 pieces of data collected in the United States to determine means and ranges of pertinent trafficability parameters for soils typed according to the United States Department of Agriculture system and the Unified Soil Classification System (USCS).

When soils are relatively dry, their trafficability is generally good, and there is little need to distinguish one from another. However, as moisture content increases, soils become less and less trafficable and soil type per se takes on importance. Every natural soil attains a maximum moisture content provided it is exposed to enough rainfall. Additional rainfall merely percolates through to deeper depths of no interest to us from a trafficability standpoint, or becomes surface runoff. While the absolute values of these maximum moisture contents vary widely from soil to soil, the fact that they occur gives us a common datum and thus a valid basis for comparing and classifying soils. The present scheme is simply a statistical analysis that considers two general moisture conditions--that is, the moisture condition prevalent during a rain when all voids are filled and free water is draining downward through the soil, and the moisture condition several hours after a rain when the free water has drained, but the voids are still filled. The former is called the maximum moisture condition, the latter the average wet-season condition. The scheme also distinguishes high-lying, well-drained topographic positions and low-lying, poorly drained positions. So far, we have not been able to specify the influence of other environmental factors, such as vegetation, parent material, and land use, although we feel that the influence of these factors could be demonstrated statistically if enough data become available.

To illustrate the scheme, I have selected fig. 2. Let us employ the scheme in a hypothetical case. We know the following information:

a. We are in a humid temperate climate.

b. We have a map showing soil types in USCS terms.

c. We know the soils are at their wet-season condition of moisture content.

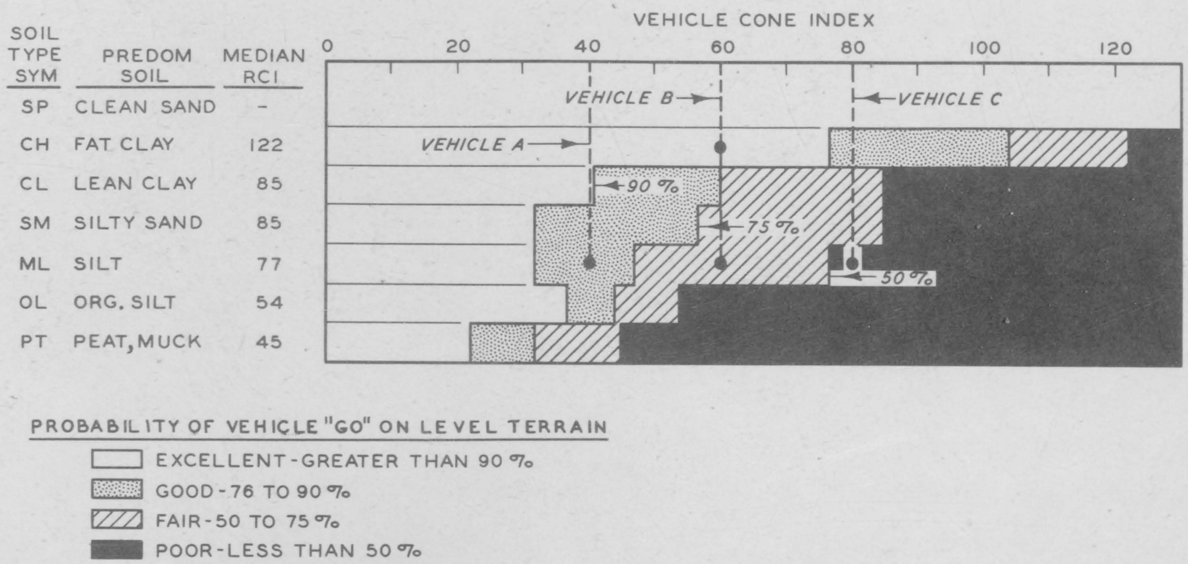


Fig. 2. Soil trafficability classification in USCS terms, low-topography, wet-season condition

d. We know low-topography conditions predominate.

e. Our vehicle has a vehicle cone index of 80.

We want to determine the probability of success of our vehicle on the various soil types. To do this, we simply match 80 to the various symbols corresponding to the soil type. For example, we can see that the probability of success is excellent (greater than 90 percent) in SP soils; good, that is between 76 and 90 percent, in CH soils; between 50 and 75 percent in CL and SM soils; and poor in ML, OL, and Pt soils.

I emphasize that the scheme is simply a statistical analysis and not rational in the sense that the reasons for soil strength occurrence can be pinned down in specific terms. Also remember the data represent only soils in humid temperate climates. We have collected some data in tropical climates, but as yet there are not enough to work up a comparable soil classification scheme for the tropics. We hope that the MERS program will provide enough data to make such a scheme feasible.

Soil-weather relations

Now let us turn to the noncontact phase of trafficability. Here the principal accomplishment has been the development of a system for predicting soil moisture content. If soil moisture content can be predicted, and if soil type is known, then an estimate can be made of soil strength in terms of cone index.

The soil moisture prediction system permits one to trace the march of soil moisture on a daily basis, provided he has knowledge of or can estimate a number of factors. The four most important are:

a. The amount of rain falling in a 24-hr period.

b. The field maximum and minimum moisture contents of the soil.

c. The percentage of a rainfall that normally will be effective in increasing soil moisture. This is called the accretion relation.

d. The rate at which a soil will dry out. This is called a depletion relation.

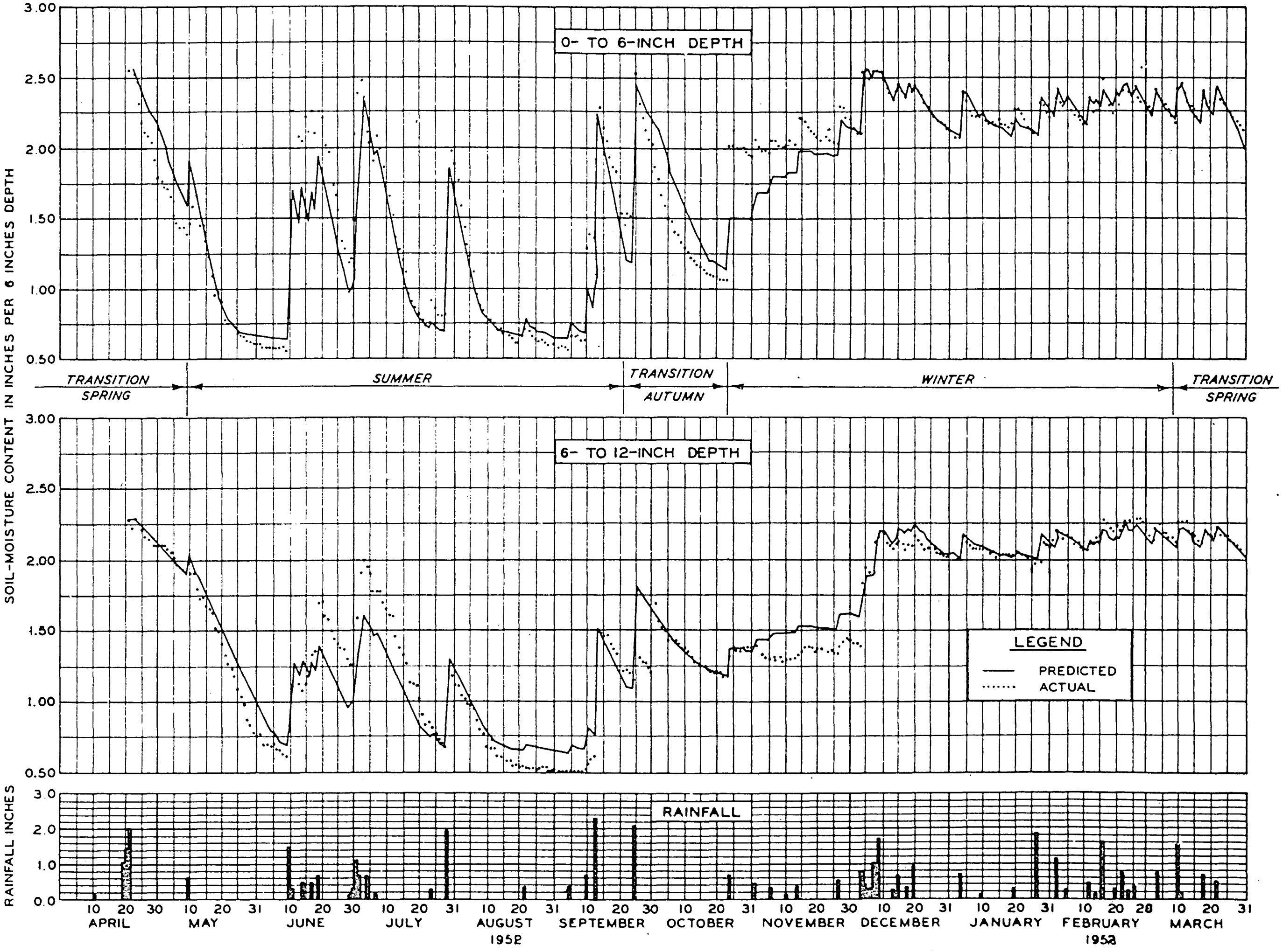
The system then is simply a day-by-day accounting procedure. Beginning with a known or estimated moisture content, this value is increased on a day in which rain falls and decreased on a day in which no rain falls.

To illustrate the system, take a look at fig. 3. This is typical, neither much better nor much worse than the several dozen such plots on file. The abscissa is time and the ordinate is rainfall for the bottom block and moisture content for the two top blocks. Moisture content is on a volumetric basis--inches of water per 6-in. layer of soil. The predicted values of moisture content are shown as a continuous line, the measured values as points.

Notice the high moisture contents following the rainfall for several days at the end of November, and the consistency of the moisture content from that time until the middle of April. This is the wet season. The average value during this period is roughly equivalent to the maximum (drained) moisture content. The average of the peak values represents the condition measured during or shortly after a rain.

The system has been tried out on approximately 750 sites with an average error of 2 to 3 percent moisture content between actual and predicted values. The accuracy is considerably better than this during the wet season, of course. This is all to the good, since trafficability usually is only a problem when a soil is at or near its maximum moisture content.

Recently, data have been collected from soils in Hawaii, Panama, Puerto Rico, Costa Rica, and Colombia. The analysis of these data is well advanced and shows that the same degree of accuracy may be expected in tropical soils. The system employed for tropical soils is the same as for



SOIL-MOISTURE PREDICTION
PARK SITE

Fig. 3.

temperate soils. Only the constants differ. The system also worked--with proper constants--for a few soils tested in Alaska some years ago. There is every reason to believe, therefore, that equally accurate prediction of moisture content will be possible for soils in Southeast Asia.

Airphoto studies

Another important accomplishment in the noncontact phase has been the study of the use of airphotos for estimating trafficability conditions. This work, done by contract with Purdue University, shows that a certain measure of success can be had through the use of conventional aerial photography. Provided the analyst is sufficiently experienced, he can make reasonable interpretation of the soil type, drainage features, topography, vegetation, etc., and synthesize these into a trafficability estimate. The Purdue work has really not advanced the art of photo interpretation significantly--nor was it expected to--but it has provided quantitative values of moisture content and cone index measured on the ground to accompany typical airphotos. The Purdue effort is probably best exploited in an analogous sense, that is if you have a photo of area X and can match it with a photo in the Purdue report, you can assume the trafficability data that accompany the Purdue photo to apply also to area X , with proper allowance for changes in climate. Airphoto analysis is, of course, an important part of MERS plans.

Other trafficability studies

Other important trafficability studies have been concerned with an aerial cone penetrometer, with the development of techniques for trafficability mapping, and with special trafficability-type tests on new vehicle concepts from time to time. One such special test, with the Marsh Screw Amphibian, will be discussed this afternoon.

Work remaining to be done

Before leaving the subject of trafficability, I will simply mention the most important areas in which further study is needed:

a. A moderate amount of fieldwork is required to bring the contact phase on snow and muskeg to an acceptable level.

b. Schemes must be developed for classifying coarse-grained soils, snow, and muskeg.

c. The classification scheme for fine-grained soils must be refined and extended to include tropical and arctic soils.

d. Means must be developed for predicting changes with time and weather in the trafficability of coarse-grained soils, snow, and muskeg.

Terrain Analyzer

In turning to the terrain analyzer studies, I am really extending the discussion on noncontact trafficability, because the overall aims and objectives are the same; namely, the development of instruments and techniques which will allow the estimation of trafficability of soils from a remote source. The main difference in the two studies is in the manner of their performance. Whereas, in trafficability research "conventional" means are employed, the terrain analyzer research seeks to exploit more exotic devices and techniques; namely, the devices and techniques of the rapidly growing science of terrain interrogation using sensors operating in various portions of the electromagnetic spectrum.

Much has already been done by others in the way of identifying targets, exposing underground installations, and revealing natural and cultural features at night and through cloud cover, using infrared and radar, and these efforts are continuing. Needless to say, we are not in this business. Our business is concerned with the problem of distinguishing one soil type from another, of measuring the existent moisture content and density of soils, and, hopefully, of even directly measuring the strength of soils. And as we pursue our business, we hope to increase it to include the determination of vegetation types and density, slope and roughness factors of the terrain, depth to water table, and information on the many other characteristics of the environment that affect military activities.

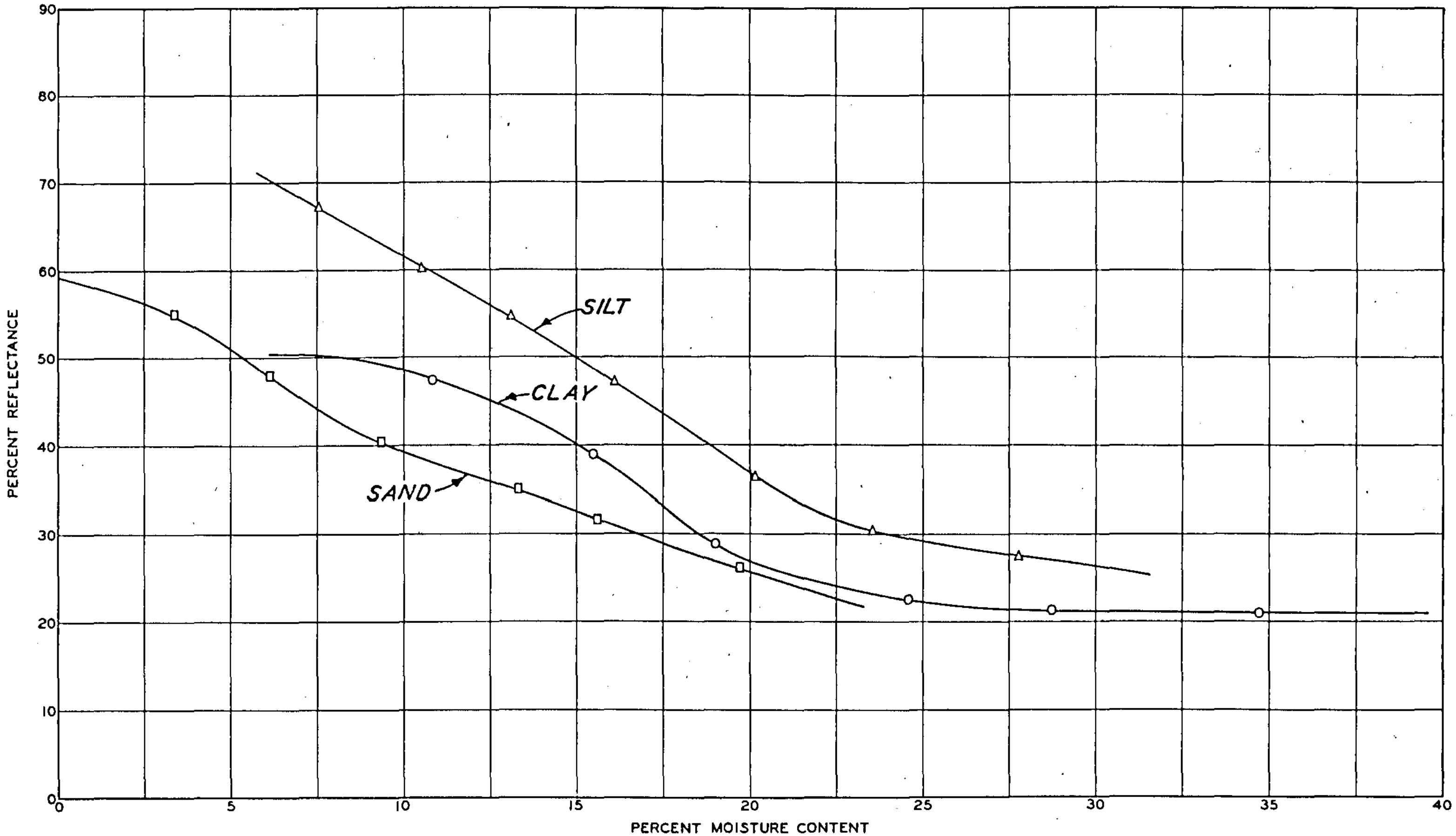
Our effort is divided into two main phases--a laboratory or feasibility phase, and a field phase. We are currently in the middle of the laboratory phase.

Realizing that no one portion of the electromagnetic spectrum is likely to be sufficient by itself to measure the various terrain factors, our program will include investigations in all portions of the spectrum which offer promise as remote sensors. To date we have completed a reasonably comprehensive program using infrared and are presently conducting studies with radar, gamma ray, and passive microwave.

Since your tour includes a briefing on the radar, gamma-ray, and passive-microwave work and a visit to the laboratories, I am only going to talk about infrared. We have performed a total of 850 tests on several soil types at varying moisture content and density, and have demonstrated that, at least in the laboratory, infrared may be used successfully to distinguish soil types and measure moisture content. Because of its very short wavelength (0.76 to 5.00 microns), infrared did not successfully measure density. For the same reason, infrared, which cannot penetrate vegetation, will never be adequate by itself as a field device in identifying soils or measuring moisture content.

To illustrate the utility of infrared in identifying soils and measuring moisture content in the laboratory, let us look at fig. 4. This is a plot of the percent energy at the 1.75-micron level reflected from a soil sample versus percent moisture content. Three soils are represented, and each soil has its own characteristic curve. Knowing the soil type and the percent reflectance, it is an easy matter to determine the moisture content. But, what can be deduced if we are not certain of the soil type and know only that 40 percent of the energy is being reflected? The answer is that the soil could be sand at 9.5 percent moisture content, clay at 15 percent moisture content, or silt at 19 percent moisture content. To resolve this, one needs another examination, perhaps several other examinations, of the soil at other infrared wavelengths or perhaps with radar or some other portion of the electromagnetic spectrum, because these examinations will reveal different characteristic curves and should permit a confident analysis by cross comparison. This example illustrates the necessity for the multisensor approach and, incidentally, should convey the idea that analysis of the data will be facilitated by computer methods.

Obviously, much remains to be done in terrain analyzer research before we can effectively fly a black-box-equipped aircraft over enemy terrain and transmit readily deciphered information on the terrain to a military commander 1000 miles away. Our immediate plans call for completion of the laboratory phase in gamma ray, radar, and passive microwave within the next year or so, emphasizing analysis of data and report writing, accomplishment of special studies for MERS such as the one Mr. Davis will describe tomorrow, and initiation of pilot field studies about 1 July 1965.



COMPARISON OF SOIL TYPES
SAND, SILT, AND CLAY
WAVELENGTH - 1.75 μ

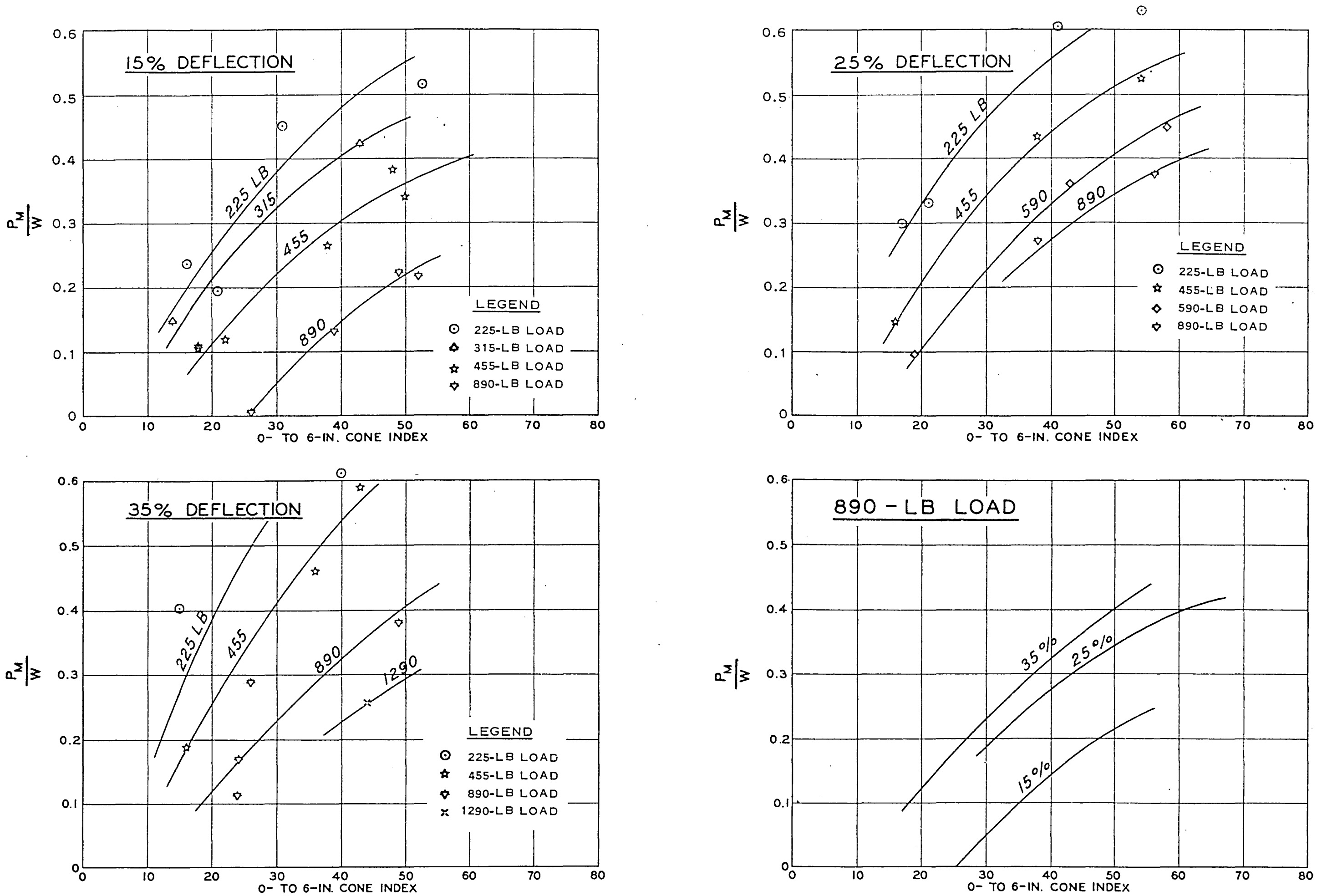
Fig. 4.

Mobility

Mobility research and trafficability research are often confused--and well they may be--since they both are concerned with the relations between vehicles and soils. However, we make certain distinctions here at the WES between the two. We see the trafficability work as an attempt to provide military commanders with useful field devices for helping them with decisions involving the movement of the vehicles under their command. We thus have sought simple tools and techniques capable of rapid employment in the field. We have not been particularly compelled to seek fundamental reasons why certain vehicle-soil relations exist, but only to make sure that there are good means of predicting their repeatability. The mobility research, on the other hand, aims higher. It attempts to develop fundamental relations between moving vehicles and the media upon which they move, in general but precise mathematical terms. Mobility research may be called an attempt to develop a basic science that will serve the land-vehicle designer in the same way that aerodynamics serves the aircraft designer.

Our greatest effort in mobility research to date has been on a program requested by the Chief of R&D, Army, to develop quantitative knowledge of the effects of varying tire dimensions and inflation pressures on the performance of the tire in various soil conditions. The immediate goal here is to provide quantitative information on tire performance that can be compared with cost and thus used to select the tire size which will be commensurate economically with the mission and desired mobility of the vehicle.

Three soils are involved in this work--sand, clay, and silt. We have virtually finished the testing on sand, and are halfway through the tests on clay. I will use a couple of plates illustrating some of our findings in sand to help focus this work. The first, fig. 5, is for one tire, a 6.00-16, 2-ply rating tire in sand. The maximum drawbar pull-weight ratio is plotted against the 0- to 6-in. cone index in each subfigure. Subfigures a, b, and c are for particular tire deflections--15, 25, and 35 percent, respectively. Each curve represents a different load. Subfigure d is for one load and three deflections. Percent tire deflection is actual deflection on a hard surface divided by tire-section height, and



LEGEND

P_M MAXIMUM PULL, LB

W TIRE LOAD, LB

FIRST PASS PULL COEFFICIENT

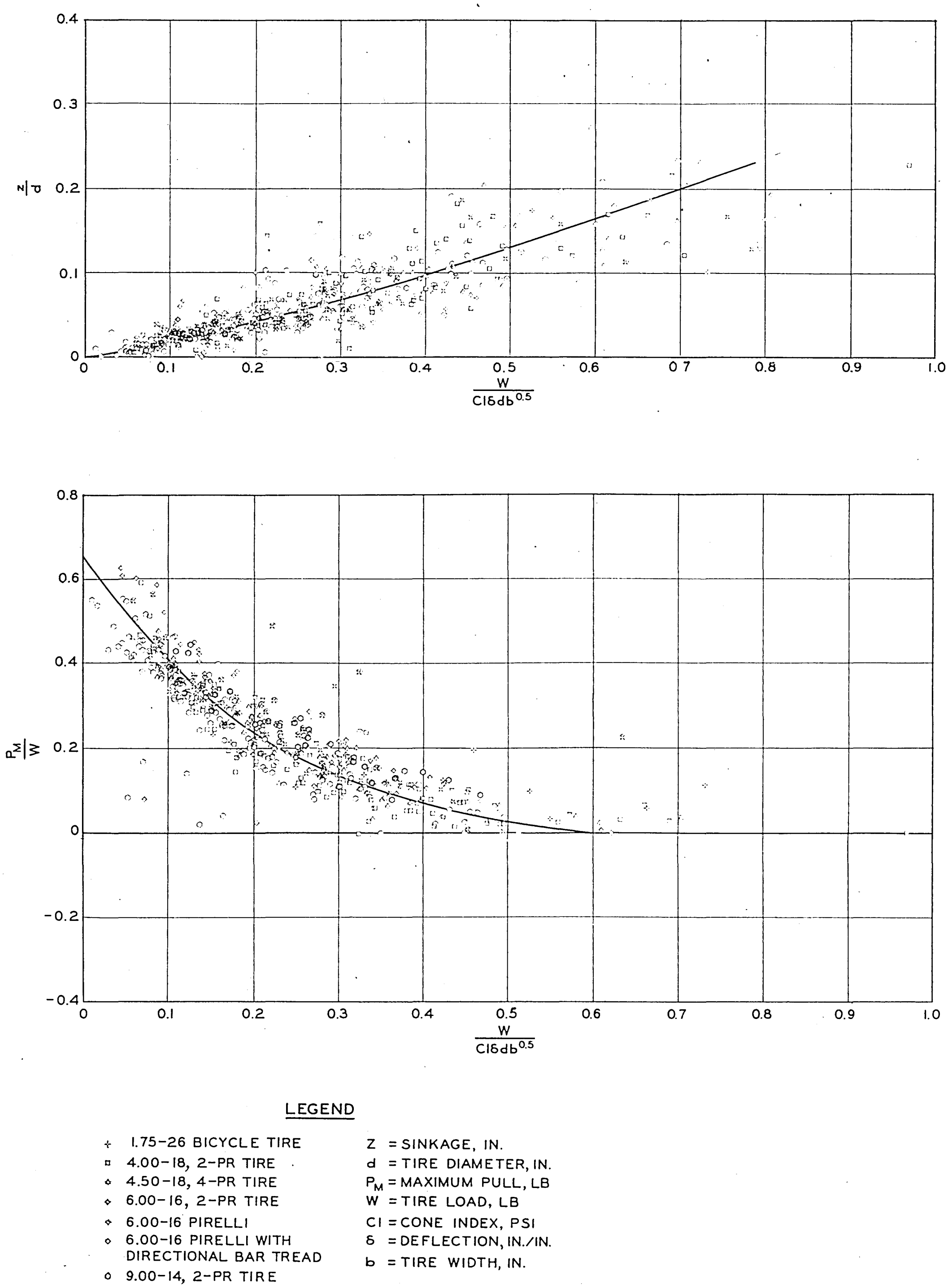
6.00-16, 2-PR TIRE

Fig. 5.

is a more useful criterion than tire-inflation pressure since it is indicative of the tire shape. It was felt that tire shapes had to be constant in these kinds of comparisons. In this example, each curve permits us to evaluate the effect of soil strength on drawbar for the given tire at a constant load and deflection. The effect of load at a given deflection may be evaluated by inspecting the several curves in one subfigure. Finally, at a given load (890 lb in this case) the effect of deflection may be seen. This kind of analysis--namely, that of systematically varying one parameter while maintaining others constant--has been the technique used in this particular study. Investigations have been made of the relations of the various wheel factors--tire diameter and width, ply rating, and inflation pressure--to the various soil factors--type, moisture, density, and strength--expressing tire performance in terms of towed force, drawbar pull, slippage, and sinkage.

It has not yet been possible to write a completely comprehensive, fully defensible theory or equation of mobility from the work done so far. However, some measure of success has been achieved in this general direction by the use of numerics. One such numeric is shown in fig. 6. Others have been used, some with considerably more success. This one, however, will serve to illustrate the numerics technique. The dependent variables--W = load, CI = cone index, δ = percent deflection, d = tire diameter, and b = tire width--are combined in the fraction shown and plotted against $\frac{z}{d}$, that is, sinkage over tire diameter, in the top figure; and $\frac{P_M}{W}$, that is, the maximum drawbar pull over the load, in the lower figure. In each case, the result is a single curve, but with a considerable amount of scatter. These are, of course, in a final sense, empiric plots. However, if one accepts the limitations of the data they represent, they can be used to assess the performance of a tire or to compare the performance of one tire with another in quantitative terms.

The more fundamental aspects of the mobility research can be illustrated by the measurements we are making to learn something of the pressure distribution pattern at a tire-soil interface and the deformation that occurs in a tire. We recognize that such studies are prerequisites to a proper understanding of tire-soil relations and thus to the generation of comprehensive theories of vehicle mobility.



LEGEND

- ✢ 1.75-26 BICYCLE TIRE
- ▫ 4.00-18, 2-PR TIRE
- ⋄ 4.50-18, 4-PR TIRE
- ⋄ 6.00-16, 2-PR TIRE
- ⋄ 6.00-16 PIRELLI
- ⋄ 6.00-16 PIRELLI WITH DIRECTIONAL BAR TREAD
- o 9.00-14, 2-PR TIRE
- ⋄ 9.00-14, 4-PR TIRE
- ⁙ 9.00-14, 8-PR TIRE
- ⊙ 4.50-7, 2-PR TIRE
- ▫ 5.00-12, 2-PR TIRE
- ⊖ 16-15-6R TERRA TIRE

Z = SINKAGE, IN.
d = TIRE DIAMETER, IN.
P_M = MAXIMUM PULL, LB
W = TIRE LOAD, LB
CI = CONE INDEX, PSI
δ = DEFLECTION, IN./IN.
b = TIRE WIDTH, IN.

$\frac{z}{d}$ AND $\frac{P_M}{W}$ VS $\frac{W}{CI\,\delta\,d\,b^{0.5}}$

ALL TIRES
MAXIMUM PULL POINT

Fig. 6.

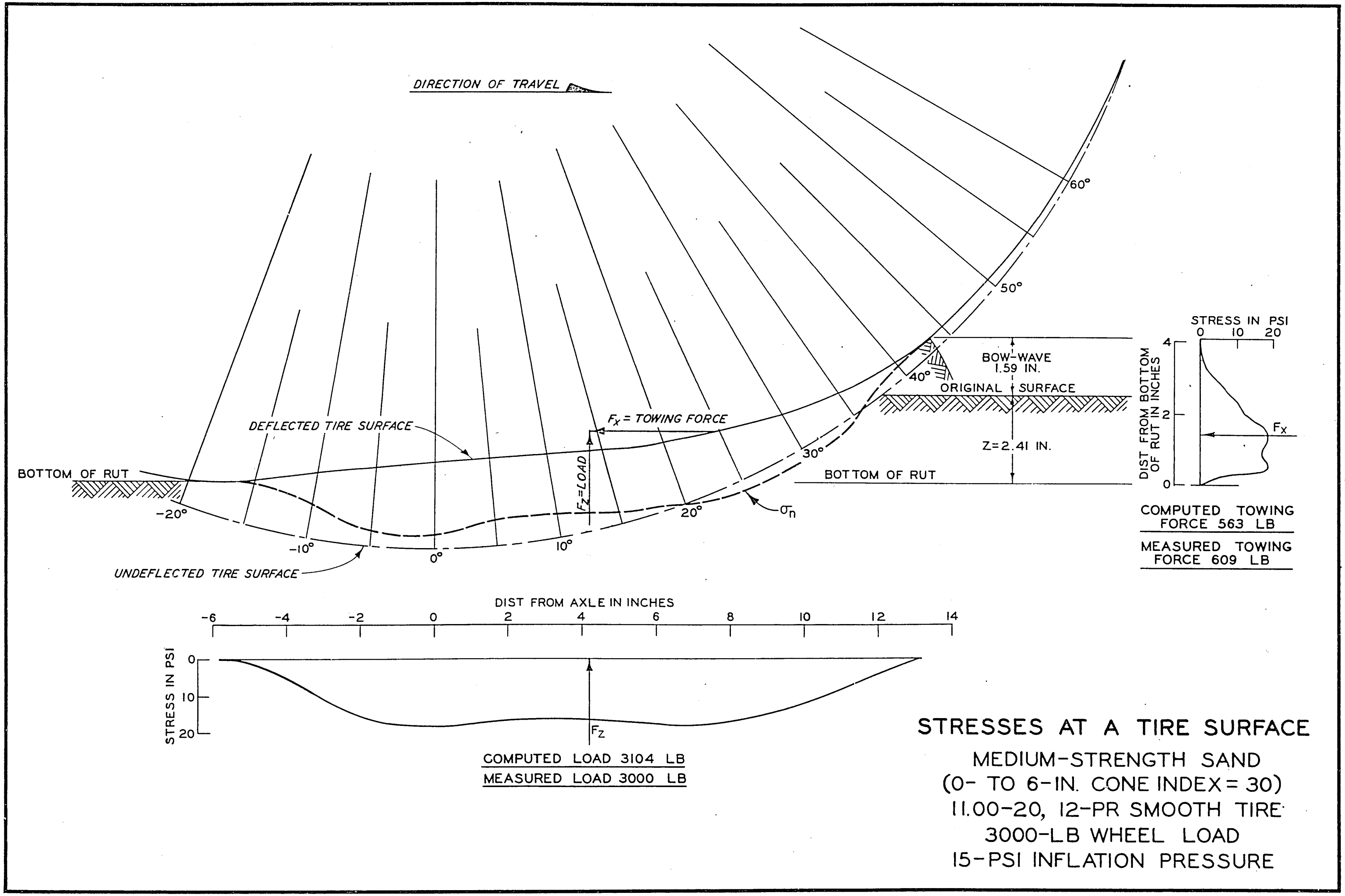
Stresses are measured at the tire-soil interface with pressure cells the diameter of a nickel embedded in the rubber of the tire. Each cell begins to measure a stress the instant it contacts the soil and continues to measure a stress until it leaves the soil again. The proper conversion of the cell measurements will permit the construction of a stress diagram such as the one in fig. 7. The contact normal stresses are shown on the heavy dashed line marked σ_n . Their horizontal components are shown to the right and their vertical components below. Note the reasonably good agreement between the summation of the vertical components, 3104 lb, and the measured load of 3000 lb at the bottom of the page, and the comparison of the computed and measured towing forces on the right. Such a diagram can help determine the resolution of horizontal and vertical forces, a necessary step in formulating theories of vehicle movement. Various tires, loads, inflation pressures, and soil conditions are used in this study.

The tire deformation work consists of the measurement of the ever-changing cross section of a tire as it moves through the soil. This is done by installation of deflection gages within the tire itself. A schematic diagram of an installation is shown in fig. 8 and consists of a linear potentiometer and a circular potentiometer. The point of the gage is embedded in the tire and moves with the tire. Thus not only inward and outward movement can be measured for a point in the tire, but also clockwise and counterclockwise movement.

Important in itself for revealing the exact sinkage a tire undergoes in a particular test and the exact shape the tire takes, it also is necessary to the proper interpretation of the stresses measured by the cells mentioned previously. Since these cells measure a normal stress, the exact location of the cell must be determined, and this is done from a measurement of the tire deformation that occurs.

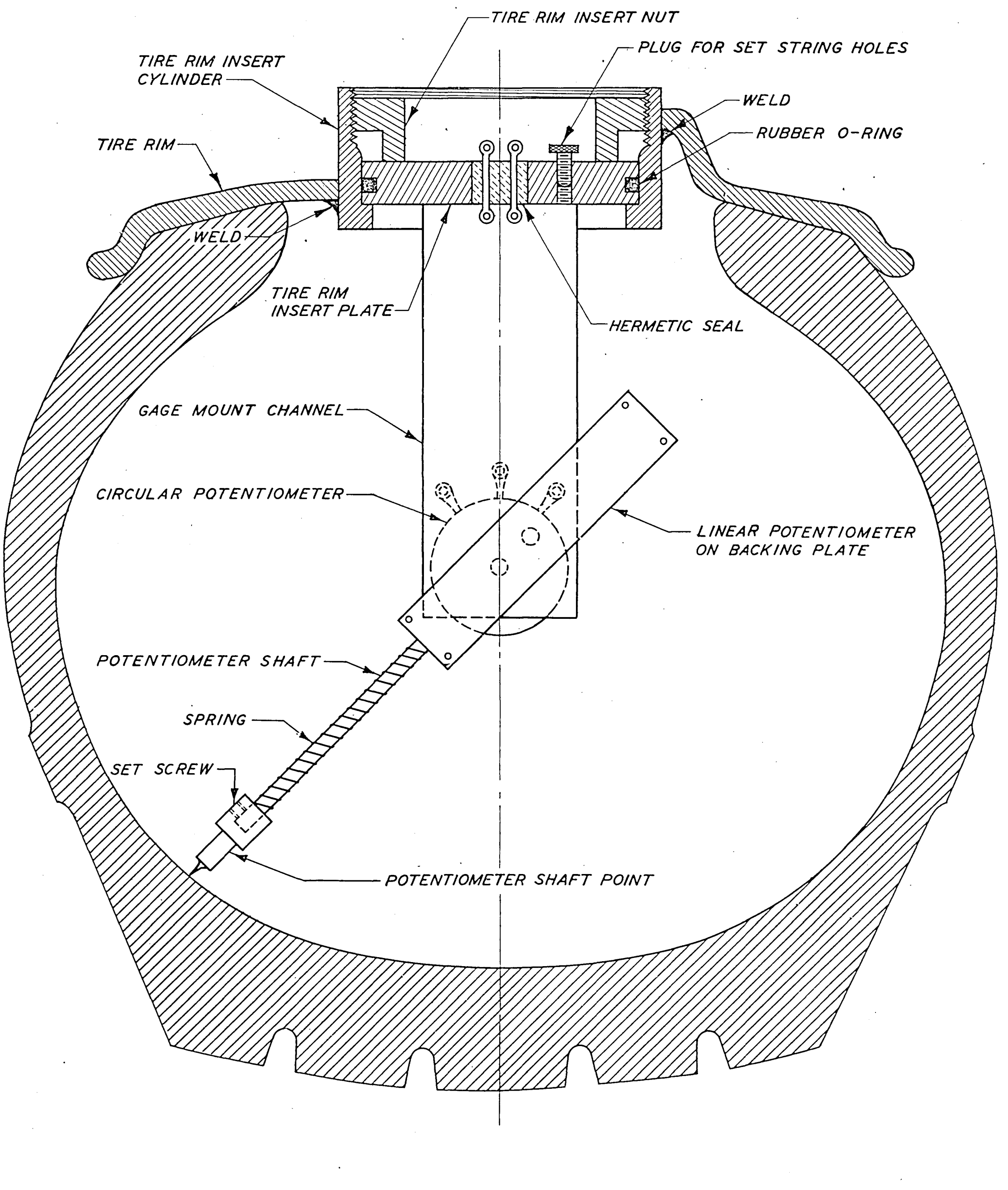
Other mobility studies include a comparison of various existing soil-strength measuring devices, a fundamental study of plates penetrating soils, a special study to investigate the validity of a locally generated hypothesis of vehicle-soil relations called the load-flow theory, and two studies recently undertaken for MERS--a study on surface traction and one on obstacles.

Much remains to be done in mobility research; and achievement of a



STRESSES AT A TIRE SURFACE
MEDIUM-STRENGTH SAND
(0- TO 6-IN. CONE INDEX = 30)
11.00-20, 12-PR SMOOTH TIRE
3000-LB WHEEL LOAD
15-PSI INFLATION PRESSURE

Fig. 7.
3897



TIRE DEFLECTION GAGE
AND MOUNT

12.00-22.5, 12-PR TUBELESS TIRE

111958-A

Fig. 8.

truly comprehensive science of vehicle-soil relations may be a long way off. The immediate goals at WES are to complete the tire study requested by the Chief of R&D, Army, to continue the kind of fundamental research illustrated by the stress and deformation studies, and to continue the studies just mentioned. Existing theories of mobility are being constantly examined and tested with the data developed and new hypotheses are being sought.

Summary

Summarizing, the principal accomplishments in trafficability have been the provision of simple tools and techniques for measuring and estimating the trafficability of soils, snow, and muskeg. These can provide practical assistance to the military commander in the field even today, but additional effort is needed to fill important gaps.

The terrain analyzer work, only just beginning, offers real hope that someday we will have the ability to interrogate terrain remotely in meaningful military terms.

The mobility research is fundamental to an understanding of vehicle-soil relations and hopefully will lead to means of intelligently designing military vehicles in the future.

Many important facets of work under these three subjects have not even been mentioned. There does exist, however, a large number of published reports on trafficability and mobility subjects. A list of these reports, with brief summaries of each, is available on request.* All the reports listed may be had on library loan; a few are still available for retention.

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* Reports published by Army Mobility Research Branch, Mobility and Environmental Division.

REVIEW OF BACKGROUND AND HISTORY OF PROJECT MERS

by

R. R. Friesz*

Before bringing you up-to-date on MERS activities since the First Advisory Committee Meeting, we thought it worthwhile to refresh your memory by summarizing the events that transpired prior to that time. This I hope to do in as few words as possible.

In February 1962, ARPA expressed its intent to the Office, Chief of Research and Development (OCRD), Department of the Army, to establish, as part of Project AGILE, a significant research effort in Southeast Asia to study the physical environment, particularly as it affects the design and employment of materiel and materiel systems. ARPA's memorandum of intent was based on a recommendation from its Combat Development and Test Center, now Military Research and Development Center, in Bangkok, Thailand, and it set off a chain of events which led to the eventual establishment of Project MERS. Because of the experience and special capabilities of the Army in various aspects of the work, ARPA requested that the Army do the following:

a. Organize and provide, essentially from "in-house" resources, a task group of scientists and technicians to conduct research and collect data in Southeast Asia with regard to surface mobility and other factors of the physical environment affecting vehicle design.

b. Provide the necessary coordinated stateside backup search support for this task from pertinent Army laboratories as may be desirable.

c. Send to Thailand, at once, a short-term survey team to conduct investigations aimed at better defining the problem and assisting in planning for the long-range effort.

If the above proposals were acceptable, it was requested that the Army immediately initiate action to dispatch the short-term team to Thailand and provide to ARPA a research proposal for accomplishing the long-term project.

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At the request of OCRD through the Office, Chief of Engineers (OCE), a meeting was held at OCE on 26-27 February 1962 to discuss ARPA's proposal and to formulate a research plan that would serve as a satisfactory Army reply to ARPA. In attendance at that meeting were representatives from OCRD, OCE, Army Research Office, Soil Conservation Service, Military Geology Branch, and WES. The conclusions reached at this meeting were as follows:

a. The overall project would apparently be assigned to WES because of WES' broad capabilities in the areas of environmental and mobility research.

b. The project would be executed in two phases. Phase 1 would be the preliminary survey and would be conducted by representatives from pertinent Government laboratories. Phase 2 would be the long-term research program that conceivably could take five years to complete. It would begin shortly after the preliminary survey was under way.

c. A WES representative was to be assigned as captain of the preliminary survey team.

d. WES was to prepare a plan of research for the overall program.

In April 1962, a revised WES plan of research was submitted to ARPA by the Army as their proposal for conducting Project TAME SEA, as it was then designated. In accordance with ARPA's additional request and a follow-up memorandum dated 20 April 1962, a team of Army ground mobility-environmental specialists was organized and sent to Thailand to conduct the preliminary short-term survey. The survey was conducted during the period 26 May to 31 October 1962. Specifically, the objectives of this study were: (a) to survey and assemble existing data from all available sources, (b) to collect appropriate environmental data to permit an evaluation of the nature and magnitude of the environmental factors that might affect ground mobility operations, (c) to assemble all data in a form that would be useful to commercial and military agencies in research on and development of special-purpose vehicles for use by indigenous armed forces in Southeast Asia, and (d) to delineate the problems and problem areas to be investigated during the course of the contemplated long-range program.

During the course of the survey, a ground reconnaissance was made in each of the major physiographic regions found in Thailand, except for the peninsula highlands. A total of 379 sites were visited, and data were collected for at least one terrain factor at each of the sites. Data for two or more terrain factors were collected at approximately 200 of these sites.

The data-collection systems employed by the preliminary survey team for such terrain factors as surface composition, surface geometry, hydrologic geometry, and vegetation were those developed primarily by the WES. Because of the reconnaissance nature of the field trips, however, some of the measuring techniques had to be streamlined to permit visiting more sites at the expense of detailed measurements.

A report on the preliminary study, entitled Environmental Factors Affecting Ground Mobility in Thailand; Preliminary Survey, was prepared by the team members and published by WES. It consists of a main report and eight appendices. The main report presents a discussion on the state of the art of measuring and predicting the effects of environmental factors on ground mobility; it presents the factor-family concept of terrain analysis, with an adaptation suitable to ground mobility purposes; and it catalogs, in handbook form, environmental data by landscape type and subunits that occur in Thailand. In addition, the report includes an estimate of the effects that would probably be imposed by the terrain factors on the performance of a highly mobile wheeled vehicle, the Gama Goat. These estimates were based on existing knowledge and the combined experience and judgment of the preliminary survey team. Eight appendices present in detail the measurement methods employed, the data collected, and appropriate discussions.

During the conduct of the short-term study in Thailand, ARPA, in July 1962, accepted the Army long-range research program as satisfactory for development into a final plan. ARPA's memorandum outlined several implementing steps to be accomplished to initiate the program within the stated context of ARPA objectives. The annual level of effort was estimated at $2,000,000 and required the immediate selection of a chief and the designation of a "single point of contact" within the Army. The Army then designated Col. H. C. Brown, Mobility Command (MOCOM), as director of the project, Mr. R. R. Philippe of AMC as "point of contact," and MOCOM as the operational agency. Col. Brown prepared a detailed proposal which included plans for the technical approach to the problem and the scheduling of various tasks. As Col. Brown's plans will be covered to some extent in the summary of the First Advisory Committee Meeting, which I will discuss following this paper, I will not go into the contents of his proposal at this time.

While awaiting the Army's final work plan, ARPA requested the Research Analysis Corporation to aid in establishing an Advisory Committee on Mobility-Environmental Research to review research plans and to make conclusions and recommendations pertinent to the development of a valid and workable research proposal. Concurrently, ARPA drew up a work statement based on the problems delineated by the preliminary survey team and on the approach as outlined in Col. Brown's proposal. In November 1962, the First Advisory Committee convened and concurred in general with the Army's plan of research. Later that month, authority to initiate Project MERS with an initial appropriation of $250,000 was granted to AMC by ARPA Order No. 400.

REVIEW OF FIRST ADVISORY COMMITTEE MEETING RECOMMENDATIONS

by

R. R. Friesz*

At about the same time that the Army was attempting to formulate Col. H. C. Brown's proposal into a final, workable, long-term research plan, ARPA requested the Research Analysis Corporation (RAC) to aid in establishing an Advisory Committee on Mobility-Environmental Research to review pertinent research plans and to make appropriate conclusions and recommendations with respect to their scientific validity, adequacy, and completeness.

A group of 12 technical experts from various governmental agencies and universities were selected as members of the committee on the basis of their experience in related fields. This committee met in November 1962 at RAC headquarters in Bethesda, Maryland, to consider Col. Brown's research plan. In attendance at this meeting were 9 committee members and 21 official observers.

Although the meeting consisted primarily of informal discussions, a few formal and informal talks were presented by some of the official observers. I shall touch lightly on the content of these talks. First, Mr. Merrill Kreipke of the Army Research Office was called upon to explain the Army's current research programs in vehicle-terrain interactions. Next, Col. Brown gave a brief summary of the background and current status of Project MERS. The various team members of the Thailand preliminary survey team were then asked to briefly summarize their findings during the short-term survey. The survey team leader, Mr. Adam Rula, began by outlining the background, purpose, and scope of the preliminary survey. Mr. Arnold Orvedal, who is Chief of the World Soil Geography Unit, followed with a short talk on the soils and their distribution in Thailand. Soil trafficability and weather and climate in Thailand were then discussed by Mr. Rula. Finally, Mr. Warren Grabau, who is Chief of the Area Evaluation

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* MERS Branch, Mobility and Environmental Division, USAE Waterways Experiment Station, Vicksburg, Miss.

Branch here at WES, talked briefly on the surface geometry, vegetation, and hydrologic geometry of Thailand. These presentations were followed by a showing of slides depicting the environmental characteristics of those areas in Thailand which were visited by the preliminary team.

Completing the scheduled talks was a presentation by Col. Brown of his planned technical approach to the overall problem of Mobility-Environmental Research in Thailand. As the main purpose of the meeting was to consider Col. Brown's proposal, it remains but to summarize the committee's conclusions and recommendations regarding his approach. This I hope to do as briefly as possible.

Rather than comment point-by-point on Col. Brown's proposal, and because they concurred in general with the plans he made and with his overall approach, the committee chose to summarize their thoughts. Three main points were emphasized:

First, the problem of off-road mobility in Southeast Asia, or anywhere else, is a very complex one that must require many additional years of effort to resolve. An initial 6-month period of investigation in the field can be but a bare beginning, at best, and can accomplish a significant but only very small part of the total objective.

Second, research to establish design parameters requires extensive experimentation and testing under carefully controlled conditions. Investigations in Thailand will provide a guide for the far more exacting programs to be carried out under controlled conditions in easily accessible sites and laboratories. A concurrent and continuing program in the United States should accompany the field data gathering and testing in Thailand. Careful account should be taken of existing domestic programs of similar nature now in progress by personnel of various Government agencies.

Third, final tests in Thailand will be conducted as verification of the preliminary Thailand work and the work in the United States.

In broad outline, the committee then referred to the plan for the entire study, which is as follows:

> The identification, classification, analysis, and documentation of those aspects of surface conditions in Southeast Asia that are of importance for evaluation and design of vehicles.
>
> The selection of test areas both in Thailand and the United States or Caribbean, representative of each of several difficult environments, and selection of test routes within these areas.

Selective vehicle testing leading to predictions of vehicle performance in Southeast Asia.

And, finally, the establishment of adequate vehicle design parameters.

Next, the committee concurred with plans for the first Thailand TDY period, which are:

1. Careful selection of typical representative areas of approximately 200 square miles each on the basis of existing air and ground identification techniques.
2. Selection of 2- to 4-mile routes for vehicle testing within the selected areas. In addition, it was recommended that several routes within each area be selected to allow a comparison of possible variability.
3. Meticulous cataloging of terrain characteristics over each of the routes selected.
4. Separate documented tests of vehicle performance over typical terrain obstacles.
5. Exploratory, but documented, tests over the selected routes within the 200-square-mile areas.
6. Choosing of at least two wheeled and two tracked standard vehicles as test instruments for the performance tests.

Several comments by the committee are worthy of mention at this time. First of all, the committee emphasized the need for intensive study along the selected test routes. Vehicle performance must be observed carefully, and points of mobility failure must be analyzed carefully. The influence on vehicles of terrain obstacles indigenous to Southeast Asia must be determined and methods required to overcome these obstacles must be developed. It was agreed that the terrain measurement techniques employed by the preliminary team were standardized and well-defined and should continue to be employed. It was further agreed that plans for the second TDY phase should be deferred until preliminary reports are available from the forthcoming first TDY effort.

This now brings us to the recommendations made by the committee. They are as follows:

First, proceed at once with the study as outlined in the paper presented by Col. Brown, with the inclusion of the modifications as suggested in the foregoing comments and as recommended below.

Second, develop a plan of research to be carried out in the United States based on the plan of action to be proposed by the Ad Hoc Working

Group. A working group, consisting of Mr. R. R. Philippe, AMC, Mr. W. J. Turnbull, WES, and Mr. R. A. Liston, LLL, was appointed to prepare a plan of action.

Third, examine terrain in the United States in terms of the environmental characteristics observed in Thailand with the aim of determining and validating analogous test areas in the United States, followed by additional experiments to establish prediction techniques and design parameters.

And, finally, give thought to the training of scientists and engineers for this type of work and the utilization through contracts of qualified personnel.

Before concluding, it seems appropriate at this time to discuss, briefly, the suggested program outlined by the Ad Hoc Working Group. To begin with, this group recommended an acceleration of work under way in classifying surface geometry, hydrologic geometry, vegetation, and soil parameters, along with a stepped-up program to better define the general operational concepts of military operations in Southeast Asia. An immediate tentative selection of test sites in the United States that are most analogous to Southeast Asia was also called for. Furthermore, better design of tests, test procedures, test route selection, and test instrumentation were recommended. Finally, it was concluded that the available prediction theories and equations should be examined for the purpose of validating, invalidating, or refining them.

GENERAL STATUS REPORT ON PROJECT MERS ACTIVITIES

by

A. A. Rula*

General Background

This discussion will present a general status report on Project MERS since the first meeting of the Advisory Committee held at Bethesda, Md., 7-9 November 1962. It will cover briefly some of the events that had to take place before the MERS program could be established within the U. S. Army Materiel Command (AMC) framework, organizational changes that were implemented at the U. S. Army Engineer Waterways Experiment Station (WES) so that this station could accept its role of responsibility in managing Project MERS for the Army, modifications made to the agreed-upon operation and funding plans for the MERS program, coordination meetings, status of MERS tasks, problem areas, and funding status.

Establishment of the MERS Program Within AMC

During the period January to mid-March 1963, AMC was concerned with the development of a plan to manage Project MERS. A series of letters passed back and forth between the Office of the Chief of Research and Development, Department of the Army, the Commanding General, AMC, and the Director, Research and Development, AMC, until a plan was agreed upon for the management of Project MERS. The Environmental Sciences Branch, Research and Development Directorate, AMC, conducted several studies that pertained to an analysis of possible courses of action it might take and the selection of the most feasible and efficient method of conducting Project MERS utilizing a minimum number of Army personnel and relying to the maximum extent practicable on contracts with civilian agencies. During the same period, WES was requested by AMC to develop an operation and funding plan in accordance with the new management guidelines. The conclusions reached by the AMC studies were: (a) Project MERS should be assigned to an existing Government facility which could provide all of the requisite

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* Chief, MERS Branch, Mobility and Environmental Division, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

elements for the administration and operation of the project; (b) of the available Government facilities, WES was the most logical operating agency because it most closely fulfilled all of the requirements considered; and (c) the impact of the assignemnt of Project MERS on the current program of WES could be minimized through adjustment to make greater use of civilian contractors on AMC programs at WES. Based on these conclusions, it was recommended that Project MERS be immediately assigned to WES for management and operation in consonance with the final agreed-upon technical operation plan. The proposed operation and funding plans prepared by WES were accepted by AMC and approved by Office, Secretary of Defense/Advanced Research Projects Agency (OSD/ARPA) at a somewhat later date.

WES Organization

WES accepted the challenge to manage Project MERS and took immediate steps to regroup its capabilities to meet the challenge. The MERS program was identified within the WES organization and assigned a branch status. Fig. 1 shows an organization chart of WES; the MERS group is identified as part of the technical staff under the Mobility and Environmental Division. A further breakdown of the MERS Branch is given in fig. 2. It can be seen that the MERS Branch is divided into two units, namely a stateside unit and a Thailand Detachment. The stateside unit has the responsibility of managing all project activities; personnel are concerned with preparing research task programs, arranging for the work to be done by WES, other Government agencies, or contract to industry, and effecting coordination to ensure maximum utilization of results. The Thailand Detachment is concerned with collecting basic environmental data, establishing the range of seasonal variations for those environmental factors of interest to the program, selecting and preparing suitable test areas, assisting in the development of a suitable system for classifying terrain types in Southeast Asia, meeting remote-area operation requirements, and assisting temporary duty (TDY) parties in the accomplishment of their mission. It is to be noted that the management staff for the MERS program consists of one military and six civilian spaces, a number slightly in excess of the five spaces originally authorized by the Assistant Secretary of the Army. The

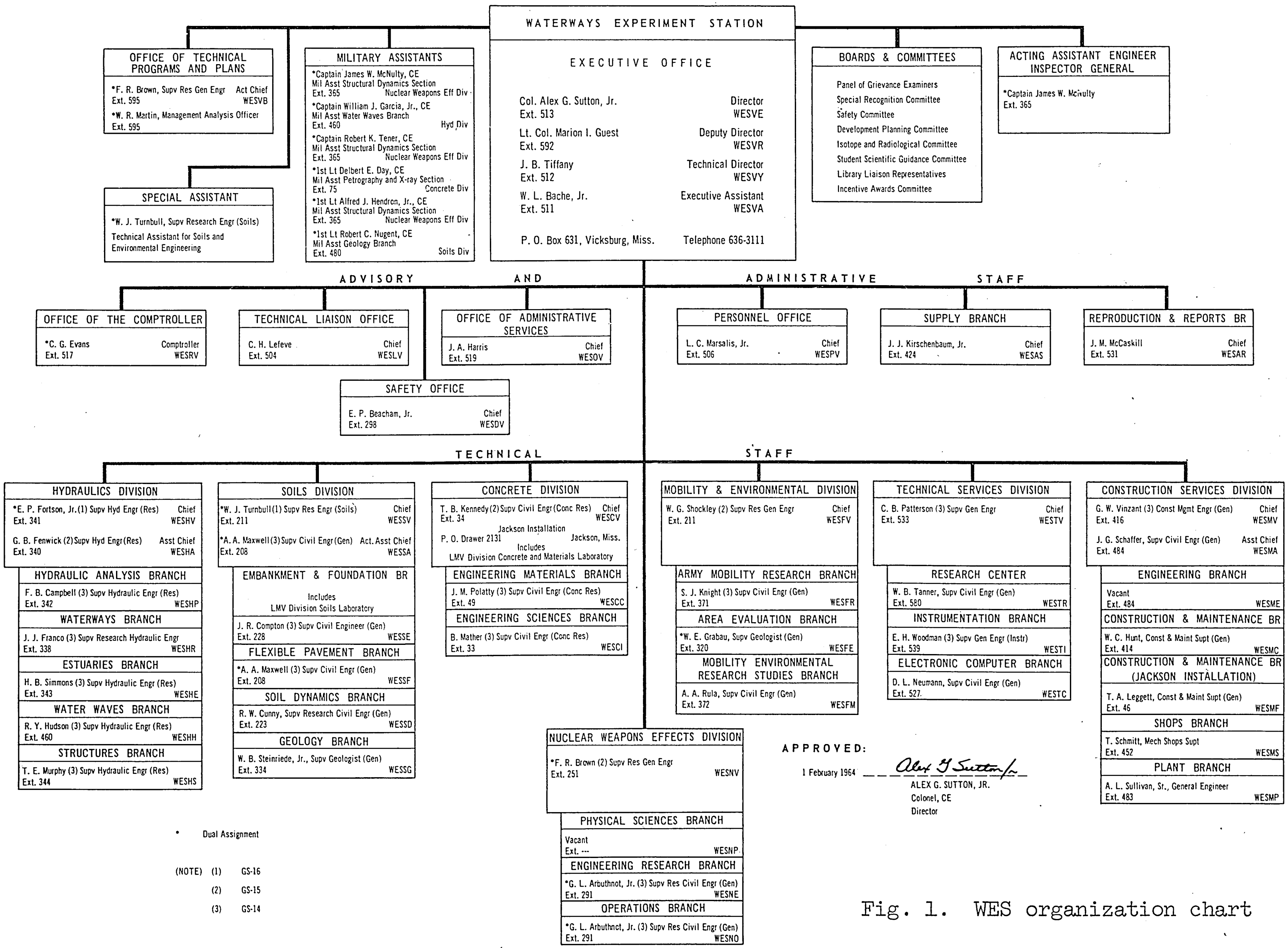

Fig. 1. WES organization chart

WATERWAYS EXPERIMENT STATION
EXECUTIVE OFFICE

MOBILITY AND ENVIRONMENTAL DIVISION

*W. G. Shockley — Chief
Supervisory Research General Engineer — GS-15
Ext 211 — WESFV

1 Secretary (Steno) — GS-06

SPECIAL ASSISTANT

*W. E. Grabau
Supv Geologist (Gen) — GS-13
Ext 320

ARMY MOBILITY RESEARCH BRANCH

S. J. Knight — Chief
Supervisory Civil Engr (Gen) — GS-14
Ext 371 — WESFR

1	Secretary (Steno)	GS-05
3	Clerk-Typist	GS-03

TRAFFICABILITY SECTION

E. S. Rush — Chief
Supv Civil Engr (Gen) — GS-13
Ext 373

3	Civil Engr (Gen) (2V)	GS-12
1	Soil Scientist (Gen)	GS-12
3	Civil Engr (Gen)	GS-09
1	Mathematician	GS-09
1	Soil Scientist (Res)	GS-09
1	Civil Engineer	GS-07
3	Civil Engrg Tech	GS-07
3	Mathematician	GS-07
1	Civil Engrg Tech	GS-06
1	Agricultural Engr	GS-05
6	Civil Engrg Tech	GS-05
1	Engrg Aide	GS-03
#1	Civ Engrg Asst (509.30)	E-2
2	Laboratory Helper	WB-07

TERRAIN ANALYZER SECTION

Vacant — Chief
Research Physicist (Gen) — GS-14
Ext 468

1	Physicist (Gen Mech)	GS-12
1	Electrical Engr (Gen)	GS-11
1	Physicist (Mech)	GS-11
1	Physicist (Mech)	GS-09
1	Mathematician	GS-07
#1	Elec-Elect Eng Asst(309.30)	E-1
3	Laboratory Helper	WB-05

MOBILITY SECTION

D. R. Freitag — Chief
Supv Civil Engr (Gen) — GS-13
Ext 447

1	Civil Engr (Gen)	GS-13
1	Civil Engr (Gen)	GS-12
3	Civil Engr (Gen)	GS-11
1	Gen Engr (Engrg Mech)(V)	GS-11
1	Civil Engr (Gen)	GS-09
2	Civil Engrg Tech	GS-09
1	Mathematician	GS-09
1	Civil Engineer (V)	GS-07
1	Mathematician	GS-07
4	Civil Engrg Tech	GS-06
1	Civil Engrg Tech	GS-05
1	Phys Sci Aide (Phys)	GS-04
2	Engrg Aide	GS-03
2	Mathematics Aide	GS-03
1	Engrg Aide	GS-02
#2	Civ Engr Asst (509.30)	E-2
2	Laboratory Helper	WB-07
3	Laboratory Helper	WB-05

MOBILITY ENVIRONMENTAL RESEARCH STUDIES BRANCH

A. A. Rula — Chief
Supervisory Civil Engr (Gen) — GS-13
Ext 372 — WESFM

1	Civil Engineer (Gen)	GS-12
1	Geographer (Phys)	GS-12
1	Secretary (Steno)	GS-05

THAILAND DETACHMENT

§Lt Col Arthur R. Simpson, CE, 059030
c/o JUSMAG - Thailand
ARPA - MERS Det
APO 146
San Francisco, California

1	Geologist (Gen)	GS-12
1	Civil Engrg Tech	GS-11

AREA EVALUATION BRANCH

*W. E. Grabau — Chief
Supervisory Geologist (Gen) — GS-13
Ext 320 — WESFE

1 Secretary (Steno) — GS-04

FIELD TEST SECTION

Vacant — Chief
Supv Geologist (Gen) — GS-13
Ext

1	Geologist (Gen)	GS-11
1	Intelligence Res Spec	GS-11
1	Civil Engineer (Gen)	GS-09
1	Civil Engrg Tech	GS-09
1	Civil Engineer	GS-07
1	Phys Sci Tech (Gen) (V)	GS-05
#1	Civ Engrg Asst (509.30)	E-2

OVERSEAS SECTION

Vacant — Chief
Supv Geologist (Gen) — GS-13
Ext

1	Botanist	GS-09
1	Civil Engineer	GS-07
1	Civil Engineer	GS-05

TROPICAL TERRAIN RESEARCH DET SAN JUAN, PUERTO RICO

B. O. Benn — Chief
Civil Engineer (Res) — GS-11
San Juan Area Office
U. S. Army Engineer District,
Jacksonville
P. O. Box 3829
San Juan, Puerto Rico

1	Botanist	GS-09
1	Civil Engrg Tech	GS-07
1	Civil Engrg Aide	GS-04

ADMINISTRATIVE SECTION

C. V. Davidson — Chief
Supv Admin Asst — GS-09
Ext 376

1	Clerk	GS-06
1	Clerk	GS-05
1	Clerk	GS-03
1	Clerk-Typist	GS-03

91 Graded
10 Ungraded
1 Officer
5 Enlisted Personnel S&E

* Dual assignment
\# Enlisted Personnel
§ Effective 12 Feb 64

Fig. 2. Mobility and Environmental Division

personnel shown under the Thailand Detachment in fig. 2 are now all in Thailand; the last member of the group arrived there about the middle of this month. The capabilities of this group are being increased by hiring of indigenous personnel and through cooperative effort with the Military Research and Development Center (MRDC), ARPA R&D Field Unit. From time to time the capabilities of the Thailand Detachment will be increased by TDY groups.

At the request of AMC, there was prepared an administrative and logistical support agreement setting forth a firm understanding of the working relations and channels of communication of various agencies with which Project MERS would be associated in obtaining support for its Thailand Detachment. The agencies involved in this basic agreement were MRDC, WES, and the Joint U. S. Military Advisory Group (JUSMAG). Copies of the agreement were forwarded to the agencies involved for approval and signature; to date, however, replies have not been received. At the moment, we are operating the Thailand Detachment by the obligation authority route through Chief, JUSMAG.

Operation Plan Modifications

Since the acceptance of the MERS operation and funding plans, further review by WES and requests made by ARPA have resulted in a slight expansion of the technical plan as well as an increase in responsibility.

WES has assumed the responsibility for negotiating and monitoring a contract to furnish ARPA's MRDC Thailand Field Unit with engineering services in connection with designing instrumentation and associated systems for research and development testing related to vehicular trafficability. Contractor support, such as equipment purchases and fabrication at WES shops, design assistance, and coordination, are also the responsibility of WES.

WES has also agreed to assume the responsibility for coordinating environmental data-collection phases of research programs which are sponsored or conducted by ARPA in Southeast Asia. The purpose of this task is obviously to minimize the duplication of effort to at least a practical level. WES has prepared a document which includes the purpose and scope of

WES participation and responsibilities and cooperation required by other ARPA groups to ensure an effective working coordination plan. Upon receipt of ARPA's approval, WES will assume the responsibility for coordinating environmental data collection, interpretation, analysis, storage, and retrieval programs of all ARPA-sponsored and ARPA-conducted projects and studies in Southeast Asia.

With the possibility of increasing the environmental effects conditions to be sought from the environmental data to be collected, it became apparent that weather considerations were more or less excluded from the operation plan. To eliminate this shortcoming, a task which includes a two-phase weather study was added to the MERS program. The general objectives of this task will be discussed later.

Coordination Meetings

In addition to the coordination meetings held with ARPA, WES representatives visited Bangkok on several occasions to coordinate MERS activities with the activities of MRDC. In August 1963, a visit was made to establish support requirements for the Thailand Detachment for the next 12 months and to develop an administrative and logistical support agreement acceptable to all parties concerned. In October 1963, another visit was made to Bangkok to assist MRDC in establishing data-collection requirements for a vegetation study that MRDC was undertaking with the Royal Thai Forestry Department.

In December 1963, Col. J. M. Flesch, OSD/ARPA R&D Field Unit, Bangkok, visited WES to discuss MERS activities scheduled for Thailand during the next 12 months and to assist in the preparation of plans for implementing the scheduled activities. It was agreed that the objectives of the MERS program could best be achieved by integrating MERS and MRDC-Thailand capabilities. Therefore, the plans were prepared accordingly. Seven primary and seven secondary areas in which detailed environmental data will be collected and tests will be conducted were tentatively selected. Each area is approximately 200 sq mi. The selection was made on the premise that these areas would include most of the significant terrain types in Thailand and that permission would be obtained to use them for test purposes. Col. Flesch is looking into the problem of acquiring access to the study areas. Fig. 3 is a map showing the location of study areas; the primary and secondary study areas are indicated by solid and dashed boundary lines, respectively. The crosshatch symbols indicate status of procuring available airphoto coverage. Because of other considerations which have appeared on the horizon, such as the ARPA Advisory Committee Meeting, etc., some changes have been made in the plans since Col. Flesch's visit.

MERS project personnel have held a number of meetings with personnel of WES and other Government agencies to arrange for responsibility for conducting MERS tasks either on an in-house basis or by assisting in monitoring contracts. Other Government agencies that have been contacted for assistance in achieving MERS objectives are: World Soil Geography Unit (WSGU), Aberdeen Proving Ground (APG), Land Locomotion Laboratory (LLL), U. S. Army Natick Laboratories (NLABS), and U. S. Army Electronics Command (ECOM). Several meetings have been held with each organization except ECOM; in the latter case we are awaiting a reply on a suggested meeting date. Proposals have been received from each organization on MERS tasks it is interested in and plans for pursuing the individual tasks. In many cases, the initial proposals are not in accord with the objectives of the MERS program. Most of the proposals have been extensions of present R&D programs currently under way or new R&D-type programs.

Personnel assigned the responsibility of managing Project MERS have considered the program as basically an engineering-development type of study wherein a large part of the MERS effort will be devoted to arranging present knowledge in a form usable to the vehicle designer and military analyst. This concept of operation is dictated by the time frame established for the MERS program. At the moment, we feel that we are on the threshold of engaging the capabilities of most of the other Government agencies on worthy MERS tasks. Considerable time has been consumed in conditioning people to thinking in terms of MERS requirements as we envision them. We feel that we must reach an early agreement on the fundamental approach to be followed in the MERS program so that the total problem can be subdivided into manageable units, yet at the end of three years reach the goals initially set forth. The conceptual approach which we have subscribed to will be discussed in another paper.

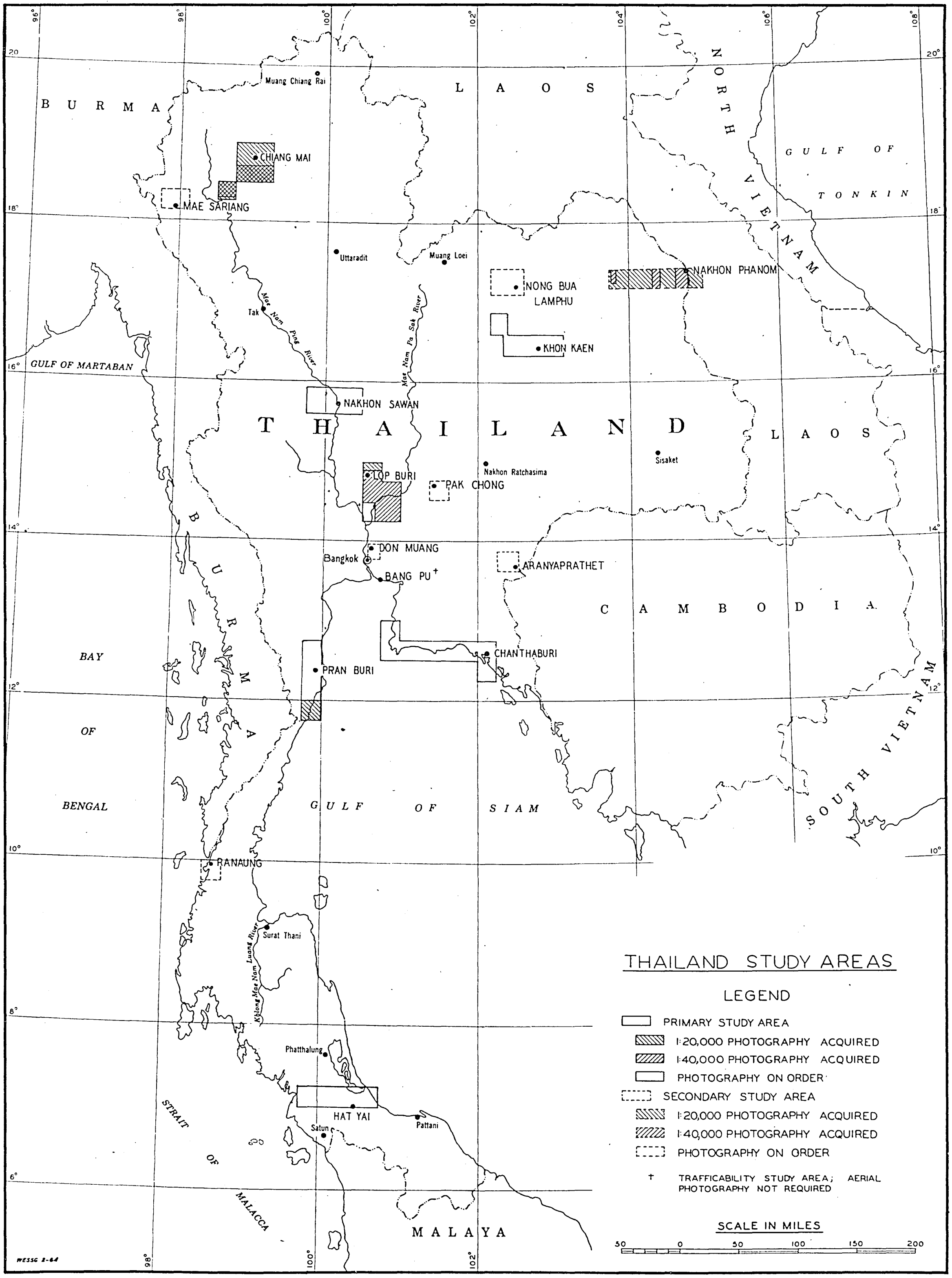
THAILAND STUDY AREAS
LEGEND
PRIMARY STUDY AREA
1:20,000 PHOTOGRAPHY ACQUIRED
1:40,000 PHOTOGRAPHY ACQUIRED
PHOTOGRAPHY ON ORDER
SECONDARY STUDY AREA
1:20,000 PHOTOGRAPHY ACQUIRED
1:40,000 PHOTOGRAPHY ACQUIRED
PHOTOGRAPHY ON ORDER
+ TRAFFICABILITY STUDY AREA; AERIAL PHOTOGRAPHY NOT REQUIRED
SCALE IN MILES
50 0 50 100 150 200
B U R M A
L A O S
NORTH VIETNAM
GULF OF TONKIN
T H A I L A N D
L A O S
C A M B O D I A
SOUTH VIETNAM
BURMA
GULF OF MARTABAN
BAY OF BENGAL
GULF OF SIAM
STRAIT OF MALACCA
M A L A Y A
Muang Chiang Rai
CHIANG MAI
MAE SARIANG
Uttaradit
Muang Loei
NONG BUA LAMPHU
NAKHON PHANOM
KHON KAEN
Tak
Mae Nam Ping River
Mae Nam Pa Sak River
NAKHON SAWAN
LOP BURI
PAK CHONG
Nakhon Ratchasima
Sisaket
DON MUANG
Bangkok
BANG PU+
ARANYAPRATHET
CHANTHABURI
PRAN BURI
RANAUNG
Surat Thani
Khlong Mae Nam Luang River
Phatthalung
HAT YAI
Pattani
Satun
WESSG 2-64

Fig. 3.

Visits to Universities and Industry

Visits have also been made to universities and industrial concerns to discuss the MERS program and to determine their interest in and potential for pursuing specific MERS tasks. Most of these contacts resulted in expressions of considerable interest in the objectives of the MERS program and of willingness to cooperate in the MERS program.

Contracts Negotiated

A summary of current university or commercial contracts that pertain to specific MERS tasks is given in fig. 4. The last contract listed is in the process of negotiation and will be consumated in the next few weeks.

RFP NO.	CONTRACT NO.	AMOUNT	TITLE OF CONTRACT	CONTRACTOR	MERS TASK NO.
	DA-22-079-eng-262 (amendment)	(Neg) $20,000 (MERS)	Compilation and Evaluation of Existing Trafficability Data	Wilson, Nuttall, Raimond, Engineers, Inc., Chestertown, Maryland	
	DA-22-079-eng-358 (Neg)	$50,000	Develop Methods for the Analysis of the Fine Structure of Sea-Land Boundary Zones	Florida State University Tallahassee, Florida	
	DA-22-079-eng-378 (Neg)	$91,500.00	Design Instrumentation for R&D Testing Related to Vehicular Trafficability	Colorado State University Fort Collins, Colorado	
64-1	DA-22-079-eng-392	$47,340.00	Study of the Present State of the Art in the Design of New Off-Road Vehicles	Wilson, Nuttall, Raimond, Engineers, Inc., Chestertown, Maryland	16
64-2	DA-22-079-eng-394	$93,860.00	Development of One-Pass Soil Trafficability Data	Wilson, Nuttall, Raimond, Engineers, Inc., Chestertown, Maryland	08a
64-4	Being Negotiated	$34,441.00	Research Study Concerning Ground Mobility Problems Associated with Vehicle Ride Dynamics	Chrysler Corporation, Detroit, Mich.	
		$337,141.00			

Fig. 4. MERS contracts

Status of MERS Tasks

The next portion of this presentation will be concerned with the status of each MERS task as outlined in table 1 of the WES operation and funding plans. A copy of this table is included as fig. 5. For some of these tasks, individual papers have been prepared; therefore, they will be mentioned only briefly.

Task 1, Determination of Remote Area Requirements for Cross-Country Mobility Missions

Work done on this task is restricted to subtask a, "After-Action

Task No.	Description	FY 1963 May	FY 1963 June	FY 1964 July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
	Remote Area Requirements														
1	Determination of remote area requirements of CCM missions													5.0	/25.0/
	Classification Systems														
2	Quantitative methods of describing terrain factors														
2a	Surface macrogeometry (topography)		/40.0/											2.0	
2b	Surface microgeometry, miscellany														/80.0/
2c	Vegetation		/40.0/											2.0	/40.0/
2d	Hydrologic geometry		/50.0/												2.5
3	Classification of soils for mobility purposes		(2.5)												(27.5)
4	Climatic techniques for defining state of the ground		/15.0/												0.5
	Measurements														
5	Noncontact sensing & interpretation of tropical terrain		(4.5)												(55.5)
6	Design & acquisition of instrumentation														
6a	Instrumentation vehicle & equipment		/25.0/						1.0						
6b	Measuring & recording instruments		/10.0/												/70.0/
6c	Data manipulation & reduction in field										/100.0/				
7	Soil testing	1.0												20.0	/9.0/
	Field Tests														
8	Development of vehicle performance relations														
8a	Dev. of one-pass soil trafficability criteria		25.0											50.0	/80.0/
8b	Dev. of obstacle capability criteria		/60.0/											30.0	/40.0/
9	Mobility in rice fields		25.0							7.5					
10	Development of mathematical model of ground mobility														
10a	Selection & description of test areas														
10b	Design of mobility tests													5.0	/20.0/
10c	Test of mobility in landform types														
10d	Verification of mobility predictions in terrain types														
10e	Development of expression for ground mobility														
	Data Collection and Environmental Analysis														
11	Collection and exploitation of env. data in SE Asia														
11a	Permanent party													85.0	/255.0/
11b	TDY parties													80.0	/240.0/
11c*	Transportation (air-ground) in SE Asia														/530.0/
12	Classification of terrain types in SE Asia		5.5							19.5					
13	Analogs of SE Asia in U. S. and vicinity														
13a	Analogs of tropical soils in U. S. & vicinity		(3.5)										6.5	(30.0)	
13b	Analogs of SE Asia terrain in U. S. & vicinity		10.0											30.0	/40.0/
14	Airphotos of test and study areas in SE Asia, U. S., & Caribbean		/30.0/												/50.0/
15	Develop terrain intelligence portrayal techniques for mobility														
	Vehicle Design and Analysis														
16	Vehicle design methodology		/60.0/											(60.0)	/55.0/
17	Procurement, transport, & modification of test vehicles													/30.0/	
18	Establishment of design parameters for vehicle engineers														
	Miscellaneous														
19	Training contractor personnel		8.5					35.0							
20	Preparation and publication of reports														
20a	Writing												10.0	(5.0)	/20.0/
20b	Drafting, editing, publishing		1.0												19.0
	Totals		76.0						410.5						
			(10.5)						(178.0)						
			/330.0/						/1684.0/						
	Grand totals		416.5						2272.5						

Task No.	FY 1965 July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
1										10.0		/30.0/
2												
2a												
2b												/80.0/
2c											2.0	
2d												
3												(20.0)
4										/15.0/		
5												(60.0)
6												
6a												
6b										/10.0/		
6c												
7										15.0		/5.0/
8												
8a									40.0	/60.0/		
8b										30.0	(60.0)	/30.0/
9												25.0
10												
10a									30.0	(20.0)		/40.0/
10b									50.0	(20.0)		/70.0/
10c									30.0	(20.0)		/80.0/
10d											20.0	/30.0/
10e												/15.0/
11												
11a									85.0	(80.0)		/155.0/
11b									80.0	(140.0)		/90.0/
11c*												/495.0/
12												
13												
13a												
13b											20.0	/50.0/
14												/50.0/
15												20.0
16										(60.0)		/60.0/
17												/90.0/
18												20.0
19												
20												
20a									10.0	(5.0)		/20.0/
20b												20.0
Totals							507.0					
							(485.0)					
							/1475.0/					
Grand totals							2467.0					

Task No.	FY 1966 July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Total Costs
1						10.0	/10.0/						90.0
2													
2a													42.0
2b													160.0
2c													84.0
2d													52.5
3													50.0
4													30.5
5					(50.0)								170.0
6													
6a													26.0
6b													90.0
6c													100.0
7						8.0	/2.0/						60.0
8													
8a													255.0
8b	10.0	(20.0)	/20.0/										300.0
9					20.0								77.5
10													
10a	20.0	(10.0)	/20.0/										140.0
10b				40.0		/20.0/							225.0
10c													130.0
10d							100.0			(100.0)	/200.0/		450.0
10e										20.0	(20.0)	/20.0/	75.0
11													
11a				40.0	(40.0)	/70.0/							810.0
11b				40.0	(60.0)	/50.0/							780.0
11c*						/100.0/							1125.0
12													25.0
13													
13a													40.0
13b													150.0
14								/20.0/					150.0
15											60.0	/40.0/	120.0
16							18.0	(50.0)		/100.0/			463.0
17								/150.0/					270.0
18										20.0	(30.0)	/50.0/	120.0
19													43.5
20													
20a										100.0	(50.0)	/100.0/	320.0
20b												30.0	70.0
Totals							528.0						7094.0
							(430.0)						
							/980.0/						
Grand totals							1938.0						7094.0

Note: All values in thousands of dollars.
8.5 (Figures not inclosed) Direct internal costs, WES, excluding contracts. Includes AMRC, AES, Geology Branch, Instrumentation Branch, and Construction Services.
(12.7) (Figures in parentheses) Exchange of funds with other laboratories and government agencies.
/26.0/ (Figures in diagonals) Contract costs, excluding WES monitoring and administration.
* Attempts are being made to provide transportation by means other than private contract; if these attempts are successful the pertinent funds will be deleted.

Fig. 5. Summary of operation and funding plans

Studies of Mobility Problems." A partial literature search has been completed, and we have been drawing heavily on recent material published in various military magazines. The magazine articles have led us to other significant reference materials. For example, in the December 1963 issue of Army, the article entitled "Report on Vietnam," by Brig. Gen. Frank A. Osmanski, identified several publications of interest to us: Lessons Learned and Tactics and Techniques of Counter-Insurgency Operations published by the Military Aid and Assistance Group in Vietnam. The MERS Thailand Detachment has been instructed to assist us in searching out available literature and obtaining copies of pertinent documents. Following the literature search, we hope to negotiate a small contract with an individual or organization experienced in this field. The contractor will be required to complete the literature review including after-action reports and operations research analyses, and to contact tactical commanders in the field to determine the types of missions expected to be encountered in remote area operations and the nature of the terrain conditions most frequently encountered in remote area conflicts. An objective analysis will be made and an appropriate report will be published.

The subtasks b, "Tactical Model and Games Study," and c, "Terrain Application of Model Study," have been given some attention; however, we feel that the coordination involved in implementing these tasks is beyond the capability of MERS management personnel. It is suggested that the Advisory Committee reconsider these subtasks and pass judgment on their significance to the MERS objectives.

Discussions have been held with representatives of Research Analysis Corporation (RAC), Bangkok office, on the subject of tactical requirements as considered by the MERS program and the possible application of any RAC operational analysis that might be adaptable to our problem. These discussions were virtually fruitless.

Task 2, Quantitative Methods of Describing Terrain Factors

This task involves collecting and collating environmental data which are sufficiently descriptive of topography, hydrology, and vegetation to support theoretical analysis of surface transport mobility.

Work has been completed on streamlining previously developed systems for classifying environmental factors for the determination of specific effects imposed on ground mobility operations. The results have been incorporated in a draft of a manual of instruction (which will be discussed in detail in another paper) for collecting environmental data. The findings will also be used at a later date in the development of appropriate classification schemes for ground mobility purposes. Preliminary examination of available data suggests that efforts to achieve a meaningful classification of terrain types of Southeast Asia for ground mobility purposes are premature. Data are too incomplete to permit establishment of reliable quantitative limits on the various factors required to define and describe terrain types. Further work on this task has been deferred until additional quantitative data are available from Thailand and certain vehicle-terrain characteristic relations are developed. Specific findings indicate that the application of the WES techniques for quantifying surface macrogeometry to selected landscapes in Thailand may be useful, but it is doubtful that all of the parameters which are used to describe the surface macrogeometry will be meaningful for mobility analysis. A catalog which includes a compilation of macrogeometry and hydrologic geometry features characteristic of Southeast Asia has been partially completed. A model study has been designed to evaluate the effects of vegetation characteristics on vehicles of various configurations and steering characteristics. Work has been done on deriving methods of correlating visibility measures with vegetation characteristics employed in the standard vegetation description system.

A request for proposal has been prepared in an effort to obtain a contract capability to collect environmental data on several of the primary study areas in Thailand. The scope of work includes the preparation of appropriate factor maps, development of methods of simplifying or improving data acquisition and interpretation techniques, and development of systems for portraying environmental data and reducing data in handbook form acceptable to vehicle designers and military analysts. The work has not been advertised; however, we believe that we are now in a position where we can support a contractor in Thailand. Invitations for proposals will be mailed next month. Other aspects of this task will be discussed in other papers.

WES has responsibility for this task. Additional capabilities will be obtained by contract as required.

Task 3, Classification of Soils for Mobility Purposes

Work plans for this task have been completed. These plans include field and laboratory programs.

The purpose of the field program is to improve the utility of existing pedological information on tropical soils in predicting vehicle mobility. Correlations between pedological and engineering soil classification systems will be sought through the use of existing data on tropical soils plus data collected during the MERS program in Thailand and elsewhere in tropical environments. Trafficability characteristics of the U. S. Department of Agriculture (USDA) and Unified Soil Classification System (USCS) soil types for several moisture levels will be established. If sufficient data are collected, a soil-trafficability classification system will be developed by correlating soil, site, and weather data in a manner that will permit the prediction of pertinent soil strength parameters and, hence, trafficability. Work on this activity will be a joint effort by WSGU and WES.

The goal of the laboratory study, which is now under way, is to develop and compare moisture content-density-strength relations of several soils occurring in temperate climates with similar relations for "equivalent" soils occurring in tropical climates. The criteria for equivalency of soils are based on similarity of parent material and/or method of deposition and similarity of soil type according to the Unified Soil Classification System. Grain-size, Atterberg limits, mineralogy, and chemical analysis tests will be run to show the degree of similarity between equivalent temperate and tropical soils. The soils to be used in the test program have been obtained from the 6- to 12-in. depth during the peak of the wet season, and appropriate soil strength and other soil property measurements have been made of the soil in its natural condition. At present, 12 tropical and 11 temperate soils are to be tested. Others will be added from Thailand. The temperate soils were collected in Oregon, Mississippi, and the Piedmont Plateau area; the tropical soils were obtained from Hawaii, Puerto Rico, and the Panama Canal Zone. Table 1 shows the soil

Table 1

Location of Site and Description of Parent Material, Soil, Topography, and Climate*

Parent Material Group			Site No. Temperate Area	Site No. Tropical Area	Area Location	Old Site No.	Parent Material	Soil Series	Soil Classification 6- to 12-in. USDA Class.	USCS Class.	USCS LL	USCS PI	Topographic Position	Wet Season Period	Annual Temp deg	Annual Rainfall in.
Residual	Igneous	Basic	US-2		Shaw, Oreg.	---	Sedimentary tuffs	Polk (or Jory)	SiC**	ML	44	17	Slope-upper	Nov-Mar	52	47
			US-5A		Salisbury, N. C.	---	Hornblende, Greenstone shists	Davidson	CL	ML	49	20	Upland flat	Jan-Mar	60	49
			US-6		Clayton, Ga.	Pied. 18E		Rabun	C	MH	76	28	Slope-upper	Jan-Mar	58	71
				PR-1	Mayaguez	P.D. 183	Serpentine	Nipe	SiCL	MH	59	21	Upland ridge	May-Oct	77	76
				CZ-2	Pedro Miguel	P.D. 140	Basalt	Arraijan	SiC	MH	87	43	Upland ridge	May-Dec	80	102
				H-1	Wahiawa, Oahu	P.D. 184	Basalt	Wahiawa	C	MH	70	25	Upland flat	Jan-Mar	70	50
		Acidic	US-4		Pomaria, S. C.	Pied. 16B	Granite, gneiss, shists	Cecil	C	CH	63	34	Upland ridge	Jan-Mar	63	45
				PR-2	Yabucoa	---	Grano-diorite	Limones	---	MH	81	42	Slope-upper	May-Nov	77	88
		Ash (Allophane clay)	US-3		Tillamoon, Oreg.	---	Volcanic ash alluvium	Quillayute	---	MH	95	15	Bottomland	All year	51	90
				H-3	Wainaku, Hawaii	S-6	Volcanic ash	Hilo	C	MH	105	29	Slope-lower	All year	73	150
	Sedimentary	Limestone (clay)	US-7		Oxford, Ala.	Pied. 28B	Limestone	Decatur	CL	CL	40	18	Slope-upper	Jan-Mar	62	53
				PR-5	Ramey	---	Limestone	Mantanzas	C**	MH	61	26	Slope-lower	May-Nov	77	58
				PR-6	Corozal	---	Limestone	Camaguey	---	CH	128	80	Slope-lower	Apr-Oct	76	71
Mixed	Unconsolidated	Grumusol	US-1		Corvallis, Oreg.	---	Alluvium	Cove	---	CH	70	39	Bottomland	Nov-Mar	52	45
			US-10		Laurel, Miss.	P.D. 13	Marl	Pachuta	C	CH	80	54	Upland flat	Jan-Mar	66	56
			US-12		San Antonio, Tex.	---		Montell	---	CH	74	42		Jan-Mar	68	27
				PR-7	Guanica	SS 216A	Lacustrine	Guanica	C	CH	92	53	Bottomland	Aug-Nov	77	34
				H-2	Wahiawa, Oahu	PD 189	Alluvium and marine	Lualualei	C	CH	89	57	Terrace flat	Dec-Jan	75	22
Water Deposited	Alluvial clays		US-9		Vicksburg, Miss.	PD 135 (No. 8)	Alluvium	Sharkey	SiC	CH	72	42	Bottomland	Jan-Mar	65	50
			US-11		Vicksburg, Miss.	Lake Centennial	Alluvium	Recent	SiCL	CH	71	41	Bottomland	Jan-Mar	65	50
				PR-3	E. coast P. R.	PD 210	Alluvium	Fortuna	SiCL	CH	58	30	Bottomland	Apr-Oct	80	58
	Alluvial silts		US-8		Vicksburg, Miss.	PD 131 (No. 3)	Alluvium	Commerce	SiL	CL	34	12	Nat. levee	Jan-Mar	65	50
				CZ-1	Fort Kobbe	PD 138	Alluvium and marine	Arraijan	---	CL	36	12	Bottomland	May-Dec	80	102
				PR-4	Barceloneta	---	Alluvium	Toa	---	MH	80	33	Nat. levee	All year	77	58

Note: Area legend: US, United States; PR, Puerto Rico; CZ, Panama Canal Zone; H, Hawaii.
* Data from sites in Thailand not included.
** Modal description.

groups and location and description of sites presently under investigation. Table 2 lists the physical, chemical, and mineralogical soil property determinations that will be made, plus the relations that will be sought. The WES has assumed primary responsibility for this study.

Table 2

Laboratory Study

Engineering Properties of Selected Tropical and Temperate Soils

Mechanical, Physical, and Chemical Properties

1. Atterberg limits
2. Mechanical analysis
3. Specific gravity
4. Percent organic matter
5. X-ray diffraction
6. X-ray emission
7. Cation exchange
8. pH
9. Soluble salts
10. Consolidation test, at optimum moisture content
11. Vertical permeability, at optimum moisture content
12. Moisture tension tests, at saturation, 0.06, 0.33, 3, and 15 atmosphere tension for field density

Moisture Content Relations to be Sought

13. Density
14. Cone index
15. California Bearing Ratio (CBR)
16. Unconfined compression
17. Wheel friction

Task 4, Climatic Techniques for Defining State of Ground

Originally, the aim of this study was limited primarily to the use of existing data to develop methods for establishing general correlation between climatic factors and state of ground indices useful in estimating soil conditions for mobility purposes. A reexamination of the significance of the effects of weather elements on ground mobility, plus the scarcity of usable weather data records, caused us to broaden the scope of this task. A plan of work which has been prepared takes into account our latest thoughts. The plan considers a two-phase study. In the first phase, appropriate weather instrumentation will be set up at each of the seven primary areas selected for detailed study and testing in Thailand. Initial plans are for a one-year detailed data-collection program, but hopefully the program can be extended for two years or at least until all the vehicle test programs are completed in Thailand. Phase 2 is to begin about one year after the start of phase 1, or when we have accumulated enough data to establish cause-effect relations between weather factor and vehicle performance parameters. These relations, in turn, will be used to develop meaningful classification systems for ground mobility purposes. Several meetings have been held with Natick Laboratories to discuss MERS plan of work on weather-climatic studies and to assess their capabilities for doing this work. At the moment, it appears that this task may be assigned to Natick Laboratories as a joint effort with a university contractor.

This task also includes a soil moisture-strength study. The objectives of this study are to obtain daily soil-moisture records and strength measurements covering the range of natural moisture contents at 20 sites in Thailand for a period of one year or more and to develop soil-moisture and soil-strength prediction relations using present techniques. The soil moisture-strength study sites will be located in the seven primary study areas, and they will include soils derived from a variety of parent materials and combinations of land use and topographic position. This study is being conducted by WES. The equipment has been shipped to Thailand, and a WES representative is now on TDY in Thailand selecting sites.

Task 5, Noncontact Sensing and
Interpretation of Tropical Terrain

This task was set up to employ aerial photo interpretation techniques as an expedient tool in preparing terrain factor maps of the study areas in Thailand. Work plans for this task have been completed. The plans include a stateside production of factor maps of the seven primary study areas in Thailand; these maps are to be produced at scales no smaller than 1:50,000 through use of existing photography and literature. Individual factor maps will be prepared for soil type, soil-moisture regime, drainage characteristics, vegetation, landform, and land use. The classifications will be established in terms meaningful for mobility purposes. This task has been scheduled for completion this fiscal year. Following the completion of this study, the program will be transferred to Thailand where the seven study areas will be sampled to provide adequate ground control for more detailed and definitive determinations than were possible in the stateside study. Arrangements are also being made to obtain by contract appropriate new photo coverage, at selected scaled and film/filter combinations, of the seven primary study areas.

Primary responsibility for this task has been assigned to the U. S. Army Cold Regions Research and Engineering Laboratory (CRREL); however, WES has a significant input on this study. Activities conducted to date by WES will be presented in a separate paper.

Before arriving at the work plans just discussed, considerable effort was expended in evaluating the present state of the art of airborne multiple-sensing techniques. In the early stages of this study, the possibility of applying multiple sensors was strongly considered. The sensors in the nonvisible portion of the electromagnetic spectrum that were considered included (a) infrared, (b) long, medium, and short radar, and (c) gamma ray. To resolve this problem, a meeting was held with experts from Government agencies and industry to determine the present terrain-measuring capabilities of these sensors. Based on the discussions at this meeting, it was concluded that the presently available multiple-sensor hardware would not significantly increase the capability for obtaining terrain information above that which can now be obtained with conventional photography. It was agreed that these sensors possess special capabilities; however, expensive R&D-type programs are required before their utility can be assessed.

During the meeting, the present status of airborne profilometers was discussed. The discussions were limited to systems using a continuous laser beam; however, other sensors such as gallium arsenide are also used. The claims made as to the accuracy of airborne profilometers are remarkable. We are very much interested in the potential of the airborne profilometer; however, at least six to eight months will be required for engineering development before equipment will be ready for testing. We have made a tentative decision not to consider the profilometer for the MERS program until it has been discussed with ARPA to determine whether the MERS program should fund such an item or whether it could be funded under other ARPA programs.

Radar studies conducted by WES and others have shown that this region of the electromagnetic spectum is capable of providing usable information for estimating surface consistency. Because of WES's unique capability in conducting controlled laboratory radar experiments, a feasibility study has been initiated to determine the capabilities of three radar frequencies for indicating surface and subsurface water conditions. The details of this study and the results achieved to date will be discussed later in the program.

Task 6, Design and
Acquisition of Instrumentation

This task is aimed at procuring and developing instruments suitable for evaluation of cross-country vehicle performance under adverse testing conditions, rapid acquisition and interpretation of terrain information, and data manipulation and reduction in the field. We have found that the development of sophisticated equipment that will expedite measuring, recording, and reduction of data entails long-term projects which are perhaps not within the time frame scheduled for the MERS program. Some of the activities conducted in this area will be discussed in another paper.

Task 7, Soil Testing

This task is concerned with laboratory processing of soil samples as required by the program. Soil samples collected for the comparative soil study and vehicle tests conducted to date have been processed, and results of standard tests have been obtained. Soil samples collected in Thailand are being processed and tested at the SEATO School of Engineering in Bangkok.

Task 8, Development of
Vehicle Performance Relations

This task consists of two major subtasks, namely, the development of one-pass soil trafficability criteria and development of obstacle-capability criteria.

One-pass soil trafficability study. Plans implemented for the one-pass soil trafficability study consist of several test programs to develop a quick and dependable method for predicting the one-pass performance of a vehicle operating in fine-grained soils.

A field testing program is being conducted by a contractor, and he will give us a report on the details of the program and the accomplishments to date. WES personnel have assisted the contractor in the data-collection and data-reduction phases of the program. Tentative plans have been made for LLL to assist in this joint effort.

Prior to the initiation of the field program, a contract was negotiated for compilation of existing trafficability data into one document and performance of such data analyses as are applicable to MERS soil trafficability studies. A report on this study will also be presented by a contractor's representative.

A special laboratory study has been begun by WES to examine the effects of wet surface soil conditions on wheel traction. It was felt that laboratory controlled conditions would provide a systematic means for studying this problem. Most of the tests will be performed on a heavy clay soil at one soil strength, using one tire size (6.00-16, 4-PR) at one deflection (35 percent), and several surface wetnesses and a flooded condition. Some tests will be run in a lean clay soil. Several tire-tread patterns and a special tire-chain device will be tested to determine the effects of treads on wheel performance. The effects of surface wetting on pull versus load relations for one pass and multiple passes will be determined.

Obstacle-capability study. This subtask is intended to establish the performance characteristics of various vehicle configurations in various kinds of obstacle fields regardless of their generic form. Work has been concentrated on identifying the total problem, selecting those portions of the overall problem which the MERS program should pursue, and developing appropriate work plans for the various problem subdivisions selected for investigation. The subdivisions of the problem with which MERS will be concerned include obstacle-vehicle geometry, traction demands imposed by terrain features, and effects of vehicle speed on ride quality. The work contemplated includes analytical/model and field studies. Additional information on this task will be presented in a later paper. WES has assumed primary responsibility for this task; APG capabilities and facilities will be used to a large extent in these studies.

An examination of the problem of ride dynamics and obstacle-crossing capabilities of ground vehicles has revealed that this is a very conplicated problem; however, considerable effort has been devoted to some aspects of the problem by industry and Government. It has also been found that a variety of analytical and statistical approaches that are applicable to various aspects of this problem have been developed. In order to assess the present knowledge pertinent to the prediction of vehicle ride and obstacle-crossing performance in the light of MERS requirements, a contract is being negotiated to provide answers to the following questions:

a. What forms should measurements of terrain and vehicles take for use in present analytical procedures?

b. What theories and mathematical approaches are being used in the solution of the vehicle-dynamics problem?

c. What are the limitations of the present theories and approaches?

d. What level of reliability can one expect from the prediction obtained?

e. What areas need further development?

In order to initiate other obstacle studies at an early date, it is planned to hold in the near future a meeting with representatives of all Government agencies, together with their respective contractors, which have investigated various aspects of the obstacle-vehicle problem. It is hoped that this meeting will provide us with the information necessary to crystallize our thinking on the remaining obstacle studies envisioned under the MERS program.

Task 9, Mobility in Rice Fields

The intent of this task is to establish the properties of rice fields in the United States and in Caribbean areas for comparison with the properties of rice fields of Southeast Asia. U. S. studies are under way, and accomplishments to date plus plans for this task will be discussed in another paper.

Task 10, Development of Mathematical Model of Ground Mobility

This task involves five major subtasks, as follows:

Selection and description of test areas. This subtask has been discussed as part of the airphoto study. As soon as the terrain factor maps are available for the selected test areas, a TDY team will be sent to Thailand to select specific areas for vehicle tests. The factor maps will be used as a guide to delineate areas worthy of testing, thus ensuring an efficient vehicle testing program.

Design of mobility tests. This subtask has been given some consideration as to the best method of conducting cross-country mobility tests. Plans have been made to work with a committee of the Society of Automotive Engineers (SAE) charged with the responsibility of standardizing vehicle performance test procedures. We understand that the testing procedures will include such performance determinations as mechanical reliability, obstacle-crossing capability, and soft soil performance. Upon evaluation of SAE procedures, WES, working with other Government agencies, will prepare a tentative manual of instructions for conducting cross-country vehicle tests. Tentative procedures, however, have been established for collecting terrain data to satisfy the development of single factor-vehicle relations.

Other subtasks. The remaining subtasks, "Test of Mobility in Landform Types," "Verification of Mobility Predictions in Terrain Types of Geographic Regions," and "Development of Expression for Ground Mobility," have not been given any special consideration because they are dependent upon the completion of other tasks.

Task 11, Collection and Exploitation of Environmental Data in Southeast Asia

Practically all the activity conducted on this task to date has been restricted to the exploitation of existing data in the United States by WES; a report on this activity will be presented tomorrow. Because of the delays in establishing the permanent party in Thailand, plus logistical support problems encountered, little or no field data have been collected. We feel that these problems have been resolved, and we hope to tackle this task with much more vigor in the near future.

TDY parties. A schedule for TDY parties has been prepared to initiate four studies in Thailand: (a) soil moisture studies, (b) selection of vehicle test sites, (c) coordination of environmental data collections, and (d) vehicle tests. The TDY groups will consist of personnel of WES, other Government agencies, and contractors. A representative of the first group departed recently for Thailand.

Transportation (air-ground) in Southeast Asia. Transportation requirements for air and ground vehicles in support of Thailand field parties have been virtually nil because a need was not established. Our present ground transportation requirements have been met by local contract; however, as yet we have no plans for acquiring aircraft support to meet our needs as they arise.

Task 12, Classification of Terrain Types in Southeast Asia

Some work has been accomplished on this task. A report on the status of this task is to be given in a paper scheduled for presentation tomorrow.

Task 13, Analogs of Southeast Asia in United States and Vicinity

This task consists of two subtasks that deal with the development of soil and terrain analogs in the United States, Caribbean area, and Southeast Asia. Some preliminary studies have been conducted by WES; however, they have been postponed until the job of mapping terrain types in Southeast Asia is completed. It is estimated that work on this task will be reinitiated in May of this year.

Task 14, Airphotos of Test Areas and Study Areas in Southeast Asia, United States, and Caribbean Area

This task is concerned with acquiring suitable air photography of special study areas as required, and exploiting the informational content of the photos. The status of the Thailand program has already been mentioned. We have obtained conventional and special aerial photographs of several areas in Puerto Rico. The results obtained to date in exploiting the informational content of aerial photos will be discussed in another paper.

Task 15, Development of Terrain Intelligence Portrayal Techniques for Mobility

This task has not been given any special attention yet; we have not been able to find an outside agency with the required capability that is willing to do the complete job as outlined in the program. We have, however, engaged the WSGU to assist WES in this task.

Task 16, Vehicle Design Methodology

Task 16 deals with assembling and analyzing all existing information on the procedures and methods used in the design of vehicles, with the ultimate objective of improving and formalizing such procedures. A contract has been negotiated on certain aspects of this task, and a report on this subject will be presented tomorrow.

Task 17, Procurement, Transport, and Modification of Test Vehicles

Task 17 is concerned with procuring, transporting, and modifying for possible testing unconventional vehicles or vehicles not available through normal channels, if their design shows promise for improving cross-country mobility in the tropics. We have used this task primarily for procuring and modifying conventional vehicles; however, we have attempted to obtain a few modified unconventional vehicles such as the Jiger without success. We may be able to obtain a modified Jiger in about six months.

Task 18, Establishment of Design Parameters for Vehicle Engineers

Task 18 will attempt to formalize a series of general, analytically derived statements defining design parameters and the various vehicle-terrain relations using the data made available through the environmental research program, the testing programs, and the study of existing procedures. Work plans have been formalized, and we hope to initiate work on compiling, organizing, and evaluating existing procedures on which information is available in the literature. It is contemplated that LLL will assume major responsibility for this task.

Task 19, Training Contractor Personnel

This task involves training of contractor personnel in special techniques used in measuring and analyzing data which will be collected in the MERS program. Since no contracts have been negotiated in this area, no work has been accomplished. However, work has been done by WES in training new employees and in preparing a manual of instruction for collecting environmental data. Some work has also been done on a manual of instructions for conducting vehicle tests to ensure the development of proper vehicle-terrain relations.

Task 20, Preparation and Publication of Reports

Task 20 is self explanatory. Since the last meeting of the Advisory Committee, a report on the preliminary survey study conducted in Thailand has been published and given wide distribution. The manual of instruction for collecting environmental data will be published within the next few months. Other reports will be published as necessary.

Problem Areas

Problem areas confronted during the first year's effort on Project MERS will be discussed briefly in several categories. The context of the problems encountered is based on the differences between supposition and reality.

Development and Implementation of Work Plans

Considerable time was spent at the beginning of this year in reevaluating WES operation and funding plans and developing work plans for implementing individual tasks. This was considered the shakedown period in which the groundwork was laid for establishing realistic goals for the MERS time frame. Once a manageable conceptual approach was agreed upon, detailed work plans were developed for many of the MERS tasks. The next step was to sell the work plan to some capable Government agency for implementation either on an in-house or contract basis. At this point, new problems usually arose, such as conditioning people to MERS thinking, etc. In many cases, a change made in one plan necessitated that changes be made in others.

WES acceptance of the responsibility for coordinating environmental data-collection phases of research programs which are sponsored or conducted by ARPA in Southeast Asia, plus a few modest additions to the MERS program by WES, will require additional capability for managing these new activities.

We have been plagued with general administrative problems for which solutions had to be found if available. For example, WES or AMC had to do the legwork to get approval of some of the other Government agencies to participate in the MERS program. In some cases, many months passed before approval was granted.

Establishment of MERS Thailand Detachment

As a result of the late establishment of MERS Thailand Detachment, some trips to Thailand scheduled for TDY groups this past year had to be deferred. We feel that this problem is now behind us, but we must accept the fact that this will put us behind on our data-collection phases of the program, especially since much of our soil and vehicle-performance data must be collected during the wet season when adverse soil conditions prevail.

Procurement

We have encountered problems in procuring vehicles for test purposes. In the procurement of standard military vehicles or spare parts, as much as six months time has been required for delivery of items. I understand that we have a No. 3 priority established. We have attempted to purchase special-purpose vehicles such as the Jiger; however, the manufacturer is not willing to let us purchase a Jiger until the new design changes have been made and tested. We have been working seven months with the Jiger Corporation on this one item.

There are also problems associated with designing and fabricating instrumentation systems which we would like to employ to enhance our ability to collect, record, interpret, store, and analyze terrain and vehicle data. The systems to which we have given some consideration are, by and large, systems that are not presently on-the-shelf items. As a matter of fact, some of the systems that we would like to employ push or exceed the state of the art. If we accept the tools that are now available, we must decide whether the data-collection time phases of the program should be extended or whether we should reduce the amount of data to be collected.

Summary

In summary, I would like to state that the above-mentioned problem areas collectively represent a MERS time frame somewhat greater than that envisioned a year ago.

Funding Status

The MERS funding status is summarized in table 3. The first part of the table represents MERS programmed funds for each task for ARPA Order No. 400, Amendments 3 and 5, authorized for fiscal year 1964. At the end of the table on the left is an estimate of MERS fiscal year 1964 funding status as of February 1964. It can be seen that the expenditures were $604,000; obligations, $866,000; planned obligations by 30 June 1964, $645,000; with a total expenditure and obligation of $2,115,000. On the right is an estimate of the total unobligated funds in the amount of $301,000.

Table 3

MERS PROGRAM - ARPA ORDER NO. 0400-64 (Amends. Nos. 3 & 5)

Programmed Expenditures

Task No.	Title	Authorization Amend. No. 3	Authorization Amend. No. 5	Total
1a	After Action Studies of Mobility Problems (Determination of Remote Area Requirements of CCM Missions)	$ 2,500	$ 23,000	$ 25,500
1b	Tactical Model and Games Study (Determination of Remote Area Requirements of CCM Missions)	1,000	--	1,000
1c	Terrain Application of Model Study (Determination of Remote Area Requirements of CCM Missions)	1,000	1,500	2,500
2a	Surface Macrogeometry (Quantitative Methods of Describing Terrain Factors)	17,000	89,200	106,200
2b	Surface Microgeometry, Miscellany (Quantitative Methods of Describing Terrain Factors)	6,000	123,000	129,000
2c	Vegetation (Quantitative Methods of Describing Terrain Factors)	17,000	150,500	167,500
2d	Hydrologic Geometry (Quantitative Methods of Describing Terrain Factors)	1,500	127,000	128,500
3	Classification of Soils for Mobility Purposes	500	30,000	30,500
4a	Soil Moisture-Strength Prediction Studies (Climatic Techniques for Defining State of the Ground)	500	50,000	50,500
5	Noncontact Sensing and Interpretation of Tropical Terrain	5,000	160,000	165,000
6a	Instrument Vehicle and Equipment (Design and Acquisition of Instrumentation)	25,500	15,500	41,000
6b	Measuring and Recording Instruments (Design and Acquisition of Instrumentation)	2,500	77,500	80,000
6c	Data Manipulation and Reduction in Field (Design and Acquisition of Instrumentation)	7,500	40,000	47,500
7	Soil Testing	500	500	1,000
8a	Development of One-Pass Trafficability Criteria (Development of Vehicle Performance Relations)	103,500	261,500	365,000
8b	Development of Obstacle Capability Criteria (Development of Vehicle Performance Relations)	40,000	132,300	172,300
9	Mobility in Rice Fields	2,000	54,000	56,000
10a	Selection and Description of Test Areas (Development of Mathematical Model of Total Mobility)	1,000	20,000	21,000
10b	Design of Mobility Test (Development of Mathematical Model of Total Mobility)	1,500	24,000	25,500
10c	Test of Mobility in Landform Types (Development of Mathematical Model of Total Mobility)	--	25,000	25,000
10e	Development of Expression for Total Mobility (Development of Mathematical Model of Total Mobility)	1,500	13,500	15,000
11a	Permanent Party (Collection and Exploitation of Environmental Data in SE Asia)	15,000	62,000	77,000
11c	Transportation (Air-Ground) in SE Asia (Collection and Exploitation of Environmental Data in SE Asia)	--	163,500	163,500
12	Classification of Terrain Types in SE Asia	5,000	21,000	26,000
13a	Analogs of Tropical Soils in U. S. and Vicinity (Analogs of SE Asia in U. S. and Vicinity)	2,500	22,500	25,000
13b	Analogs of SE Asia Terrain in U. S. and Vicinity (Analogs of SE Asia in U. S. and Vicinity)	2,000	22,000	24,000
14	Airphotos of Test Areas and Study Areas in SE Asia, U. S., and Caribbean Area	7,000	74,000	81,000
15	Development of Terrain Intelligence Portrayal Techniques for Mobility	2,500	15,000	17,500
16	Vehicle Design Methodology	47,000	128,000	175,000
17	Procurement, Transport, and Modification of Test Vehicles	5,000	15,000	20,000
--	Trafficability Tests with Marsh Screw Amphibian*	--	21,000	21,000
--	Coordination of ARPA Environmental Data-Collection Programs	--	20,000	20,000
--	Unscheduled ARPA Activities	$ 92,500	18,000	110,500
	Totals	$ 416,000	$ 2,000,000	$ 2,416,000

ESTIMATE OF MERS FY 64 FUNDING STATUS - FEBRUARY 1964

Expenditures	$ 604,000
Obligated	866,000
Planned Obligations by 30 June 1964	645,000
Total Expenditures and Obligations	$ 2,115,000

Authorized FY 64 Funds	$ 2,416,000
Expenditures and Obligations	2,115,000
Total Unobligated Funds	$ 301,000

* Total funding for this job is $36,000 ($15,000 on Amend. No. 4, $21,000 on Amend. No. 5).

DISCUSSION

Col. Lynch referred to Mr. Rula's statement about difficulties encountered in attempting to procure a Jiger, emphasizing that ARPA has four of these vehicles in Thailand at the present time. Mr. Rula explained that we needed a modified version of this vehicle for testing purposes since it was the lightest 6-by-6 wheeled vehicle that may have a potential military use. However, the present power train is unsuited for testing because maximum torque cannot be obtained at low speeds. Col. Lynch stated that ARPA has shipped four Jigers to Thailand and that these vehicles could be made available for MERS testing upon completion of ARPA tests. It was agreed that WES would coordinate its requirements for the Jiger with ARPA.

MARSH SCREW AMPHIBIAN

by

E. S. Rush*

Background

Requirements for the Marsh Screw Amphibian and funds for its development originated at the Advanced Research Projects Agency (ARPA). The vehicle was designed and built by Chrysler Corporation for the Navy. The vehicle was subjected by its builders to considerable testing on water, marshland, tidal mud flats, sand, and snow.

Since quantitative measurements of terrain conditions had not been made in the Chrysler test program, it was not feasible to directly compare the Marsh Screw's performance with that of other vehicles on similar terrain conditions. Accordingly, the Navy requested us to undertake a limited but controlled test program with the Marsh Screw on soil conditions occurring near Vicksburg, measuring vehicle performance and soil conditions in the same quantitative terms used in other vehicle-soil evaluations.

The test program was conducted last fall. A report on this program has been published and furnished each member of the Advisory Committee.

Description of the Marsh Screw

The Marsh Screw is a vehicle with an unusual concept of locomotion which places it outside the normal tracked and wheeled vehicle classifications.

The vehicle travels on two 26-in.-diameter, 13-ft-long rotors. Two helical blades are welded to each rotor and the rotors are counterrotated to give forward and backward thrust to the vehicle. Turning is accomplished by cutting power and applying brakes to one rotor and applying power to the other. When both rotors are made to turn in the same direction, the vehicle will move laterally; however, there is no provision for steering while it is moving laterally.

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* Chief, Trafficability Section, AMRB, Mobility and Environmental Division, Waterways Experiment Station, Vicksburg, Miss.

The vehicle weighs 2850 lb and has a pay load capacity of about 1000 lb. Ground clearance is 20 in.

By making certain assumptions and using the tracked vehicle mobility index formula, the vehicle cone index was computed to be 8 when empty, and 11, loaded. This compares favorably with actual test results, at least in one area, in that the vehicle was able to travel, with certain reservations, on a soil with a rating cone index as low as 6 to 10 and containing a great deal of free water. The qualification "containing a great deal of free water" is important, as will be developed later.

In considering how the Marsh Screw story should be presented most effectively in 20 min, we concluded that we should lean mainly on the movies that were taken during the test program conducted here.

The first movie sequence is one with sound. It was assembled before all testing had been performed and therefore must be considered as incomplete--not the "whole story." It will probably convey an impression of superior performance on soft soils that is not entirely deserved. A part of the movie shows the vehicle operating on sand. In watching these scenes on clay and sand, bear in mind that the vehicle was always operating at full throttle.

(Movie)

You have probably concluded by now that the Marsh Screw is (1) not the ideal all-purpose vehicle some people still dream about, and (2) it is a pretty good soft-soil performer. You are certainly right about No. 1, but No. 2 deserves a little more elucidation. Unless the soft soil is also very wet, wet to the extent that water stands on its surface, the vehicle will not perform well. The secret of the Marsh Screw's success is that there must be a low coefficient of friction between the rotors and the medium; in other words, there must be lubrication.

Remember, if you will, that the rotors remained generally clean in the soft-clay scenes, except, of course, when the vehicle was performing multiple passes and rutting deeply.

The next very short scene will show the vehicle making its first pass on a similar clay of about the same softness in another area. Here, the surface of the soil was comparatively dry and no free water was standing. You will see the vehicle struggle at full throttle to make one pass.

(Movie)

During the movie: Note the adherence of soil to the rotors, also the difficulty of steering. This is again at full throttle.

Although not shown in the movie, the vehicle was not able to back up in its own tracks. It remained immobile straining its engine, but unable to turn the rotors against the high friction of the soil. This occurred repeatedly in test after test in this particular area.

A special test section was prepared in an attempt to investigate further, soil stickiness effects on the Marsh Screw. This test section was a compacted buckshot clay topped with 6 in. of dry, powdery buckshot clay, and watered down with a fire hose. At the time of the test, the soil was very wet in the top 4 to 5 in. and very sticky. There was no free water on the surface. You will see that the vehicle could not move under the initial conditions. However, when additional water was sprinkled on the rotors and on the soil, stickiness was reduced, slipperiness or lubrication increased, and the vehicle was able to move to some degree.

(Movie)

During the movie: Note tow cable used for assistance on first pass, and ability to travel easier after watering.

In the next scenes you will watch the M29C weasel and then the Marsh Screw travel over simulated rice-field dikes varying in height from 13 to 20 in. The water between the dikes was about 8 in. deep.

(Movie)

Comments during movie

This is the weasel. The vehicle on the right is an instrumentation vehicle where accelerations experienced by the test vehicle are being recorded. The weasel traversed the test course in 28 sec and experienced a maximum acceleration of 1.35 G's in the direction of travel.

The Marsh Screw experienced difficulty getting over the dikes. The engine stalled on the first dike. On the second dike, the loose weight shifted to the extreme rear of the vehicle, causing the front to rise high in the air. The engine stalled on this dike also. The vehicle crossed dike 3 with very little difficulty. The nose cone of the vehicle's rotors dug into the fourth dike, making it necessary for the vehicle to back up and obtain momentum to cross this dike. The Marsh Screw developed longitudinal accelerations of over 3 G's during its travel through the simulated rice field, and required 78 sec to traverse it.

(Note Marsh Screw eating up dikes; on fourth dike, if it had not chewed through, it might not have made it. Also remember that the dikes are 13 to 20 in. high.)

Summary

The Marsh Screw can operate well on softer soil than any other known vehicle of its general size and purpose, but only if there is an excess of water present to provide lubrication between the rotors and the soil. Under such conditions, it can maneuver well and attain speeds up to an estimated 20 miles an hour.

The efficiency of the Marsh Screw goes down as the coefficient of friction between rotors and soil goes up. On a soft, sticky soil, where adhesion forces are high, the Marsh Screw performs poorly. On a firm, dry soil, pure friction inhibits performance. Performance on such soils can be improved by reducing friction with water sprinkled on the soil surface. On a dry sand where friction forces are likewise high, the performance also is poor. The addition of water here probably would not help much.

The Marsh Screw developed a drawbar pull of about 26 percent of its weight and climbed a slope of about 18 percent on sand. These figures fall far short of those that can be realized by a weasel, for example.

On the clay soil, the maximum drawbar pull measured was 42 percent of its weight. This probably represents the best effort of the Marsh Screw, and probably occurred when soil conditions were optimum. The soil was very wet on the surface and had a cone index of about 40. Lower pulls were experienced on both sides of cone index 40 in the testing program.

Because of its rigidity, the Marsh Screw must be classed as having poor obstacle-crossing abilities.

We have tried to tell the Marsh Screw story in an impartial way, discussing and illustrating strengths and weaknesses as well. We think that despite its obvious weaknesses, the Marsh Screw's outstanding ability in water and wet, soft soil makes it worthy of continued development. Obviously, in order to exploit the screw principle fully, some means must be found to reduce the friction between rotors and soil in comparatively dry soils, or to increase the vehicle's power to overcome this friction. Equally obvious is a need to improve the vehicle's obstacle-surmounting abilities. How these improvements can be effected, or whether they can effected at acceptable compromises in weight, simplicity, ruggedness, and dollars and cents is the problem that must be answered.

DISCUSSION

Col. Lynch asked the Advisory Committee to include in their report recommendations on what to do with the Marsh Screw. Before opening the meeting to discussion on this subject, he emphasized that the Marsh Screw was conceived for operations in Mekong Delta type of terrain and that ARPA feels the vehicle should be developed for military use. A series of discussions then ensued which compared the concept of the Marsh Screw to other previous experimental, special-purpose screw, wheeled, and tracked vehicles. Next, the performance of the Marsh Screw in grassland areas was discussed and its good water speed capability (8-10 mph) was observed. It was emphasized that during the wet season this vehicle would have little difficulty in traversing the Bangkok Plain and much of the Korat Plateau in Thailand, and the Mekong Delta area in South Vietnam. Even during the dry season the canals and streams in the Bangkok Plain would afford avenues of access to much of the area. The discussions finally concluded on an agreement that 10-15 vehicles should be produced as soon as possible for test and evaluation in South Vietnam.

CONCEPTUAL APPROACH TO THE DEVELOPMENT OF TERRAIN-VEHICLE RELATIONS

by

R. D. Wismer*

Project Goals

The ultimate goal of Project MERS is to provide the vehicle designer and the ground mobility analyst with quantitative information concerning the effect of the various features of the physical environment on surface vehicle movement. This is a noteworthy endeavor even in its simplest form, and we might add, not a new one. However, one element is different from other projects and that is the three-year time frame of the MERS project. This time frame now qualifies the stated goal to "the development of the most useful quantitative information for the vehicle designer and mobility analyst that is possible in a three-year program." This now removes the project from the mystic and, in fact, supplies the basis for its existence.

The inclusion of the vehicle designer, mobility analyst, and three-year time limit in the project goal makes two very strong implications concerning the conduct of the program. First, all the elements of the ground mobility problem must be considered and developed to a common level of quantification. Second, existing knowledge in all elements must be exploited to a maximum, possibly to the extent that it will comprise 80 percent of the total fund of knowledge at the conclusion of the program. The time frame of MERS makes the latter implication obvious; however, the former implication may not be obvious to many and deserves amplification.

The proposition for developing the quantification of all the elements of the ground mobility problem to the same degree is based on a dual premise:

a. Both the vehicle designer and the mobility analyst require quantitative information.

b. The quantification of ground mobility is dependent upon the quantification of each element of the total problem.

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* MERS Branch, Mobility and Environmental Division, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

If the premise is accepted, the proposition must be accepted. No factual information can be offered at the present time to support the premise. However, to the WES personnel involved, acceptance of the premise is intuitive because of the engineering basis of the program.

Research Approach

Recognizing the project goals and their implication to the conduct of the program, WES has developed a general approach to the development of the required information which is presented in the form of a flow chart in fig. 1. This approach was developed to ensure orderly development of the required results and to allow for several phases of development to evolve. The stated approach is considered necessary because of the interdependency of the results of the various elements. The chronology of plan is outlined as follows:

a. Identify pertinent vehicle and environmental factors.

b. Identify the vehicle-terrain relations to be sought and the analytical and statistical procedures that might be applicable.

c. Design vehicle test and data collection procedures necessary to satisfy the requirements established in items a and b above.

d. Conduct controlled vehicle tests to test vehicles singly against each environmental factor.

e. Develop valid single vehicle performance-environmental factor relations for a representative range of vehicles.

f. Relate analytically or statistically vehicle and single environmental factor characteristics to vehicle performance parameters.

g. Evaluate the relations developed in item f by predicting single vehicle-environmental factor performance and comparing predictions with test results.

h. Modify the relations developed in item f and repeat item g, if an improvement in prediction accuracy is indicated.

i. Reexamine items b and c, emphasizing environmental factors operating in combination.

j. Predict vehicle performance in multiple environmental factor situations, using single vehicle-environmental factor relations.

k. Conduct controlled vehicle tests against environmental factors operating in concert.

l. Compare predictions with test results and develop appropriate analytical or statistical relations between vehicle performance parameters-vehicle and environmental factor characteristics.

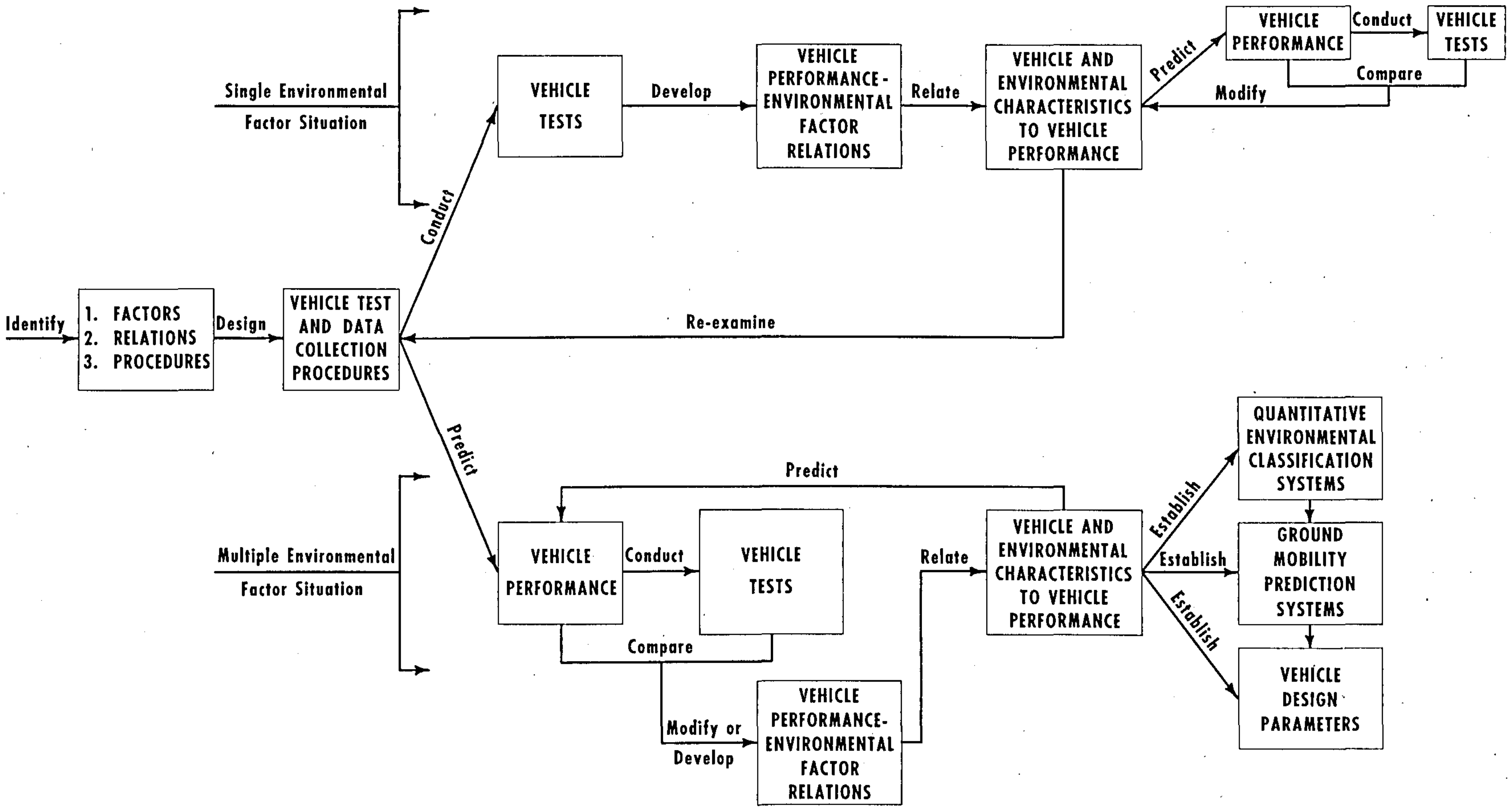


Fig. 1. WES concepts for quantification of ground mobility

m. Establish quantitative systems for classifying environmental factors based on the class internal requirements dictated by item i.

n. Arrange the knowledge developed in a form most useful to vehicle designers and ground mobility analysts.

It should be noted that the accomplishment of each element or task is not intended to be treated as an end in itself but as an additional bit of knowledge directed to the accomplishment of the project objectives, for the utility of the developed information is the real goal, and this utility is directly related to the depth of development of the least-developed element of the total problem.

Messrs. Knight and Grabau identified many of the vehicle and environmental factors pertinent to the ground mobility problem in their respective papers. I shall discuss some additional ones today; however, most of my presentation will be concerned with the identification of the terrain-vehicle relations to be sought in Project MERS and a possible form of a ground mobility expression.

Conceptual Terrain Vehicle Relations

Since the ultimate goal of Project MERS is to provide the vehicle designer and the ground mobility analyst with quantitative information concerning terrain-vehicle interaction, it is essential that an early assessment be made of the terrain-vehicle relations required and the form in which they should be developed. This has been attempted in the following paragraphs under two general classifications: (a) soil-vehicle relations, and (b) obstacle-vehicle relations. The specialized definition of surface obstacles used in this context makes it possible to include all the inhibiting features of the terrain, except soil consistency, in the obstacle classification, and thus the two classes result.

Soil-vehicle relations

The relation between soil consistency and vehicle mobility will be sought on several levels in the MERS program. Emphasis on all levels will be placed on one-pass performance because of the concepts of remote area conflict included in the program. The one-pass soil-vehicle relations developed will consider speed and maneuver capability as well as straight-line "go" or "no-go" ability.

Definition of soil-vehicle relations that will permit the prediction of trafficability by the military analyst achieves only one of the MERS goals. Special attention will be given in the development of all soil-vehicle relations to increasing the utility of the results in establishing design parameters for vehicle engineers. This requires quantification of both pertinent soil and vehicle characteristics in relation to vehicle performance. The existing instruments and techniques of soil-vehicle mechanics will be exploited to their fullest in an attempt to place the resulting techniques on as rational a basis as possible.

The primary soil-vehicle relations to be sought in the program are: (a) drawbar pull-soil strength, (b) drawbar pull-vehicle slip, (c) vehicle speed-soil strength, and (d) vehicle maneuver-soil strength. These relations are discussed below.

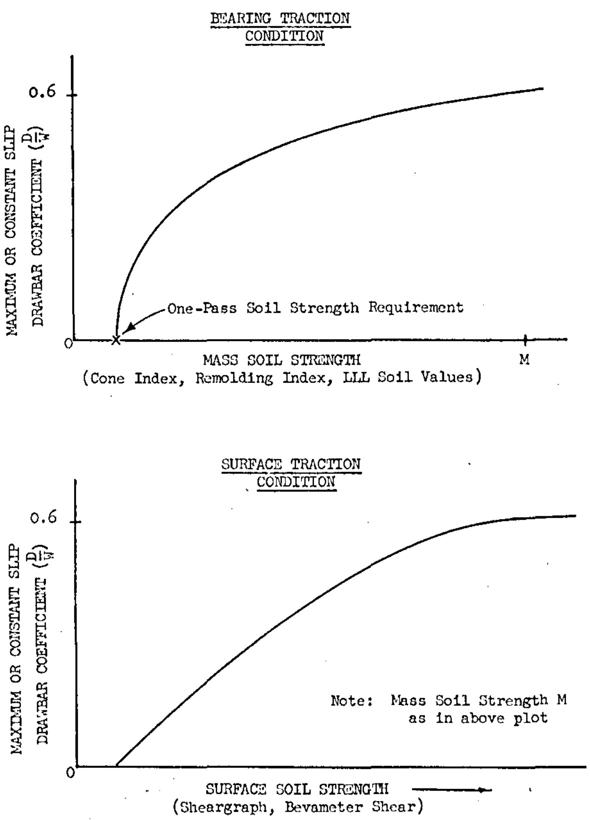


Fig. 2. Drawbar pull-soil strength relations; single vehicle

Drawbar pull-soil strength relations. The development of drawbar pull-soil strength relations is of primary importance in the program because of the emphasis on the "degree" of mobility and the development of vehicle design parameters. It is essential that the "usable" traction a vehicle or locomotion concept can develop be quantitatively related to soil strength in such a manner as to achieve the program objectives, and that this relation span the range of soil strengths significant to vehicle mobility, e.g. from immobilization to the maximum traction. Representative drawbar pull-soil strength relations for a single vehicle are presented in fig. 2. As is customary, the drawbar pull is reported as a ratio of drawbar pull to vehicle weight, termed the drawbar coefficient. It is also designated as a maximum or constant-slip drawbar coefficient because, as will be discussed later, drawbar-pull development is a function of vehicle slip as well as soil consistency.

Examination of fig. 2 reveals that two separate drawbar pull-soil strength relations have been identified for a single vehicle and a single soil type, one depending on mass soil properties, the other on surface soil properties. This has been done to dramatize the difference between the normal vehicle immobilization or low-traction development condition, which occurs with extensive vehicle sinkage and observable motion resistance, and the vehicle failure that has been attributed to soil "slipperiness," which occurs with a relatively small amount of vehicle sinkage and very little observable motion resistance. The nature of the vehicle failure attributed to "slipperiness" implies a layered terrain condition for which traction strains are confined to the surface layer of low strain resistance, whereas the bearing strains are transmitted to the underlying material of high strain resistance. The surface layer may be soil at a high moisture content, loose soil particles or pebbles, wet vegetation, or organic material. Regardless of the composition of the surface layer or its thickness, as long as this layer possesses lower strain resistance than the underlying material and the traction strains are confined to this layer, the end result is the incongruent vehicle failure with insignificant sinkage which has been attributed to "soil slipperiness." In many cases, the difference between a "slipperiness" or surface traction failure and relatively high mobility will be determined by the aggressiveness of the vehicle's traction elements; for, if the vehicle can cut through the weak surface layer and exploit the higher strain resistance of the underlying material, tractive failure will not result.

Recognizing the mechanics of the two general types of soil-vehicle failures leads to development of the desired relations on two bases (fig. 2): mass soil properties and surface soil properties. To make the consideration all inclusive, one would have to replace "soil properties" with "surface material properties." In any event, the implication of the dominant soil-strength or surface material strength condition is apparent in fig. 2.

An indication of the magnitude of the effect of a weak surface layer is observable from fig. 2. The surface traction curve is representative of a soil condition with mass soil strength greater than M as indicated on the bearing-traction curve, yet the drawbar coefficient varies from zero to maximum depending on the strength of the surface layer.

The zero drawbar point marked on the bearing-traction curve defines the one-pass soil strength requirement of the given vehicle, which is the soil strength condition which will just permit passage of the vehicle in a straight-line path at approximately 2 mph. The one-pass soil strength requirement determined on a straight-line go or no-go basis and the zero-drawbar-pull soil strength condition are expected to be equal; however, the final one-pass soil strength requirement assigned a vehicle for purposes of predicting soil trafficability will be slightly greater to allow for soil nonuniformities.

Drawbar pull-vehicle slip relations. Having observed the dependency of drawbar pull development on soil strength, it is now appropriate to examine another factor affecting drawbar pull, that of vehicle slip. This is attempted in fig. 3 for two types of conventional vehicles and two general soil types. It is apparent from fig. 3 that drawbar pull development

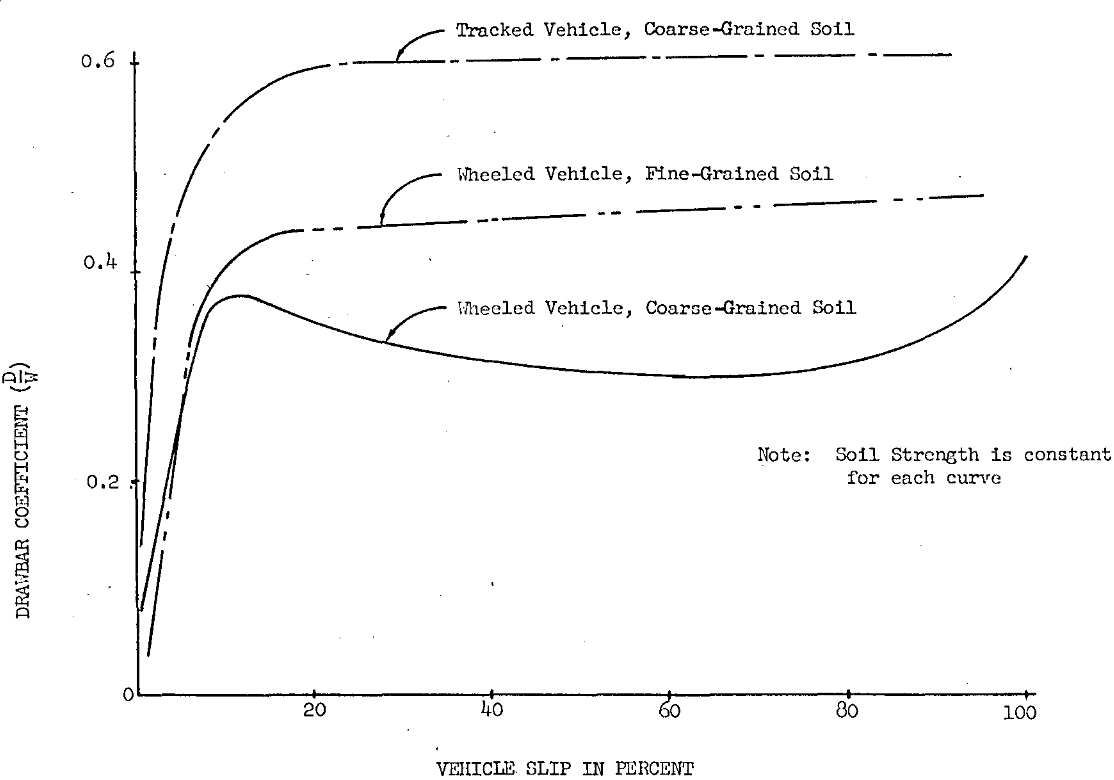


Fig. 3. Drawbar pull-vehicle slip relations

is a function of vehicle slip for all the soil-vehicle systems represented. Further examination of fig. 3 reveals that the drawbar pull developed at a given vehicle slip is a function of the traction element and the soil type, as well as soil strength (fig. 2). Thus, the drawbar pull-slip curve of a given vehicle expresses the traction efficiency of the soil-vehicle system under consideration. This information presented in the proper form, which ideally would be a mathematical relation between elements of the traction and soil systems and drawbar pull development, is of great value to a vehicle design engineer in choosing the proper vehicle traction system with regard to the mission of his vehicle.

Vehicle speed-soil strength relations. In the final analysis, one of several possible criteria of ground mobility is the time required to get from one point in a physical environment to another. Assuming a relative equality of path lengths, which is not justified in the abstract, this criterion of ground mobility becomes speed. Thus, the speed capability of vehicles with respect to soil strength in a level, straight-line path situation is of considerable importance because it puts an upper limit on ground mobility for each soil-vehicle system considered.

The speed capability of representative vehicles will be determined over a range of soil strengths significant to ground mobility. A characteristic relation between vehicle speed and soil strength is presented in fig. 4. In addition to vehicle speed and soil strength, data will be collected concerning engine rpm, vehicle slip, and vehicle torque to be used in analytical studies of the relation between pertinent soil-vehicle characteristics and speed capability.

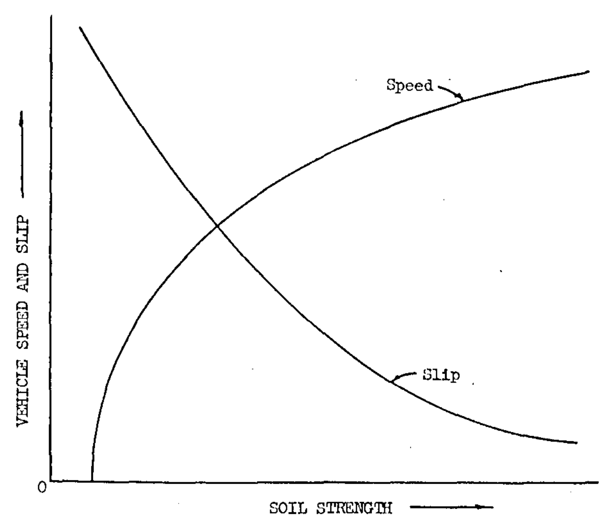


Fig. 4. Vehicle speed-soil strength relation; single vehicle

The expected relation between vehicle slip and soil strength for the resulting speed levels is also presented in this figure to point out the importance of traction efficiency in this case. The maximum speed for many soil-vehicle systems will result from a compromise of maximum available traction and translation speed loss due to wheel slip; e.g., the maximum speed condition will probably occur at an intermediate point on the pertinent drawbar pull-slip curve (fig. 3).

Vehicle maneuver-soil strength relations. Obstacle circumvention is one of the demands of cross-country movement on the excess traction developed by a vehicle. This demand arises from the fact that as a vehicle turns or maneuvers to avoid surface obstacles, it increases its motion resistance because of nontracking wheels, side motion of tires and tracks, or steering moments depending upon vehicle characteristics. Experimental quantification of the relations between the pertinent variables will be pursued on a steady state turning radii basis as shown in fig. 5. The results of these tests will be used in analytical analyses of the relation between soil-vehicle characteristics and maneuverability employing the motion resistance concept described.

Obstacle-vehicle relations

Having considered the primary soil-vehicle relations, it is now appropriate to examine the pertinent obstacle-vehicle relations. As explained previously, the term "surface obstacle" refers to all features of the terrain, except soil consistency, that inhibit surface vehicle movement. This includes such features as trees, rocks, stumps, deadfalls, ditches, dikes, small streams, etc. The effects of such surface obstacles on vehicle movement range from outright immobilizations, through radical limitations in average operational speeds, to relatively minor speed reductions, depending primarily upon relative obstacle-vehicle characteristics.

For ease of understanding, surface obstacles can be classified as either surmountable or insurmountable, based on the required mechanism of vehicle negotiation. Reflection upon these class groupings will show them to be indiscrete; e.g., a 2-in.-diameter vegetation stem is a surmountable obstacle to an M60 tank, an insurmountable obstacle to a Jiger, and can be either a surmountable or an insurmountable obstacle to an M37, depending upon available traction.

Surmountable obstacles. As the class designation infers, surmountable obstacles are physically crossed or climbed by the vehicle rather than avoided or circumvented as is done for insurmountable obstacles. The primary factors affecting vehicle mobility with respect to surmountable obstacles are dynamic soil compressibility, vehicle dynamics, and obstacle-vehicle geometry. Although the physical manifestation of this problem is three dimensional, first-order approximations of the problem can be obtained by considering a two-dimensional case (vertical plane) and assuming that all obstacles will be encountered squarely.

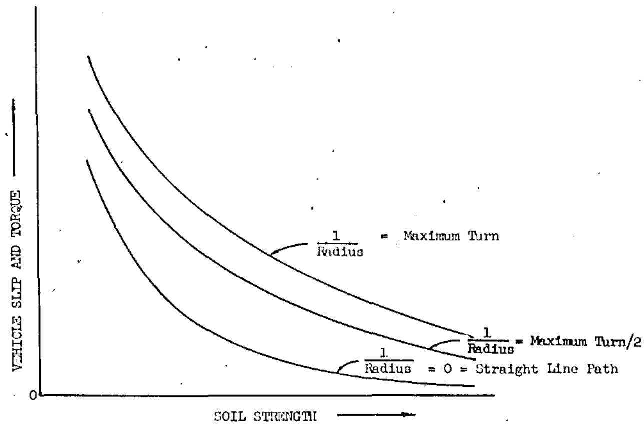


Fig. 5. Vehicle maneuver-soil strength relation; single vehicle

Vehicle mobility for a single vehicle with respect to surmountable obstacles is presented as a three-parameter surface in fig. 6. The dependent parameter is vehicle mobility and the independent parameters are

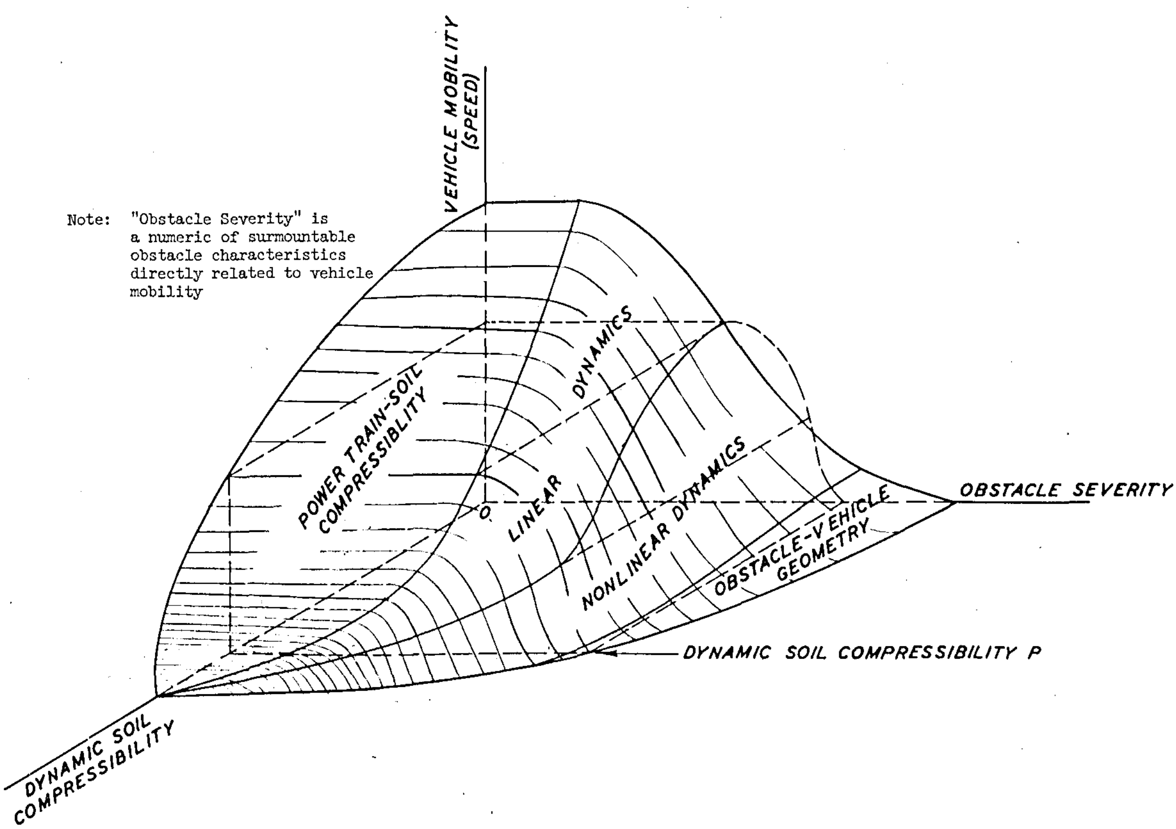


Fig. 6. Conceptual relations; surmountable obstacles, single vehicle

"obstacle severity" and "dynamic soil compressibility." Vehicle mobility can be considered in terms of speed for this discussion; however, the independent parameters, obstacle severity and dynamic soil compressibility, require further amplification if the concept of the system is to be properly understood.

The term "obstacle severity" is envisioned as a numeric of surmountable obstacle characteristics that is directly related to vehicle mobility for a soil condition of given dynamic compressibility. As can be seen in the vehicle mobility-obstacle severity plane of fig. 6, the relation is also inverse; for, as obstacle severity increases, vehicle mobility decreases.

The term "dynamic soil compressibility (dsc)" is envisioned to be a measure of the ability of the soil to absorb dynamic energy. In this case, the dynamic energy of concern is that created by a vehicle as it crosses irregular terrain. Dynamic soil compressibility is presumed to be inversely related to soil shear strength; i.e., as dynamic soil compressibility increases, soil shear strength decreases. This conceptual soil property has been introduced to emphasize the importance of energy absorption by the soil in the surmountable obstacle problem and to admit the possibility that a separate soil measurement may be required to quantify it.

As shown in fig. 6, the surmountable obstacle-vehicle problem can be separated into relatively discrete elements according to the controlling factor for vehicle mobility. These elements are represented as portions of the three-parameter surface. The controlling factors for vehicle mobility constituting these portions of the total problem are: power train-soil compressibility, linear dynamics, nonlinear dynamics, and obstacle-vehicle geometry. To be sure, all of the factors cited can be and often are present in each of the identified bands of the problem spectrum; however, in each, one factor is dominant with respect to limiting vehicle mobility.

The limiting condition attributed to the characteristics of the vehicle power train and the dynamic compressibility of the soil is represented as the flat portion of the three-parameter surface (fig. 6). When the dynamic compressibility of the soil is zero (vehicle mobility-obstacle severity plane), vehicle mobility for small values of obstacle severity is limited by the speed capability of the vehicle's power train. However, as dynamic soil compressibility increases, vehicle mobility for small values of obstacle severity is primarily limited by the ability of the soil to resist traction strains. At the other end of the problem spectrum, i.e. large values of obstacle severity, vehicle mobility is primarily limited by relative obstacle-vehicle geometry, which defines the extreme right portion of the vehicle mobility surface presented in fig. 6.

In contrast to the physically imposed limitations on vehicle mobility at the two extremes of the surmountable obstacle problem spectrum, the limitations in the middle of the problem spectrum are driver imposed. These limiting conditions are those labeled linear and nonlinear dynamics in fig. 6. The reduction of vehicle mobility with increasing obstacle severity in the linear dynamic region is an expression of the discomfort or objection of the vehicle driver to increasing vehicle vibration that is primarily linear in quality. In contrast, the reduction of vehicle mobility observed in the nonlinear dynamic region is caused by the driver's concern for his safety and the structural integrity of the vehicle with respect to the increasing vehicle vibration that is primarily nonlinear in quality.

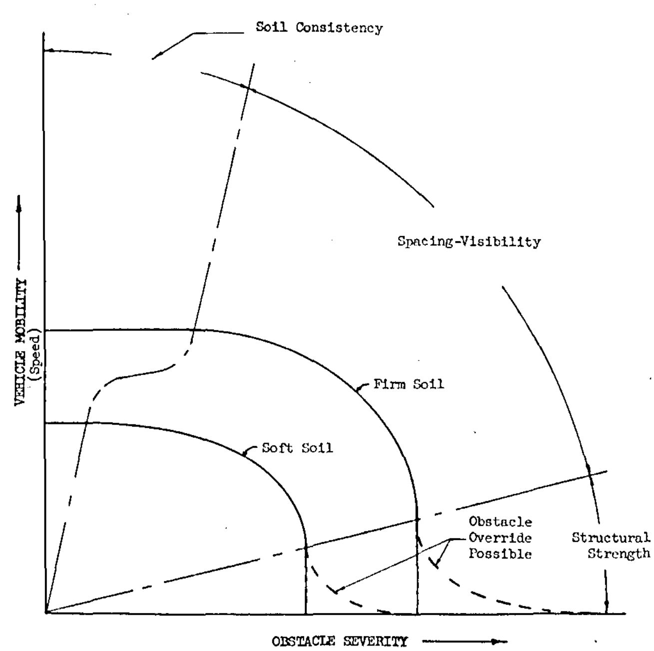
Critical examination of the spectrum of the surmountable obstacle problem as presented in fig. 6 will reveal that the limitation of vehicle mobility by the vehicle power train and dynamic soil compressibility for small values of obstacle severity is not really an obstacle-vehicle limitation but is, in fact, a soil-vehicle limitation. This is true and the power train-soil compressibility region is actually the transition zone between the soil-vehicle and obstacle-vehicle problems. However, this in no way minimizes the effect of dynamic soil compressibility on vehicle performance for intermediate values of obstacle severity as shown in the vehicle mobility-obstacle severity plane of fig. 6. The solid curve shown in this plane represents vehicle mobility on a rigid/unyielding terrain (dsc = 0) for which all the dynamic energy of the vehicle must be absorbed by the vehicle, while the dashed curve represents vehicle mobility on a soft/yielding terrain (dsc = P) for which both the soil and the vehicle absorb the dynamic energy of the vehicle. It is apparent from the comparison of these curves for equal values of obstacle severity that a yielding terrain may permit greater vehicle mobility for intermediate values of obstacle severity than an unyielding terrain because of the reduced dynamic energy transmitted to the vehicle body and driver.

At present, both analytical/model and field studies are planned for the linear dynamics and obstacle-vehicle geometry facets of the surmountable obstacle problem. Research activity with respect to nonlinear dynamics will await developments in the linear dynamics and obstacle-vehicle geometry areas because of the complexity of nonlinear dynamic systems. Hopefully, adequate interpolation for the nonlinear dynamic region can be made from the results of the other studies.

In pursuing the research of the limiting condition areas, it should be kept firmly in mind that the separation of the problem is merely expedient with respect to the conduct of the required work and that the problem is a continuum and the boundaries separating the identified elements are really "gray" areas of unknown width.

Insurmountable obstacles. The insurmountable obstacle problem is primarily a problem of obstacle avoidance. It differs from the surmountable obstacle problem with respect to two basic considerations: (a) the geometry of the problem is basically two dimensional, in this case the horizontal plane; and (b) vehicle dynamics is not of prime importance, at least to the extent that dynamic soil compressibility is not a significant parameter.

A graphical representation of the conceptual relation between vehicle mobility and "obstacle severity" for insurmountable obstacles, considering a single vehicle, is presented in fig. 7. "Obstacle severity" in this context is



Note: "Obstacle Severity" is a numeric of insurmountable obstacle characteristics directly related to vehicle mobility

Fig. 7. Conceptual relations; insurmountable obstacles, single vehicle

envisioned as a numeric of the dominant insurmountable obstacle characteristics related to ground mobility such as spacing, visibility, and structural strength. The hypothetical numeric is assumed to be directly related to vehicle mobility.

As done for surmountable obstacles, the spectrum of the insurmountable obstacle problem (fig. 7) can be separated into discrete elements according to the controlling factor for vehicle mobility: soil consistency, spacing-visibility, and structural strength. The limitation of soil consistency will only be considered as a secondary factor limiting vehicle mobility in the spacing-visibility and structural-strength regions. Whereas the soil consistency and structural strength limitations on vehicle mobility arise from physical limitations of the vehicle and the environment, the limitation of vehicle mobility in the spacing-visibility region is related to such physical factors as obstacle spacing, vehicle geometry, turning radii, and maneuverability (soil dependent), as well as the human factor of driver caution due to restricted visibility.

The conceptual research plan for insurmountable obstacles is essentially the same as it was for surmountable obstacles. However, the controlling factor of structural strength is a special situation essentially limited to vegetation stands consisting of closely spaced plants of small stem size; only field studies are envisioned with respect to this element of the problem. Both analytical/model and field studies are planned for the spacing-visibility situation.

The remarks concerning the problem continuum, factor dominance, and the "gray" area of the boundaries made with respect to surmountable obstacles are equally applicable to insurmountable obstacles.

Available Traction Concept

The first factor considered by both the vehicle designer and the ground mobility analyst in attempting to unravel the ground mobility problem is that of traction. This may seem such an obvious fact of life that it is unsophisticated to even mention it. For, in fact, is this not the reason that trafficability or soil-vehicle mechanics research is more than 15 years old, whereas mobility-environmental research is still in its infancy? The answer is obvious, and it leads to the concept of developing a ground mobility expression based on available and required traction, which has been suggested before by many researchers in the field.

Before pursuing this concept, it should be noted that a ground mobility expression on such a basis can not stand alone even for the mobility analyst, let alone for the vehicle designer. The problem of terrain-vehicle geometry must also be considered in its many manifestations with special attention given to resulting vehicle dynamics to assess properly the total problem. However, this does not reduce the available traction concept to an academic exercise because the expression puts an upper limit on ground mobility.

Several forms of a possible traction-based mobility expression are presented in fig. 8. The first expression considers the total available

TOTAL TRACTION EXPRESSION

TOTAL AVAILABLE TRACTION = Motion Resistance + Slope Demand + Maneuver Demand + Vegetation Override Demand + Obstacle Crossing Demand + Speed Demand

EXCESS TRACTION EXPRESSION

EXCESS AVAILABLE TRACTION = TOTAL AVAILABLE TRACTION - Motion Resistance = Slope Demand + Maneuver Demand + Vegetation Override Demand + Obstacle Crossing Demand + Speed Demand

SPEED CAPABILITY EXPRESSION

Speed Capability = EXCESS AVAILABLE TRACTION - Slope Demand - Maneuver Demand - Vegetation Override Demand - Obstacle Crossing Demand

Fig. 8. Ground mobility expression, available traction concept

traction and its disbursement in the form of motion resistance (straight-line operation), slope demand, maneuver demand, vegetation override demand, obstacle crossing demand, and finally, speed demand. Because information concerning total traction is often unavailable, the second expression based on excess available traction may have more utility, especially to the mobility analyst. The excess traction expression is obtained by subtracting motion resistance from the total traction expression as shown (fig. 8).

Once the environmental factors of a given environment are quantified in terms of traction demand, specific routes can be chosen on a mission basis and evaluated. The first evaluation might be on a "go or no-go" basis by neglecting the speed term of either of the two traction expressions, and the final evaluation on a "degree of go" basis using the speed capability form of the traction expression.

The designer of military vehicles, however, would probably use the first expression, that based on total traction. Using estimates of traction demands based on numerical evaluation of the various inhibiting factors which a vehicle would have to negotiate to be able to move across country in a given environment, the vehicle designer could determine the maximum traction that the design vehicle would have to develop. It is worthy of note that the obstacles or soils which the vehicle must cope with are not the average conditions; instead, they are the worst conditions along the best available routes in the environment. One cannot establish these conditions in terms of probability functions; however, statistical processes can be employed to optimize a vehicle design intended for use in different environments which are not radically different with respect to imposed limitations on surface vehicle movement.

The ground mobility expression described is not submitted as an only possibility. It is merely a suggested possibility.

Summary

The goal of Project MERS with respect to the needs of the vehicle designer and ground mobility analyst for more quantitative information concerning terrain-vehicle interaction is presented. The requirements of the stated project goal and the three-year time frame are translated into a research approach for the development of the required terrain-vehicle relations. The research approach adopted develops the terrain-vehicle relations from the single environmental situation to the multiple environmental situation.

The required terrain-vehicle relations are divided into two discrete categories: (a) soil-vehicle relations, and (b) obstacle-vehicle relations. A further subdivision of the obstacle-vehicle problem is made in terms of surmountable and insurmountable obstacles which are shown to be indiscrete categories. The spectrum of each terrain-vehicle relation is presented and

separated into regions with respect to the dominant factor limiting vehicle mobility.

Finally, the form of a possible ground mobility expression based on available and required traction, which considers the primary terrain factors, is presented.

COMPILATION OF EXISTING TRAFFICABILITY DATA

by

G. T. Cohron*

Background

A new array of trafficability research endeavors dictates that existing data be utilized to the fullest possible extent. The WES/AMRB trafficability section has been conducting vehicle tests in soils since 1946. Over this period, test techniques have been changed several times. Parameters now known to be needed for proper analysis either were not measured in earlier tests (such as remolding) or were measured by different methods than now used (cone penetrometers). Some data were not reported, even though collected, because they did not apply directly to the problems at hand. These are thus not readily accessible. However, some of the information needed to complete the previously collected data for current reanalysis was still recoverable.

Project Objectives

This project was designed to compile all available test data, to translate them into common, current terms, and, insofar as possible, to complete them in some important respects. Complete specifications were drawn up on vehicles, tires, and soils as pertinent to the various tests. Finally, this information will be presented in a form which may be either used for manual computations or entered on punched cards for rapid analysis and/or consultation via computer. Some preliminary computations will be made immediately in support of the first-pass trafficability studies.

Progress

Work on the project started in July 1963 with a search for all available information on trafficability tests and the design of forms to reduce all of it to a common "language." In order to simplify the task by

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* Vice President, Wilson, Nuttall, Raimond, Engineers, Inc., Chestertown, Md.

avoiding endless repetition, separate forms were designed to contain test data (fig. 1), wheeled vehicle specifications (fig. 2), tracked vehicle specifications (fig. 3), tire data (fig. 4), and soils information (fig. 5). (The examples shown are the final reproducibles into which data from work sheets are typed.) By November 1963, most available test data had been recorded on work sheets and a bibliography had been compiled on the sources of data.

November and December were spent in gathering all sorts of missing information as indicated by gaps in the data sheets.

Values which were not available but which could be reasonably estimated from closely related data were estimated and keyed as estimates. Some effort was also spent in studying the programming possibilities of the gathered information and the form for its presentation to minimize difficulties of transcription onto tape or punched cards. The final form lends itself equally well to manual computations.

Necessary sidetracks were taken from time to time for analysis work. A brief study to check the correlation of different size cone penetrometers was done. Remolding, a phenomenon not recognized in earlier work, was studied with a view to making reasonable estimates where this important information was missing. The sources of data were carefully reviewed so that a summary of their contents and findings could be presented in the final report.

A good portion of January was devoted to designing the final reproducible data forms and in planning the format of the report. Writing of the report covering completed phases was also begun. The reproduction processes were set up and the needed materials purchased.

Currently, designated test data have been worked into data forms with the exception of one group of tests conducted by TRECOM in 1962 (which will not be available until March 1964) and typing of information onto the final reproducible forms has begun. Vehicle specification sheets are being reproduced and work sheets for soils data are being put onto the final reproducibles. Final keying numbers are being added. Tire information has been plotted on graphs showing (1) loading-deflection curves as a function of inflation pressure, and (2) deflection-contact area curves, where available. Over 200 of these curves covering different tire sizes have been plotted in

TEST DATA SHEET

VEHICLE ________ TIRE ________

SHEET NUMBER	1 ☐☐☐☐ 2 ☐☐☐
VEHICLE NUMBER	3 ☐☐ 4 ☐ 5 ☐
SOILS SHEET NUMBER	6 ☐☐☐
DATA SOURCE	7 ☐☐

7 SOURCE OF DATA

REPORT NO. ________
SUPPLEMENT NO. ________

TITLE ________
DATE ________ AGENCY ________
SITE ________
ITEM NO. ________ TEST NO. ________
LANE NO. ________ DATE ________

TEST DATA

KIND OF TEST SP 8 [1] __ DBP 8 [2] __ TOW 8 [3] __ SP. & DBP 8 [4] __

PASSES COMPLETED ____ 9 ☐☐ NO. OF PASSES WITH DATA 10 ☐☐

IMMOBILIZATION NO 11 [0] __ YES: FWD. 11 [1] __ RVS. 11 [2] __

TOWED LOAD ________

33 QUALITY OF GO PASS NO. 35

1. EASY — LESS THAN 1/40
2. SLIGHTLY DIFFICULT — 1/20 TO 1/40
3. DIFFICULT — 1/10 TO 1/20
4. EXTREMELY DIFFICULT — MORE THAN 1/10

34 QUALITY OF TEST 0. GOOD TEST

1. TORQUE STALL
2. SUBMERGED OBSTACLE IN LANE DEPTH
3. RUT CONTAMINATION FROM WATER
4. STUMP INTERFERENCE WITH UNDERCARRIAGE
5. EXCESSIVE ROLL FROM RUT UNDULATIONS
6. RUT WIDER THAN TRACK OR TIRE
7. OTHER

SOIL CRITICAL LAYER FOR VEHICLE ________

BEFORE TRAFFIC STRENGTH					SOIL TYPE	
DEPTH	DEPTH	CI	RI	RCI	USCS	USDA
0-6"		12	13	14		
6-12"		15	16	17		
12-18"		18	19	20		
18-24"		21	22	23		

MOISTURE CONTENT (%) - DRY DENSITY (LB./CU. FT.)

PASS	0-6" MC	0-6" D	6-12" MC	6-12" D	12-18" MC	12-18" D	18-24" MC	18-24" D
24 0	25	26	27	28	29	30	31	32
24 ☐☐	25	26	27	28	29	30	31	32
24 ☐☐	25	26	27	28	29	30	31	32

REMARKS ________

MEASURED CONE INDEX VALUES													NO. OF POINTS AVGD.	RUT DEPTH AVG.	RUT DEPTH L	RUT DEPTH R	DRAWBAR PULL (M - MAXIMUM, C - CONTINUOUS)	
PASS		0	3"	6"	9"	12"	15"	18"	21"	24"	27"	30"						
35 0	AVG.	36	39	42	45	48	51	54	57	60	63	66	69	70	71	72	73	M
	MAX.	37	40	43	46	49	52	55	58	61	64	67					74	C
	MIN.	38	41	44	47	50	53	56	59	62	65	68						
		36	39	42	45	48	51	54	57	60	63	66	69	70	71	72	73	M
		37	40	43	46	49	52	55	58	61	64	67					74	C
		38	41	44	47	50	53	56	59	62	65	68						
		36	39	42	45	48	51	54	57	60	63	66	69	70	71	72	73	M
		37	40	43	46	49	52	55	58	61	64	67					74	C
		38	41	44	47	50	53	56	59	62	65	68						
		36	39	42	45	48	51	54	57	60	63	66	69	70	71	72	73	M
		37	40	43	46	49	52	55	58	61	64	67					74	C
		38	41	44	47	50	53	56	59	62	65	68						

Fig. 1.

VEHICLE M-38 Jeep 1/4 Ton Truck, (4 x 4) — Category Tested- Tow.___ S.P. X P.M.___

Source of Information TM 9-2800

DIMENSIONS:

Length	132-1/2 in.	Tread	49 in.	Angles of- Approach	45 °
Width	62 in.	Wheelbase	80 in.	Break	____ °
Height	71-3/4 in.	Ground Clearance	8-3/4 in.	Departure	35 °

TIRES:

Size	7.00 - 16	Tire Mounting		Rim	4.50 EO
Ply Rating	6	Front- Single X	Rear- Single X	Overall Diameter	30.8 in.
Tread	NDMS	Dual ___	Dual ___	Section Width	7.15 in.
Number of Tires	4	Tandem ___	Tandem ___	Section Height	6.17 in.

SUSPENSION AND STEERING:

Ride	Springs- Air ___	Conformance	Through	Steering- Ackerman X
Soft X	Coil ___	Good ___	Suspension X	Articulation ___
Hard ___	Leaf X	Some X	Articulation ___	Turning Circle (curb to curb)
Severe ___	Torsion ___	None ___	Bogie Mvt. ___	36 ft. 6 in.

DRIVE TRAIN COMPONENTS:

Engine - Gas 70 Octane		Transmission	Differential
Gross HP	60 @ 4000 RPM	Speeds- Fwd 6 Rvs 2	Locking X
Net HP	54 @ 4000 RPM	Automatic ___	Non-Locking ___
Gross Torque	___ @ ___ RPM	Mechanical X	No-Spin ___
Net Torque	105 @ 2000 RPM	Torque Converter_ Ratio ___ :1	Ratio ___ :1

WEIGHT:

Front Axle (s)	1240 lb.		1390 lb.		___ lb.
Rear Axle (s)	1210 lb.		1860 lb.		___ lb.
Net	2450 lb.	Off-Road	3250 lb.	On-Road	___ lb.

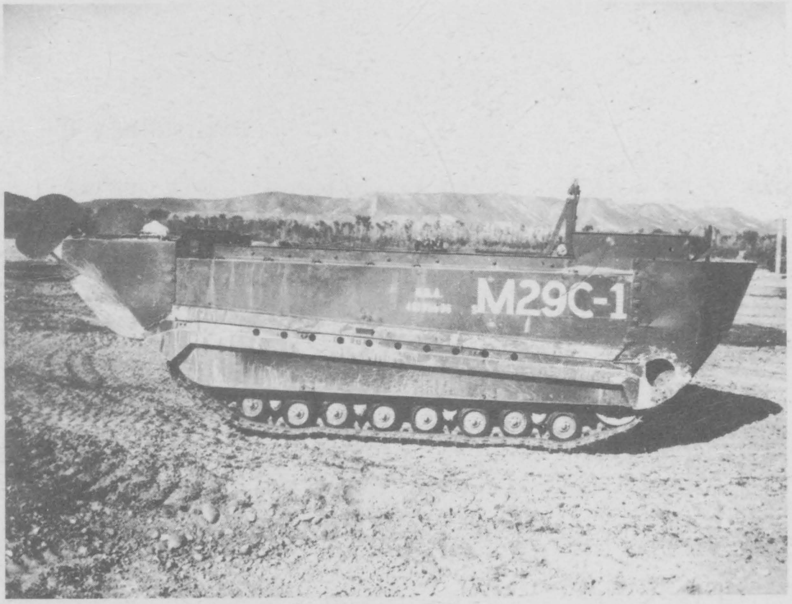
PERFORMANCE:

Maximum Speed	65 MPH	HP/Ton	33.2	Critical Layer	6 - 12 in.
Maximum Towed Load	1000 lb.	% Gradeability	58		

VEHICLE WEIGHTS, CONTACT AREAS, AND PRESSURES

Key Number	Gross Vehicle Weight (lb.)	Test Data Source	Load (lb.) Front Wheel	Inf. Press.	Defl.	C.A. Meas.	C.R. Calc.	Load (lb) Rear Wheel	Inf. Press.	Defl.	C.A. Meas.	C.P. Calc.	C.A. Total	C.P. Average
1	3550		718	40	0.45	16.5	43.5	1057	40	0.68	24.5	43.2	82	43.3

Fig. 2. M38 jeep 1/4-ton truck (4x4)



VEHICLE M-29C WEASEL AMPHIBIOUS — Category Tested- Tow. ___ S.P. X P.M. ___

Source of Information TM 9-2800, TM 3-240-0,9,14

DIMENSIONS:

Length	192 in.	Tread (Gage)	45 in.	Angles of- Approach	47 °
Width	67-1/4 in.	Ground Clearance	10-1/2 in.	Departure	36 °
Height	71 in.	Belly Width	25 in		

TRACKS:

Type		Contact Area		Shoes	
Rubber Bushed		Length	78 in.	Pitch	4-1/2 in.
Metal to Metal Joints		Width (Each)	20 in.	No. in Contact with Ground	36
Belted (Band)	X	Total Area	3,120 sq.in.	Grouser Hgt. 1 in. Rubber ___ Metal	X

SUSPENSION:

Ride		Springs		Ground Conformance		No. Bogies	16
Soft		Air		Good		Single	
Hard	X	Leaf	X	Some	X	Dual	X
Severe		Torsion Rod		None		No. Rollers	

Idler in Contact ___
Sprocket in Contact ___
Sprocket Location- Front ___ Rear X

STEERING:

Articulation- Intraunit (Wagon) ___ Interunit (Polecat) ___
Turning Circle (Curb to Curb) 24'

Skid- X Clutch-Brake X
Controlled Differential ___
Regenerative ___

L/T 1.73
CRITICAL LAYER 3-9"

DRIVE TRAIN:

Engine		Transmission and TRANSFER		Fuel	
Gross HP	___ @ ___ RPM	Speeds- Fwd. 6 Rvs. 2		Gas	X
Net HP	65 @ 3600 RPM	Automatic		Diesel	
Gross Torque	___ @ ___ RPM	Mechanical	X	Octane	72
Net Torque	130 @ 1800 RPM	Torque Converter ___ Ratio ___ :1		Capacity	35 gal.

PERFORMANCE:

Maximum Speed	36 MPH	Net HP/Ton	21.8	Overall Ratio- High	4.22 :1
Maximum Towed Load	4,200 lb.	% Gradeability	100	Low	33.25 :1

KEY NUMBER	VEHICLE TEST WEIGHT (lb.)	CONTACT PRESSURE (PSI)	MODIFICATIONS TO VEHICLE, REMARKS, & KEY for TOWED LOADS REPORT
1	5,975	1.91	TM 9-2800
2	5,640	1.8	TM 3-240-9
3	5,840	1.6	TM 3-240-0

Fig. 3. M29C weasel amphibious

TIRE NUMBER T- 032

TIRE SIZE 7.50 - 16 TREAD All Service PLY RATING 6

RIM 4.50 CE DATE TESTED 6/8/44 REF.

SOURCE Goodyear Tire and Rubber Company, Akron 16, Ohio

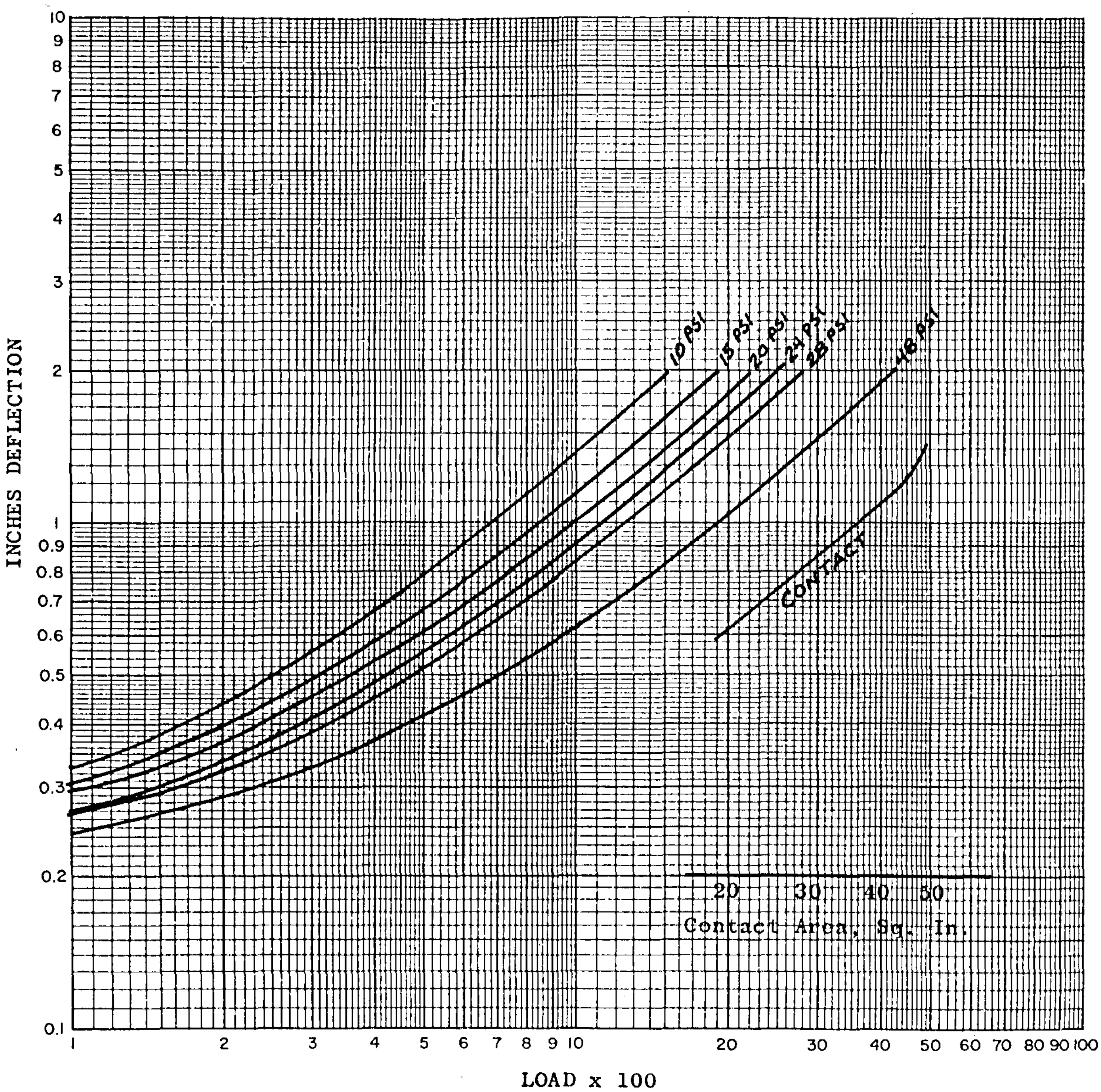


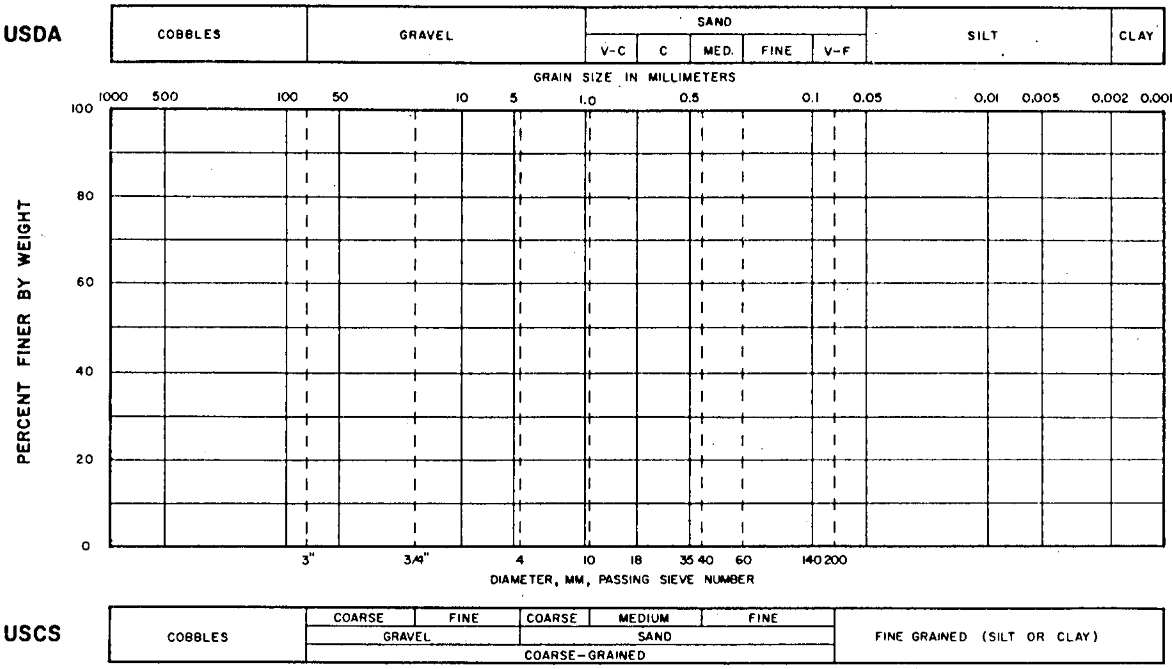
Fig. 4.

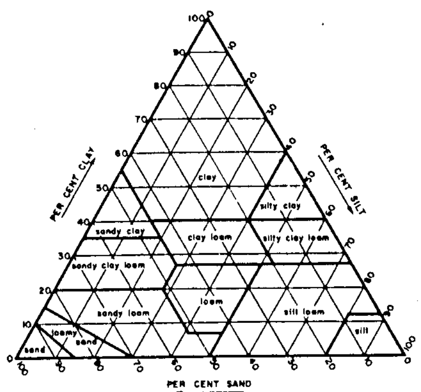
SOIL DATA SHEET———USCS & USDA CLASSIFICATIONS

SOURCE OF DATA ______________________________ SHEET NO. ______________

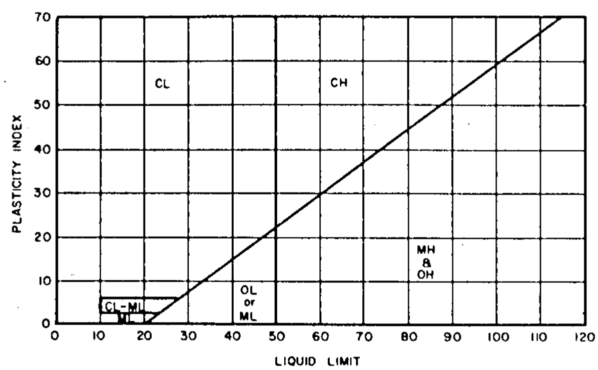
AREA ______________________________ DATE ______________

GRADATION CURVE





USDA SOIL TEXTURAL CLASSIFICATION



USCS PLASTICITY CHART

SAMPLE NUMBER	DEPTH INCHES	FIELD MAXIMUM MC (%)	ORGANIC MATTER (%)	pH	USCS							USDA			
					LL	PL	PI	GRAVEL	SAND	FINES	TYPE	SAND	SILT	CLAY	TYPE

Fig. 5.

final form and await only the final numbers keying them to test data sheets before they are finished.

Analysis of Test Data

Of a total of 525 wheeled vehicle tests reviewed recently, there were only 43 having directly usable data for first- or second-pass analysis. Out of 555 tracked vehicle tests, there were 41. For direct analysis, then, there is little hope for generalization on the basis of these meager data alone. A few additional data have been reviewed still more recently, but the proportion of directly usable material remains about the same.

An approach has been developed, however, which will take advantage of most of the 1500 tests compiled here. The graph showing cone index-performance data (fig. 6) was compiled by a combination of the data collected in this project and some of the new data being collected in the first-pass trafficability study. It can be seen that the combination of the old multiple-pass information and the new low-pass information allows the construction of prediction curves of the type shown here with more confidence than with either of the two studies alone. It should be pointed out that these data could have been plotted against RCI as well as CI, and more justifiably so, had there been sufficient data.

Several things are implicit on the sample analysis shown:

a. A plot of old trafficability data will immediately point to the need for new data, particularly at the low-pass end of the curve;

b. Future test vehicle weights must correspond to the old test vehicle weights if the data are to be directly comparable; and

c. Drawbar pull coefficients (or slope-climbing ability) must receive more careful attention in future tests if the analysis plot is to be accurately defined. This will be necessary until such time as a clear relation between the two curves shown in fig. 6 can be established.

The test data lend themselves (less completely) to another analytical need. Those tests for which remolded soil strength is available may be used to make a preliminary estimate of the influence of successive vehicle passes on the residual soil strength. For a given pass number, the ratio of "after traffic" cone index (CI_a) to "before traffic" cone index (CI_b) may be presented as a percentage of the soil remolding index (RI):

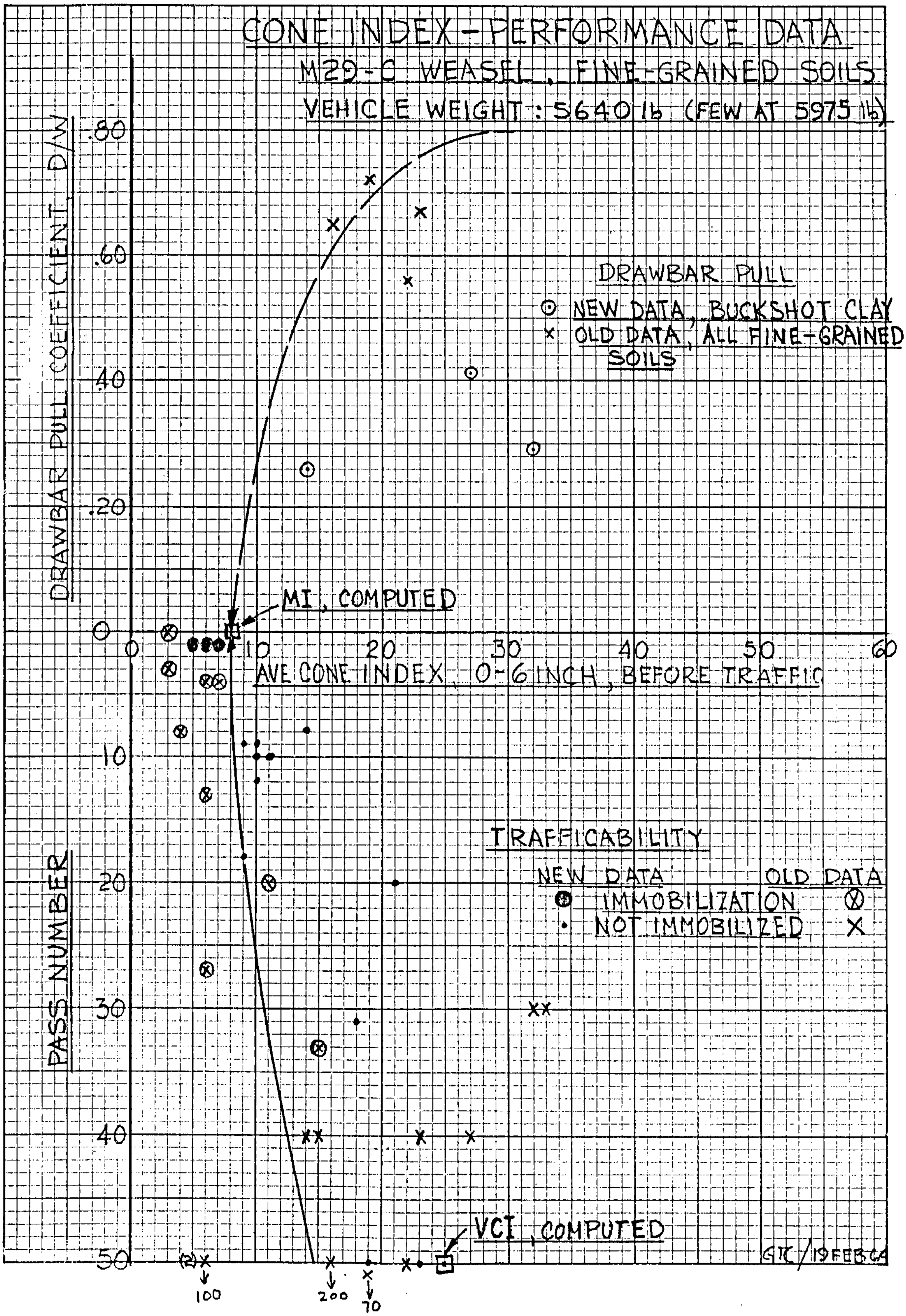

CONE INDEX - PERFORMANCE DATA
M29-C WEASEL, FINE-GRAINED SOILS
VEHICLE WEIGHT: 5640 lb (FEW AT 5975 lb)
DRAWBAR PULL COEFFICIENT D/W
.80
.60
.40
.20
0
10
20
30
40
50
60
AVE CONE INDEX, 0-6 INCH, BEFORE TRAFFIC
MI, COMPUTED
DRAWBAR PULL
NEW DATA, BUCKSHOT CLAY
OLD DATA, ALL FINE-GRAINED SOILS
PASS NUMBER
TRAFFICABILITY
NEW DATA
OLD DATA
IMMOBILIZATION
NOT IMMOBILIZED
VCI, COMPUTED
GTC/19FEB64
(2)
100
200
70

Fig. 6.

$$\frac{CI_a}{CI_b} = n \cdot RI, \text{ at "x" number of passes.}$$

By plotting n against x for various soil types, the extent of remolding occurring under vehicle action can be studied as a function of pass number. This should be valuable in indicating the proper remolding procedures for low-pass prediction. A series of correlative tests along these lines is being done now in the first-pass trafficability study.

Organization of the Final Report

Over 1500 trafficability and drawbar pull tests have been recorded for 45 tracked vehicles, 48 wheeled vehicles, and 7 towed vehicles. Information has been gathered on 65 tires. Some 125 soils were involved in the various tests and all available information has been recorded on them.

The final report will consist of nine volumes of information. They are as follows:

- Volume I - Formal Report: organization, conduct, discussion, significant findings, and bibliography
- Volume II - Wheeled Vehicle Specifications
- Volume III - Tracked Vehicle Specifications
- Volume IV - Soils Data
- Volume V - Section 1: Wheeled Vehicle Tests
- Volume VI - Section 2: Wheeled Vehicle Tests
- Volume VII - Section 1: Tracked Vehicle Tests
- Volume VIII - Section 2: Tracked Vehicle Tests
- Volume IX - Tire Data

ONE-PASS SOIL TRAFFICABILITY STUDY

by

C. J. Nuttall, Jr.*

Object

It is the object of this study to develop and validate, within approximately one year's time, working first-order definitions of:

a. A reliable strength index for fine-grained soils which will be applicable to the prediction of go, no-go performance of vehicles on their first pass on a straight path over level terrain; and

b. A nominal vehicle load index to be used with the above soil strength index to establish whether or not a given vehicle will go;

and means to calculate:

c. One-pass drawbar pull and slope performance in soils having strengths in excess of the minimum required for one vehicle pass on level terrain;

d. The increment of soil strength index (and/or vehicle load index) necessary to permit a vehicle to maneuver freely during a single pass; and

e. The probable speed of a given vehicle operating in a total terrain situation where the soil strength index exceeds the net vehicle load index.

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

* President, Wilson, Nuttall, Raimond, Engineers, Inc., Chestertown, Md.

Approach

The study has begun on the assumption that the required basic soil and vehicle indices can be developed by extension of the WES semiempirical cone penetrometer system, in which the soil strength index is termed the "rating cone index" (RCI) of the soil, and the nominal load index of each vehicle is expressed as the "vehicle cone index" (VCI), or the minimum soil strength (in cone index units) necessary for its support and traction.

Preliminary examination of the alternative Land Locomotion Laboratory/ Bekker soil measurement method has indicated that a reasonable basis exists for converting the cone penetrometer indications to approximate values of the sinkage parameters used in the LLL/Bekker analytical design procedures, should these be desired. The current early state of this analysis is summarized in Appendix I.

One of the reasons for adhering to the cone penetrometer approach is the availability of extensive cone index vehicle data collected by WES over the years during their development of 50-pass criteria. These are being restudied as part of this program. The first step in this restudy, the organization and compilation of these earlier data in fully accessible form, has been described in the previous presentation by Cohron. There presently appears to be a good possibility to employ these data usefully in the determinations of the required new first-pass criteria.

However, past data, in that soil strength range sufficient only for one or a few passes of a given vehicle, are not as extensive as had been hoped for initially. As a result, the program has been reoriented in these opening months more around further field tests than was originally planned. These new tests, conducted here in Mississippi by AMRB, are currently under way. They began in mid-December in order to capitalize upon advantageous river-stage conditions which made certain important, local, heavy clay test areas available at that time.

The Test Vehicles

The test program includes a number of vehicles representing a range of running gear types, gross weights up to about 20,000 lb, and average to good overall practical mobility. Five vehicles of particular interest from the research viewpoint have been selected as the "backbone" of the test program and will be most extensively tested. These are:

Tracked Vehicles	Normal Test Weight, lb
(1) M29C weasel	5,960
(2) D4 standard tractor with 12-in. tracks	13,585
with 24-in. tracks	13,585
(3) Polecat	12,600
Wheeled Vehicles	
(4) M37, 3/4-ton, 4x4 with 9.00-16, 8-PR tires	7,270
with 46x18 Terra tires	7,270
(5) M34, 2-1/2-ton, 6x6 with 11.00-20, 12-PR single tires	17,540

Vehicles (1), (3), (4), and (5) have been simply instrumented for the measurement of drive line torques.

The WWII <u>weasel</u>(1) was selected because it is still the most mobile vehicle (in soft terrains) which the Army has ever accepted wholly into the system. As a result, extensive performance data are available on it in all types of difficult off-road terrains. These, and the vast field experience with this vehicle, make its performance a useful "yardstick" for judging the performance of other vehicles, old or new.

The standard <u>D4 tractor</u>(2) is another "old reliable," well known and extensively tested. It represents both another weight class and another basic track type.

The <u>polecat</u>(3) is basically a conversion of two WWII weasels into a single, single-engined, articulated steering, tracked vehicle. It is included primarily to permit investigation of the effects of this type of steering on various aspects of soft terrain performance. Its close relation to the weasel is helpful in this regard, reducing the number of variables to a practical minimum.

The two basic wheeled vehicles are a 4x4(4) and a 6x6(5) of conventional form. Both will be tested primarily on their normal high-mobility tires. Both are familiar, and between them they cover a convenient weight range. The latest version of the <u>Gama Goat</u> will also be included in the basic group, once it becomes available, although no attempt will be made to measure drive torques on it.

These five (or six) vehicles will be particularly important in the planned development of maneuvering and speed criteria, where the tests will be designed to examine a number of simple, first-order hypotheses concerning the relations between each of these desired performance features, the VCI, and the RCI (or similar, related indices to be developed and defined as the work progresses).

Insofar as possible, all tests will be conducted in four natural terrains having, respectively:

a. a heavy clay soil,
b. a light clay soil,
c. a silty clay soil, and
d. a silty loam soil.

Within each area and soil type, tests will be run in soils having a wide range of soil strengths as measured by cone indices (with and without various degrees of remolding corrections). This range will be the result primarily of differences in natural moisture content at the time and/or precise place of the tests.

Program Details

1. Basic first-pass trafficability criteria

Basic, straight-line, first-pass trafficability criteria will be determined for each vehicle of interest by means of the combined drawbar pull and multipass traffic analysis outlined in the preceding discussion by Cohron, using various configurations of the cone index, as for example:

a. 0-6 in. average with usual remolding treatment;
b. 0-6 in. average with no remolding correction;
c. 0-6 in. average with partial remolding correction (10 blows, 20 blows, 50 blows, etc.); and
d. 3-9, 0-12, or 6-12 in., as in a-c above.

In each case, tests will be conducted in a range of soil strengths which produces results from very low drawbar outputs to very low sinkages, and immobilizations during self-propelled, level, straight-line operation on the first through approximately the tenth pass. Smooth curves drawn through the pooled data from both the new tests and previous programs, plotted on a common cone index base, will be extrapolated to a common zero-drawbar-pull, one-pass-only intercept, as demonstrated by Cohron. This intercept will be the primary estimator of minimum VCI requirements for a given vehicle.

> (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 20-30 percent slip--or maximum DBP--data family in this case, even though this is not necessarily so in the case of multipass trafficability.)

The data for each vehicle in the several soil types will be examined to determine which method of determining RCI gives the most nearly constant estimate of required first-pass VCI. The results from the several vehicles will next be compared and a best-compromise RCI procedure determined. Finally, all of the data will be reanalyzed on the basis of the single preferred RCI procedure, corresponding VCI's for each vehicle will be found, and the accuracy of the resulting overall procedures will be estimated.

Simple, approximate relations between the first-pass VCI's (VCI_1) developed and existing 50-pass VCI's (VCI_{50}) will be sought, to aid in estimating VCI's for other vehicles, from the extensive 50-pass data already published by WES. The possibilities of extending and/or modifying present WES and/or LLL equations so as to predict the VCI for any vehicle from its geometric and mechanical arrangement and characteristics will also be examined at this stage.

2. First-pass slope criteria

The phase 1 program above will also provide the basic first-pass slope vs RCI_1 information required. These data will be analyzed in terms of (RCI_1-VCI_1) and (RCI_1/VCI_1) to determine the extent to which simple generalized curves similar to those developed by WES on a 50-pass basis may be appropriate for 1-pass data. The relation between these and the earlier 50-pass curves will also be examined.

The individual D/W vs RCI curves for each vehicle in each soil type will be used in the further stages of the study outlined below, however, rather than any approximate generalization, for obvious reasons.

3. Incremental soil strength required to permit free maneuvering

The attempt to develop valid estimates of the minimum excess of RCI, over VCI, necessary to permit a given vehicle to maneuver freely in a level, weak-soil terrain will begin with two crude but reasonable assumptions:

a. The requirement for increased soil strength during maneuvering results from increased motion resistance which, in turn, imposes higher tractive loads on the soil/vehicle interface; and

b. The effects of such increased resistances may be roughly equated to the effects of increased tractive efforts necessitated by slope and/or drawbar loads.

The experimental approach will be to measure, via drive line torquemeters in four of the basic vehicles, the torque required to maintain headway 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. Where areas of more-or-less uniformly varying soil strength are available, the minimum radius turn will be made along courses which cover the full range of strengths, and actual immobilizing soil data will be recorded.

The torque data will be analyzed in terms of the increment at a given turning radius over that required for straight-ahead operation at the same soil strength. This increment, reduced to an equivalent increase in traction via calculations through the drive line to the sprocket or tire, will be treated as a drawbar load. The basic drawbar/slope vs RCI curves developed in phase 2 above will be shifted accordingly. This will produce a new--higher--effective VCI which will be compared with actual immobilizing conditions determined (where possible) as noted in the preceding paragraph.

The data will also be compared with simple analyses in which the increased resistance is assumed to arise from one or more of the following:

a. Increased rut formation due to loss of tracking;

b. The work necessary to rotate the vehicle/soil contact patch(es); and/or

c. Reduction in thrust of tractive elements to produce steering moments in skid-steering.

In general, center-jointed, wheeled, articulated vehicles (such as the XM520 5-ton GOER) might be expected to have practically no increment in resistance from steering; ordinary 4x4 vehicles, increments from a only; 6x6 and articulated tracked vehicles, increments from a and b; and skid-steered vehicles, from all three. These resistances will be treated as follows:

a. To begin the analyses, the increased rut formation will be assumed to be a simple geometric problem in the plane of the soil surface. That is, the increase in plane area of disturbance will be considered to be the major index, and changes in rut depth will be neglected. The ratio of total rut width (measured in the field and developed in simple diagrams) along a radius when in a steady turn to the straight-ahead rut width normal to the course will be compared directly to the ratio of shaft torque in the turn to straight-ahead shaft torque. Cross plots will be prepared of this ratio as a function of both RCI and radius (as the reciprocal--to facilitate inclusion of the straight-ahead data--$1/r = 0$). The tests on the 4x4 will be most critical of the first assumption at this point, for obvious reasons. If these show the assumption to be at all acceptable, similar calculations could be made to estimate maneuver requirements for other 4x4 machines. Also, this component will be removed from the data for other types of vehicles where other types of losses are also postulated. In this way a crude, step-by-step checking of the several proposed calculation procedures should be possible.

b. The work necessary to rotate the vehicle/soil contact patches (assumed identical and equally loaded--for present discussion only) may be estimated from the resisting moment:

$$M = \frac{n \times W_1 \times f \times \ell}{k} \tag{1}$$

where

n = the number of such patches

W_1 = the load carried by each

f = the effective (or equivalent) friction coefficient in the patch

ℓ = the length of the patch

and k = a constant depending on load distribution, actual patch shape, etc.

$= 4$

The power expended to overcome this moment is

$$P = M \times \omega$$

where

ω = the angular velocity

and the forward speed is

$$V = r \times \omega$$

where

r = the turning radius.

The equivalent resistance (R_s) is then

$$R = \frac{M\omega}{r\omega}$$

or

$$\frac{R_s}{W} = \frac{f}{4} \left(\frac{\ell}{r}\right) \qquad (2)$$

Because ℓ is relatively small on tire contact areas, this factor will (for the moment, at least) be neglected for 4x4 vehicles, and for the front wheels of 6x6 vehicles. The rear bogie of a 6x6, however, has an appreciable effective contact length, combined with a decidedly nonoptimum load distribution to boot. The equation above, or some more appropriate minor variant of it, will be used in the analysis of 6x6 vehicles, and all tracked vehicles.

c. The reduction in traction on one side necessary to produce a steering moment on skid-steered vehicles may be estimated very approximately from equation 1 which expresses the required moment. The moment available is given by

$$M_a = (T/2 + \Delta T_1)t/2 - (T/2 - \Delta T_2)t/2$$

$$= \frac{t}{2} (\Delta T_1 + \Delta T_2) \qquad (3)$$

where

T = traction required to proceed in a straight line (including any towed and/or slope load)

ΔT_1 = increase in traction on one side of the vehicle

ΔT_2 = decrease in traction on the other

and t = center line-to-center line track tread

In order to make a turn, the available moment must at least equal the resisting moment (inertia forces and other types of dynamic behavior are neglected in this simple analysis); i.e.,

$$\frac{nW_1 f \ell}{k} = \frac{t}{2} (\Delta T_1 + \Delta T_2) \tag{4}$$

or, taking $n = 2$ and $k = 4$

$$\Delta T_1 + \Delta T_2 = W f \left(\frac{\ell}{t}\right) \tag{5}$$

In the simple limit, with no external resistance,

$$\frac{\Delta T_1}{W_1} = \frac{\Delta T_2}{W_1} = f$$

and $\left(\frac{\ell}{t}\right)_{max} = 2$, which is the well-known approximate limit on tracked vehicle proportions for skid-steering.

For present purposes, however, the quantity of concern is the incremental increase in traction required to maintain headway; i.e., to keep the total traction constant

$$\left(\frac{T}{2} + \Delta T_1\right) + \left(\frac{T}{2} - \Delta T_2\right) = T$$

$$\Delta T_1 = \Delta T_2 = \Delta T \tag{6}$$

For the track which must produce this increase, this is then

$$\frac{\Delta T}{W_1} = \frac{f}{2} \left(\frac{\ell}{t}\right) \tag{7}$$

Unless the soil will support this order of increased load--which may be treated as an incremental resistance--steering will be accompanied by a reduction in performance which will lead to immobilization. It does not matter that only one track is involved. Accordingly, skid-steering losses will be considered as an increase in resistance

$$\frac{R_{ss}}{W} = \frac{f}{2} \left(\frac{\ell}{t}\right) \tag{8}$$

and treated similarly to the other losses in relation to the basic drawbar/slope vs RCI curves.

For each type of vehicle, the several resistances will be totaled as applicable, and the hypothesis tested that the increment in RCI required to permit free maneuvering is the same as that required for developing a drawbar pull of equivalent magnitude.

4. Means for estimating speed

In order to approach the estimation of maximum straight-ahead vehicle speed in level terrain when available soil strength is in excess of the minimum required to assure "go" performance, it will--for a start, at least--be assumed that the basic drawbar, or slope, vs RCI curve can be immediately interpreted as the arithmetic inverse of the soil motion resistance (R) vs RCI curve. Maximum speed (V) will be calculated from the relation

$$V = \frac{k \ hp \ \eta}{R} \qquad (9)$$

where

hp = net vehicle engine power

η = overall flywheel-to-ground mechanical efficiency

k = a dimensional constant

= 375 when hp is horsepower, and V is in mph

and $R = (D/W)_{max} - (D/W)_{RCI}$ from the basic curve.

For test purposes, η (or $\eta \cdot hp$) for each of the several vehicles used in the test may be calculated from drawbar-pull tests on hard surfaces, using both propeller-shaft torque readings (when available) and drawbar/speed relations (D = R in equation 9).

Full-throttle speed tests will be run on selected vehicles in several soil strengths. Care will be taken to insure a long enough run to reach equilibrium, and that engine speeds (read on tachometers) are within the ungoverned (or normal) range. Where actual engine speed is less than cataloged maximum (and where measured hard-surface data are not available in the speed range experienced), power will be taken to be a simple linear function of revolutions per minute.

5. Combined estimates

The basic hypothesis which will be tested in a small number of trials--assuming the foregoing methods show some promise of usefulness--will be that the effects are simply additive, for purposes of estimating increments of VCI and speeds, where RCI's are ample.

6. "Slipperiness" investigation

Concurrently with phase 1, the "slipperiness" and "stickiness" aspects of trafficability will be reexamined in the one-pass light.

The term slipperiness, while vague and potentially misleading, has in use referred to a limited, relatively definable situation causing vehicle immobilization. Roughly, it refers to situations in which a vehicle develops insufficient traction to overcome a moderate slope-load (or other external load) despite its having sufficient flotation to prevent any appreciable rutting. Implicitly excluded are such obvious "end-points" in such a definition as traction failure on a limiting, dry concrete slope (of about 70 percent). It has generally been observed, in connection with test areas where vehicle failures have been described as due to slipperiness, that the soil was markedly stratified, consisting of a bed of essentially firm material overlain by a relatively thin, substantially wetter layer, usually of the same material. The wetter, surface layer will normally have less shear strength and will develop less friction with rubber, steel, etc., than the drier base material. Those vehicles whose tractive gear is not sufficiently aggressive to cut through this layer and exploit the higher shear and/or friction of the underlying bed material will experience premature tractive failure. The part played by the weak surface layer in such cases is crudely analogous to that of a lubricant. The term slipperiness, accordingly, has some descriptive basis. The particular vehicle-soil relation to which it refers, however, can only be studied rationally in terms of a more accurate mechanical concept. The relatively simple one of a pure tractive failure within the weaker, surface layer appears adequate for this purpose.

In recent field trials in Panama, slipperiness immobilizations were numerous. The cone penetrometer, as might be expected where the action of a thin surface layer governed performance, was a relatively insensitive indicator of this behavior.

A brief exploratory field and laboratory study has begun to establish approximate ranges of slipperiness indices (such as external and internal friction and/or cohesion of surface soil layers) associated with various general soil types, as functions of their cone indices, surface and underlying moisture content, and depth of surface "wet" layer. Effects of surface "puddling" are also being examined. Measurements are being made with the simple, portable Cohron Sheargraph.*

At the moment, small natural test sites, artificially wetted, are being explored concurrently with the complete sampling of soils in nearby areas to determine their suitability as further vehicle test sites, and with some reexamination of possible "partial" remolding behavior of the same range of soils. It is expected that a wide range of soils and conditions will be explored in this way with a modest effort and within a short period of time.

At a later stage in this phase of the study, possible means for predicting the occurrence of slipperiness will be outlined from existing knowledge, such as the WES moisture content prediction studies, agricultural percolation data, etc., but no experimental work in this area is presently contemplated.

7. Final report

The results of the several separate subinvestigations will be consolidated into a single report which outlines:

a. Suggested soil measurements and procedures apparently necessary to predict first-pass, level, straight-running, go, no-go trafficability of the soil component of a terrain system;

b. Means for approximating the nominal load index for use with the above soil measurements in predicting first-pass, level, straight-running, go, no-go performance of any given vehicle;

c. Methods to estimate separately the increments of soil strength necessary to permit, during a first-pass, free maneuvering, drawbar pull, and slope-climbing of a given degree;

d. Means to estimate vehicle maximum speed, as limited by soil strength and vehicle power, in complex terrains where the net soil strength at any point exceeds that required simply to assure go performance;

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* This instrument, manufactured under U. S. Patent by Wilson, Nuttall, Raimond, Engineers, Inc., is described in an Operation Manual for the Cohron Sheargraph, published by that company in July 1963.

e. A statement of the probable precision and/or generality of each of the above solutions and of their known limitations; and

f. An outline of further research work considered necessary to improve precision, and/or generality in specific areas of application.

APPENDIX I

Generalizing Cone Index Results for Use in Design Via the Land Locomotion Procedures

The basic concept of the cone index, with its supporting techniques, was developed during the period 1945-55. The complete method has proven itself both in extensive fieldwork and, more recently, in laboratory studies.

Beginning in about 1954, a second, more elaborate penetrometer system for quantifying soil reaction to load was developed by Bekker and the U. S. Army Land Locomotion Laboratories (LLL) in Detroit. This second system was designed to meet the needs of a proposed semiempiric analytical framework for the treatment of vehicle-soil relations also advocated by Bekker. Apparatus for making the plate-penetration measurements required for (a part of) this second system is heavy and bulky, does not lend itself to extensive field use, and has not proven reliable as a basis for field studies.

Notwithstanding, exponents of the LLL/Bekker system maintain that the three parameters (k_c, k_ϕ, and n) developed from their plate measurements are more useful for vehicle design purposes than the (nominally) one-dimensional average cone indices normally determined by use of the light, simple WES cone penetrometer. On the other hand, the extensive field and laboratory success of the WES cone index system suggested its adoption in the present extended context. In addition, use of the cone index is attractive because:

a. Vast quantities of data are already available in many soil types and many areas of the world in terms of cone indices.

b. The instrument used is well developed, light, compact, and well adapted to field use.

c. In past field and laboratory programs, cone penetration data has proven to be the most consistent and reliable of all types taken. Moreover, because of the simplicity of the test procedures, cone tests can readily be replicated in connection with the individual vehicle or other tests.

d. Finally, and of great importance, the cone index concept explicitly embraces and organically incorporates means to estimate changes in soil strength which accompany large deformations (remolding) such as are usual under vehicle action.

Some reasonable technical reconciliation of the field advantages of the cone penetrometer and of the purported design usefulness of the LLL penetrometer parameters was evidently desirable early in the present program. Although the time frame of the project did not permit extension, even in part, of any of the several "correlation" programs undertaken in the past, a review of existing data and reports has indicated that useful relations may already be available.

A method for calculating WES cone indices from the LLL/Bekker parameters was demonstrated by Janosi (1959).* Despite a questionable (and unnecessary) assumption regarding the effective size assigned to each differential section of the cone (which has little effect on the end result anyway), Janosi's cone index equation (for the standard 0.5-sq-in. cone) when considered at reasonable depths of penetration (6 in. or more) becomes simply

$$CI_{z_o} = \left(k_\phi + \frac{k_c}{0.4} \right) z_o^n \qquad (1)$$

The more usually used average cone index from the surface to some depth z_o may be written

$$\overline{CI}_{o-z_o} = \frac{\left(k_\phi + \frac{k_c}{0.4} \right) z_o^n}{(n + 1)} \qquad (2)$$

Note that the exponent n has the same meaning in both systems; i.e., n may be estimated from the experimental curve of cone index vs depth of penetration. Thus, according to equations 1 and 2, the cone results can be used to estimate two of the LLL/Bekker parameters, the combined parameter $K \left(= k_\phi + \frac{k_c}{0.4}\right)$ and n . n may readily be calculated from the cone readings via use of equations 1 and 2 which, combined, give:

$$n = \left(\frac{CI_{z_o}}{\overline{CI}_{o-z_o}} \right) - 1 \qquad (3)$$

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* Z. Janosi, Prediction of WES Cone Index by Means of a Stress-Strain Function of Soils. OTAC, Land Locomotion Laboratory Report No. 46, November 1959.

Equation 1 or 2 may also be solved for k_ϕ (say) in terms of CI or $\overline{CI}$, z_o , n , and k_c . Taking equation 2, for example, and considering the 0-6-in. average cone index,

$$k_\phi = \left(\frac{n + 1}{6^n} \cdot \overline{CI}_{0-6}\right) - 2.5\ k_c \tag{4}$$

Once $\overline{CI}_{0-6}$ and n are determined from a given set of cone penetration data, the corresponding relation between k_c and k_ϕ is a simple straight line. Any point on this line will represent a pair of values which could equally well account for the observed average cone index (at the observed value of n). Were this all we knew of the matter, it would indeed seem hopeless to estimate reasonable k_c and k_ϕ values from cone penetrometer data.

However, LLL has conducted considerable study of the values of k_c and k_ϕ in various specially compounded (completely remolded) soils--summarized by Trask, Snow, et al. (1962)*--and has also published some values for natural soils (Janosi, 1959).** Examination of these data indicates that for any given soil, over a wide range of moisture content, there is a reasonably close relation between k_c and k_ϕ of the form

$$k_\phi = M\ k_c^m \tag{5}$$

A preliminary analysis of the available data has been made on this basis and figures A1 to A5 have been prepared. Each plot is for a fixed value of n (or in practice a reasonably small range); each shows contours of constant $\overline{CI}_{0-6}$ (via equation 2) in the k_c - k_ϕ plane; each also shows the complete available data for soils falling in the respective n-range, plotted as lines of the form given in equation 5.

The soils considered (both natural and specially compounded) are all fine grained of various classes. The few natural soils are specifically identified.

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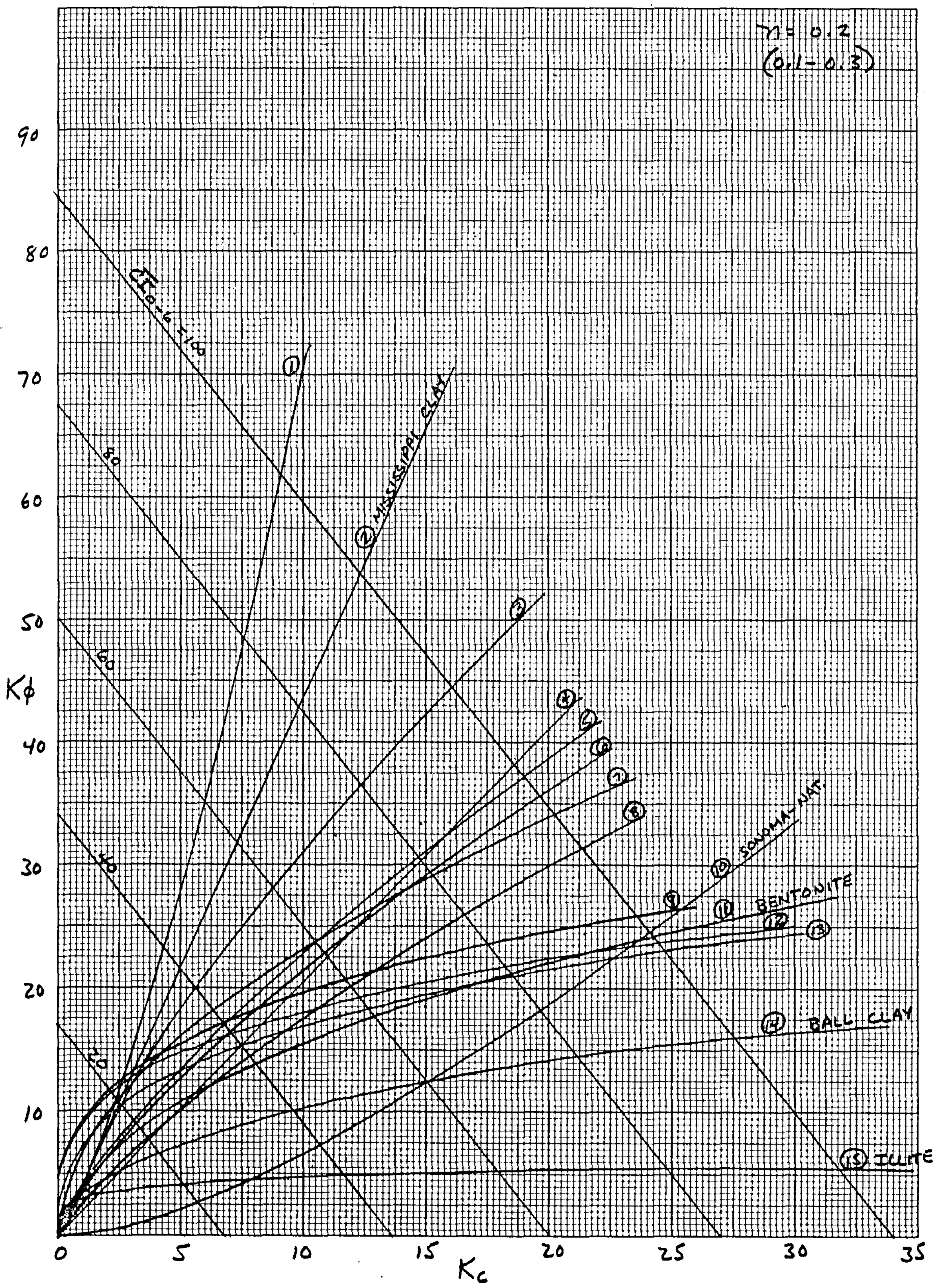
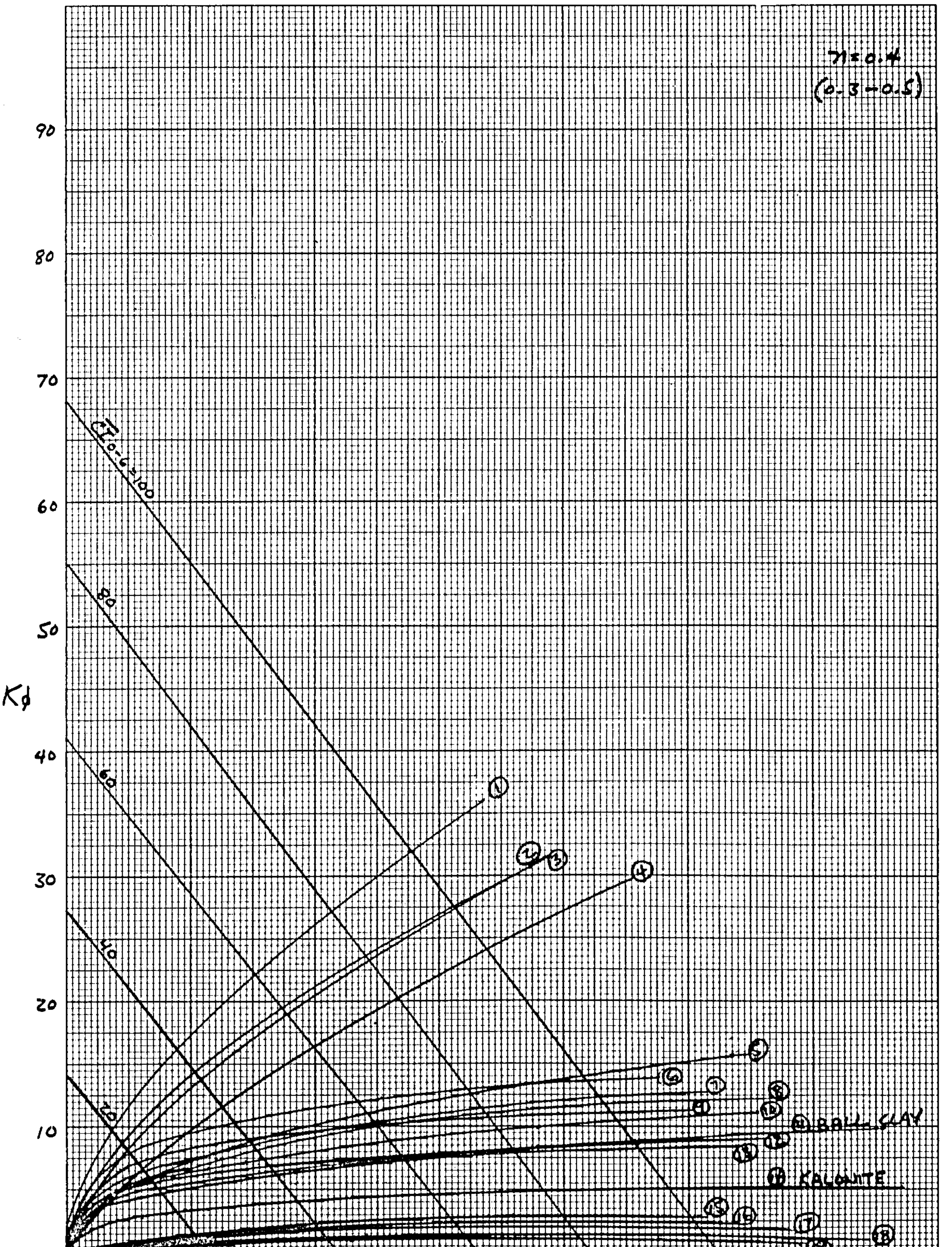
* P. D. Trask, D. T. Snow, et al. (1962), Pressure Sinkage Tests on Synthetic and Natural Clay Soils. OTAC, Land Locomotion Laboratory Report No. RRLL75, April 1962.

** Z. Janosi, op. cit.



n = 0.2
(0.1 - 0.3)
90
80
70
60
50
40
30
20
10
Kφ
0
5
10
15
20
25
30
35
Kc
MISSISSIPPI CLAY
SONOMA-NAT.
BENTONITE
BALL CLAY
ILLITE

Fig. I-1



η = 0.4
(0.3 – 0.5)
90
80
70
60
50
40
30
20
10
0
5
10
15
20
25
30
35
Kφ
Kc
CI 0-6 = 100
80
60
40
20
BALL CLAY
KALONITE

Fig. I-2

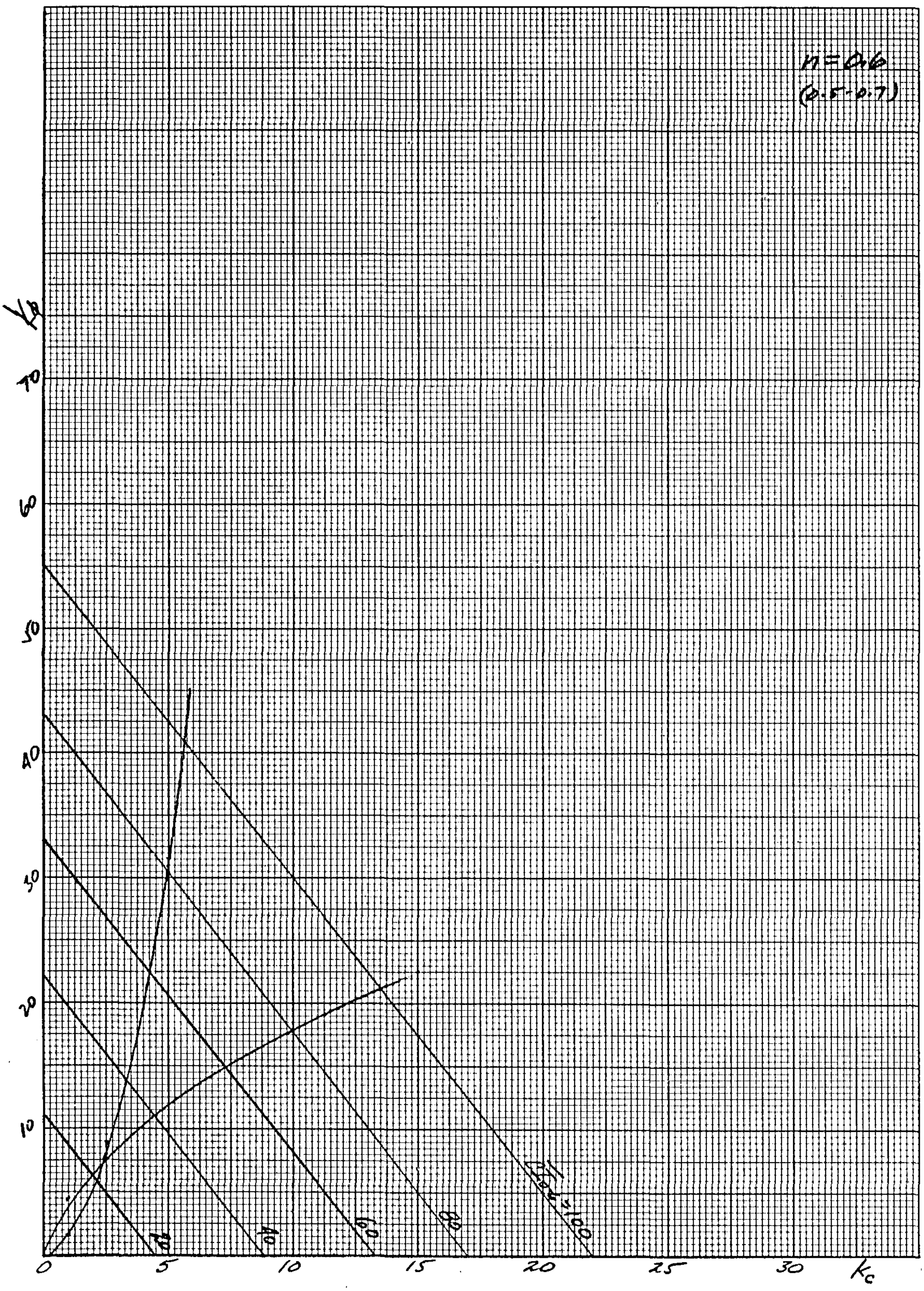


Fig. I-3

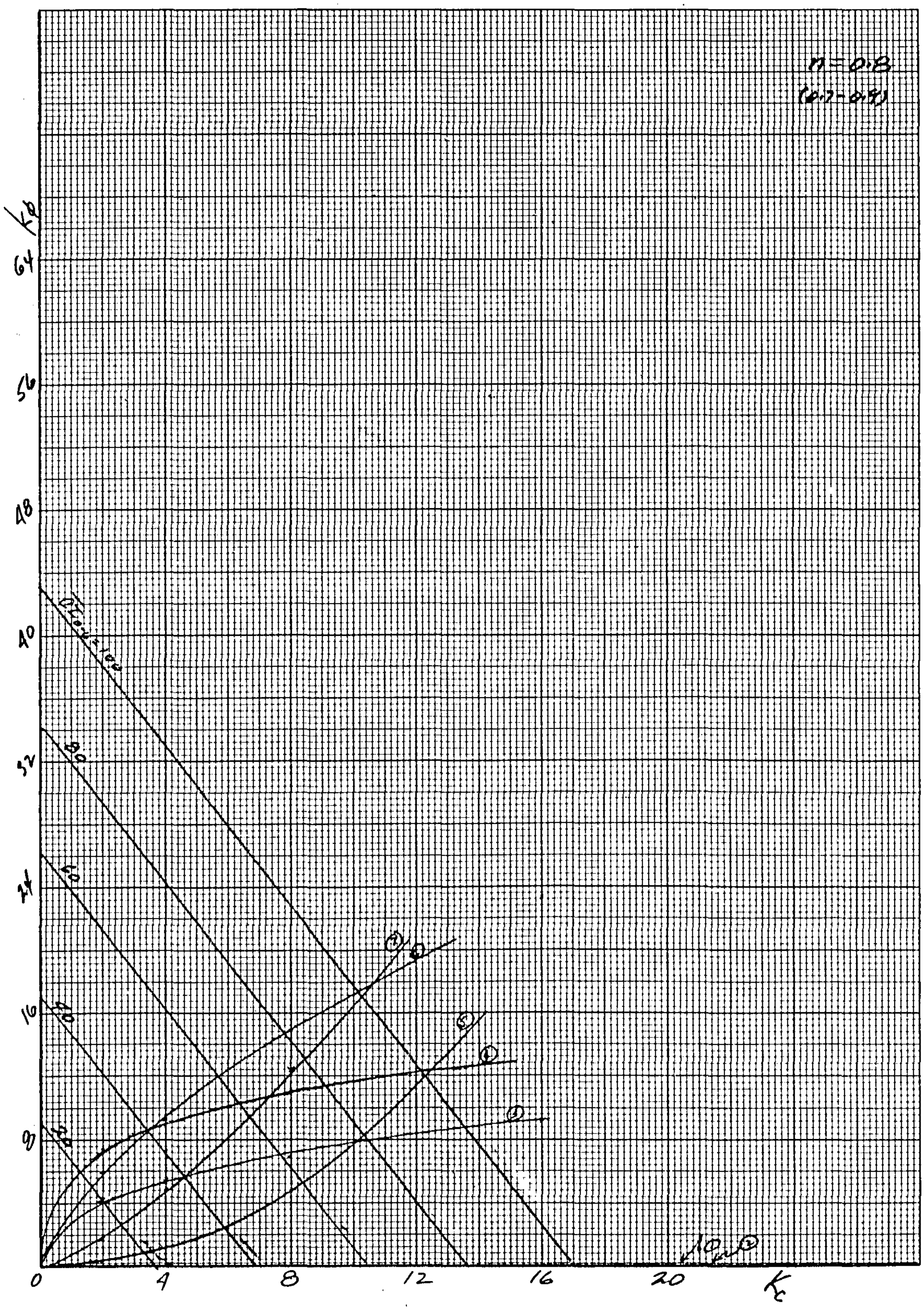


Fig. I-4

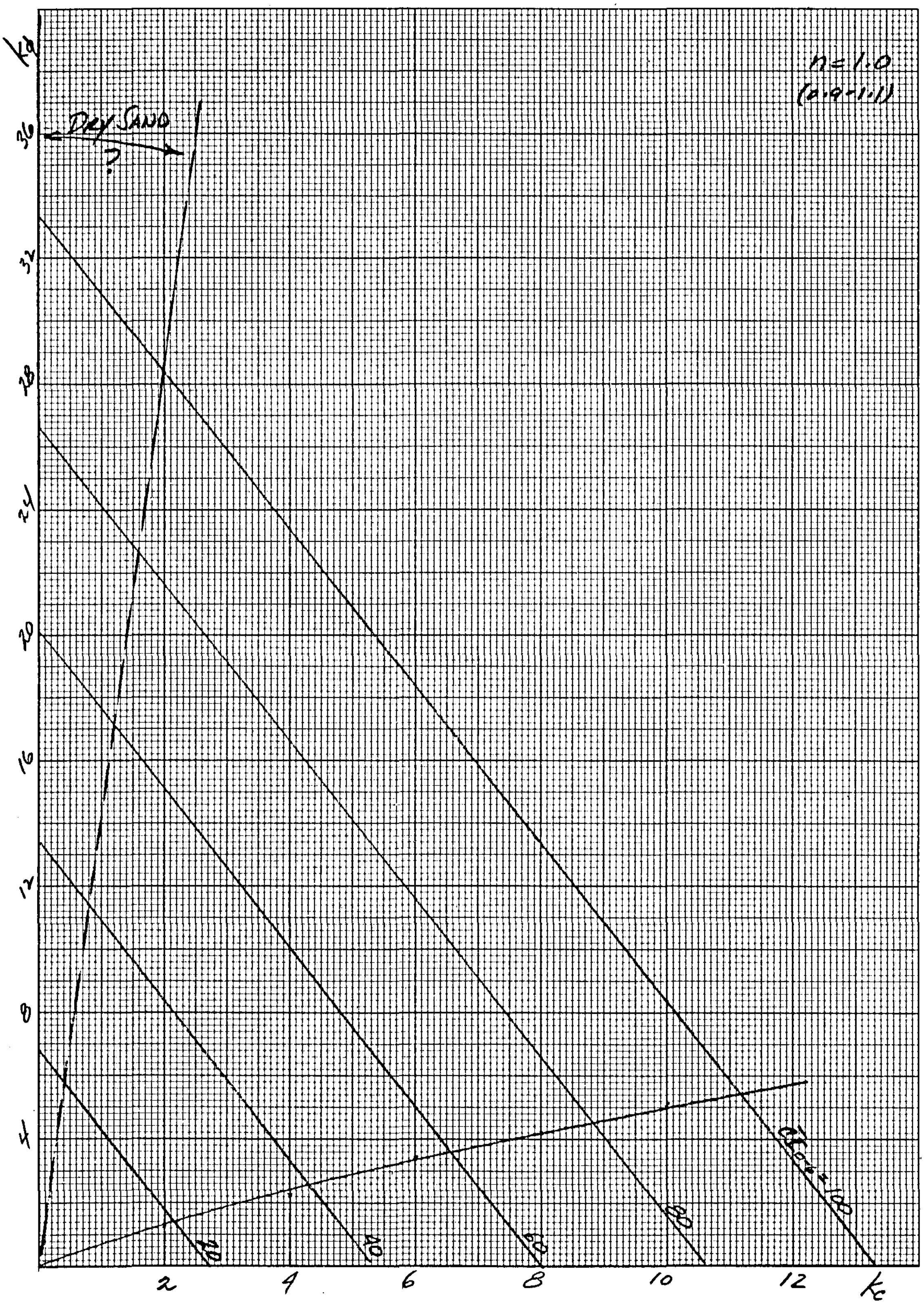


Fig. I-5

From these preliminary plots, it appears that data from the cone penetrometer may, in fact, be sufficient, when augmented by soil textural class and perhaps clay mineral, to establish k_c and k_ϕ values within a relatively narrow range which should be adequate for design analysis in fine-grained soils. Even without these additional data the range does not appear forbidding.

In addition, Janosi (1959)* also includes data on a dry sand indicating that for this type of material, $n = 1$, and $k_c = 0$. Thus, the range for this material may be indicated as shown on the figure for $n = 1$.

While it is evident that the picture could usefully be augmented by further data, especially on natural soils, it seems adequate already to permit the present work to proceed on the basis primarily of using the more field-worthy cone penetrometer for the bulk of the soil strength determinations. LLL has been invited to participate in the present project by taking readings by their "bevameter" penetrometer system. The data they develop in the field, on natural soils, will, of course, be incorporated on a continuing basis into the analysis as it is developed further.

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* Z. Janosi, op. cit.

MOBILITY IN RICE FIELDS

by

J. G. Kennedy*

Rice fields constitute a large enough percentage of the earth's surface in Southeast Asia to justify the initiation of a special study to determine their significance in the MERS program. In Thailand nine-tenths of the cultivated areas are occupied by rice fields, and cultivated areas occupy 20 percent of the total area.** Thus, 18 percent of the entire country of Thailand is covered with rice fields. In terms of acreage, this amounts to approximately 22 million acres.

Because rice is grown in the U. S., an investigation was initiated to study the characteristics of U. S. rice fields, including cultural practices and seasonal variations, and their effects on ground mobility. The results of this study will be used to develop plans for executing a more extensive study of rice fields in Southeast Asia.

The overall objectives of the MERS study of rice fields are to:

a. Identify the characteristics of rice fields that affect ground mobility.

b. Develop methods for quantifying the effects of rice fields on vehicle performance.

c. Arrange the knowledge developed in a form most useful to vehicle designers and ground mobility analysts.

The immediate objectives of the U. S. rice-land study are to:

a. Determine seasonal changes in soil moisture and strength, vegetation, and hydrologic geometry in rice fields.

b. Determine the effects of rice-field cultural practices on soil trafficability and compare with other cultural practices.

c. Review existing literature pertinent to rice-field characteristics, cultural practices, and rice-field distribution.

My talk today will be confined to the principal findings to date from the U. S. study, and when possible, I will draw comparisons between the

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* Trafficability Section, AMRB, Mobility and Environmental Division, Waterways Experiment Station, Vicksburg, Miss.

** M. Y. Nuttonson, The Physical Environment and Agriculture of Thailand. American Institute of Crop Ecology, Washington, D. C., 1963.

rice fields of the U. S. and those of Thailand. The Thailand data were obtained from the report on the preliminary survey.

Three general areas were selected for the U. S. study, one each near Stuttgart and Kelso, Arkansas, and Crowley, Louisiana. We began our study in March 1963 by making a preliminary survey of the three areas. During this survey, 22 sites were visited and measurements were made of soil moisture content and strength. Also obtained were soil samples for laboratory analysis. Measurements also were made of surface geometry and hydrologic features. Owners of the fields in which test sites were located were interviewed to obtain information on the cultural practices employed in these fields, such as approximate dates and methods of planting, flooding, drainage, and harvest. The final selection of 15 study sites was made primarily on the basis of variety of soil types, since the range in variation in cultural practices, vegetation characteristics, surface geometry, and hydrologic features was considerably less than the variations in soil type. According to USDA soil classification, four soil series and three textural types were investigated.

Nine visits were made to each rice field, with the visits scheduled to coincide with various cultural practices employed in each study area. On each visit, measurements were made of moisture content, density, cone index, remolding index, vegetation height, depth of flooding, and depth of water in irrigation canals and ditches. Also a complete history of the cultural practices employed since the last visit was obtained, and a record of the rainfall.

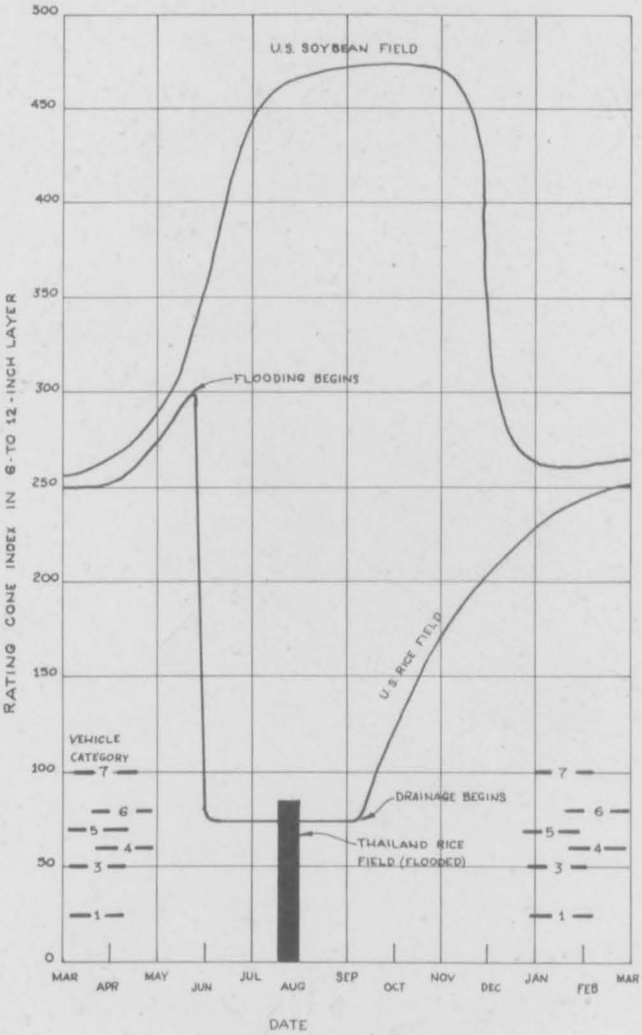
Rice is rice, and the essential environmental factors necessary to successful growing of rice are the same whether in the U. S. or Thailand. Rice is adapted to regions of high temperature and prolonged sunshine, and usually is grown in silty or clayey topsoils overlying impermeable or nearly impermeable subsoils so that water can be retained on the flooded rice fields for as long as three to five months during the growing season. Also required are dikes to hold the irrigation water on the fields.

Cultural practices in the U. S. differ widely from those in Thailand. All phases of rice production in the U. S. are highly mechanized, whereas in Thailand, most rice production is accomplished with buffalo, bullock, and hand labor.

The first step in growing rice is to prepare the fields for planting, which usually is done in the U. S. in late winter and early spring. The land is plowed to a depth of from 4 to 6 in. and is then disked and leveled, since a well-leveled field reduces the number of dikes. After the seedbed has been prepared, the field is planted. During the planting, the dikes are constructed. Flooding of the field usually is started about four to six weeks after planting. The field may be drained periodically for short periods to control water plants or to allow for fertilizing. It is drained approximately 10 days before harvest to allow the ground to dry sufficiently to support the heavy harvesting equipment. Harvesting usually is started in the early fall.

In Thailand, dates of land preparation vary widely; however, in general, the land is prepared in late spring, when the rains begin. During the 25 to 30 days in which the land is being prepared, the seed is planted in a nursery in a well-prepared mud seedbed. The fields are then flooded and the water allowed to stand for several weeks to soften the soil and drown the weeds. The soft soil is worked with a wooden plow, drawn by animals, to a depth of 4 in. until it is in a slurry form. The field is soaked for several more days, then harrowed to break up the mud clods and remove the weeds. It is then ready for planting. The 25- or 30-day-old rice plants are then removed from the nursery and transplanted in the flooded field. During the early growing season, the field may be drained for a short period to control land crabs. It is then reflooded and remains flooded until one week prior to harvest, in the late fall or early winter.

Although sufficient data have not been collected to draw firm conclusions, certain trends in the changes that occur in trafficability of rice fields with time, changes in weather, and cultural practices are evident. Fig. 1 illustrates these changes. First of all, I want to emphasize the fact that this chart is a composite of all data collected in the U. S. rice lands on fine-grained soils. It includes several soil types and represents average conditions found in those areas, and is not to be applied to any one area. On this schematic figure are two solid lines, one labeled "U. S. rice field" and the other "U. S. soybean field." These lines show the trafficability of the rice field and that of an adjacent field which was not irrigated--a soybean field in this case.



Category	VCI Range	Standard Military Vehicles
1.	20-29	M29 weasel, M76 otter, and Canadian snowmobile are the only known military vehicles in this category
2	30-49	Engineer and hi-speed tractors with comparatively wide tracks and low contact pressures
3	50-59	Tractors with average contact pressures, tanks with comparatively low contact pressures, and some trailed vehicles with very low contact pressures
4	60-69	Most medium tanks, tractors with high contact pressures, and all-wheel-drive trucks and trailed vehicles with low contact pressures
5	70-79	Most all-wheel-drive trucks, a great number of trailed vehicles, and heavy tanks
6	80-99	A great number of all-wheel-drive and rear-wheel-drive trucks, and trailed vehicles intended primarily for highway use
7	100 or greater	Rear-wheel-drive vehicles and others that generally are not expected to operate off roads, especially in wet soils

Fig. 1. Schematic comparisons of soil trafficability

Trafficability is expressed in terms of rating cone index in the 6- to 12-in. layer and is shown on the Y-axis. Also shown are vehicle category numbers 1-7 and a tabulation of the range of vehicle cone index for each vehicle category. For example, category 6 vehicles can make 50 passes across an area only in soils with a rating cone index of 80 or greater. The X-axis represents time, and indicated on the chart are two important cultural practices. One is labeled "flooding begins," in the last part of May; the other is "drainage begins," in the first week of September.

Beginning in March, the trafficability rating of the rice field and that of the adjacent soybean field are in close agreement. They both increase as the spring rains cease and the soil begins to dry. The trafficability rating continues in close agreement until the last of May, when the rice field is flooded, saturating the loose, plowed and disked topsoil and causing some wetting of the lower depths and a sharp decrease in strength to a rating cone index of 75. If you will look at the heavy vertical line marked "Thailand rice field," which represents the average of several values measured in fine-grained soils, you will see that the trafficability of flooded Thailand fields is in the same ball park as that of the flooded U. S. rice field. The strength of the flooded field remains fairly constant until the field is drained. While the rice field is flooded, the soybean field continues to gain strength as the plants begin to grow and the soil loses moisture through evapotranspiration, and the strength levels off about August. Around the first week of September, the rice field is drained and the soil begins to gain strength rapidly as it loses moisture, and continues to gain strength through harvest, about the last of September, and plowing, about the first of October. The rate of strength increase is slowed somewhat by the onset of fall rains in November, and at this time, the soybean field, which has been harvested, begins to lose strength rapidly. By about the middle of February, both the rice field and the soybean field are back to about the same strength as in the beginning.

If you will compare the vehicle categories with the trafficability ratings of the U. S. and Thailand fields, you will see that category 6 and 7 vehicles are the only vehicles that cannot make 50 passes across the level flooded field, and they were designed primarily for highway use. However, based on 75 percent of the vehicle cone index, even these vehicles could make at least one pass.

On the basis of the limited amount of data available, we may conclude that soil strength per se will probably not be a major problem in rice-field mobility. However, it is possible that some flooded rice fields are weaker than those investigated so far and this feature will be further investigated. Also, the dikes and irrigation canals which are necessary to rice growing will provide serious obstacles to cross-country movement.

The effect of dikes and irrigation canals on cross-country movement in Thailand cannot be studied satisfactorily in the U. S. because wide differences occur. There are few canals in the U. S., and they are widely distributed. On the other hand, in the south end of the Bangkok Plain in Thailand, canals exist as a closely woven network. The major irrigation

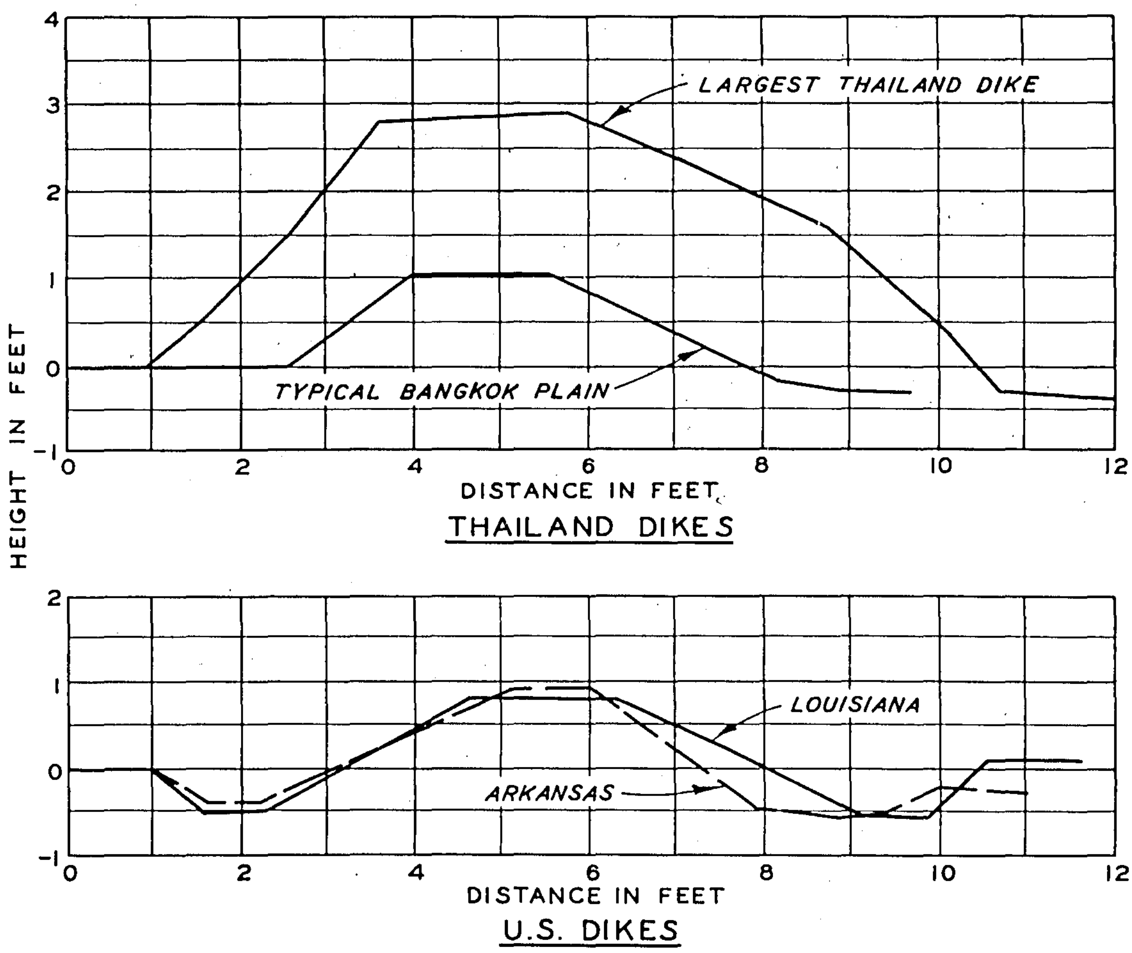


Fig. 2. Cross sections of Thailand and U. S. dikes

canals in the U. S. and Thailand will offer serious mobility problems, and most will require major engineering effort, either bridging or sloping of the banks, to make them passable. The small field irrigation canals and ditches, both in the U. S. and Thailand, can probably be negotiated with minor difficulty. The U. S. dikes are generally of a uniform size and are spaced at wide intervals, while the Thailand dikes may occur in a variety of sizes and shapes very closely spaced.

The upper part of fig. 2 shows cross sections of dikes in Thailand. The small dike is typical of the ones found in the Bangkok Plain, and the height compares closely with that of U. S. dikes. These dikes are not major obstacles. However, the larger Thailand dike illustrated is a major obstacle. Dikes in Thailand, other than those in the Bangkok Plain, vary widely in size, shape, and spacing and must be considered serious obstacles to cross-country movement. Since the larger dikes are not found in the U. S., it is apparent that the effects of dikes on mobility either must be investigated in Thailand or, if studies in the U. S. are undertaken, Thailand-type dikes must be constructed as was done for the Marsh Screw tests.

The rice plants and the water in the rice fields also will be mobility problems. The vertical visibility radius of the driver of small vehicles will be reduced when the vehicle is crossing rice fields, especially during the latter part of the growing season as mature rice plants reach a height of approximately 50 in. Experience with cross-country movement of vehicles has demonstrated that even though no major obstacles exist, drivers are very reluctant to drive rapidly in situations in which their ground visibility is obstructed. Vegetation also will be a threat to small tracked vehicles, as it is possible that the coarse rice plants may become entangled in the track mechanism and cause immobilization. Also, frontal resistance of rice plants may be great enough to prevent forward movement. Vehicles forced to traverse flooded rice fields for long periods will probably develop serious mechanical trouble as submersion almost always results in the deterioration of certain parts. In the Central Plain of Thailand, floating rice is grown in deepwater areas where the water may reach a depth of 6 ft for short periods. Swimming vehicles operating in this area could possibly develop trouble caused by the rice plants fouling the propellers. Also, entanglement of vegetation with various components of the vehicle may create more drag than the water-propulsion system of the vehicle can overcome. These problems, except for the deepwater rice, can be investigated in the U. S. rice fields.

Summarizing, there is sufficient similarity between U. S. and Thailand rice fields to justify further study in U. S. rice fields from the standpoint of soil strength. The effect of the rice plants on vehicle mobility, with the exception of deepwater rice, may also be investigated in the U. S. rice fields.

Soil strength per se is probably not a serious problem in most rice fields even when they are flooded, but this feature should be investigated further in Thailand.

The most serious deterrents to mobility offered by rice fields are the irrigation canals and dikes associated with the rice fields. Their effects on mobility can best be studied in Thailand, but may be studied in the U. S. by constructing analogous models.

The future plans for the rice-field study call for continuing the U. S. study through April 1964 in order to have one complete year of record. After completion of field testing, a report of the findings of the U. S. study will be prepared. Plans are being made to extend the rice-land study to countries in Southeast Asia. Field testing will be performed in countries to which we can gain access, and the information obtained will be extrapolated to other areas.

Within the next 12 months, visits will be made to Thailand and several accessible Southeast Asian countries to collect a modest amount of data on rice-field characteristics, namely, cultural practices, geometric features, and soil types, and relate these characteristics to landform. Work will begin on the development of a system for classifying rice fields in terms meaningful to ground mobility purposes. Existing rice-field distribution maps of Southeast Asia will be obtained and evaluated, and rice fields having similar internal characteristics that impose a specific effect on ground vehicles will be mapped.

DISCUSSION

Gen. Wienecke objected to Mr. Kennedy's inference that soil trafficability in rice fields is apparently no problem. He was assured that this statement applied only to large, level, bottomland areas in the United States in which the soil type and cultural practices were similar. It was recognized that as cultural practices varied, particularly in terraced rice fields, the combination of obstacle and soil consistency would be impassable to most ground vehicles. Mr. Philippe stressed the usability of the Ganges area in India and Pakistan for rice-land studies because of the variability in cultural practices and sizes of dikes.

Mr. Wismer's paper was then discussed briefly. Mr. Philippe posed a question as to when an insurmountable obstacle becomes surmountable, and was assured that it varies with each vehicle. Mr. Philippe also cautioned against designing a vehicle for each mission, stressing the importance of identifying the critical conditions for which to design. Mr. Jebe then injected a few comments on off-road mobility which are worthy of mention. In emphasizing driver influence on vehicle speed, he mentioned observing tests in relatively flat terrain with only a tall grass cover. The fastest average speed attained even under these good conditions was only 14 mph. Mr. Rula seconded this observation by stating that the fastest average speed they were able to obtain in tests in Thailand with the Gama Goat in relatively simple terrain types was 14.8 mph.

ENVIRONMENTAL DATA-COLLECTION MANUAL

by

E. E. Addor*

The satisfactory achievement of the goals of Project MERS is dependent at least in part upon adequate and consistent description of the environments in which the tests are to be conducted. A manual, in which rules for data collection are set forth clearly and precisely, is an efficient means of assuring at least a modicum of the desired consistency. Partly for this reason there is being prepared such a "Manual" for the collection of environmental data.

Based upon the environmental factor family concept developed by the Area Evaluation Branch, the manual is comprised of several "parts." Each part includes a brief introductory discussion of the factor family (or subdivision thereof), followed by directions for sample site selection, this in turn followed by specific "by-the-numbers" instructions for the measurement procedures, amply illustrated.

The factor families considered for inclusion in the manual are these: Surface Composition, Surface Geometry, Hydrologic Geometry, Vegetation, and Weather. Some of these are subdivided, and the "parts" of the manual are numbered on this basis. These are:

- Surface Composition
  - Soil Classification (Part I)
  - Soil Moisture (Part II)
  - Engineering Characteristics (Part III)
- Surface Geometry (Part IV)
- Hydrologic Geometry (Part V)
- Vegetation
  - Vegetation Structure (Part VI)
  - Taxonomic Composition
  - Visibility Characteristics (Part VII)
- Weather

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Surface Composition is concerned with the composition and physical properties of the materials composing the surface of the earth, regardless of their origin. Surface here is defined as the surface 24 in., and includes soils, rocks, peat, snow, ice, or whatever--except water. For data-collection purposes, it is divided into three categories:

a. Soil Classification, which encompasses the indentification of basic physical characteristics, such as texture, mineralogy, structure, and genetic attributes. In general, the classifications required are the Unified Soil Classification System, and the U. S. Department of Agriculture Pedological System, including the normally accepted "Great Soil Group" series.

b. Soil Moisture is a basic constituent of the surface materials in many places, but it is not included in most classifications. This is because it nearly everywhere varies with time. However, all other things being equal, it is the most important factor in controlling soil strength. For this reason detailed information on the relation between soils and moisture content is necessary before engineering properties of the material can be predicted.

c. Engineering Characteristics consist of a group of related factors describing specific physical properties of the soil-water system as a whole. The factor values are stated as numerical indicators derived from standard laboratory or field tests, including Atterberg limits and measures of soil strength.

Surface Geometry refers to the configuration of the surface of the earth; and in this case the surface is defined as--theoretically at least--only the surface layer of molecules. Such things as slopes, ravines, embankments, ditches, rice bunds, etc., are examples of surface configurations which produce effects upon various military activities. It is emphasized that this factor concerns only the actually physical configuration as it exists here and now, regardless of its origin, man-made or otherwise.

Hydrologic Geometry refers to the size, shape, and distribution of water bodies of all kinds. In this case there are both temporal and dynamic considerations involved, since the shapes, sizes, distributions, and current velocities vary with time, and since current velocities vary from place to place even within a given water body at a given time.

Perhaps it is well to note here that temporal variations occur among the other factor families also, but not usually so abruptly as with water bodies.

Vegetation as a factor family includes all of the characteristics associated with the mass of the vegetation, whether on land, in the air, or in the sea (or other water).

Structure as defined here involves the gross physical attributes of the vegetation--the surface geometry of the total mass of a plant assemblage. This includes such factors as stem size and spacing, height, branching habits, thorniness, etc.

Taxonomic Composition is a measure of the genetic content of the given assemblage, as determined by the constituent species and the relative proportion of each. It is, for example, assumed that the genetic characteristics of a plant assemblage will determine its response to chemical defoliants; and it may also in some instances provide a crude index to other characteristics of the environment, such as soil characteristics, surface geometry, etc.

This at present consists of a species list, and space is provided for it on the structural data form. A special "part" of the manual is not devoted to this factor.

Visibility Characteristics is a measure of the screening effect of the vegetation. Visibility in the total sense involves a variety of phenomena not all related to vegetation per se. It includes the amount and quality of available light, physiological variations in observers (e.g., color blindness, myopia, etc.), and psychological reactions of the observer as determined by his experience and familiarity with a given situation. As considered here, these factors are ignored as much as possible, and the visibility becomes a function primarily of the number, size, and distribution of obstructions. It is in fact an "artificial" property of vegetation in that it is a measure of an effect on a specific activity--seeing.

Weather, as a factory family in this context, concerns the atmospheric layer from the earth surface to a height of about 150 ft. It is descriptive micrometeorology, and includes light quantity and quality; intensity, duration, and frequency of rainfall; duration and frequency of specific levels of humidity and of temperature; and duration, frequency, direction, and force of air movements. Like Hydrologic Geometry, it requires temporal and dynamic considerations.

So little is known, however, about the way these factors operate, or how to measure them adequately to establish their modus operandi, that there are not now included in the manual instructions for collection of weather data.

In the manual, the discussion introductory to each part includes a comment as to the state of knowledge of that particular topic, the scope (i.e., content), and definitions. In general, no particular effort is devoted to explanation of rationale, except to the extent that, as we believe, a slight understanding of rationale provides psychological salve, thus rendering the instructions more acceptable to the user, and thus in turn assuring a more rigid adherence to the instructions.

The data requested by the manual are in considerable excess, both as to quantity and quality, of that known to be pertinent to ground mobility, hence to Project MERS. Originally, the manual was to be designed for use on Project MERS, and was to provide instruction for collecting environmental data known or presumed to be pertinent to ground mobility. However, since the Area Evaluation Branch was given the larger responsibility of coordinating environmental data collection for all ARPA projects, it was decided to enlarge the scope of the manual to include the total environment relative to all activities, i.e., to render it compatible with the objectives of the Project MEGA. This of course can be done without in any way diminishing its utility to the Project MERS, since the same difficulties pertain. These difficulties are enumerated as follows:

a. The description systems for some of the factor families are not well developed, and correlatively, procedures for obtaining data of known pertinence are not well established for some factor families, and

b. The data now known to be pertinent to ground mobility may be less than that ultimately found to be pertinent.

Only one consideration adds to the difficulty of enlarging the scope of the manual, to wit:

c. The data are expected to be applicable to other, future tests and analyses, the scope and purpose of which cannot be foreknown.

These three considerations are reconciled, in any event, as follows: When the description system for a factor family is poorly developed, or when the pertinence of a given kind of data is not known, that fact is explained in the manual, and then the instructions are provided. It is presumed that, as a result of the instructions having been followed in these cases, the data will have consistency if nothing more; then when the pertinency of a given kind of data does become established, the collected data will become applicable with a known and uniform expectancy of error. Then, when a valid procedure becomes established for the collection of such data, the manual will be revised accordingly.

This anticipated revision of the manual is a part of its design, and is not considered a defect. Knowledge of the ultimate kinds of data required, and adequate collecting techniques both can be expected to evolve only concurrently with an understanding of the environmental factors affecting the various activities. The manual must be considered a tool for pursuit of this knowledge and improvement of these techniques, and as such its main function is twofold--to assure consistency in the data collected, and to provide guidance in the correction of its own deficiencies.

DISCUSSION

A short discussion transpired on the content of the data-collection manual being prepared by WES. The importance of weather was debated, including those field measurements that would be taken. It was concluded that the manual should be published immediately and disseminated to all ARPA-sponsored projects that require environmental data collection in fulfilling the objectives of their projects to determine the adequacy of the manual in meeting their requirements.

REVIEW OF PUBLISHED ENVIRONMENTAL DATA OF SOUTHEAST ASIA

by

J. H. Shamburger*

Of utmost importance in initiating a research study is the location and the evaluation of published and unpublished information pertaining to that field of interest. Such an approach is being used for the MERS program. The search for literature of SE Asia actually originated in July 1962 as part of the preliminary survey when a limited study was made by contacting various agencies in Thailand to determine the availability and usefulness of published and unpublished data pertaining to the problem at hand--ground mobility. The results of this study were published as an appendix to the technical report covering the preliminary field survey.

Before I continue let me mention that for the purpose of this study SE Asia includes the countries of Thailand, Burma, Laos, Vietnam, Cambodia, and Malaya. Although it was somewhat dormant while the results of the preliminary survey were being assembled, the task of locating literature on SE Asia was by no means terminated by the limited study conducted in Thailand. The search for published information was reinstated in May of last year with particular emphasis being placed on locating material on Thailand. The reason for directing initial efforts to Thailand was because of the possible assistance these data might render in planning and conducting the field surveys in that country.

The objectives of the literature survey are to locate, collect, analyze, and evaluate all data which would assist in describing in quantitative terms those physical attributes of SE Asia that affect ground mobility. These physical attributes or environmental factors include geometric configuration of the landscape, surface composition, vegetation, and hydrologic characteristics of water bodies. The term data, for this study, includes maps, aerial photographs, and written text or descriptive material published and unpublished.

The search for data was initiated by examining the bibliographies of

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the Research Center Library at the WES. After this source was exhausted the survey was expanded primarily to the Military Geology Branch of the U. S. Geological Survey, Soil Conservation Service of the Department of Agriculture, Army Map Service, and the Aeronautical Chart and Information Center (ACIC). Personal contacts were made with these agencies in May and October of last year.

The Military Geology Branch files furnished the majority of the bibliographic material for the literature portion of this study. This agency has compiled an extensive bibliography of SE Asia and surprisingly has referenced these data in a manner somewhat similar to our environmental factors but, of course, inclusive of a much wider range of subjects. As expected, the references obtained from the Soil Conservation Service were predominantly soils publications; however, some good references on vegetation were also included. The documents library at Army Map Service provided a limited amount of data from the Engineer Intelligence Files which are believed to be useful. Repetition of references in the files of these three agencies was a minor problem that had to be dealt with.

Availability of topographic maps of SE Asia was obtained from Army Map Service stock records and ozalid indices and IBM cards. The stock indices list the coverage that is available as off-shelf maps, and are published annually with periodic supplements. The ozalid indices cover old series or out-of-print maps of which photographic copies can be obtained. In addition to topographic maps, other types of maps such as geological, soil, vegetation, etc., of world areas are listed on IBM punch cards. At our request, Army Map Service furnished us with a complete listing referred to as a tab run or machine listing of all maps available from them on the SE Asian countries. I might add that approximately 90 percent of the map reference cards presently in our files was obtained from these tab runs.

Aerial photographic coverage was determined from the Aeronautical Charts and Information Center which is the prime depository of negatives of aerial photographs exclusive of the U. S. and its territories. Air photo indices are available from this agency or photographs can be ordered by coordinates. We were informed only last week that the Defense Intelligence Agency is in the process of assuming the responsibility as the film depository from ACIC.

After the bibliographies were assembled, it was necessary to request the references through the WES Research Center which obtained the material on interlibrary loans for periods of 2 to 3 weeks for examination and evaluation. This ordering process was not as simple as it may sound because the proper number of references had to be ordered and the requests had to be staggered to allow sufficient time for review. I might add that we haven't achieved perfection yet. The references were first divided into two broad categories: maps exclusive of stock AMS maps and written data. Once this simple division was made each category was to be further subdivided into surface geometry, surface composition, vegetation, and hydrologic geometry. Two additional types of categories, general and climatic, were included shortly after the review of references was initiated.

Because of the urgency of completing the literature search on Thailand, all of the references for this country have been placed in their proper category and about 70 percent of them have been evaluated. I would like to briefly summarize our findings on Thailand at this time. The general category is the largest single collection in our bibliography, and presently consists of approximately 625 references on Thailand. While these data are usually too general in nature to be of specific use, they give a background of the country and in some cases specific facts are mentioned which can be useful under another category. By contrast, some of the information is absolutely useless; however, this fact is not known until a reference is examined.

References that fall under the surface geometry heading are very limited in number simply because very little quantitative work has been done in this field. The available data are composed of the usual qualitative descriptions of terrain and landforms. Nevertheless, this small amount of data may become important during the mapping phase.

The file of surface composition references is one of the larger collections and consists of 260 references. One reason for this data accumulation is that geological information is also included in this category. The soils data are, for the most part, general in nature and usually in pedological terms comparable to the U. S. Department of Agriculture classification, which will require translating it into more quantitative terms before utilizing these data in the MERS project. The geological material, unimportant in many cases, may be applicable to areas where soil data are lacking or limited.

References on vegetation total 135 individual articles and vary from very general to detailed, with little or no in-between. The material gives either detailed information relating to species and occurrence, or broad general descriptions for extensive areas. In most instances, references do not contain quantitative descriptions of stem diameter, height, and spacing, etc., of vegetation stands; however, data concerning the diameter and height of particular species are sometimes included.

Available references on hydrologic data total 255. Approximately half of these references are maps of irrigation projects. The other references include stream discharge, velocity, and depths crossed by the major highways. Information concerning cross sections, soil composition, and bank conditions of streams and rivers is consistently absent. Some reconnaissance reports list streambed material in such terms as ranging from mud to dirt and from stone to rock. Records are available for approximately 540 gauge stations where stream depth and velocity are recorded along with the amount of overflow and duration of overflow.

Climatic data are available from approximately 80 weather stations spaced throughout Thailand. Detailed data concerning temperature, rainfall, relative humidity, etc., are available from 33 of these stations beginning in 1946 and continuing to the present.

Topographic maps at a scale of 1:1,000,000 and 1:250,000 are available for all SE Asia. Complete topographic map coverage of Thailand, except for the peninsula, at a scale of 1:50,000 is available at WES. The 20-meter contour interval limits the application of these maps to the MERS study. Very spotty coverage at a scale of 1:25,000 is also available for Thailand and has been requested where it covers any part of the seven areas selected for detailed field investigations. Topographic map coverage at scales larger than 1:250,000 for the remaining SE Asian countries is not as complete as that for Thailand and the contour interval is larger where contours occur.

Complete air photo coverage of Thailand north of latitude 10° North is available. This coverage is intermixed at scales of 1:20,000 and

1:40,000. Complete coverage of Thailand, except for a few small gaps, is also available at a scale of 1:60,000. Sporadic coverages at scales varying from 1:10,000 to 1:66,000 are also available.

The number of references in our files which constitutes the environmental bibliography on Thailand total approximately 1300. Although not separated into categories, references on file for the other SE Asian countries include 1100 on Burma, 1270 on Malaya, 700 on Indochina, 870 on Vietnam, 200 on Laos, and 170 on Cambodia. Approximately 30 to 40 percent of these references are maps. Practically all of the references are written in English except that 25 percent of the publications for Laos, Cambodia, Vietnam, and Indochina are in French. Totaling the number of references, we obtain a figure of 5600 references, which is quite sizeable in quantity; however, I can assure you that the number of these references that will be useful to the MERS program will be considerably less than 5600.

How are we going to present these data? It is our present plan to publish a series of four reports covering the SE Asian countries. Reports will be prepared on Thailand, Burma, and Malaya. The countries of Laos, Vietnam, and Cambodia will be combined into one report. The reason for combining these countries is because a considerable amount of data was published under Indochina which, as you know, was made up of these countries.

The reports will contain annotations for each reference reviewed giving a brief description of the nature and extent of data contained. The annotated references will be grouped in accordance with the environmental factors they pertain to. It should be pointed out that in numerous cases one reference will overlap into more than one factor. Where this happens there will be a cross-reference notation. To expedite locating the more valuable references geographically, plates will be prepared showing this information. These data will be presented on small-scale maps for each of the categories where feasible. In certain areas where an abundance of data exists, large-scale maps will be used to adequately present the information. Areas will be outlined and assigned numbers corresponding to specific references. Combinations of these factor data maps will outline specific areas where data are scarce or absent.

Plates will be prepared to denote the reliability and usefulness of the evaluated references shown on these maps. Here again a map will be prepared for each environmental factor.

The extent of map coverage at various scales will be shown on a series of plates. This can be done with a series of overlays indicating the type of map, i.e. topographic, geologic, soils, etc., shown.

Plates showing the extent and scale of unclassified air photo coverage for each country will be prepared. The agency where this coverage is available will also be included. I might add that aerial photography for the seven primary study areas in Thailand has been ordered.

As previously mentioned our evaluating efforts have been and are being concentrated on Thailand, and a report presenting the results of this study should be published this fiscal year. As soon as practical, efforts will be diverted to the other SE Asian countries and reports published on them. The idea of extending the literature search to foreign sources in England, France, Australia, and New Zealand is being considered; however, action on this approach will be delayed until more data from domestic sources are evaluated.

PREDICTION OF TERRAIN CHARACTERISTICS IN THAILAND BY AIRPHOTO INTERPRETATION

by

W. K. Dornbusch, Jr.*

A major MERS requirement is the prediction of those terrain characteristics in Southeast Asia that affect ground mobility. To accomplish this objective, the most suitable means of identifying terrain characteristics is to determine them from such existing sources as maps, aerial photographs, published data, and ground reconnaissance. Such considerations as the scale and acceptable degree of generalization revealed that the use of aerial photography supplemented with maps, ground reconnaissance, etc., would be the most valid method of making these identifications.

Limited examination of aerial photographs by the preliminary survey team while in Thailand revealed that certain patterns were repetitive throughout large areas. With this in mind, this study was initiated to develop interpretive techniques to systematically describe aerial photo patterns and quantify these patterns in terms of their terrain characteristics. The study is being conducted in selected areas, shown in fig. 1, believed to be representative of environmental conditions throughout Thailand. We hope that developing a technique of this type within these areas will provide valid means of extrapolating data into remote areas without the necessity of ground measurements.

This study was initiated by examining the current state of the art of photo interpretation to determine its applicability to our particular problems. While considerable progress has been made in photo interpretation since the end of World War II, an examination of references in this field revealed that they provide surprisingly few techniques that will enable the precise determinations necessary to meet our requirements in Thailand. Compounding this inadequacy are ancient cultures that have endured for thousands of years that have produced agricultural and land-use practices unlike those normally encountered. One such example is the almost complete

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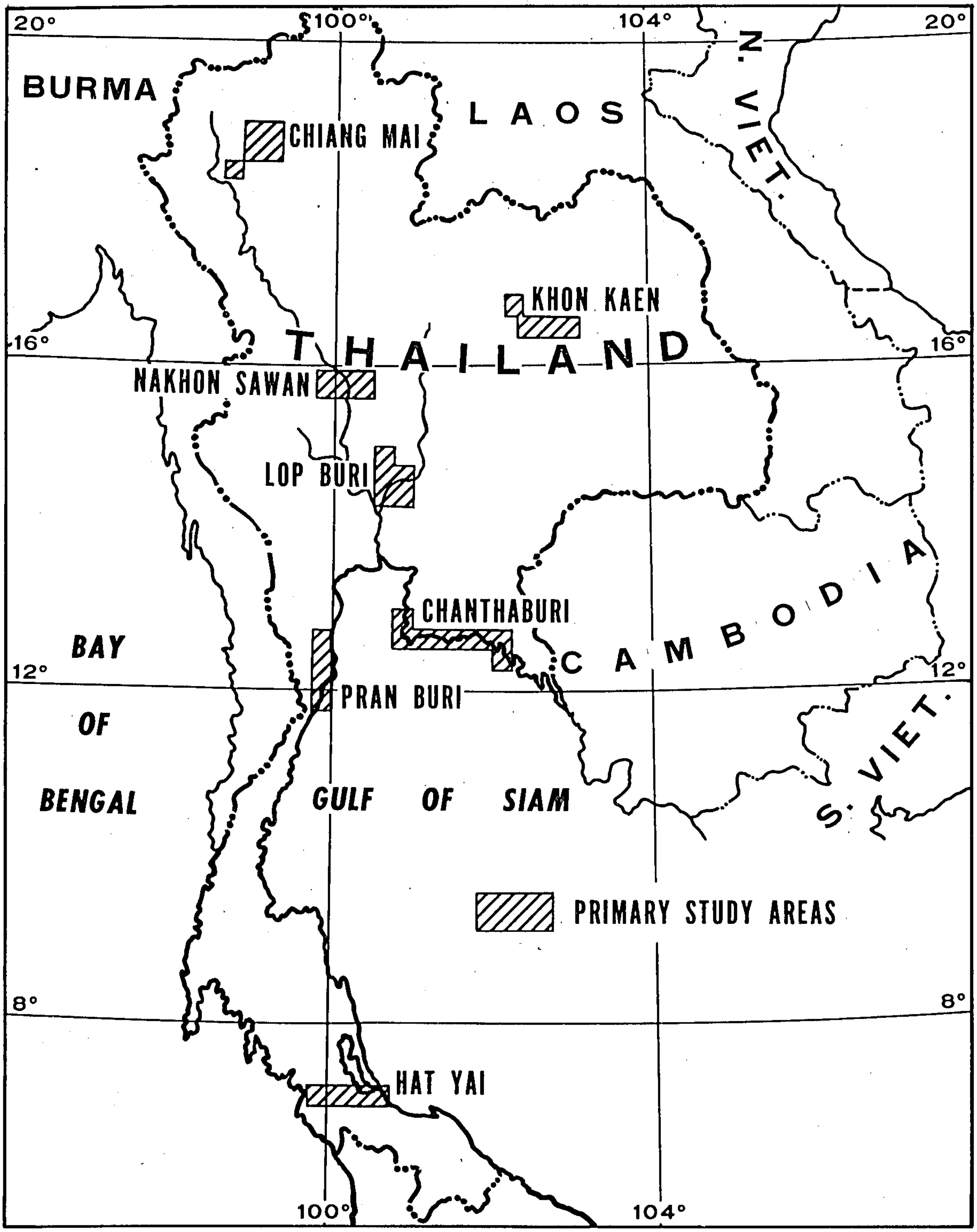

20°
100°
104°
20°
BURMA
LAOS
N. VIET.
CHIANG MAI
KHON KAEN
16°
THAILAND
16°
NAKHON SAWAN
LOP BURI
CHANTHABURI
CAMBODIA
BAY
OF
BENGAL
12°
PRAN BURI
12°
S. VIET.
GULF OF SIAM
PRIMARY STUDY AREAS
8°
8°
HAT YAI
100°
104°

Fig. 1.

absence of natural drainage in cultivated areas which has resulted from the diversion of practically all of the rainfall into the rice fields for irrigation purposes. Since existing techniques are largely ineffective, new methods must be developed that can be applied with greater utility towards predicting in quantitative terms terrain characteristics in Southeast Asia.

If quantitative terrain data pertaining to specific aerial photo patterns are to be extrapolated into remote areas, a method must first be developed to establish the degree of similarity between the patterns. Too often areas are delineated on aerial photographs and assigned the same identity simply because they look alike. Our efforts have been directed towards developing a descriptive fabric that will enable valid and conclusive comparisons to be made of the geometric, tonal, and textural characteristics of the patterns.

Analysis of selected aerial photography of Thailand has resulted in developing a descriptive photo pattern classification which should be applicable to all of Southeast Asia. In this system each pattern is described in terms of eleven different categories which describe the geometrical, tonal, and textural variations. I would like to briefly describe the categories at this time. Because time does not permit a discussion of the mapping units of each of these categories, a copy of the pattern classification key is included in table 1 at the end of this paper.

The <u>pattern area</u> is the basic mapping unit. It may be selected as large as can be conveniently described by a single pattern or a group of patterns. Normally areas containing more than five patterns are avoided because of cartographic complications.

All patterns may be divided into either <u>areal</u> or <u>linear.</u>

An <u>areal pattern</u> is one that extends conspicuously in two dimensions. Below a width of approximately 0.1 in. the pattern is considered linear provided it meets additional criteria.

<u>Linear patterns</u> are those that occupy a narrow band and have a length to width ratio exceeding 10:1 and a width less than 0.1 in.

All patterns whether areal or linear are further classified as regular, semiregular, irregular, or amorphous.

<u>Regular patterns</u> have long-range periodicity, i.e., the basic mapping unit repeats itself at regular spacings over long ranges.

Semiregular patterns have short-range periodicity.

Irregular patterns have essentially no periodicity. However, it can have an appearance of homogeneity and uniformity of distribution of components.

Amorphous patterns are free of texture by virtue of low tonal contrast and a grain size that is beyond resolution.

A component is the basic unit of areal patterns and of some wide linear patterns. It represents the smallest entity of the pattern that can be extended by means of spacing of components, unit cell size, and unit cell shape to form a pattern.

Component size is a measure of the short dimension of the component.

The grain size is used in describing coarse patterns where individual components are large enough to reveal an internal structure.

The unit cell is a hypothetical parallelogram, the corners of which are occupied by four identical components.

Unit cell shape is the ratio of the lengths of the sides of the unit cell.

Unit cell width or component spacing is the average width (short dimension) of the unit cell. In irregular patterns it is the average spacing of components from center to center.

The dominant tones of the pattern are considered as white, light gray, medium gray, dark gray, and black.

Contrast is the range in tone within a pattern.

Symmetry. Two types of asymmetry describe the position of the characteristic black lines occurring along one side of the pattern area or component. The side on which the dark lines, identifiable as shadows, occur is designated as either the positive or negative shadow side. A line or an area having no shadow along one side is considered as symmetric. The shadows, of course, become increasingly less conspicuous as the scale of the photography becomes smaller.

The curvature of linear and some areal patterns is conveniently classed as straight, simply curved, and multiple curved. In such cases there are no curves, one or two curves, or more than two curves per 0.5 mile. A curve is accepted as any inflection greater than 10 degrees.

It is also desirable to know arrangement, orientation, and occurrence of pattern areas as they occur in space. These categories, while providing information pertaining to the spatial distribution of the patterns, do not influence the degree of similarity between individual patterns. These categories are:

Areal or linear arrangement, the distribution of individual patterns within an area.

Orientation, merely an indication of the alignment of the pattern areas with reference to north.

Patch or pattern area spacing, the distance between centers of patches. In cases where patches are isolated, or continuous over large portions of the photograph, this determination is disregarded.

Once a pattern or patterns have been described the data are coded and stored on hand-punched cards. This card system enables convenient storage, rapid retrieval, and allows the cards to be sorted for one, several, or all of the various categories. Fig. 2 illustrates the method used to store the data on a card. First the pattern is drawn to scale and the name of the area and the number of the photograph are noted. Each category is assigned groups of holes which form a single row just inside the four edges of the

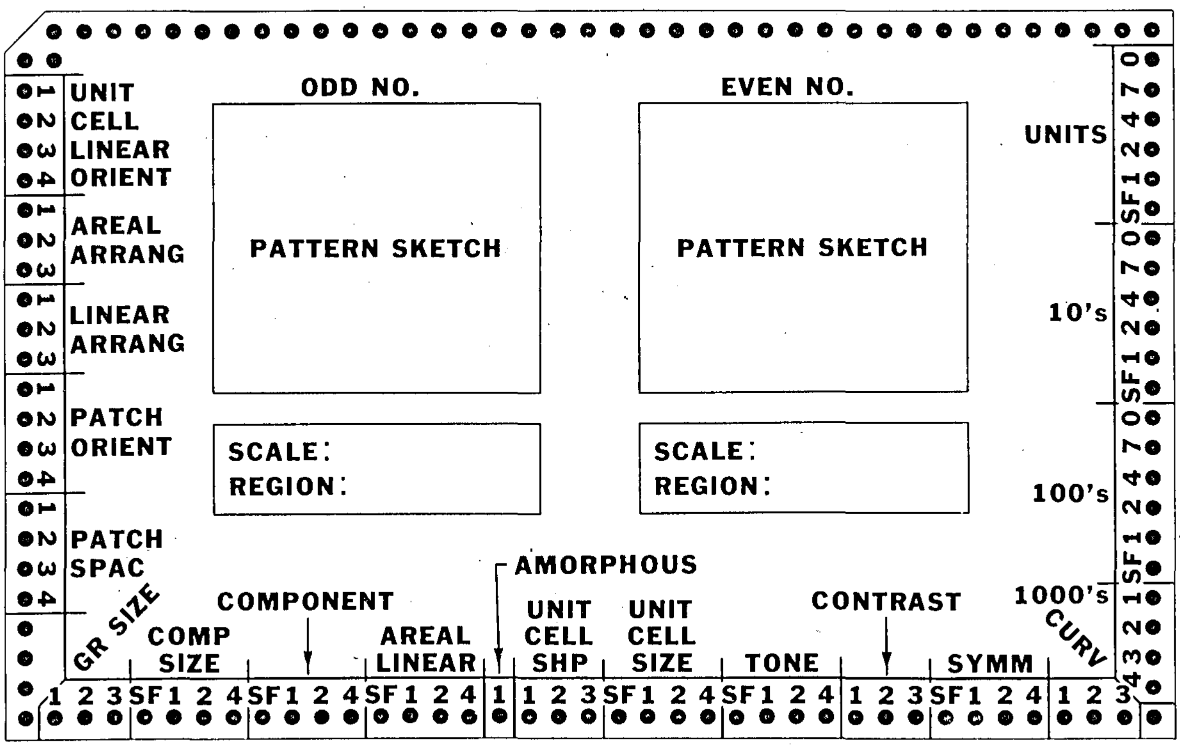

Fig. 2. Data storage card for airphoto pattern classification

card. After a pattern has been classified the appropriate unit for each characteristic is punched on the card. After pattern cards have been accumulated for a number of study areas these data should prove useful in the selection of test areas and future analog studies.

Up to this point we have only a system that describes and classifies airphoto patterns. The next step is to introduce terrain conditions in the pattern descriptive system in order to determine if a pattern or patterns are indicative of specific characteristics.

Our basic assumption in the interpretation of the patterns was that similar or identical patterns will have similar terrain characteristics. Therefore, to establish the validity of this assumption the patterns must be quantified in terms of those environmental factors that affect ground mobility and a comparison made between the patterns and their terrain characteristics. This type of comparison for one of the environmental factors was made recently in Puerto Rico.

While many similar patterns could have been selected in Thailand, there was no immediate way to accurately determine their terrain characteristics. Rather than delay attempts to verify these relations, a group of patterns was chosen in Puerto Rico, a country in many ways physically and climatically similar to Thailand. Conclusions resulting from the correlation of the patterns with terrain characteristics should be expected to hold true in Thailand.

Eight similar airphoto patterns were selected and described according to the classification system previously discussed. They consisted of rounded components with even two-dimensional spacing and shadows on the positive side of the components. The patterns were distinguished on the basis of contrast, spacing interval between components, and arrangement of pattern areas.

Each photograph was examined for the desired groups of patterns and then classified in terms of the individual pattern. USDA soil maps of Puerto Rico were examined and soils within the particular patterns were tabulated. The comparison revealed a uniformity of characteristics among soils associated with these patterns suggesting that the patterns are valuable indicators of certain soil characteristics. Each pattern indicated the following:

(1) mostly sand soils

(2) the soils were on flat to gentle slopes

(3) the soils were greater than 1 ft thick, usually several

(4) friable (surface)

(5) noncohesive to slightly plastic (subsoil)

(6) no fragments

(7) low in organic content

Further examination of the photographs indicated that even subtle distinctions in patterns caused by differences in the spacing of components can result from slight differences in the soil characteristics. Generally, it appears that patterns with the closest spacing of components usually indicate a higher clay content of the soil.

A similar treatment of three additional patterns characteristic of sugarcane fields in northern Puerto Rico revealed that within the area considered soil characteristics could be predicted with a considerable degree of accuracy. Plans for the next 12 months include the following studies:

a. We feel that the correlation established between soil data and the photo patterns described by our system warrants continued efforts to determine if correlations exist between other environmental factors and the patterns.

b. The pattern description classification should also be expanded to include regions in Thailand that are dissimilar to the present study area. Determining the effect that enlarging or reducing the scale of photography would have on photo pattern identification would be another consideration.

c. To standardize the procedure used in the interpretation of aerial photo patterns, preliminary efforts have been initiated towards compiling a list of all the factors that affect terrain characteristics. Each characteristic should be examined on the basis of these factors, weighted according to importance, and evaluated.

Table 1

CLASSIFICATION KEY FOR AERIAL PHOTOGRAPHIC PATTERNS

SPECIFIC CATEGORIES

Pattern types--Areal, linear, and amorphous

Areal Patterns

Patterns extending conspicuously in two dimensions.

1. Regular
2. Semiregular
3. Irregular

Linear Patterns

Patterns occupying a narrow band and having a length to width ratio exceeding 10:1 and a width less than 0.1 in.

4. Regular
5. Semiregular
6. Irregular

Amorphous--patterns that do not fall into the definition of areal or linear.

Component--basic unit of areal patterns and some wide linear patterns.

1. Rounded areas
2. Paralleograms
3. Other polygons
4. Four lines
5. Two lines
6. Irregular

Component size--measure of the short dimension of the component.

1. Small (< 0.2")
2. Intermediate (0.02 to 0.05")
3. Large (> 0.05")
4. Small to intermediate
5. Intermediate to large
6. Small to large

Grain size--used where individual components reveal an internal structure.

1. Fine (< 0.01")
2. Intermediate (0.01 to 0.02")
3. Coarse (> 0.02")

Tone--intensity of the shading of all patterns.

1. White
2. Light gray
3. Medium gray
4. Dark gray
5. Black

Contrast--range in tone within patterns.

1. Low (range of less than two tones)
2. Intermediate (range of two or three tones)
3. High (range of four or five tones)

Unit cell shape--ratio of the lengths of the sides of the unit cell.

1. Short (1:1 to 3:2)
2. Intermediate (3:2 to 3:1)
3. Long (over 3:1)

Table 1 (Concluded)

Unit cell width or component spacing--average width (short dimension) of the unit cell.

1. $< 0.025''$
2. 0.025 to $0.05''$
3. 0.05 to $0.2''$
4. 0.2 to $1.0''$
5. $> 1.0''$

Symmetry--the presence or absence of the characteristic black lines along one or both sides of a pattern area or component.

1. Symmetric
2. Black on positive shadow side of pattern
3. Black on negative shadow side of pattern
4. Black on positive shadow side of components
5. Black on negative shadow side of components

Curvature--any inflection greater than 10 degrees.

1. Straight
2. Simply curved (one or two curves per 0.5 miles)
3. Multiply curved (more than two curves per 0.5 miles)

GENERAL CATEGORIES

Areal arrangement--distribution of individual patterns within an area.

Areal Patterns

1. Continuous
2. Mottled or mutual
3. Isolated

Linear Patterns

1. Singular or parallel
2. Branching and/or converging
3. In preferred directions

Pattern area spacing--distance between centers of patches.

1. $< 0.2''$
2. 0.2 to $0.5''$
3. 0.5 to $1.5''$
4. $> 1.5''$

Pattern area orientation--alignment of pattern areas with reference to north.

1. 338 to 23^{o}
2. 23 to 68^{o}
3. 68 to 113^{o}
4. 113 to 158^{o}

RADAR STUDIES FOR DETECTION OF SURFACE AND GROUNDWATER

by

B. R. Davis*

One factor affecting off-road trafficability of military vehicles is the presence of water tables near the surface of terrain. In order to detect these water tables and determine their depth, electromagnetic energy of sufficiently long wavelength to penetrate the upper few feet of soil must be used. Short wavelength sensing devices such as conventional aerial photography and infrared scanners can at best only provide an inference of the presence of water tables. This is not meant to imply, however, that these sensors are not of tremendous value in remote terrain interrogation, but that their value is somewhat limited to backup data for longer wavelength sensors such as radio and radar when characteristics concerning subsurface features are of principal interest.

Tests are currently in progress at WES to determine the capabilities of the radar portion of the electromagnetic spectrum as a remote means of detecting the presence of water tables. The radar sets being used in these studies operate in the Ka-, X-, C-, and P-band portions of the spectrum at frequencies varying from 300 megacycles for P-band to 36,000 megacycles for Ka-band. Use of such a wide range of frequencies is dictated by the differences in depth-of-penetration capabilities of the four bands. In the analysis of terrain from a trafficability standpoint, we are interested in variations of soil parameters and other features within the top 2 ft. No one frequency band can provide this information for all soil conditions which might be encountered. For example, P-band frequencies will penetrate 2 ft in wet clays whereas the C-band frequencies may only penetrate a few inches. In dry sands, however, the P-band frequencies will penetrate several tens of feet while C-band provides information on the upper 2 ft.

Fig. 1 is an illustration of the test facility being used in these studies. The building itself is an open-ended wooden arch structure of 50-ft radius. The use of wood and open-ended construction cuts down on

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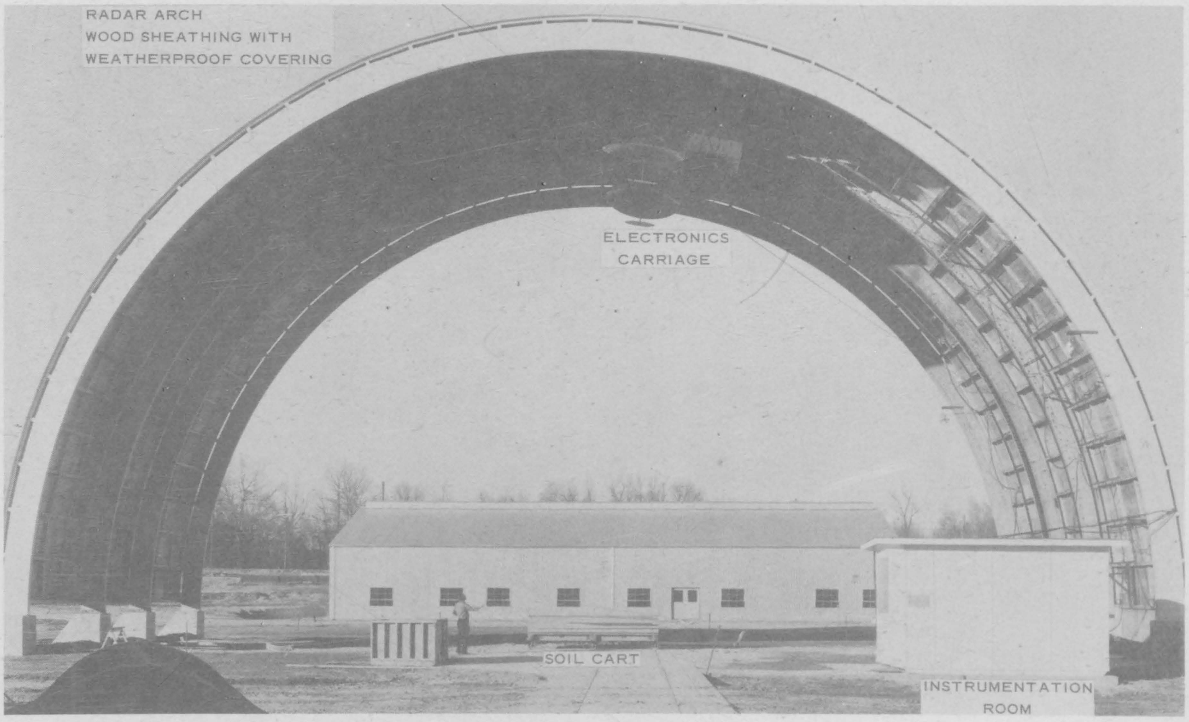

Fig. 1. Radar test facility

the spurious reradiation characteristics of the building and allows for isolation of the effects of changes in weather conditions. In the center of the building is a hydraulic lift which is used to insure proper focusing of the radar beam on the soil sample throughout the tests. The radar sets are mounted on a carriage assembly, shown in fig. 2, which can traverse the arch of the building from zero to 90 degrees. This feature allows information to be gathered at varying aspect angles throughout the tests. Each radar set uses two antennas, one for transmitting the radar signal and the other for receiving it. Use of two antennas such as this reduces the cross talk between radar receiver and transmitter and helps to insure that all of the return radar signal being recorded is actually coming from the soil sample itself and is not merely a sampling of the transmitted signal. Several other features are also incorporated in the radar sets to provide greater isolation of the return signal, including pulse-type transmission with range-gating capabilities and the use of microwave absorbent material in critical areas.

A cross section of the test cart for soil samples being used for this study is shown in fig. 3. It is almost completely constructed of wood and is built up using approximately 4-in. layers of wood. The capacity is

Fig. 2. Electronics carriage

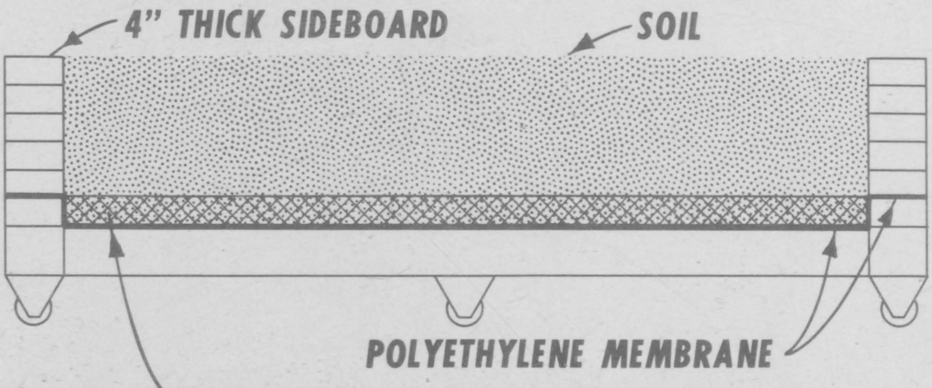

Fig. 3. Cross section of radar test cart and soil sample

approximately 20,000 lb of soil. For the initial tests, we are using the ideal situation where there is a clear definition between the water table and the soil above it. In construction of the soil sample, a special polyethylene membrane which is highly transparent to radar is first placed in the bottom of the cart. Soil of the type to be tested is then compacted into the lower 4 in. of the test cart and supersaturated with water to simulate a water table. Another polyethylene membrane is then placed over this supersaturated layer of soil to prevent seepage of water into the upper layers of the sample. Soil with varying degrees of moisture content is then used to fill the cart to a thickness of 24 in. Using this method we are able to determine the ability of radar frequencies to detect water tables underlying a given soil type from its driest to its wettest condition. In later tests the upper polyethylene membrane will be removed to allow the difference between the water table and upper soil to become less pronounced.

There are two main types of tests being conducted using these water-table samples. One is the soil signature and the other a depth-of-penetration test. The first test, soil signature, is made by measuring the reflected radar signal from the soil sample as the radar carriage assembly travels from vertical incidence to an angle of incidence of 30 degrees. Typical results of these tests are shown in figs. 4 and 5. Fig. 4 is an X-band radar soil signature for Long Lake clay at a moisture content of 10 percent. An illustration of the type data which can be extracted from this recording is given in fig. 5. This shows the reflectivity characteristics of Openwood Street silt for C-band radar plotted as a function of γ return versus changes in moisture content. In order to determine whether or not these signatures are influenced by the water table at the bottom of the cart, special depth-of-penetration tests are conducted.

In these depth-of-penetration tests, the full soil sample is scanned by the various radar sets from 85 to 95 degrees and a recording made of the return signal. Four inches of the sample is then trimmed off and the sample is scanned again. This procedure is repeated until no soil remains above the water table. Due to the difference between the reflectivity characteristics of the water table and the soil above it, standing waves are produced in the soil cart if penetration is obtained. As the radar signal first strikes the surface of the soil sample, a portion of this

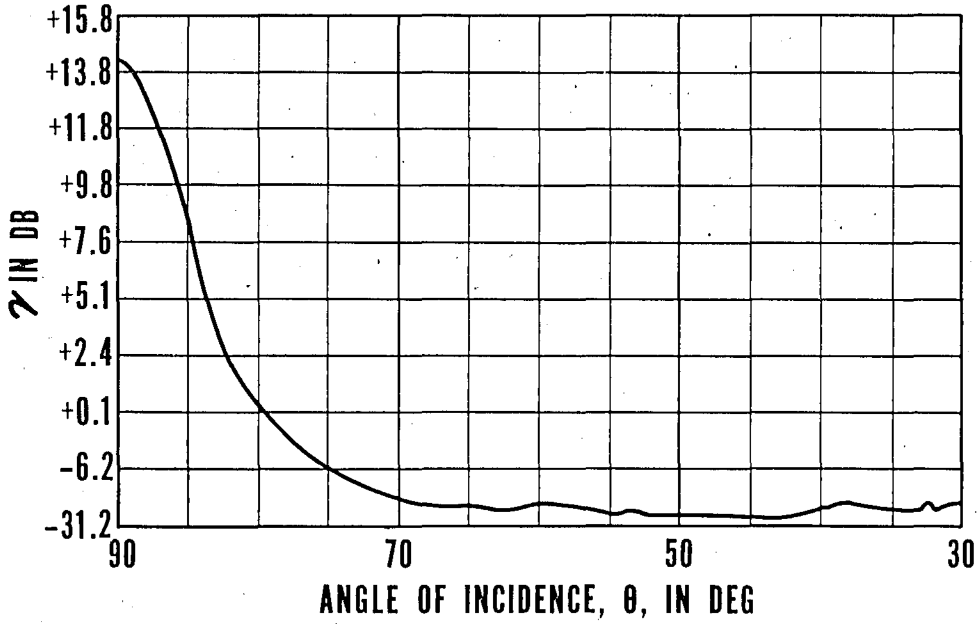

Fig. 4. Typical radar signature, Long Lake clay; frequency, X-band; moisture content, 10.1 percent

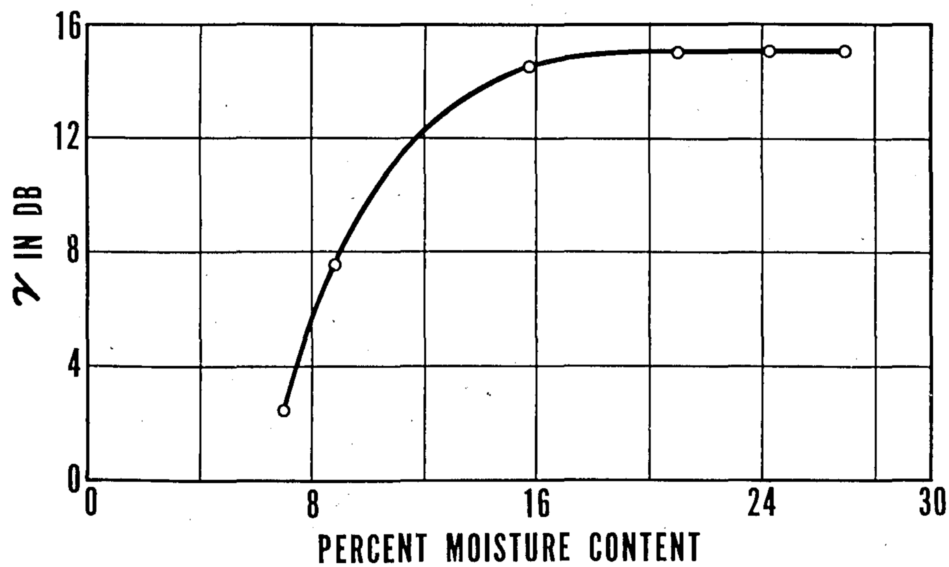

Fig. 5. Radar reflectivity characteristics, Openwood Street silt; frequency, C-band; angle, 90 degrees

signal is reflected back to the receiving antenna. The remainder of the signal penetrates into the sample and travels through to the water table. At this soil-water table interface, a large majority of the signal which has penetrated into the sample is reflected and travels back to the surface of the sample. The wavelength and speed of this standing wave varies with a change in dielectric constant which is a function of moisture content for a given soil type. As the speed of the wave and the thickness of the soil sample change, the phase relation between this standing wave and the signal reflected by the surface of the soil sample will change. This will result in alternate reinforcement and destruction of the surface reflectance. The phasor diagram given in fig. 6 illustrates this. Item 1 of the phasor diagram shows the standing wave reinforcing the surface return, while item 2 illustrates the destructive characteristics of the standing wave. This alternate reinforcement and destruction of the return signal causes a cycling effect to be produced as illustrated in fig. 7. This is a plot of the return signal from Yuma sand at vertical incidence versus changes in depth to water table for P-band.

Since our program is in the early stages, some theory has to be used to visualize how this type information can be utilized to determine if a water table exists, and if so, how far beneath the surface it is. Data from our other radar studies, however, indicate that this should be possible. As an illustration of how this might be done let us take the case of dry Yuma sand. First we have to establish reflectivity curves such as shown in fig. 5 for each radar band at varying degrees of moisture content and the depth of penetration capabilities of the respective bands. If the return is then measured from an unknown area, and Ka- and X-band returns are normal while C- and P-band have indications of standing waves, the depth to the water table can be determined by knowing the penetrations of C-band. Information from other sensors such as infrared, visible photography, and gamma-ray could be used to verify the findings of radar.

Future Plans

Tests will be continued for the next two months to better establish the feasibility of using the radar portion of the spectrum as a remote means of detecting water tables. The data from these studies will then be completed and a report written on the findings.

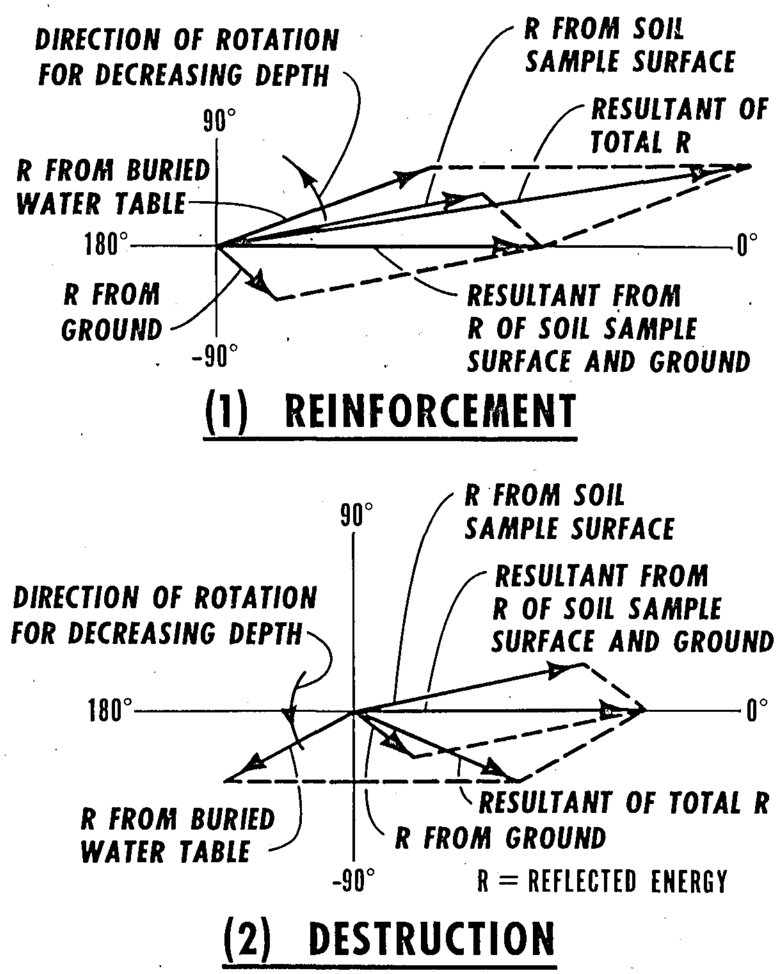

Fig. 6. Radar return phasor diagram

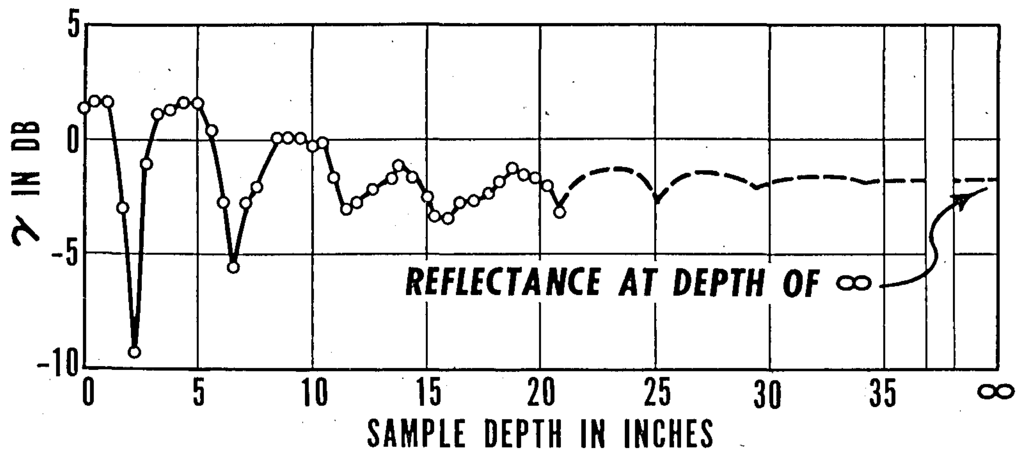

Fig. 7. Depth of penetration data. Sample No. T9, 17 January 1964 Yuma sand, 19.2 percent moisture, γ value at 90 degrees plotted, P-band horizontally polarized

DESIGN AND ACQUISITION OF INSTRUMENTS AND TEST VEHICLES

by

R. D. Wismer*

Introduction

With the implicit requirements for environmental data collection and field determination of terrain-vehicle interaction in the MERS program, the need for the most efficient measuring, recording, and reduction equipment possible is obvious. The need for procuring and modifying a large number of test vehicles is inherent if the intended vehicle tests are to consider a representative range of vehicle characteristics, which they must if the resulting relations are to be meaningful and useful. Considerable efforts have been expended toward the accomplishment of this work during the past six months, and increased emphasis will be placed on this in the coming months.

Delay in obtaining test vehicles has been incurred because of the lack of sufficiently high procurement priority; however, the primary concern has been with the time required for the design and fabrication of field instrumentation systems. The requirements for these systems are so demanding in terms of sensitivity, reliability, and speed of operation that sophisticated electronic systems result; and in certain cases, state-of-the-art knowledge is insufficient to produce key elements of the required systems. The question then becomes whether there is sufficient time and money to develop these systems under Project MERS. A "for instance" of this problem will be discussed later in this paper.

Numerous individual measuring and recording instruments, both hand and electrically operated, have been obtained for MERS test activities. Some of these instruments have been retained for testing in CONUS; others have been shipped to Thailand for test activities there. In addition to individual instruments, several small, multicomponent instrument systems have been designed and fabricated primarily for use in the one-pass soil trafficability tests.

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The remainder of this paper will be concerned with the procurement and major modification of test vehicles and with the design and fabrication of two relatively large instrumentation systems, namely, an instrument-load vehicle system to be used in the conduct of field drawbar pull-slip tests, and a cross-country vehicle test instrumentation system.

Procurement and Modification of Test Vehicles

Vehicles

A rather large assemblage of vehicles has been mobilized for MERS vehicle test operations. A wide variety of vehicle characteristics is represented by the present assemblage of vehicles, and additional range will be obtained by the temporary acquisition of special vehicle concepts including articulated wheeled vehicles and screw-propulsion vehicles, as well as extremely heavy and extremely light conventional vehicles. Representative vehicles included in this program are:

a. M151 (jeep), 1/4-ton, 4x4, wheeled vehicle
b. M37 (weapons carrier), 3/4-ton, 4x4, wheeled vehicle
c. M35A1 (cargo truck), 2-1/2-ton, 6x6, wheeled vehicle
d. M29C (weasel), 1/4-ton, tracked vehicle
e. D4 (engineer tractor), tracked vehicle
f. Polecat (arctic personnel carrier), 1-ton, articulated, tracked vehicle

Modification of test vehicles

Of the above list of vehicles, all but the M151 and D4 have been or will be instrumented for the measurement of drive torques.

The major modification of test vehicles to date has been confined to the M151 and M37. These vehicles were modified to accommodate large-diameter, high-flotation tires as shown in figs. 1 and 2. A comparison of the tire geometry and test inflation pressures of the standard- and high-flotation tires for each vehicle is summarized in table 1. It is readily apparent from this table that the diameter and width of the high-flotation tires are from 18 to 192 percent greater than the respective dimensions of the standard tires. In addition, the test inflation pressures and tire ply rating of the high-flotation tires are approximately half those of the

Fig. 1. M151, 1/4-ton utility truck modified for 36x20-14R
high-flotation tires

Fig. 2. M37, 3/4-ton cargo truck modified for 46x18-16R
high-flotation tires

Table 1

Comparison of Tire Geometry and Test Inflation Pressures

Standard and High-Flotation Tires

M151 and M37

Item	M151 Standard Tire 7.00x16	M151 High-Flotation Tire 36x20-14R	M37 Standard Tire 9.00x16	M37 High-Flotation Tire 46x18-16R
Tire diameter, in.	30.5	36.0	35.0	46.0
Tire width, in.	7.2	20.0	9.6	18.0
Rim diameter, in.	16.0	14.0	16.0	16.0
Ply rating	6	4	8	4
Test inflation pressures, psi	8.5, 30.0	3.0, 15.0	6.5, 30.0	3.0, 15.0

standard tires. All these factors add to increase traction development and obstacle-negotiation ability of the vehicle. The increased traction development and motion resistance for certain soil conditions also increase the power requirements of the vehicle which can become a serious limitation on vehicle mobility. In any event, the addition of varying tire geometry and contact pressures to the test program using two basic vehicle configurations is the first step, however crude, in quantifying the effect of vehicle characteristics on vehicle performance.

Instrument-Load Vehicle

Because of the program emphasis on drawbar pull-slip tests for a wide range of vehicles on very soft soil conditions, a special instrument-load vehicle system has been designed by WES. This system is designed to furnish a load or drawbar pull reaction at several vehicle slip levels to test vehicles ranging in gross vehicle weight from 500 to 13,000 lb. These vehicles will be tested in soil conditions exhibiting a rating cone index as low as 7. The system consists of an articulated, tracked vehicle equipped with electronic data-measuring and recording equipment and an automatically controlled vehicle restraining system.

Basic vehicle

The basic vehicle used in the system is a polecat, 1-1/2-ton, articulated, tracked (fig. 3), manufactured by Ambulitter Corporation of Chestertown, Md. The vehicle consists of two units joined by an articulation joint. The front unit houses the engine, vehicle controls, and driver. An instrumentation center is located in the rear portion of the front unit. The rear unit has a deck area of 55-1/2 sq ft upon which the automatically controlled vehicle restraining system will be assembled.

The vehicle possesses good soft-soil performance because its 13,000-lb gross weight is distributed at a nominal unit ground pressure of 2.1 psi. The vehicle also exhibits good maneuverability by means of its articulated design which includes hydraulically operated steering pistons at the articulation joint. Good soft-soil performance and maneuverability are essential characteristics of the instrument-load vehicle because of the adverse terrain conditions in which it must be operated to test the entire range of soil strengths significant to the test vehicles.

System operation

As previously stated, the purpose of the instrument-load vehicle system is to increase the efficiency of vehicle drawbar pull-slip tests in natural soils of low consistency. To accomplish this, an electronically controlled mechanical system for restraining test vehicles at varying levels of vehicle slip will be installed on the rear unit of the instrument-load vehicle, as shown in fig. 4.

The system operates as follows:

a. The test vehicle is connected to the cable of the mechanical restraining system.

b. The test vehicle proceeds down the test lane at a prescribed engine speed which produces a wheel or track speed of approximately 2 mph.

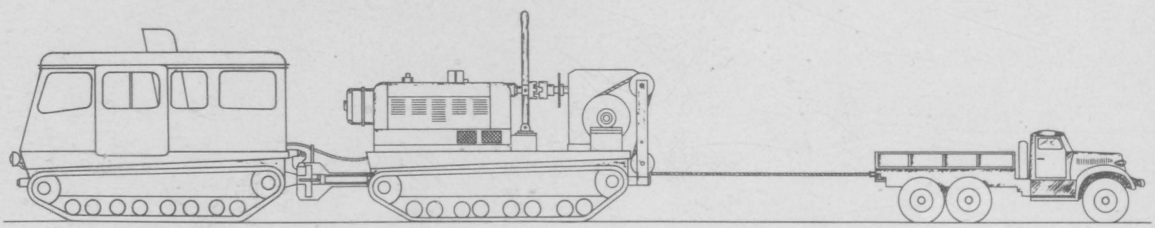
c. The cable is payed out at speeds of 2 mph until a steady-state condition is attained.

d. The speed of cable pay-out is then reduced by a programmed amount while the engine speed, and thus the wheel or track speed, of the test vehicle is held constant. This causes the slip of the vehicle to increase to a higher value. This condition is maintained for at least two vehicle lengths.

e. This procedure is repeated several times in a continuous, programmed manner with each reduction in the speed of cable pay-out causing the vehicle to increase its slippage to a higher level.

During this procedure, all the pertinent variables such as cable speed and

Fig. 3. Articulated, tracked vehicle (polecat) for use as MERS instrument-load vehicle



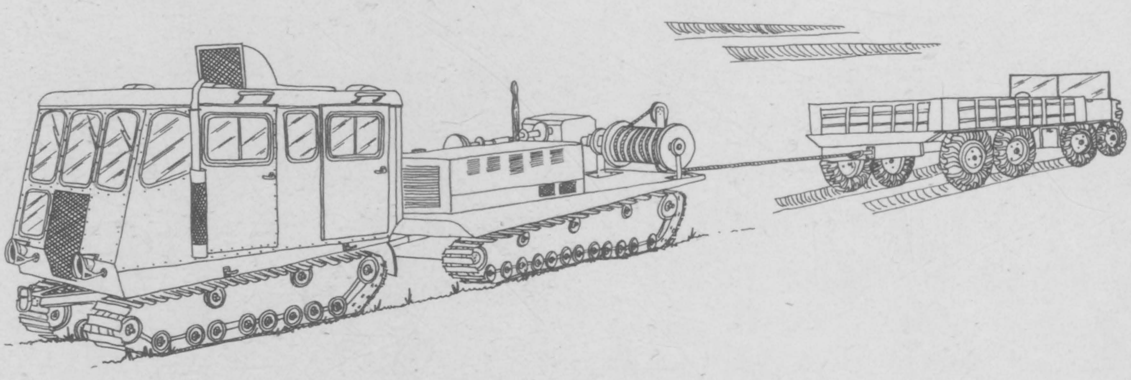


Fig. 4. Operation of instrument-load vehicle

tension, and test vehicle wheel or track speed are recorded in the instrumentation center of the instrument-load vehicle.

The mechanics of the system and the resulting drawbar pull-slip data are presented in fig. 5. The top plot of fig. 5 shows the different speed levels of the cable in comparison to the constant wheel or track speed of the test vehicle. As shown in the bottom plot of fig. 5, the slip condition of the vehicle is calculated using the cable and wheel or track speed according to the equation presented, and plotted as shown. The drawbar pull of the vehicle is recorded by the tension in the cable shown in the middle plot of fig. 5, and is plotted as shown on the drawbar pull-slip curve.

Thus, using this system, accurate, carefully controlled drawbar pull-slip curves of test vehicles of varying size can be obtained in a single vehicle pass of approximately 200 ft in length.

Cross-Country Vehicle Test Instrumentation

As discussed in an earlier paper, terrain-vehicle relations will be developed on at least two distinct levels, the first level being a consideration of single environmental situations, the second level being a consideration of multiple environmental situations. Once the multiple environmental situation is mastered, vehicle testing will be concentrated on proof-testing the developed relations and quantifying terrain class edge effects. This will be accomplished by what has been termed a cross-country mobility test. The essence of this test is: (a) to traverse the environment between the two points along a generally preselected route, (b) to continuously monitor the vehicle's performance, and (c) to compare measured performance with predicted performance. The problem to be discussed at this time is the manner and means of monitoring the vehicle's performance. The vehicle performance parameters to be monitored are:

a. Position or location

b. Dynamic response

c. Drive torque and engine speed

d. Fuel consumption

e. Speed

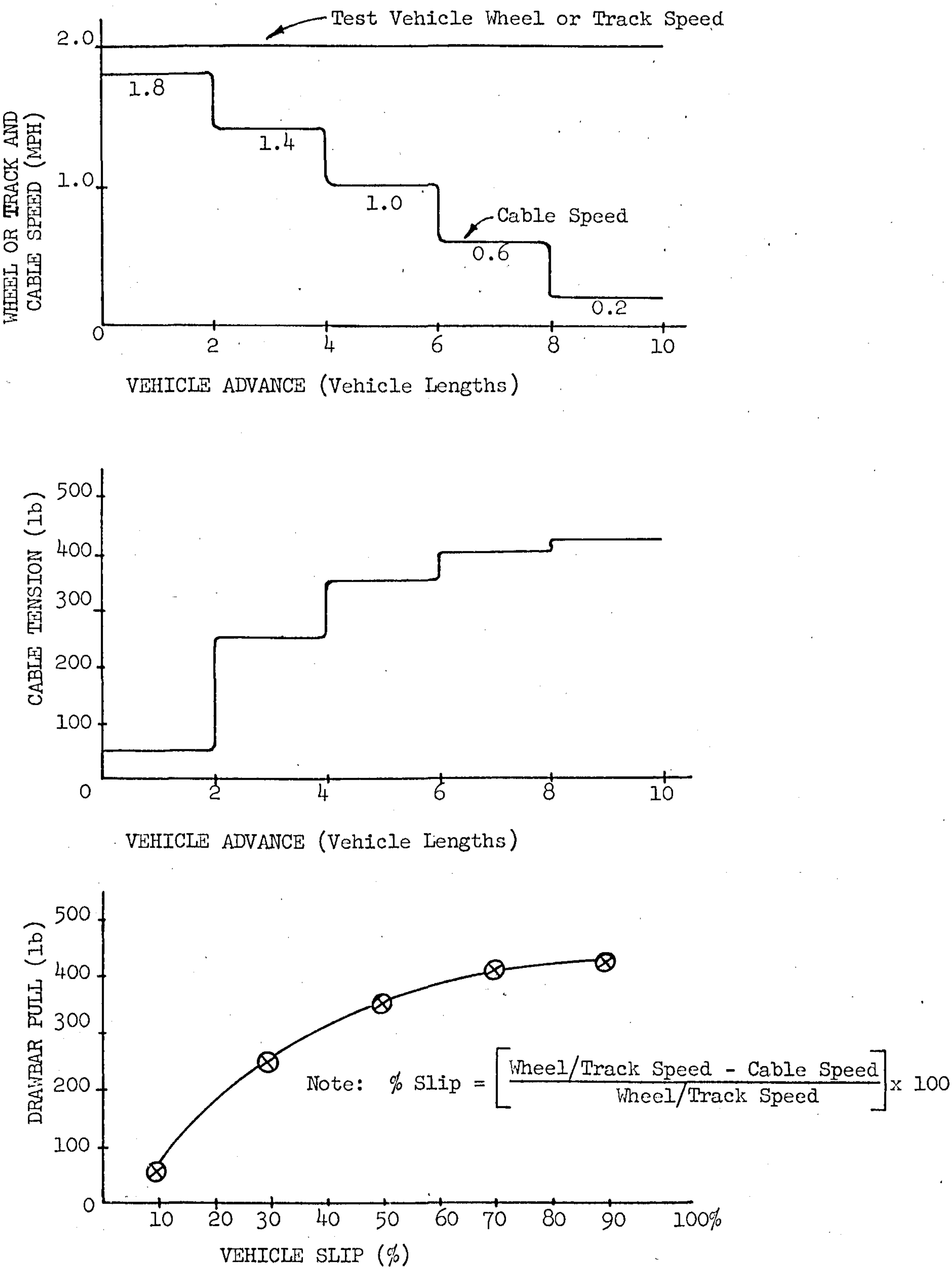


Fig. 5. Mechanics of instrument-load vehicle system for developing drawbar pull-slip curve

The last four items can be handled very nicely with existing instrumentation systems. The first item, that of vehicle position or location in the physical environment, is another matter.

The establishment of vehicle position in the environment to a high order of accuracy is essential to the comparison of measured and predicted vehicle performance. For, if vehicle performance is predicted on the basis of a set of environmental factors which the vehicle never encounters, the comparison of measured and predicted performance is hopelessly muddled; however, if the position of the vehicle in the test environment is known at all times, the measured-predicted performance comparison can always be made, no matter how far the vehicle wanders from the preselected route.

Masked on top of this problem is the required length of the test course which prohibits the use of physical markers, unless no other means exist. Thus, the test requires a sophisticated instrumentation system.

Two instrumentation systems have been suggested as possible solutions to the problem, one employing a tellurometer, and the other a radio-direction finder. Given sufficient time, funds, and logistic capability in the field, either one could be made operable. The unanswered question is which of these systems or, in fact, what system can be made operable within the MERS limitations on these three items?

DISCUSSION

Prof. Woods inquired if WES was going to use color aerial photography and if WES had solicited the help of CRREL. An affirmative reply was given to both questions. Prof. Woods emphasized the importance of using aerial photos for interpreting soil properties, explaining that the Bureau of Public Roads and Soil Conservation Service are mapping soil properties in Indiana and Illinois from aerial photos. A question was raised as to why WES was going to have additional photography flown in Thailand, and it was explained by Mr. Rula that the available photography (1:40,000 and 1:20,000) was not adequate. It was mentioned that MERS will obtain panchromatic, infrared, and color photography for the seven primary study areas at a scale of 1:15,000, using a 6-in. focal length lens. Some 1:5000-scale strip photography will also be obtained. It was further recognized that high-quality photographs acquired according to the above specifications would expedite the application of airphoto techniques in determining terrain information.

Mr. Liston questioned the statement in Mr. Wismer's paper about the importance of knowing the exact location of the test vehicle at all times. It was explained to Mr. Liston that it is imperative to know the location to be able to determine which terrain factors actually contributed a significant effect on the vehicle's performance. To know that a critical condition does exist is meaningless if the vehicle does not encounter it; if the critical condition was avoided purposely, this is another matter, but it most certainly should be known. Also, an adequate navigation system would ensure that on long test courses the test vehicle would be traveling on the intended test course.

CLASSIFICATION OF TERRAIN TYPES OF SOUTHEAST ASIA

by

W. E. Grabau*

The task of classifying the terrain types of Southeast Asia in such a way that the distinctions will be meaningful to mobility analysts is of major importance. The reasons for this are several. However, before plunging off into the depths, some definitions are in order. In order to classify, we must first have some definable units of classification, and some rules for the way in which the units are put together to form larger units.

In this context, the basic element is what we call an "environmental factor." For example, topographic slope is an environmental factor. So is stem spacing of plants. So is the shear strength of soil. That is, an environmental factor is a definable and measurable attribute of nature.

The environmental factors can then be subdivided into classes, the limits of which are chosen because they appear to be significant for one reason or another. For example, the range of slopes between 4.3 and 8.5 degrees is a "factor class." The range of stem spacing between 1 and 2 meters is also a factor class, and so on.

An area throughout which the same array of factor classes is exhibited is called an "environmental facet," or just "facet" for short. For example, all areas, contiguous or not, which exhibit the same slope class, stem spacing, stem size class, same soil strength class, and so on through the entire gamut of significant factors, constitute a single "facet." The facet is the basic building block, because, since all factor classes are similar (i.e. exhibit values within an acceptable range of variance), it can with reasonable safety be presumed that the effect on vehicle performance will be the same throughout.

The next step in the hierarchy is the "landform component." A landform component is an area composed of an array of facets which are always arranged in the same way with respect to each other. For example, let us

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consider the general class of things called rice fields. In the middle of Bangkok Plain, for example, the slopes are nearly zero; the surface geometry expression consists almost exclusively of very low, symmetrical dikes, the soils are quite firm, the fields contain no trees or termite mounds, and so on. This combination of factor classes arranged in a particular way results in a specific array of facets which, together, combine into a definitive landform component. However, this particular landform component does not, by any means, represent all rice fields. For example, at the edge of the Bangkok Plain the slopes are still zero, but the dikes are higher and they are asymmetrical because the fields are slightly terraced, the soils are softer when wet (and harder when dry), and there are trees and termite mounds in the fields (Sara Buri). Thus, the rice fields on the edge of the Bangkok Plain constitute a different "landform component" than the rice fields in the middle of the plain.

The next and final step up the hierarchy is the assemblage of landform components into "landscape types." A landscape type is an area throughout which a specific array of similar landform components is present, and in which those components are arranged into similar geometric positions with respect to each other. For example, the Bangkok Plain northeast of Bangkok consists of limitless rice fields separated by numerous shallow canals, and a very few natural stream channels. Farther to the north, the canals become very few and far between, but the stream channels become more numerous. The same landform components are obviously present, but their relation to each other is different, and this means that there are two landscape types. The justification for this is simply that the two areas would impose somewhat different effects on cross-country mobility.

Classification of an area like Southeast Asia in such terms as these is relatively easy, once the techniques for describing and mapping the individual factors in entirely quantitative terms is at hand. The process is time-consuming but relatively straightforward. The problem is to describe the different environments in suitable terms. Those terms, of course, must be quantitative for reasons which Mr. Wismer, in his talk on the development of terrain-vehicle relations, made abundantly clear. At this point we are badly handicapped by a lack of detailed knowledge of the kinds of things that affect vehicle mobility. However, we are not entirely helpless, since we do have a small body of information derived from actual testing, leavened with a good deal of office analysis and imagination. And, of course, we do have a very large body of information on the effects of one factor family, namely soil characteristics.

In general, these factors, factor family by factor family, are as follows:

Surface Materials

1. Soil mass strength (measured as cone index, remolding index, and/or bevameter values)
2. Soil surface strength, or "slipperiness" (possibly measured by a sheargraph)

Surface Geometry

1. Slope (measured as an angle from the horizontal)
2. Periodicity (a measure of the number of times per unit distance that slopes change by a specific amount)
3. "Roughness" of microgeometry (a complex set of values describing the properties of small features of the surface. The following list of terms is derived from the Stone-Dugundji system, but it is quite possible that this system will be unsuitable for mobility purposes. An alternative and quite possibly superior system is one being developed by Bogdanoff and Kozin for the Land Locomotion Laboratory)
    - a. Range of prominent heights
    - b. Height of tallest feature
    - c. Range of slopes of prominent features
    - d. Repetitiveness of features
    - e. Overall irregularity of features: the "avoidance value"
    - f. Cell length: the distance required to include all "significant" features

Hydrologic Geometry

1. Water depth
2. Current velocity
3. Wave properties
    - a. Amplitude
    - b. Periodicity

(There is real doubt in our minds as to the validity of this factor family, at least insofar as vehicle mobility is concerned. Our investigations indicate that the major problem in what we might call the "hydrology-vehicle system" is that of getting into, and getting out of, the water. If the bank is too steep, the vehicle swamps, or bottoms out, or cannot get a purchase on the bank, and so on. These conditions are illustrated schematically in fig. 1. This problem is, in our estimation, sufficiently important to warrant special effort. Accordingly, Florida State University is working on methods to measure, describe, and classify what we have called "water-land interfaces," using the streams, lagoons, beaches, mud flats, and lakes along the Florida coast as their models. In addition, the MEGA project has an independent contract with Vanderbilt University; their models are streams and lakes in Kentucky and Tennessee, an utterly different environmental context.)

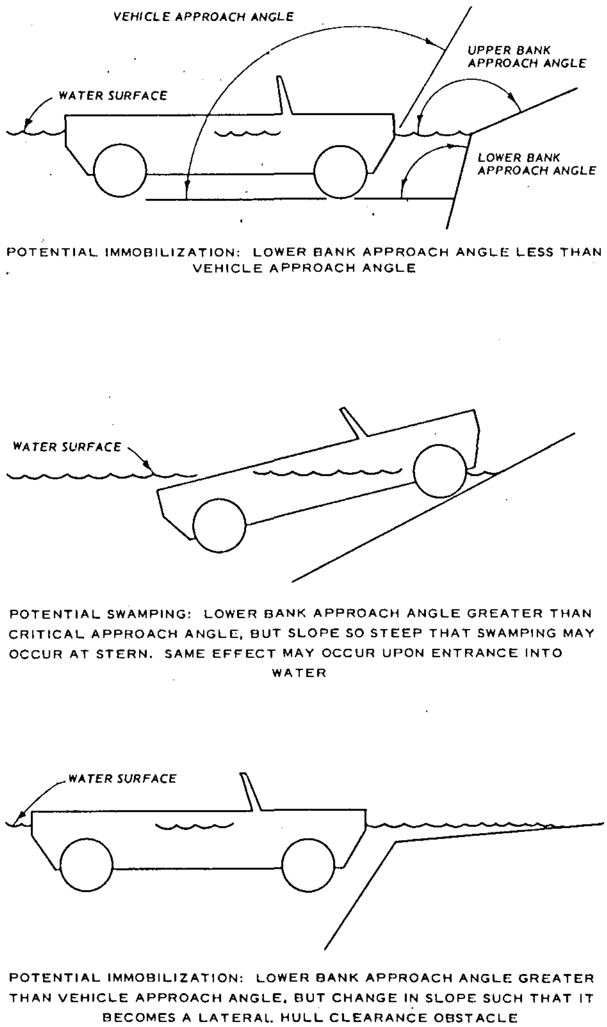

Fig. 1. Significance of bank configurations on amphibious vehicles

Vegetation

1. Stem size
2. Stem strength (a measure of resilience)
3. Stem distribution
    a. Spacing (the mean nearest-neighbor distance)
    b. Cluster tendency (a complex value relating average population density to nearest-neighbor values)
4. Attachment (a value describing the tendency of "individual" stems to be attached to other plants)
5. Effective spacing (a value describing the unobstructed space between plants)

6. Visibility
    a. Ground visibility (a measure of the height at which downward-directed vision is obstructed)
    b. Forward visibility (the mean distance forward that a standard object can be identified)

Atmospherics

1. Temperature
2. Humidity
3. Precipitation
    a. Intensity
    b. Periodicity
4. Light intensity
5. Wind velocity

We are spending a relatively large amount of effort on refining our ability to describe and classify environmental factors specifically for mobility purposes because we are convinced that such capability is one of the keys to better mobility. The chain of logic here is a bit tortuous, but it seems to lead inevitably to one conclusion.

First, let us start from the premise that it is our desire to provide the vehicle designer with knowledge concerning the conditions the vehicle will be called upon to meet. This automatically means that we need to know two kinds of things:

a. The total variance exhibited by each individual significant factor (which has been outlined), and

b. The actual combinations in which factors are found in nature. We need this, of course, because many of the factors operate synergestically to produce either greater or lesser effects than the sum of their individual effects, and because some factors which are known to be significant simply do not occur in certain combinations. As a ridiculous example, one need not be concerned with waves when the water depth is zero, and one need not worry about visibility when there is no vegetation. There are also a number of much more subtle exclusions, and there are no doubt many that we have not recognized.

Obviously, the two requirements (that is, total variance of individual factors, and the range of combinations of factors) will have been satisfied when every landform component in our area of interest has been identified. In this context, identified means classified, since it will have been identified on the basis of the complex of factor classes that it exhibits.

How do we do this? Here our procedure departs somewhat from traditional forms. Our concept depends on the assumption that every factor is actually independent of every other factor. That is, ideally, there is no redundancy in the system of description. In practice, we keep finding bugs, but so far they have been small ones. Our procedure is to map the distributions of factor classes, one map to one factor per season (because the whole aspect of the landscape may change with the seasons).

For example, let us assume that we are interested in the landscape types during the dry season. Over much of northeastern Thailand, the soil mass strength would be high, except for narrow bands representing river and canal channels, and some little blobs representing reservoirs; these are, after all, the only places where the soil will be wet, and therefore soft. The soil surface strength distribution map would be strongly similar, except that it would contain some small areas where the ground tends to be covered with little spherical laterite nodules. The slope map, of course, would show an utterly different distribution, and the boundaries between units would at least partly cut across the map unit boundaries of the two preceding maps. And so on, through the whole spectrum of factors, perhaps 30 in all.

Having the maps, we now overlay them successively, and each unique combination of factor classes becomes, by definition, an "environmental facet." Obviously the process depends heavily on detailed environmental knowledge, which is one reason why we have concentrated so much attention on data collection, airphoto interpretation, noncontact sensing, and so on.

Once having all the facets classified, we are now in a position to do a whole host of things with reasonable intelligence. First, we find that the landform component is a more convenient unit to work with and, since no detail is lost in the process of classifying in such terms, we will map in terms of such components. Having this, we are now in a position to do the following things.

a. We can select test areas with confidence. We will know where all areas of any one landform component are located, which means that we can select the most convenient location for test purposes.

b. We will be able to tell how many tests will be necessary to be reasonably certain that we have tested all significant environmental complexes. In this context, it is of interest to note that tests almost surely need not be conducted in each different landform component. Some of these--probably many of them--will be arranged in graded sequences. In such situations, two or three tests to establish the performance gradients will be adequate; all the intervening landform components making up the continuum can be ignored.

c. We will be able to define within narrow limits the area of applicability of a given test. This is possible because we will presumably be able to tell where all areas of similar landform components are located. Thus, extrapolation will be relatively easy and reliable.

d. We will be quite sure that we will actually have examined all significant combinations of factors, because it will be a simple task of tabulation to see what combinations actually occur, and locate where they are. If we lack a ground sample in an area that looks different (remember that much of our basic determinations will come from photo interpretation), it will be a simple matter to visit it on the ground and check its characteristics.

e. Finally, once the test sequences are completed, so that we can correlate performance with landform component, we will be able to define the relative advantages of different routes across country. We regard this matter as so important--it is, after all, the final product of any so-called "total mobility expression"--that it is worthy of a modest discussion here. Let us begin with what will sound like a digression.

Most discussions on the evaluation of terrain for mobility purposes tend to describe the presence of inhibiting characteristics in terms of the areal coverage (that is, the extent) in the area of interest. For example, one finds such statements as "Slopes in excess of 40 percent cover 80 percent of the area." The clear implication is that the area so described is very difficult if not impossible to move through. This is, however, not necessarily true; it is quite possible to arrange steep slopes in such a way (Puerto Rico) that they can be readily avoided. If this is the actual situation, such statements give a dangerously faulty impression. The element which has been overlooked is the distribution of the slopes, and it is, we think, apparent that mobility depends heavily on the obvious fact that distributions differ.

This returns us to the mobility analyst, who must select routes across country. If he is to do this intelligently, he must know how inhibiting conditions are distributed, so that he can select the best route. That is, he operates by intelligent choice; his procedure is rational, and is not at all dependent upon probability functions. His problem is to take advantage of the (usually) relatively small percentage of best terrain in any given landscape type. Thus, in any given landscape, logistical vehicles, and even to some extent tactical vehicles, must face the worst conditions on the best routes, and not some idealized, generalized, or hypothetical average condition. Which is why we are paying so much attention to where things are, in addition to what things are.

STATE-OF-THE-ART OF OFF-ROAD VEHICLE DESIGN

by

C. J. Nuttall, Jr.*

Object

The broad object of this study is to determine just how off-road performance is currently "designed into" new vehicles, so that the final results of the MERS studies may be cast in a form which will prove truly useful in designing the more mobile vehicles required in the future. To this end, more detailed goals have been set up as follows:

- a. to outline the manner in which off-road performance requirements are currently developed and defined;
- b. to outline present procedures and methods used in designing vehicles to meet these requirements;
- c. to illustrate the types of compromises which become necessary in practical design, and generally how they are reached;
- d. to delineate the technical and philosophical problems faced by the vehicle designer in using current terrain data and vehicle-terrain relations in the design process; and
- e. to recommend, from study of the foregoing, means for presenting off-road performance requirements, terrain data, and vehicle-terrain relations which will make these more useful than at present to the vehicle designer and to ground mobility analysts.

Discussion

The design of ground-crawling motor vehicles for operation on off-road is a complex process which involves mechanical, structural, materials, legal, and economic considerations, as well as vehicle-terrain relations. The latter are themselves both highly complex and highly variable. Vehicles are often immobilized by conditions whose immediate areal extent is only of the order of the vehicle planform. The mode of such failure can vary widely. In addition, off-road terrains abound in conditions which need not immobilize a vehicle but which severely restrict its average operational speed.

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The general types of problems with which an off-road vehicle must cope are well known and even reasonably well understood in broad, qualitative terms. The general directions in which vehicle characteristics should move in order to improve off-road performance are also known--lower nominal ground loadings, better load distribution, lower tare weights, softer suspensions with greater depth, articulation, increased angles of approach and departure, increased ground clearances, and increased power:weight ratios, to name a few. Unfortunately, as in most engineering problems, improvements in these characteristics (particularly changes large enough to show a clear performance advantage in the finished machine) can only be made at the expense of other characteristics, such as load-carrying capacity and/or volume, shipping dimensions, ruggedness, first cost, etc.

The vehicles in the field today, whether military or commercial, represent compromises, optimizations of the total design problem based upon the judgment of their designers. These optimizations prove to be more or less reasonable depending both on the skill of the designer and on the terrains in which they are evaluated. Most are unconsciously biased towards the maximization of relatively simple, tangible features, such as deck height, cargo area, and first cost, at the expense of the relatively intangible performance of the vehicle off-road, despite the fact that the latter is the very reason for the existence of the machine. In a few notable cases of specialized commercial vehicles intended for specific jobs in especially difficult terrain (where failure would be entirely too obvious) the bias has tended in the other direction. As a result, these vehicles have not necessarily been suitable for the more generalized situations facing the military.

The objectives of most military vehicle design are usually relatively diffuse. Attention must be given to everything from the proper stowage of OVM on up to the vehicle's mobility. In the face of such a wide range of detailed requirements the design scales have rarely tipped in favor of a truly high level of mobility. There is every reason to expect that better quantification of vehicle-terrain relations and of the probable occurrence (on a proper regional basis) of critical terrain configurations will, by making performance more tangible, result in more nearly optimum designs, i.e. more mobile off-road vehicles for the military.

It is essential, however, that the two types of terrain information, vehicle-terrain relations and the occurrence of significant terrain features, be developed in the form and to the extent which will prove most acceptable and directly useful to the designer, particularly if the research results are to be reflected in improved designs within a relatively short time. To insure this, those charged with the terrain research should be made cognizant of the total design problem. This understanding must begin with the current procedures by which military vehicle performance requirements are recognized, developed, and eventually reduced to specific vehicle requirements. It must include a general understanding of present design and development procedures, methods now used to reach controlling design decisions, and the final gauntlet which must be run by developed designs before they enter the military system. Finally, the terrain researcher should be aware of the broad limitations (and their intrinsic stringency) imposed by factors other than terrain-vehicle interactions.

Approach

The investigation is currently proceeding along four main lines. First, a number of "case histories" of off-road vehicle developments are being studied. These include military and commercial vehicles, old and new, good and not-so-good. Their histories are being traced from the gleam of a requirement to their appearance, too often disappointing, as hardware in the field. As part of this line of approach, the official military development route is being traced, along with some of the unsanctioned byways.

Second, interviews are being conducted with the engineers and designers, in industry and in government, who direct and accomplish the actual design work, from concepting to production detailing.

Third, the current status of research on terrain analysis and vehicle-terrain interaction is being critically reviewed. In particular, the extent that available results have been made available to the designers in workable, useful form is being examined.

Finally, an attempt is being made to formulate, in gross generalized terms, the mechanical, structural, materials, legal, and economic limitations which, with the known mechanics of vehicle-terrain interaction, form the envelope within which the design of ground-crawling motor vehicles must currently be conceived.

It is expected that information developed in these parallel efforts will, when carefully "married" and interpreted, lead to objective conclusions as to the substance and form of terrain inputs which will be of most use in the future.

Progress to Date

This project is now entering its fifth month. Study has begun of the development cycle of a number of vehicles, going back to World War II and including also some which are still not ready to buck the system. Certain tendencies are already apparent with regard to military vehicle development. For instance, although, through the years, improved mobility has regularly been a major excuse for new design and development effort, the initial emphasis is usually lost in the shuffle long before a final item appears at the other end of the pipe. It is suggestive that the period of gestation for vehicles developed through normal channels (currently about six years) can be expected to span two or three rotations in the military commands and staffs at the requesting agency, the development agency, and the user boards. It is even likely to bridge a change in national administration.

A second "for instance" is that while there have been a number of relatively more mobile vehicles proposed and even developed, they have invariably run into the problems of the "cost" of the improvement, whether in terms of dollars, reductions in pay load, departures from commercial automotive practice, or whatever. In almost every case, the cost has been judged too great for the gain.

Interviews conducted to date indicate that the current state of knowledge in vehicle-soil relations, for example, is not generally consulted--or when consulted, is not found particularly illuminating. The feeling is generally that the results are already known qualitatively, and that the present quantifications are suspect and/or of little use in the final analysis. At the same time, it is clear that the military design procedure is moving, however slowly, towards a parametric design approach similar to that which has successfully guided aircraft development for the past twenty years or more.

The parametric approach, of course, is not entirely new. Any designer, whether he recognizes it or not, performs a parametric analysis in his head (or his bones, if you will) whenever he creates a new machine. The success of his creation, more often than not, depends on how well he has performed this analysis, on how thoroughgoing his selection of important parameters has been, how good his reference data, how correct his cause/effect relations, and how sound his judgment of competing values. A good designer, in a complex and uncomputerized field, can achieve remarkable results; a poor one, atrocious ones. The one certainty is that a committee of designers can only achieve committee results. A good, formal, computerized parametric approach, however, can make a committee smell like a genius.

There is one vast blank in any parametric approach to off-road vehicle design at the moment which cuts through the whole procedure, from the selection of important parameters to the exercise of final judgment. That is in the quantification of off-road performance, and of the valuation of that performance.

This is despite some twenty years of modest but surprisingly continuous research on "vehicle mobility." This research has been largely oriented until quite recently towards improving vehicle performance in weak terrains--muds, sands, snows, marshes, and wet soils generally. The results of this work have been sound, but unspectacular. In general, they have shown, over and over again, that significant gains in mobility can only be made by making major changes in the form and concept of the vehicle. They cannot be made through minor variations within the wheel wells inherited from passenger cars. They cannot be made "for free." Unfortunately, what constitutes a reasonable "cost" for a given mobility gain--and how to equate paper gains with operational advantages (which may be the same thing)--has been outside the scope of the technical considerations. Suffice to repeat that, to date, the amounts the Army has been willing to pay for improved off-road performance have been uniformly penurious.

Studies of limits on design imposed by factors other than terrain considerations--strength of materials, power-weight ratios of "state-of-the-art" power plants, etc., and dollar costs--have not produced any startling results as yet. They have served, however, to emphasize in still another way that off-road vehicle design is essentially a normal mechanical engineering problem, surrounded by a number of (thus far) immutable physical and economic laws, and dampened by a great viscous reservoir of trial-and-error experience.

PLANS FOR THE NEXT 12 MONTHS

by

A. A. Rula*

Introduction

All of the major activities of Project MERS have been placed into seven general categories. These are: (a) remote area requirements, (b) classification systems, (c) measurements, (d) field tests, (e) data collection and environmental analysis, (f) vehicle design and analysis, and (g) miscellaneous. My comments on plans for the next 12 months will be restricted to these seven general areas, followed by an estimate of funds required for Fiscal Year 1965 to meet the schedule of programmed activities.

Plans

The plans scheduled for MERS during the next 12 months for each of the seven general categories are as follows:

Remote area requirements

The plans for this activity include the execution of a small contract for completing the literature search and contacting tactical commanders in the field to determine remote area requirements for cross-country mobility missions.

Classification systems

The manual of instructions for collecting environmental data will be published and distributed. Modifications to the manual will be made as a need arises.

We have reached a practical limit on exploiting existing data; therefore, a small amount of effort will be devoted to this task during the next 12 months or until MERS field data become available.

Work initiated on compiling data collected by WES on tropical soils and other environmental factor data for other studies will be completed.

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As additional soil data are collected, they will be cataloged and data analysis will be performed as necessary. This study will also be coupled with the tropical soil analogy study. Visits will be made to areas in the Caribbean to collect soil and other environmental factor data to fill in the gaps of terrain conditions that occur in Southeast Asia for which data have not been collected to date.

Most of the laboratory work on the comparative soil study, including several Thailand soils, will be completed. A draft report will be partially completed.

Weather data collection in Thailand at seven sites will be initiated.

The soil-moisture study will be begun, and we should have about eight months continuous data records collected by the end of the next 12-month period.

The plan for coordinating environmental data-collection phases of ARPA-sponsored projects in Southeast Asia will be implemented once it is approved by ARPA.

Measurements

The first-order aerial photo study of the seven primary study areas will be completed and moved to Thailand to refine boundary conditions.

The airborne profilometer will be considered, and decision will be made as to its future application in the MERS program.

The radar-feasibility study will be completed and reported on. Future work with radar will be dependent upon the results of the feasibility study.

The procurement and development of instruments suitable for measuring vehicle performance parameters will be completed; the instruments will be tested; and a duplicate set will be fabricated for Thailand. The present contract for providing MRDC engineering services will be renewed.

Field tests

The activities on the development of one-pass vehicle performance relations will be continued with somewhat greater emphasis. The present United States study on fine-grained soils will be completed, and this work will be extended to include tests on soils that have a low or no plasticity. When wet, these soils liquefy under vehicular load; therefore, they deserve special attention. Furthermore, much of the

Khorat Plateau in Thailand is covered with such surface material.

Plans for the obstacle study will be completed in the next few months, and the study will be implemented as soon as possible. Single vehicle-obstacle testing will be initiated first, to be followed later by size-spacing factor testing. Most of the testing will be done in the United States, with some scheduled in Thailand.

The contract on ride dynamics will be completed, and the results of the contract will be used to judge additional activities that should be pursued in this general area.

The rice field studies will be expanded to include visits to accessible Southeast Asia countries to collect data. A classification of rice fields will be initiated.

Specific sites within the seven primary test areas and possibly the secondary study areas will be delineated for vehicle testing, assuming, of course, that a right-of-entry has been obtained. Test procedures for conducting mobility tests will be completed and field-tested. Single vehicle-terrain factor testing will be initiated first, to be followed later by multiple-terrain factor testing. As soon as pertinent relations are established, they will be incorporated in the ground-mobility expression. It is hoped to engage a contractor on the development of a parametric-type analysis which will include all the terrain and vehicle elements that must be considered in a comprehensive ground-mobility expression.

Data collection and environmental analysis

The tasks that fall in this general category will be given a great deal of attention in the next 12 months since the final results of the MERS program are dependent on the data that will be collected. The literature search will be completed and exploited for its maximum utility. A report will be prepared which will include an abstract of items examined and an appropriate evaluation of their utility. Airphoto coverage will be obtained for the Thailand study areas using several film/filter combinations. A rather substantial contract will be negotiated to collect data in Thailand, improve data acquisition and interpretation techniques, and develop systems for portraying environmental data. Temporary duty (TDY) groups will also be sent to Thailand to assist in the data-collection program as required. The work on analogy studies will continue, and improvements will be made as soon as data become available.

Vehicle design and analysis

The present contract on vehicle-design methodology will be completed and, upon evaluation of the findings, appropriate studies will be established and implemented. Early next year an analysis of all information on methods used in the design of vehicles will be performed. Where possible, improvement will be made and procedures formalized.

Procurement and modification of test vehicles to be used in the United States and Thailand test programs will be continued as required.

Miscellaneous

During the next year, a significant portion of WES effort will be devoted to selecting and training contractors in data collection, reduction, and analysis procedures. Manuals of instruction will be published and used in the training programs.

Several reports are scheduled for completion during the next 12 months. Upon publication, they will be given wide distribution.

Funds Required for FY 1965

The funds required for FY 1965 to conduct the work schedule outlined are summarized in table 1. The funds scheduled for each programmed MERS task are separated on the basis of WES, other Government agencies, and contract requirements. The last column on the right gives the total funds programmed for each task. The individual totals are given at the end of the table. It can be seen that the total funds required are $2,483,500; however, an excess of $301,000 from FY 1964 leaves a balance of $2,182,500 required for FY 1965.

Summary

In summary, I would like to say that it has been rather obvious that much of our time in the last 12 months has been spent in laying the groundwork and developing work plans that we at least feel are sound. It is equally obvious that we have collected very little data and that most of

Table 1

Summary of Operation and Funding Plans

Task No.	Description	FY 1965 Costs WES	OGA*	Contract	Subtask Total	Task Total
	Remote Area Requirements					
1	Determination of remote area requirements of CCM missions	$ 5,000	$	$ 20,500	$	$ 25,500
	Classification Systems					
2	Quantitative methods of describing terrain factors					127,000
2a	Surface macrogeometry	21,000			21,000	
2b	Surface microgeometry, miscellany	5,000		70,000	75,000	
2c	Vegetation	19,000			19,000	
2d	Hydrologic geometry	12,000			12,000	
3	Classification of soils for mobility purposes	5,000	5,000			10,000
4	Climatic techniques for defining state of the ground	52,000	20,000			72,000
	Measurements					
5	Noncontact sensing and interpretation of tropical terrain	92,000	60,000			152,000
6	Design and acquisition of instrumentation					35,000
6a	Instrumentation vehicle and equipment					
6b	Measuring and recording instruments			10,000	10,000	
6c	Data manipulation and reduction in field	5,000		20,000	25,000	
7	Soil testing	20,000				20,000
--	Engineering services (MRDC-Thailand)	2,000		128,000		130,000
	Field Tests					
8	Development of vehicle performance relations					580,000
8a	Development of one-pass soil trafficability criteria	100,000	40,000	160,000	300,000	
8b	Development of obstacle capability criteria	100,000	50,000	130,000	280,000	
9	Mobility in rice fields	50,000				50,000
10	Development of mathematical model of ground mobility					355,000
10a	Selection and description of test areas	50,000	20,000		70,000	
10b	Design of mobility tests	50,000		70,000	120,000	
10c	Test of mobility in landform types	70,000		80,000	150,000	
10d	Verification of mobility predictions in terrain types	10,000			10,000	
10e	Development of expression for ground mobility	5,000			5,000	
	Data Collection and Environmental Analysis					
11	Collection and exploitation of environmental data in SE Asia					460,000
11a	Permanent party	85,000		195,000	280,000	
11b	TDY parties	80,000		100,000	180,000	
11c	Transportation (air-ground) in SE Asia					
12	Classification of terrain types in SE Asia	25,000				25,000
13	Analogs of SE Asia in U. S. and vicinity					175,000
13a	Analogs of tropical soils in U. S. and vicinity	65,000		50,000	115,000	
13b	Analogs of SE Asia terrain in U. S. and vicinity	40,000		20,000	60,000	
14	Airphotos of test and study areas in SE Asia, U. S., and Caribbean	2,000				2,000
15	Develop terrain intelligence portrayal techniques for mobility	5,000		15,000		20,000
--	Coordination of ARPA environmental data collection in SE Asia	10,000		10,000		20,000
	Vehicle Design and Analysis					
16	Vehicle design methodology		35,000			35,000
17	Procurement, transport, and modification of test vehicles	22,000		88,000		110,000
18	Establishment of design parameters for vehicle engineers	20,000				20,000
	Miscellaneous					
19	Training contractor personnel	5,000				5,000
20	Preparation and publication of reports					55,000
20a	Writing	10,000	5,000	20,000	35,000	
20b	Drafting, editing, publishing	20,000			20,000	
	Totals	$1,067,000	$230,000	$1,186,500		$2,483,500
				Less FY 1964 unobligated funds		301,000
				Total funds required for FY 1965		$2,182,500

* Other Government agencies.

our tasks are starving for data which we must obtain before we can advance much further. We have realized these shortcomings, and we hope that the next 12 months will erase this deficiency.

DISCUSSION

In reference to Mr. Rula's paper, Mr. Tedesco asked who was to do the vehicle ride dynamics study and if the work which had been done to date on power spectral density (PSD) was to be considered. Mr. Rula explained that WES had tentatively selected Chrysler Corporation to do the ride dynamics study and that the work on PSD will be reviewed as to applicability. A brief discussion on the human factor problem next ensued and was concluded by Mr. Rula's statement that MERS would not be able to go into sufficient detail to meet all of the human engineering requirements. Finally, Col. Jones mentioned that ARPA had recently contracted for some airphoto work in Thailand and that it was possible ARPA's contractor could satisfy MERS aerial photo requirements in Thailand. It was agreed that Col. Jones and Mr. Rula would discuss this matter in more detail.

CONCLUSION

The meeting was adjourned at 3:25 p.m. on 25 February to allow the committee time for preparing its report. The meeting was concluded at approximately 11:30 a.m. on 26 February with the submission by the Advisory Committee of a draft copy of its report. This report is included as Appendix A. As recommended by the Advisory Committee in its report, an ad hoc committee was appointed to look into the application of an airborne profilometer to obtain terrain profile information. The ad hoc committee held a meeting on 6 March in Washington, D. C., and the report of this committee is included as Appendix B.

APPENDIX A

Advisory Committee Report

Second Meeting
ARPA ADVISORY COMMITTEE
ON MOBILITY ENVIRONMENTAL RESEARCH

24-26 February 1964

Introduction

At the invitation of the Director of the Remote Area Conflict Office, ARPA Project AGILE, the ARPA Advisory Committee on Mobility Environmental Research held its second meeting on 24-26 February 1964 at the U. S. Army Engineer Waterways Experiment Station. At its first meeting on 7-9 November 1962, the Committee accepted a plan for MERS proposed by Col. Harold C. Brown with certain modifications which were stated in the Committee Report (see Vol. 1, Conclusions and Recommendations, Technical Paper RAC-TP-80, December 1962). This second meeting was devoted to the review of progress to date and the plan of work projected at least through the next year. Additionally and by specific request, the Committee considered results of experiments with the Marsh Screw Amphibian, and proposals for action with regard to this vehicle are included in its recommendations.

The Committee wishes to express its pleasure with the thoughtfulness in preparation for the meeting and directness of the presentations by the WES; otherwise, it would not have been possible to cover so much ground.

In general, the Committee considers progress to date satisfactory, particularly in view of obstacles imposed upon the project. The proposal for future work is accepted with the exceptions contained in the statements below. The proposal on "delta mobility," prompted by a specific request from ARPA, deserves particular attention inasmuch as this represents a significant change in direction from the Committee's previous recommendations, which were directed solely to MERS.

Delta Mobility

The Advisory Committee, in response to ARPA's request for analysis of the effectiveness of the Marsh Screw Amphibian and determination of a future expanded development program, recommends a three-part delta mobility program as follows:

1. Short range. The Committee was impressed with the ability of the Marsh Screw to operate in inundated land common to delta regions and suggests that a limited number of these vehicles be obtained at once with the aim of determining their general utility under these special conditions in Vietnam. The Committee requests that it be informed of the results.

2. Intermediate range. The Committee suggests a survey of existing vehicles which are capable of operating in soft ground and flooded terrain conditions (e.g. marshes) to determine performance characteristics and the modifications that would make the vehicles acceptable to the problem at hand. For military use, the vehicles must be amphibious and have a water-speed capability approaching 10 mph.

3. Long range. The Committee concludes that any vehicle suited to employment on soft, cohesive soils will require mechanical devices abhorrent to normal vehicle design concepts. The Marsh Screw Amphibian and the Marsh Buggy are good examples. The Committee suggests that studies be initiated at once with two objectives as follows:

   a. Analysis of environmental factors significant to the design of such a vehicle and determination of the combination of factors necessary to be met by the design.

   b. Execution of parametric designs, based upon these optimized criteria, of various concepts including but not limited to wheels, tracks, and screws, and comparison of the results by cost effectiveness.

Project MERS

The Committee reviewed Task 1, "Remote Area Requirements," and recommends that subtasks 1b, "Tactical Model and Games Study," and subtask 1c, "Terrain Application of Model Studies," be deferred because these subtasks are not timely until additional information is developed.

Funding

The Committee agrees that WES should continue to look into application of an airborne profilometer to obtain terrain profile information. An ad hoc committee will look into the details of the problem and make appropriate recommendations.

The Committee recommends that WES expedite transfer of FY 1964 MERS funds to other Government agencies for work on agreed-upon MERS tasks, and that the FY 1965 program be carefully reviewed with the aim of putting as much of the money in other Government organizations as feasible.

Environmental Tests

The Committee was impressed by the thoroughness of research on available material on environmental data of Southeast Asia and wishes to commend the author. In this respect, it recommends that greater emphasis be placed on establishing the handbook of instruction, and that the section on weather be completed as soon as possible. The voluminous collection of data for Project MERS will require a standard which the outline of this handbook might provide.

The Committee has discussed with the WES staff the plans for conducting environmental tests with vehicles in Thailand. It was reaffirmed that standard vehicles would be utilized as test instruments and that the previously determined number of two vehicles each, wheeled and tracked, could be the minimum number tested; however, it may be desired to add not over one vehicle in each class to the program. The Committee emphasizes that within the time frame of the MERS project, the majority of environmental tests utilizing vehicles are to be conducted in analogous areas in the United States (or the Caribbean) and only gross testing will be performed in Thailand.

APPENDIX B

Report of AD HOC COMMITTEE ON APPLICABILITY OF AIRBORNE PROFILOMETER

6 March 1964

Introduction

At the meeting of the ARPA Advisory Committee on Mobility Environmental Research on 24-26 February 1964 at the U. S. Army Engineer Waterways Experiment Station, the Committee recommended the formulation of an ad hoc committee to look into the application of an airborne profilometer for obtaining terrain profile information. The committee organized to look into the details of the problem and make appropriate recommendations consisted of the following members:

Lt. Col. J. L. Jones	Advanced Research Projects Agency (ARPA)
Mr. A. Tedesco	Advanced Research Projects Agency
Mr. R. F. Jackson	U. S. Army Materiel Command (AMC)
Mr. R. E. Frost	U. S. Army Cold Regions Research and Engineering Laboratory (CRREL)
Mr. R. R. Friesz	U. S. Army Engineer Waterways Experiment Station (WES)

During the open discussions at the second meeting of the Advisory Committee, it had been pointed out that ARPA (SEACORE and SEASURE) had negotiated a contract for the acquisition of ground data in Thailand by aerial sensing means and that it may be possible for that program to provide ARPA (MERS) with the required aerial photography of the seven selected primary study areas in Thailand. It was determined that the ad hoc committee should also consider ARPA's offer to provide aerial photographs, keeping in mind the time frame of Project MERS and the required photo specifications.

Consequently, a meeting was held at ARPA on 6 March 1964 to consider whether it is feasible for MERS to fund additional research on an airborne profilometer and to determine the action to be taken by MERS in obtaining aerial photography of the seven primary study areas in Thailand. In addition to the committee members, the following individuals were present:

Participants

Mr. J. W. Rinker	U. S. Army Cold Regions Research and Engineering Laboratory
Mr. B. R. Davis	U. S. Army Engineer Waterways Experiment Station
Mr. Alfred Stringham	Rome Air Development Center
Dr. G. J. Zissis	Institute of Defense Analysis

Observers

Mr. K. D. Robertson Mr. Kent T. Yoritomo	U. S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency

This report presents appropriate conclusions and recommendations as determined at this meeting and is submitted for further consideration of the Advisory Committee.

Airborne Profilometer

Several basic conclusions as to the usefulness and planned application of the airborne profilometer were resolved, as follows:

a. Aero Service Corporation. This company is willing to company-sponsor the development of the profilometer at no cost to the Government. No obligation of money will be necessary until ARPA is completely satisfied that the system is working properly. The profilometer will be ready for an airborne acceptance test by WES in July 1964.

b. ARPA. ARPA has no plans nor will authorize expenditure of ARPA (MERS) funds for developing the airborne profilometer. Because of some obvious drawbacks of the profilometer and because it is relatively unproven, the profilometer should first be field-checked in a selected test area in the United States.

c. AMC. The potential of the airborne profilometer is worth checking, and WES is the logical agency to do this.

d. WES. The primary technical specifications of the profilometer of interest to WES are the vertical and horizontal resolution capabilities. If a vertical resolution of 0.1 ft is desired, the best horizontal resolution one can obtain is 10 ft. The horizontal resolution can be improved only by sacrificing the vertical resolution. Thus, when a 3-ft horizontal resolution is used, the best vertical resolution that can be expected is 4 in. To sum up the resolution capabilities, the proposed profilometer would be the best available system of this type to date if it performs as well as predicted. It will not, however, meet the critical terrain measurements as desired by WES for Project MERS.

Based on the foregoing conclusions, the ad hoc committee recommends the following:

WES should monitor the development of the airborne profilometer. To check the accuracy of the profilometer system a test area in the United States, whose data terrain profile has already been obtained, should be used.

Aerial Photographs of Primary Study Areas in Thailand

It was concluded that: (a) the ARPA (SEACORE, SEASURE) contractor could not meet the desired aerial photo specifications desired by WES for Project MERS, nor provide the photography within the required time frame. (b) CRREL would provide ARPA with a set of the terrain factor maps of the seven primary study areas in Thailand.

The ad hoc committee recommends that WES obtain the desired aerial photography by contract with a qualified commercial organization. It may be possible for the ARPA (SEACORE, SEASURE) program to add additional flights at a later date to its program in Thailand, which would be beneficial to the ARPA (MERS) program.