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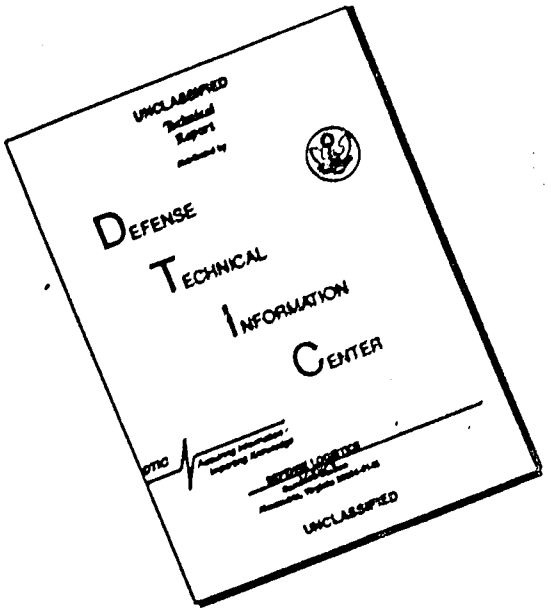
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AN EXPLORATORY STUDY OF THE EFFECTS OF TERRAIN SURFACE OBSTACLES ON VEHICLE PERFORMANCE

WILSON, NUTTALL, RAIMOND ENGINEERS, INC.,
CHESTERTOWN, MARYLAND

MARCH 1965

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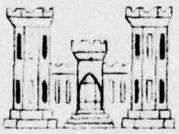
AN EXPLORATORY STUDY OF THE EFFECTS OF TERRAIN SURFACE OBSTACLES ON VEHICLE PERFORMANCE

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WILSON, NUTTALL, RAIMOND ENGINEERS, INC.
Chestertown, Md.

Prepared Under Contract No.
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ABSTRACT

Wilson, Nuttall, Raimond Engineers, Inc., Chestertown, Md., AN EXPLORATORY STUDY OF THE EFFECTS OF TERRAIN SURFACE OBSTACLES ON VEHICLE PERFORMANCE - G. T. Cohron, R. A. Werner, February 1965, 223 pp - illus - tables. (Contract No. DA-22-079-eng-394 (Neg.).

Unclassified report

This was the first major attempt to correlate terrain surface obstacles (lateral, longitudinal, and vertical) with vehicle performance. Purpose of the study was to develop and/or evaluate (1) measurement systems necessary to permit quantitative description of vehicle performance and the terrain on which vehicles are operated (2) test methodology including proper experimental design (3) methods of analysis leading to quantitative vehicle-performance relations (4) approximate limits for both "immobilization" and "no-effect" values of important parameters and (5) a study plan which will include an analytical framework within which more extensive future studies should be analyzed. Analysis of test data revealed the important terrain-vehicle relations for cross-country mobility and the proper methods of measuring and analyzing important terrain-vehicle parameters.

UNCLASSIFIED

1. Terrain-Vehicle Relations
2. Surface Obstacles
3. Testing Procedures
4. Contract DA-22-079-eng-394 (Neg.)

I. Cohron, G. T.
II. Werner, R. A.
III. Wilson, Nuttall, Raimond, Contract Report No. 113-2

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PREFACE

The research covered by this report was conducted jointly by WILSON, NUTTALL, RAIMOND Engineers, Inc., under Contract No. DA-22-079-eng-394 (Neg.), Modification No. 4, and Waterways Experiment Station, U. S. Army Engineers. This study constitutes a portion of the Mobility Environmental Research Study (MERS), sponsored by the Advanced Research Projects Agency (ARPA) of the Office, Secretary of Defense (OSD), for which the Waterways Experiment Station (WES) is the prime contractor, and the U. S. Army Materiel Command is the service agent. In particular, this study is concerned with the "Development of Obstacle Capability Criteria, Task 8(b)," as identified in the WES Operation and Funding Plan for OSD/ARPA, Mobility Environmental Research Study. The funds employed for this study were allocated to WES under ARPA Order 400 with Ammendment No. 5. Substantial assistance in personnel and equipment was provided by the Waterways Experiment Station principally through the Area Evaluation Branch, AEB, the cognizant technical agency. Direct participation was also received from the Army Mobility Research Branch and Instrumentation Branch. Participating personnel are listed in Appendix I.

The program first required development of detailed test plans and procedures to test specific hypotheses. AEB provided the single and multiple longitudinal obstacle test concepts and the work concept used in the analysis and evaluation of test data. Then test sites were selected and carefully specified tests were conducted. Data were then reduced from field records and oscillograms and analyses were made. The entire process covered a period of four months, from 1 July to 31 October 1964.

Extensive motion picture coverage was made for all test

groups and assisted in developing an understanding of the tests. Typifying sections will be cut from the movie print to demonstrate the dynamic aspects of the tests.

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SUMMARY

The terrain-vehicle study was sponsored by the Advanced Research Projects Agency through Project MERS. The MERS program has been designed to discover, define, and quantify all those factors which influence the off-road performance of military vehicles with two major goals:

1. To establish a quantitative environmental descriptive system which would permit the evaluation of world terrains in terms useful to the design of military vehicles and the prediction of cross-country mobility of existing military vehicles/or classes thereof.

2. To develop a quantitative cross-country mobility prediction system employing the environmental descriptive terms established in item 1.

Because of the complexity of the total problem, simplification was necessary to understand the problem. In this study, component parts of the problem were studied individually to develop the proper basic understanding of the more complex total problem to come later. Specifically, this investigation was designed to develop and/or evaluate the following:

1. Measurement systems necessary to permit quantitative description of vehicle performance and associated factors.

2. Test methodology including proper experimental design.

3. Methods of analysis leading to quantitative vehicle-performance relations.

4. Approximate limits for both "immobilization" and "no-effect" values of important parameters.

5. A study plan which will include an analytical framework within which more extensive future studies should be analyzed.

The study was further broken down into three, single, terrain factors (lateral, longitudinal and vertical obstacles, as defined in the Introduction). The three basic types of single terrain obstacle factor tests were conducted with two military vehicles over a wide range of terrain parameters (i.e., tree spacing, tree diameter, vertical obstacle height). The M37, 3/4 ton truck, was used in the lateral, single and multiple longitudinal, and vertical obstacle tests. The M29C Weasel, was used in the lateral and vertical obstacle tests.

Tests were conducted in Warren and Hancock Counties, Miss., (Appendix II). Principal conclusions of the study are, as follows:

Lateral Obstacle Tests

1. The maximum permissible speed of the vehicles coursing through lateral obstacle arrays was accurately defined in terms of the ratio of mean obstacle spacing and vehicle width.

2. "Immobilizing" lateral obstacle spacing was specified in terms of vehicle width, but the "no-effect" spacing could not be defined simply.

Single Longitudinal Obstacle Tests

1. Maximum override force and override work could be approximated

in terms of diameters of Pine and Oak trees pushed over in these tests.

2. The maximum tree size which was pushed over could be estimated in terms of the available tractive effort.

Multiple Longitudinal Obstacle Tests

1. The resistance to overriding multiple stems is greater than the sum of the overriding resistance of individual stems.

Vertical Obstacle Tests, Driver Tolerance

1. Driver response in terms of comfort levels could be specified for the test driver, for all vertical obstacles, in terms of the magnitude and frequency of vertical accelerations measured under the driver's seat.

2. Vertical acceleration at the driver's seat appeared to be a better criterion of comfort than jerk or longitudinal acceleration.

Single Non-Deformable Vertical Obstacles

1. Maximum vertical acceleration varied with the height of single, non-deformable vertical obstacles and with the speed of the vehicle, but not with the shape of the obstacles used in this study.

2. Maximum longitudinal accelerations exhibited generally lower magnitudes and about the same proportionality as vertical accelerations with respect to obstacle size, but

were hypersensitive to obstacle shape.

Multiple Non-Deformable Vertical Obstacles

1. Vertical accelerations over the multiple obstacle course were similar in magnitude to those for the same obstacle alone when crossed at the same speed.

Single Deformable Vertical Obstacles

1. Maximum vertical accelerations at the M37 driver's seat increased linearly with obstacle height and with the 0.404 power of obstacle strength (Cone Index).

2. Maximum negotiable vertical obstacle size increased when obstacle strength decreased.

Detailed test plans were developed for each group of tests and have been included in the appendices to this report. Advanced plans covering some simple combinations of terrain obstacle factors were developed using the knowledge gained from this exploratory phase. These test plans have been submitted independently. They represent a beginning to the second step in progress toward the total terrain-vehicle model.

INTRODUCTION

Background

In order to create the proper conceptual atmosphere for the one-pass terrain-vehicle studies, we must begin with a definition of the scope of problems embraced by the terminology and, further, this definition must be couched within the total concept of the Mobility Environmental Research Study (MERS) program for vehicle performance evaluation. In its broadest sense, terrain-vehicle studies can be defined as the evaluation of all those factors which influence the off-road performance of vehicles. Terrain parameters act in endless, often complexly interrelated combinations to inhibit a vehicle's theoretically possible speed of advance. These may be as simple as a long-radius curve in a race track or as complicated as a vegetated, eroded slope with slippery soil.

The MERS program has been designed to discover, define and quantify all those factors which influence the off-road performance of military vehicles with two major goals:

1. To establish a quantitative environmental descriptive system which would permit the evaluation of world terrains in terms useful to the design of military vehicles and the prediction of cross-country mobility of existing military vehicles/or classes thereof.

2. To develop a quantitative cross-country mobility prediction system employing the environmental descriptive terms established in item 1.

The terrain-vehicle study was directed toward the first-order identification -- on an essentially empirical basis -- of both speed-limiting and immobilization-producing terrain factors. These were studied individually where possible and will ultimately be brought together in tests involving simple combinations of factors. This study laid the groundwork for more extensive and comprehensive tests planned for the future by identifying important variables, defining the range of their importance, and in establishing the types of measurements indicated to be important in the determination of them.

The complexity of such a program was recognized. It was therefore necessary to make gross simplifications in the degree to which each of the individual contributing factors would be treated. A series of relatively simple single-factor tests was planned which would identify those parameters most important to the off-road performance of vehicles on a first-approximation basis.

Purpose

This study was designed to develop one-pass vehicle performance criteria for representative vehicles (one wheeled and one tracked) and terrain surface irregularities on a vehicle/surface irregularity scale ratio basis. Component parts of the problem were studied individually at first to develop the proper basic understanding of the more complex total problems to come later. Specifically, this investigation was designed to develop and/or evaluate the following:

1. Measurement systems necessary to permit quantitative description of vehicle performance and the terrain on which vehicles are operated.

2. Test methodology including proper experimental design.

3. Methods of analysis leading to quantitative vehicle-performance relations.

4. Approximate limits for both "immobilization" and "no-effect" values of important parameters.

5. A study plan which will include an analytical framework within which more extensive future studies should be conducted.

All of these evaluations were attempted on a rudimentary dimensionless basis to effectively eliminate the vehicle form, size and type from the total problem.

General Scope

The lateral obstacle tests involved the performance of vehicles coursing through an array of lateral obstacles (in this instance, the trunks of trees). The hypothesis stated that if the mean lateral obstacle spacing was great enough so vehicle immobilization could not occur, the maximum attainable vehicle speed would depend on the mean spacing of the obstacles and the width of the vehicle. Four test sites of carefully selected mean lateral obstacle spacings were thus chosen for testing purposes. The driver was instructed to drive through the test course at the maximum allowable speed. The "speed made good" was then calculated from the straight-line distance and the time required for course traversal. Path elongation was also calculated in an attempt to correlate laboratory and field tests.

The longitudinal obstacle tests involved overriding individual trees while measuring certain vehicle and terrain-parameter characteristics. A wide range of tree diameters were overriden for this series of tests. The traction requirements -- implying both speed reduction and limiting conditions -- were studied as a function of tree strength, tree diameter, longitudinal force on the vehicle and the type of vegetation failure. The effect of a combination of these obstacles was also studied to determine the additional force requirements to override multiple obstacle arrays.

The vertical obstacles tests involved the performance of vehicles over simple obstacles. A single obstacle of a given size, if smaller than that required for immobilization, should have a corresponding maximum speed at which it may be traversed without severe discomfort or impending vehicle structural damage. A test course was thus constructed with three different sizes of single, non-deforming (timber) obstacles. The obstacles were approached at slow speeds at first and speed was gradually increased until, in the driver's opinion, the maximum safe speed had been reached; however, in most cases, the driver would not specify safe speeds. Limits of acceptable vertical acceleration were estimated. Once this had been done, the effect of a combination of these obstacles was also studied to determine if multiple obstacle arrays had an additional influence on vehicle speed and acceptable vertical acceleration over that of a single one.

The vertical obstacle studies on non-yielding obstacles were conducted with less-than-critical obstacle size in order to evaluate surface geometry influence on speed. In addition to these studies, limiting deforming obstacle sizes were studied.

Detailed test plans were developed for each group of tests and have been included in the appendices to this report. Advanced

plans covering some simple combinations of terrain obstacle factors were developed using the knowledge gained from this exploratory phase. These test plans have been submitted independently. They represent a beginning to the second step in progress toward the total terrain-vehicle model.

DEFINITIONS

Absolute Minimum Turned Radius:	The minimum turning radius used in a vehicle traversal of a lateral obstacle array.
Average Minimum Turned Radius:	The average turning radius used in a vehicle traversal of a lateral obstacle array.
Cell Diameter:	The diameter of the circle required to enclose 20 obstacles.
Cone Index:	An index of the mass shearing resistance of soil obtained with a Cone Penetrometer.
Jerk:	Average time rate of acceleration increase.
Lateral Obstacle:	Requires vehicle motion in the lateral plane (maneuvering) for negotiation of the obstacle.
Longitudinal Obstacle:	Requires vehicle motion in the longitudinal plane for negotiation of the obstacle.
Mean Lateral Obstacle Spacing:	(.224) Cell Diameter - the mean distance between lateral obstacles.

Path Elongation Factor:	Ratio of the actual circuitous path length and the straight-line distance between two points.
Pushbar:	A device for measuring the force required to override trees.
Relative Steering Power:	The power input (or rate of doing work) required of the driver to make any turn.
Sheargraph:	An instrument used to measure the shearing strength properties of the soil surface.
"Speed Made Good":	*Straight-line course length* ÷ total elapsed time.
Terrain Obstacle:	Any feature of the terrain, except soil consistency, that inhibits surface vehicle movement.
Tractive Effort:	Longitudinal force acting at the wheel/track - soil interface.
Tree Penetrometer:	A device designed to indicate the depth of penetration of a 10° circular cone under a constant force.

Vertical Obstacle:	Requires vehicle motion in the vertical plane for negotiation of the obstacle.
Visibility Index:	A distance/dot loss system used to determine the visibility. The middle section of a 4' x 8' target which incorporates 25 dots was used at distances of 0-100 feet from the observer.

RESEARCH APPROACH

In order to study the terrain with all of its variable factors, it must be broken down into "pure", single factors. Then, as knowledge is gained of single factors, simple combinations of factors can be considered and the interaction of these single factors approximated. Eventually, the single factors will be combined into a "total" terrain. This study is concerned with the singular effects of the following terrain factors groups: lateral obstacles, longitudinal obstacles, and vertical obstacles.

The primary determinations sought for the lateral obstacle tests were:

1. The experimental verification of Randolph's laboratory study of path length increase with vegetation spacing.[1]

2. The relation of path length increase to "speed made good" and traction limitations.

3. The evaluation of visibility influence on vehicle speed, using a modified version of visibility factors.

The primary determinations sought for the longitudinal obstacle tests were:

1. To determine the manner in which a vehicle will override a single tree and to what degree this is a function of tree diameter, tree type, pushbar height, and soil strength.

[1] Reference No. 20, Bibliography.

2. To determine the maximum tree size and strength for immobilization.

3. To determine the override factor in a clump of trees as a function of tree diameter, tree height, tree spacing, soil strength and pushbar height.

The primary determinations sought for the vertical obstacle tests were:

1. To determine the acceleration limits acceptable to a driver.

2. To correlate limiting multiple obstacle accelerations with those of the single obstacle tests as a check for possible inconsistencies or additional influence.

3. To determine the influence of deformation on the maximum negotiable vertical obstacle in relation to soil strength.

4. To determine the no-go obstacle height for deformable obstacles.

To measure the terrain factors, an "instrument" had to be used. In this study, the M37, 3/4-ton truck, and M29C Weasel, were used as the instruments. By varying certain terrain parameters (i.e., vegetation height and diameter, vertical obstacle height) and holding certain vehicle parameters constant (i.e., vehicle width, ground clearance), the terrain parameters could be measured in terms of vehicle reaction (i.e., "speed made good", accelerations) with respect to the terrain.

The measurements taken for each test type were determined on the basis of past experience and knowledge of the important parameters; however, some of the measurements taken were the results of "brain storming" sessions. Because this study was of an exploratory nature, some terrain and vehicle parameters were measured which yielded insignificant data.

The analysis procedure was selected on the basis of past experience and knowledge; however, because this was an exploratory study, parts of the analysis were simply made on the hypotheses of interaction between various parameters.

The procedures for testing and analyses are more thoroughly expounded upon in the test plans in the appendices.

LATERAL OBSTACLE TESTS

OBJECTIVES

The major objective of the lateral obstacle tests was to approximate the relation between the spacing of lateral obstacles (in this instance, the trunks of trees) and vehicle characteristics using the speed of vehicles operating within them as performance criteria. Another prime objective was to relate the field tests to model tests previously conducted by WES in the laboratory by establishing correlative factors.

SCOPE

Twenty-seven lateral obstacle tests were conducted in four sites (Appendix II) during this testing program. The M29C Weasel, and M37 3/4-ton truck, were used for thirteen and fourteen tests, respectively, with the mean stem spacing/vehicle width ratio ranging from 1.1 to 4.3.

Test plans, data analysis procedures, summary data tables and sample measurements are included in Appendix III.

DISCUSSION OF RESULTS

Relationship of Maximum Vehicle Speed to Lateral Obstacle Spacing

In order to gain an appreciation of the physical aspects of the environment, Figure 1 through 4 show the various vegetation spacings used in the tests for the M37, 3/4-ton truck.

The test courses were chosen and prepared painstakingly to eliminate most of the possible influence of terrain factors other

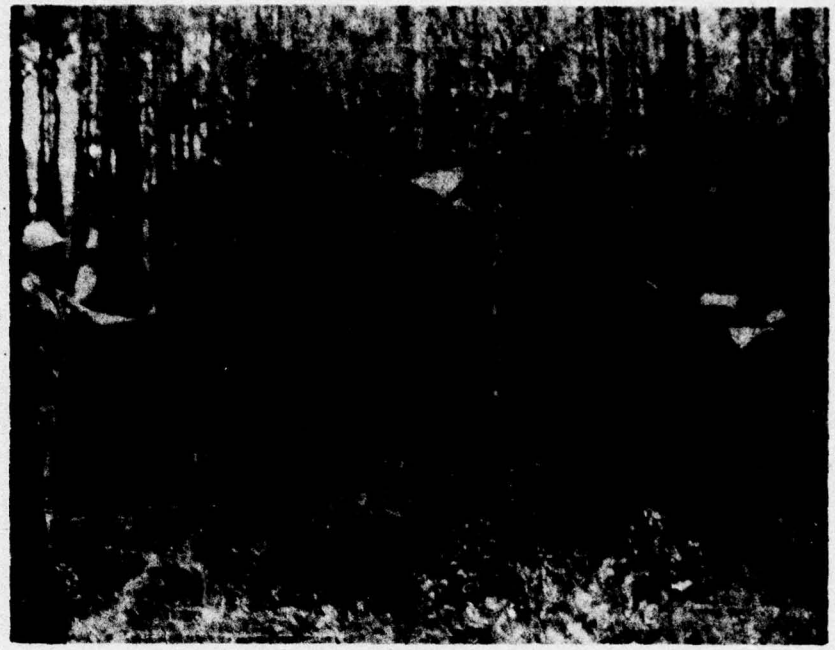


Figure 1 - M37 Truck, Test Site 3; Mean Obstacle Spacing is 8.0 Ft., Ratio of Mean Obstacle Spacing to Vehicle Width Equals 1.3.



Figure 2 - Test Site 2; Mean Obstacle Spacing is 13.6 Ft., Ratio of Mean Obstacle Spacing to Vehicle Width Equals 2.2.



Figure 3 - M37 Truck, Test Site 4; Mean Obstacle Spacing is 17 Ft., Ratio of Mean Obstacle Spacing to Vehicle Width Equals 2.8.

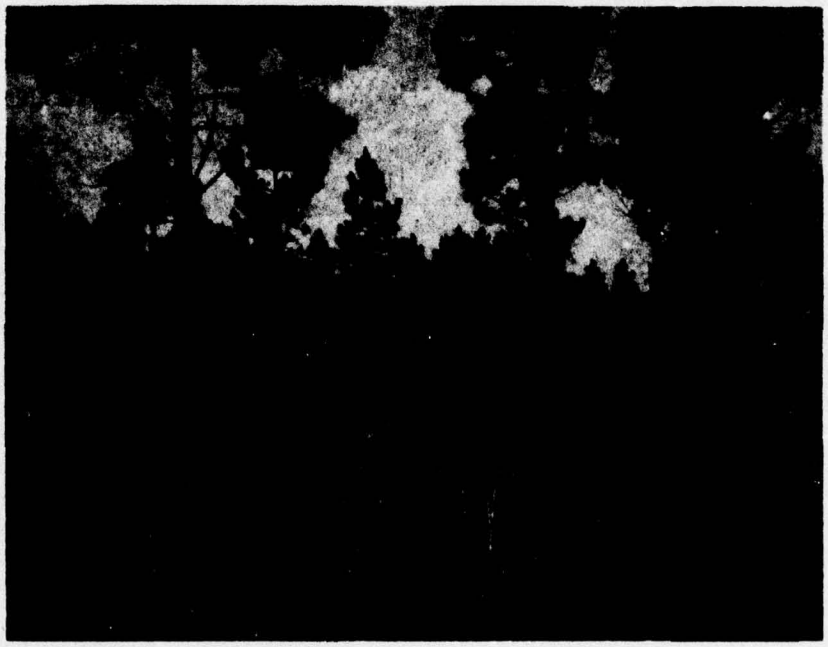


Figure 4 - Test Site 1; Mean Obstacle Spacing is 25.1 Ft., Ratio of Mean Obstacle Spacing to Vehicle Width Equals 4.1.

than the spacing of the vegetation itself. Instrumentation installed on the test vehicle recorded vehicle-related variables for other checks. Before confidence could be placed in the relationship determined between maximum speed and lateral obstacle spacing, 4 separate data checks were made, none of which indicated significant influence in the prime determination:

1. Average tractive effort required to maintain vehicle motion, (Figures 5A and 5B):
   a. did not vary appreciably with speed,
   b. did not exceed that available from the vehicle,
   c. did not exceed that available from the soil.
2. The short-duration vertical accelerations at the driver's seat (ride) were measured at the time of the tests and confirmed by subsequent statistical analyses (p. 53) to be well within acceptable limits (Figure 6).
3. Visibility conditions (Figure 7) were thought to have negligible influence on vehicle speeds. (Visibility measurement explained in Lateral Obstacle Test Plan, Appendix III.)

The tractive effort required to maintain vehicle motion was calculated from the torque on the shaft connecting the transmission and transfer case. In some instances, the maximum recorded tractive effort expended by the vehicle exceeded that available; however, the maximum peaks were of short duration which had little effect on the vehicle speed because of the vehicle's momentum.

Visibility for each site was measured in terms of the distance per dot loss. A 4' x 8' target which incorporated 75 dots, divided into three equal areas, classified as low, medium, and high, was used at 50 foot increments on the four points of the compass to

Figure 5A

GROSS TRACTIVE EFFORT VS. VEHICLE SPEED
M37, 3/4 Ton Truck
⊙- Avg. Tractive Effort
⊟- Max. Tractive Effort
Average Tractive Effort
Available From Soil = 4430 Lbs.
Tractive Effort Available From Vehicle
2500
2000
1500
1000
500
0
5
10
15
20
VEHICLE SPEED, MPH
GROSS TRACTIVE EFFORT, LBS.
(Computed from the Torque Meter.)

Figure 5B

GROSS TRACTIVE EFFORT VS. VEHICLE SPEED
M29C, Weasel
⊙- Avg. Tractive Effort
⊡ - Max. Tractive Effort
Average Tractive Effort Available From Soil = 8740 Lbs.
Tractive Effort Available From Vehicle
2500
2000
1500
1000
500
0
5
10
15
20
VEHICLE SPEED, MPH
GROSS TRACTIVE EFFORT, LBS.
(Computed from the Torque Meter.)

Figure 6

VERTICAL ACCELERATIONS OF DRIVER'S SEAT - LATERAL OBSTACLE TESTS
● - M37
X - M29C
AVG. VERTICAL ACCELERATION, G's
SPEED, (MPH)
1.5 Slightly Disagreeable
Distinctly Perceptible
Barely Perceptible
1.0
0.8
0.6
0.4
0.2
0
2
4
6
8
10
12
14
16

Figure 7

VISIBILITY INDEX VARIATION
NOI Lateral Obstacle
Test Sites
VISIBILITY INDEX (0-100'), FT. PER DOT
50
40
30
20
10
0
0
20
40
60
80
100
120
VEGETATION CELL DIAMETER

determine the visibility. The dot count was made with a surveyor's level with the lens 4.5 feet above the ground. Subjectively, the driver stated that the obstacles were not obscured by limited visibility. On the basis of the visibility index and subjective reasons, the influence of visibility on vehicle speed has been considered to be negligible.

As an extra precaution, the driver was allowed to walk over the course, assisting in the location and staking of holes and stumps (each of which became another clearly-marked obstacle to be avoided) in order to be assured that all possible vertical obstacles (bumps) had been eliminated. The ride would, therefore, not be a deterrent to attainment of maximum speed. He knew that the vehicle was to be driven at the highest possible speed without hitting any lateral obstacle even before he walked over the course.

The start and end points of each course were located well within the confines of homogeneous vegetation stands so that maximum speed could be attained before entering the timed section. The start and end points were clearly marked, but no routes were pre-selected. The driver was extremely skillful and the results shown in Figure 8 are presented with confidence that they represent the maximum speeds attainable with the particular test vehicles.

Figure 8 indicates the relationship between maximum speed and the ratio of mean tree spacing to vehicle width. Thus, if tree spacing is considered to be the only limitation, cross-country "speed made good" for the M37 and M29C may be computed by the equation

$$V = 10.4 \ln \left[\left(\frac{.224D}{W}\right) - 0.3\right] \qquad \text{Eqn. (1)}$$

$$\text{for } 1.3 < \frac{.224D}{W} < 4.4$$

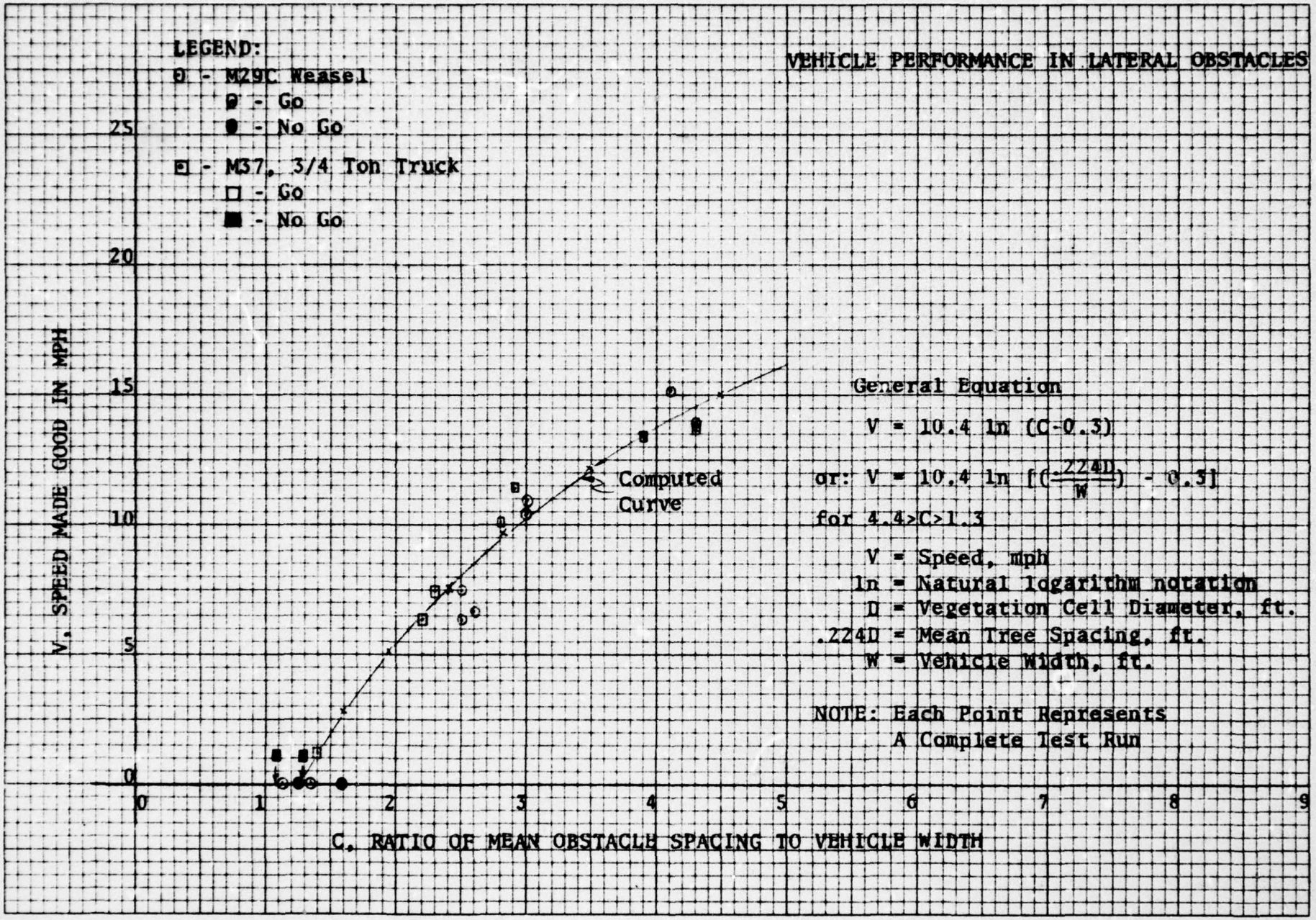

VEHICLE PERFORMANCE IN LATERAL OBSTACLES
LEGEND:
- M29C Weasel
- Go
- No Go
- M37, 3/4 Ton Truck
- Go
- No Go
V, SPEED MADE GOOD IN MPH
0
5
10
15
20
25
0
1
2
3
4
5
6
7
8
9
C, RATIO OF MEAN OBSTACLE SPACING TO VEHICLE WIDTH
Computed Curve
General Equation
V = 10.4 ln (C-0.3)
or: V = 10.4 ln [(.224D/W) - 0.3]
for 4.4>C>1.3
V = Speed, mph
ln = Natural logarithm notation
D = Vegetation Cell Diameter, ft.
.224D = Mean Tree Spacing, ft.
W = Vehicle Width, ft.
NOTE: Each Point Represents
A Complete Test Run

Figure 8

where

V = Vehicle "speed made good", miles per hour

ln = Natural logarithm notation

.224D = Mean obstacle spacing, ft,

D = Vegetation cell diameter, ft.

W = Vehicle width, ft.

The "speed made good" term was computed from the straight-line course length divided by total elapsed time. This was believed to be the most meaningful method of determing speed, giving the effective speed between two points. Subsequent data collected by AEB for the M113 indicates that this equation may not hold true for other vehicle systems. This is probably due to the improper accounting of other variables such as, specific power, hp/ton, sweep width, and steering response of the vehicles.

The lack of scatter in the data reflected the homogenity of the test courses, the lack of variation in driver technique and in particular, the applicability of the statistically determined method of sampling for lateral obstacle spacing. Simply stated, the mean lateral obstacle spacing was computed from the diameter of the circle required to enclose 20 obstacles (cell diameter). The theory has been thoroughly discussed in "Quantitative Physiognomic Analysis of the Vegetation of the Florida Everglades", Howard L. Mills, Marshall University, May 1963.

The intercept of the curve on the zero-speed axis occurred at a spacing/width ratio of 1.3. Above this "immobilization" point, speed became increasingly less sensitive to spacing. The "no-effect" lateral obstacle spacing was impossible to specify, there being no clean "break" in the curve. The upper limit of this curve is very likely governed by vehicle parameters, such as, specific power, steering response, and sweep width.

Correlation of Field and Laboratory Obstacle Spacing Studies

A series of model tests had been conducted by AEB in randomly-spaced obstacle arrays which indicated that the increase in path length (ratio of the actual circuitous path length and the straight-line distance between two points) of the model vehicle traverse could be related to obstacle spacings. Since model tests were conducted under conditions of perfect visibility (the operator looks down upon the whole array from above), it was thought that the "real" visibility conditions would be reflected by a comparison of field and laboratory data.

Although field path length increases were larger than those of the laboratory, no correlations could be found (Figure 9). The reasons center around the incredible measurement accuracy required to determine the very small differences in actual path and straight-line distances. Large changes in obstacle spacing produced small changes in the path length; therefore, the path length increase was not a sufficiently sensitive indicator of passage difficulty. Obstacle spacing was found to be the most sensitive indicator of passage difficulty.

Vehicle Design Implications

There were vehicle design implications in the lateral obstacle studies. If Figure 8 is valid for a significant range of vehicle widths it would indicate that linear increases in vehicle width produce unfavorable non-linear decreases in permissible speeds in a given obstacle array.

Figure 10 shows both the average minimum and the absolute minimum turned radii required of the M37 at different obstacle spacings. The average curve indicates the nominal level of steering corrections and the absolute curve indicates minimal design levels which must be

Figure 9

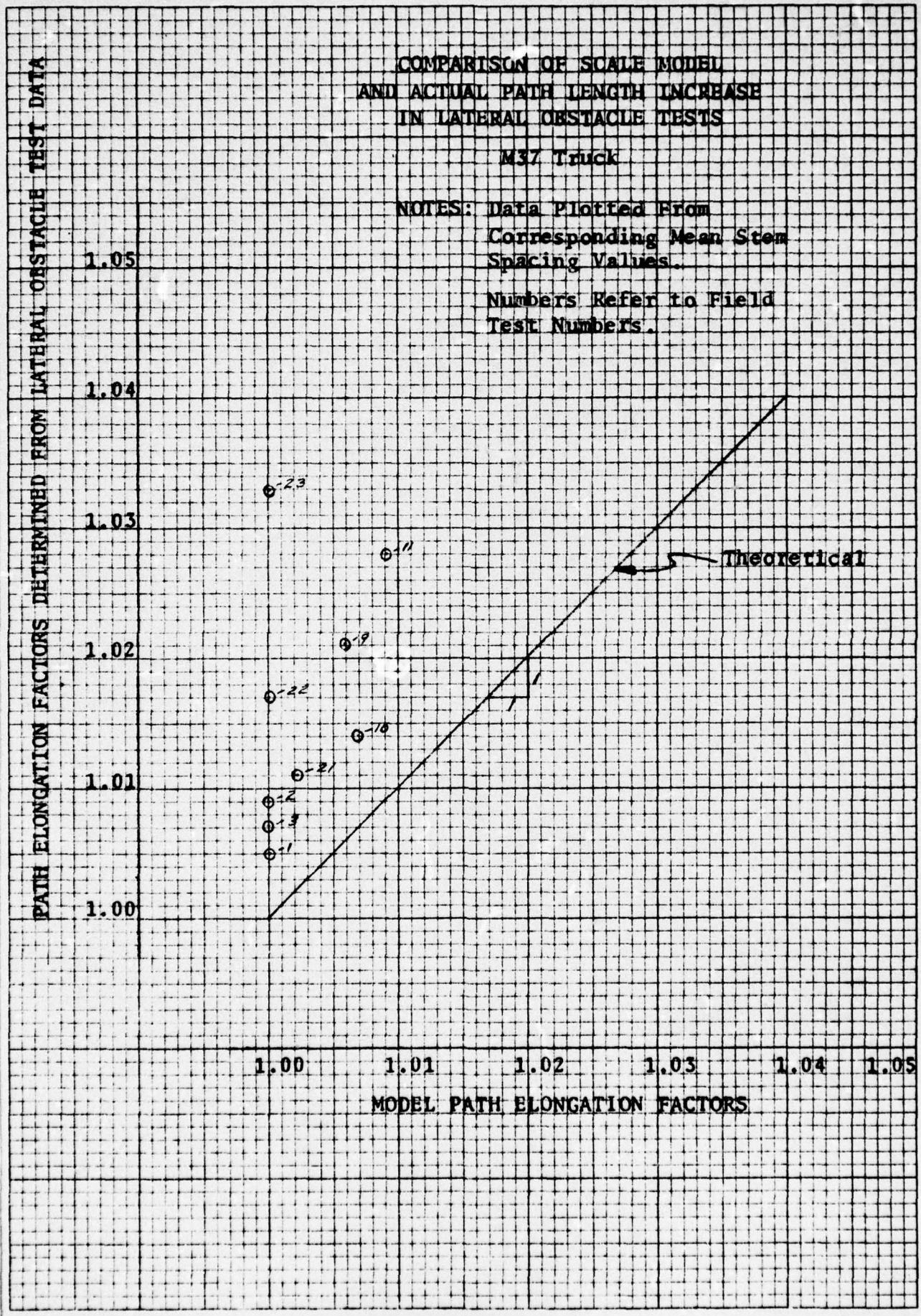

COMPARISON OF SCALE MODEL
AND ACTUAL PATH LENGTH INCREASE
IN LATERAL OBSTACLE TESTS
M37 Truck
NOTES: Data Plotted From
Corresponding Mean Stem
Spacing Values.
Numbers Refer to Field
Test Numbers.
PATH ELONGATION FACTORS DETERMINED FROM LATERAL OBSTACLE TEST DATA
1.05
1.04
1.03
1.02
1.01
1.00
-23
-11
-9
-22
-10
-21
-2
-3
-1
Theoretical
1
1
1.00
1.01
1.02
1.03
1.04
1.05
MODEL PATH ELONGATION FACTORS

Figure 10

46956

Figure 11

THE INFLUENCE OF VEGETATION SPACING ON RELATIVE STEERING POWER REQUIRED OF THE DRIVER
M37 TRUCK
RELATIVE STEERING POWER REQUIRED
RATIO, MEAN OBSTACLE SPACING TO VEHICLE WIDTH
0
1
2
3
4
5

satisified. The more closely the lateral obstacles were spaced, the larger the steering corrections (smaller turning radii) became. Even when the ratio of obstacle spacing to vehicle width was as much as 2.2, the driver occasionally turned the steering wheel to "lock" in order to negotiate the course.

The relative severity of steering corrections made by the driver may be examined. Assuming that a constant force is applied to the rim of the steering wheel to make any turn, the rate at which the wheel is rotated will be a measure of the power input (or rate of doing work) required of the driver. The rate of steering wheel rotation will be in direct proportion to the severity of the maneuver required (minimum turning radius/actual average turning radius) and vehicle speed (higher rate of steering wheel rotation is required to execute a given turn at higher speeds). In effect, this parameter is related to the power (in relative units only) which the operator expended in achieving the indicated speeds. It can be seen that even though the speeds were slower in the closely-spaced obstacles, relative power requirements were greater (Figure 11, p. 26). Power assistance for steering will become of particular benefit as maneuver severity increases.

SUMMARY OF RESULTS

1. The maximum permissible speed of an M37 or an M29C operating within an array of insurmountable lateral obstacles can be computed by the following equation:

$$V = 10.4 \ln \left[\left(\frac{.224D}{W}\right) - 0.3\right]$$

$$\text{for } 1.3 < \frac{.224D}{W} < 4.4$$

where

V = Vehicle "speed made good", miles per hour

ln = Natural logarithm notation

D = Vegetation cell diameter, ft. (A statistically reliable measure of spacing; the diameter of a circle which encloses 20 obstacles.)

.224D = Mean lateral obstacle spacing, ft.

W = Vehicle width, ft.

2. Credibility was given the results above because:

   a. Average tractive effort required to maintain vehicle motion:
      (1) did not vary appreciably with speed,
      (2) did not exceed that available from the vehicle,
      (3) did not exceed that available from the soil.

   b. The short duration vertical accelerations fell generally within our "Barely Perceptible" range (0.25 to 0.47 g's) with a few in the lower part of the "Distinctly Perceptible" range (0.47 to 1.50 g's).

   c. The visibility index (distance divided by dot count at that distance) was constant between 5.5 and 6.5 ft. per dot except for Site One where an exceptionally good condition gave 56 ft. per dot.

3. Immobilization of test vehicles occurred at an obstacle spacing/vehicle width ratio of 1.3.

4. Full lock turns were occasionally made in lateral obstacle spacings 2.2 times as wide as the vehicle.

5. The relative power required of the driver for steering increased 44% as the ratio of mean obstacle spacing to vehicle width was reduced from 4.4 to 2.6.

LONGITUDINAL OBSTACLE (SINGLE TREE OVERRIDE) TESTS

OBJECTIVES

The objectives of this group of tests were threefold:

1. Delineation of those tree parameters sufficient to describe the work expended in overriding single trees.

2. The delineation of maximum tree sizes which can be pushed over in terms of the required horizontal force.

3. The delineation of procedures to facilitate more comprehensive tests.

These objectives have been achieved with the limited number of the tests involved. The tests were conducted statically (Figure 12) so that inertial forces would not cloud the data. This will



Figure 12 - M37 Truck with Pushbar to Measure Horizontal Force.

permit "safe" estimates of energy expenditure and maximum tree size which can be pushed over.

SCOPE

The M37, 3/4-ton truck, was used to measure the longitudinal force required to override the 46 trees selected for the single Longitudinal Obstacle Tests. The 46 tests included 29 Pine and 17 Oak trees ranging in diameter (measured 42" above the ground) from 1.0 to 6.4 inches.

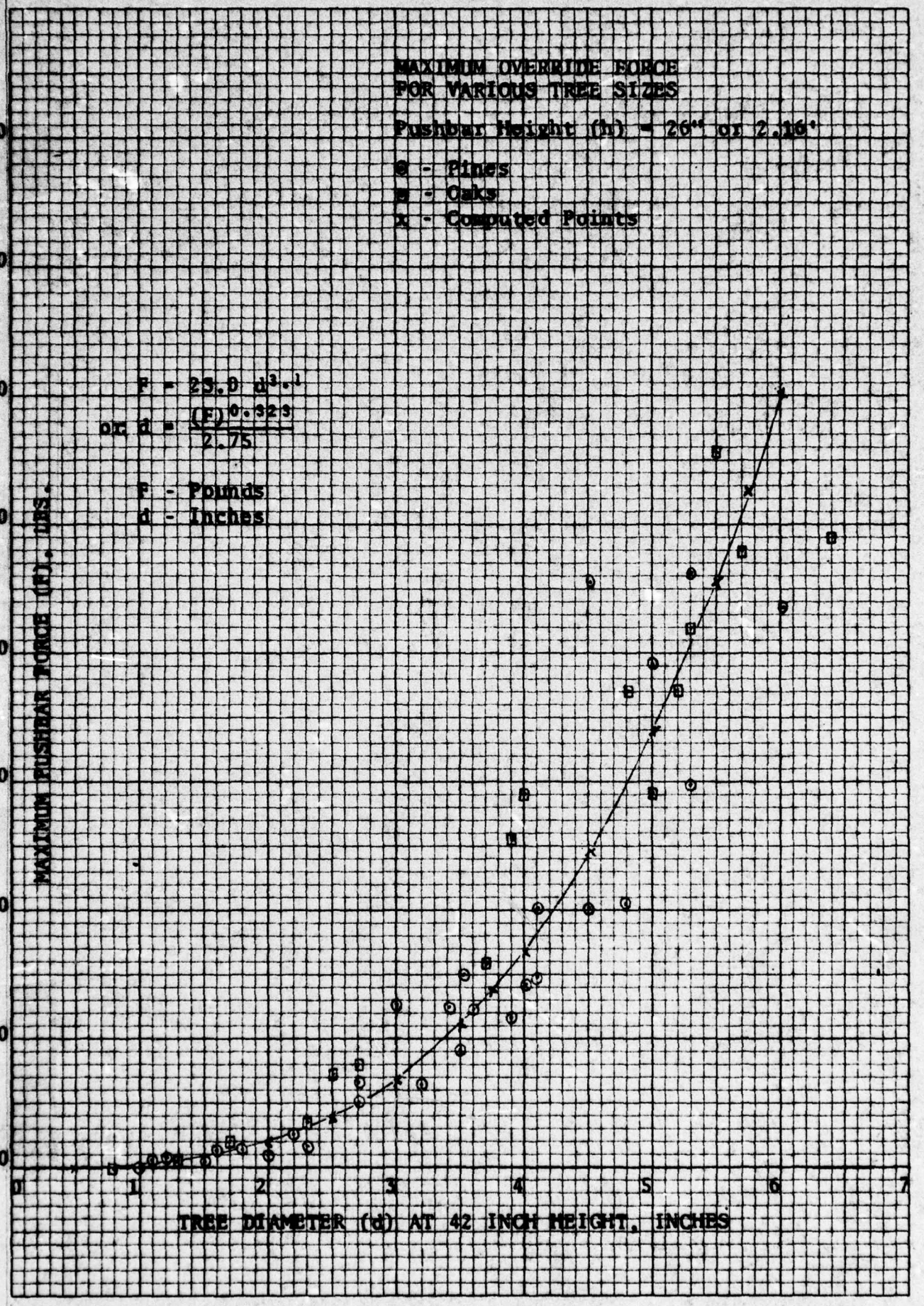
Test plans, data analysis procedures, summary data tables, and sample measurements are included in Appendix IV.

DISCUSSION OF RESULTS

Determination of Maximum Override Force

Both Pines and Oaks were involved in the override tests, in anticipation of an increase in maximum override force with stem hardness. No difference could be found, however. The plot of maximum force vs. tree diameter (Figure 13) revealed that all trees fell essentially within the same scatter band and no species-dependent trends were discernible. The same was true for a plot of override work (the integral of force times distance); however, four data points indicate that it may be possible with the collection of additional data, to separate Oak and Pine tree override work requirements. Thus, it has been possible to describe the mean resistance of a tree to override simply in terms of its diameter. It is hypothesized by the authors, that the override work and maximum override force are indirectly proportional to the pushbar height. It may be possible to make more implicit

Figure 13


MAXIMUM OVERRIDE FORCE
FOR VARIOUS TREE SIZES
Pushbar Height (h) = 26" or 2.16'
⊗ - Pines
⊞ - Oaks
x - Computed Points
F = 25.0 d^3.1
or d = (F)^0.323 / 2.75
F - Pounds
d - Inches
MAXIMUM PUSHBAR FORCE (F), LBS.
8000
7000
6000
5000
4000
3000
2000
1000
0
0
1
2
3
4
5
6
7
TREE DIAMETER (d) AT 42 INCH HEIGHT, INCHES

definitions in terms of other variables once enough additional data have been collected to account for the considerable scatter in data points.

It was anticipated that the relationship between maximum override force and tree diameter would have to be described by different equations on either side of a mean diameter of about 3.5". Usually, with the 26" pushbar, trees below this diameter "failed" by elastic yield. Trees larger than 3.5" usually failed either by rupture just above the ground, or by uprooting. This break may be contained within the data but if so, is masked by scatter.

Single Tree Override Tractive Effort Requirements

Figure 13 shows a plot of the maximum override force for the various tree sizes and types covered in these tests. The curve shown on Figure 13 is the computed "best fit" curve as determined by the equation:

$$F = 23.0\ d^{3.1} \qquad \text{Eqn. (2)}$$

where

F = Maximum pushbar force, lbs.

d = Tree diameter at 42" height, inches

The maximum pushbar force developed by a vehicle can not be greater than the maximum drawbar pull available under the specific soil conditions. Thus, drawbar pull (P) may be substituted as the equivalent of pushbar force (F). A predictive equation may thereby be derived which will allow computation of the maximum tree size in terms of soil shearing strength and pertinent vehicle parameters. By rearranging Equation 2, the maximum tree

diameter (d_{max}) may be computed as follows:

$$d_{max} = \frac{[P_{max}]^{0.323}}{2.75} \qquad \text{Eqn. (3)}$$

P_{max} can be computed for a rubber-tired vehicle from the following equation:

$$^{2}P_{max} = A\, a_{ur} + W\tan\alpha_{ur} \qquad \text{Eqn. (4)}$$

where

A = Total ground contact area of tires, sq. in.

a_{ur} = Ultimate soil-to-rubber adhesion, psi

W = Gross vehicle weight, lbs.

α_{ur} = Ultimate soil-to-rubber friction angle, degrees

P_{max} may be computed for tracked vehicles - with or without rubber road pads - and other wheel vehicles with agressive tires by the simple substitution of appropriate soil shearing strength parameters to replace a_{ur} and α_{ur} (Ref. 24).

Using Equations 3 and 4, a series of predictions were made based upon computed maximum tractive effort from the Cohron Sheargraph measurements and vehicle characteristics (Table 1). If the computed d_{max} was less than the measured tree diameter, a "no-go" situation was predicted. Conversely, a computed d_{max} larger than the actual tree diameter would allow a "go" prediction. The results were reasonably consistent and, as pointed out, independent of tree variety.

[2] Reference 4, Bibliography.

TABLE 1 - PREDICTED OVERRIDE MAXIMUM TREE SIZE

Experimental			Theoretical		
			Computed Maximums		
Experimental Go - No-Go	Measured Tree Diameter, In.	Tree Species	Available Tractive Effort,* lb.	Tree Dia., In.	Predicted Go - No-Go
No Go	6.4	Oak	2900	4.8	No Go
No Go	5.7	Oak	2900	4.8	No Go
No Go	5.5	Pine	5300	5.6	Go
No Go	5.3	Oak	4400	5.4	Go
Just Go	5.3	Pine	5000	5.5	Go
Go	5.3	Pine	5200	5.6	Go
Go	5.2	Oak	4200	5.3	Go
Go	5.0	Oak	4200	5.3	Go
Go	5.0	Pine	4900	5.5	Go
Go	4.8	Pine	4100	5.3	Go
Go	4.5	Pine	5300	5.6	Go
Go	4.0	Oak	2600	4.6	Go

* Computed from rubber-to-soil sheargraph data.

Single-Tree Override Work

What is probably the most significant result from this test series was the determination of work required to override trees of various sizes. Override force-distance curves were plotted from the recorded data for the various tree sizes, (Appendix IV). The area under the curve, then, was the work required. A plot of these data (Figure 14) was a straight-line on log-log paper and the equation for the line could be conveniently determined:

$$W = 27.2\ (d)^{3.63} \qquad \text{Eqn. (5)}$$

where

w = Work per tree, lb.-ft.

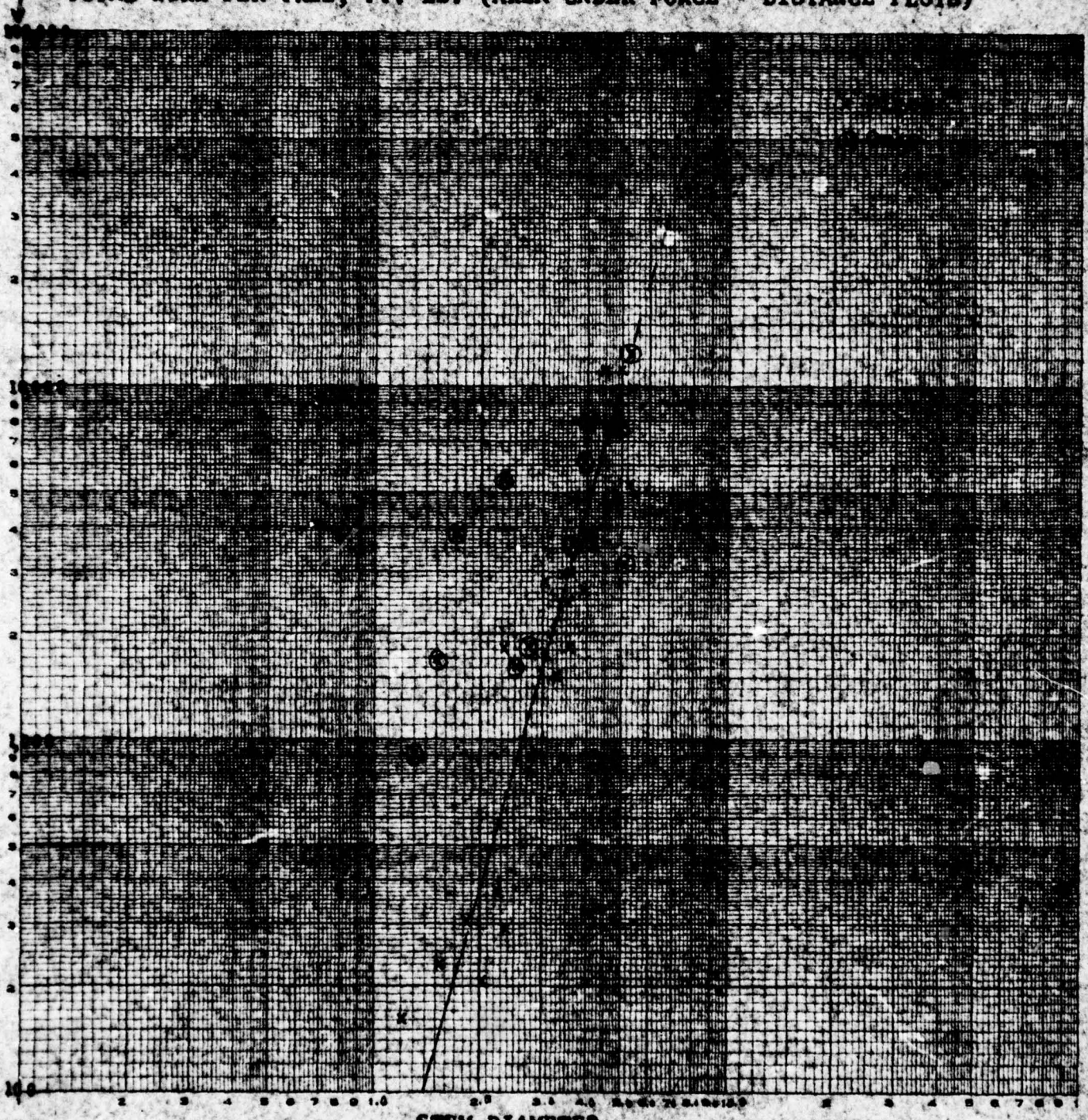
d = Tree diameter, inches

Figure 14

WORK REQUIRED TO OVERRIDE TREES

For M37 Truck

All Trees (Oaks and Pines)



$W = 27.2 (d)^{3.63}$

W = Work per tree, lb-ft.

d = Tree Diameter, inches

This equation will allow the computation of energy requirements for any particular vehicle to override any given tree standing alone. Recent data, however, indicate corrections will be necessary to account for changes in soil strength. Also, when the tree spacing is such that it does not act as if standing alone, (e.g., crown interference occurs), an additional correlative factor must be added (to be discussed in a subsequent section).

If a vehicle is required to maneuver around larger trees and override smaller trees, the override work curve can be used to compute vehicle speed on the basis of horsepower requirements to override vegetation. Then, once the maximum tree size to be overriden has been computed, the maximum speed around larger trees may be computed from Figure 8, with additional information not yet available on the influence of spacing on the additional override moment (or force) and the probable number of trees in the different size classes.

A practical no-effect size may be specified for individual stems from either the work curve or the equation for tractive effort requirements. A spacing value must be determined before the no-effect size can be sensibly specified since very small stems normally do not occur alone but appear in multiple array. This remains to be done.

Factors Influencing Stem Failure Modes

There were 19 stem fractures (Figure 15) and root failures (Figure 16) in the 46 Single Tree Override Tests. All these failures occurred at diameters 3.5 inches or greater. Below 3.5 inch diameters, most stems accepted the strain without complete fracture (Figure 17). Figure 18 indicates that there

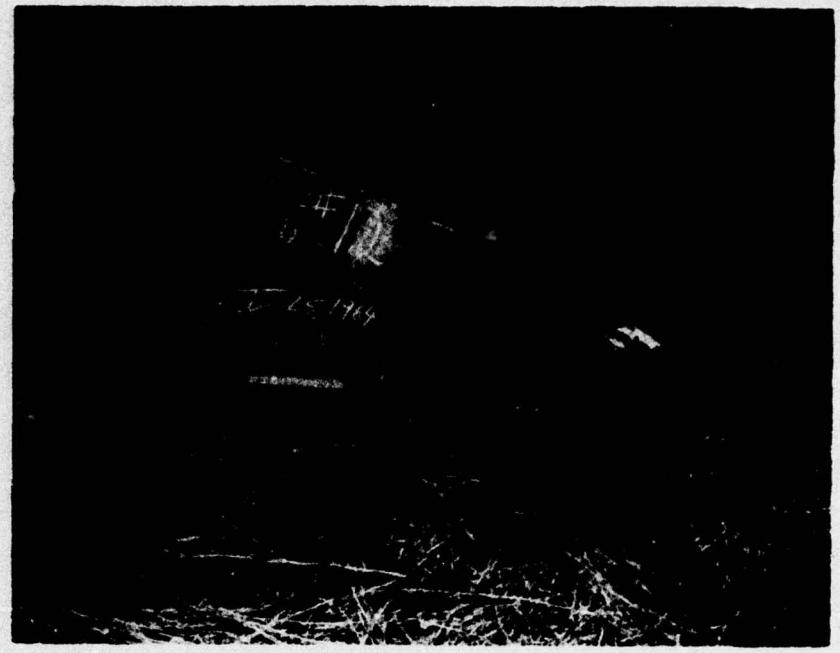


Figure 15 - Typical Stem Fracture, Pine.



Figure 16 - Typical Root Failure, Pine.

was a tendency to incur stem fractures as the mass strength (Cone Index) of the soil increased, although there was insufficient data for more exact definition of the trend. Larger trees, requiring more pushbar force, required more soil strength in order to produce a stem fracture.



Figure 17 - Stem Failure by Strain, Incomplete Fracture (Pine).

The procedures developed to study this aspect of terrain impedance were sufficient for an initial study of the problem. Since it was not possible to evaluate the effects of pushbar height directly nor to distinguish between Pines and small Oak trees, more comprehensive tests should give particular

Figure 18

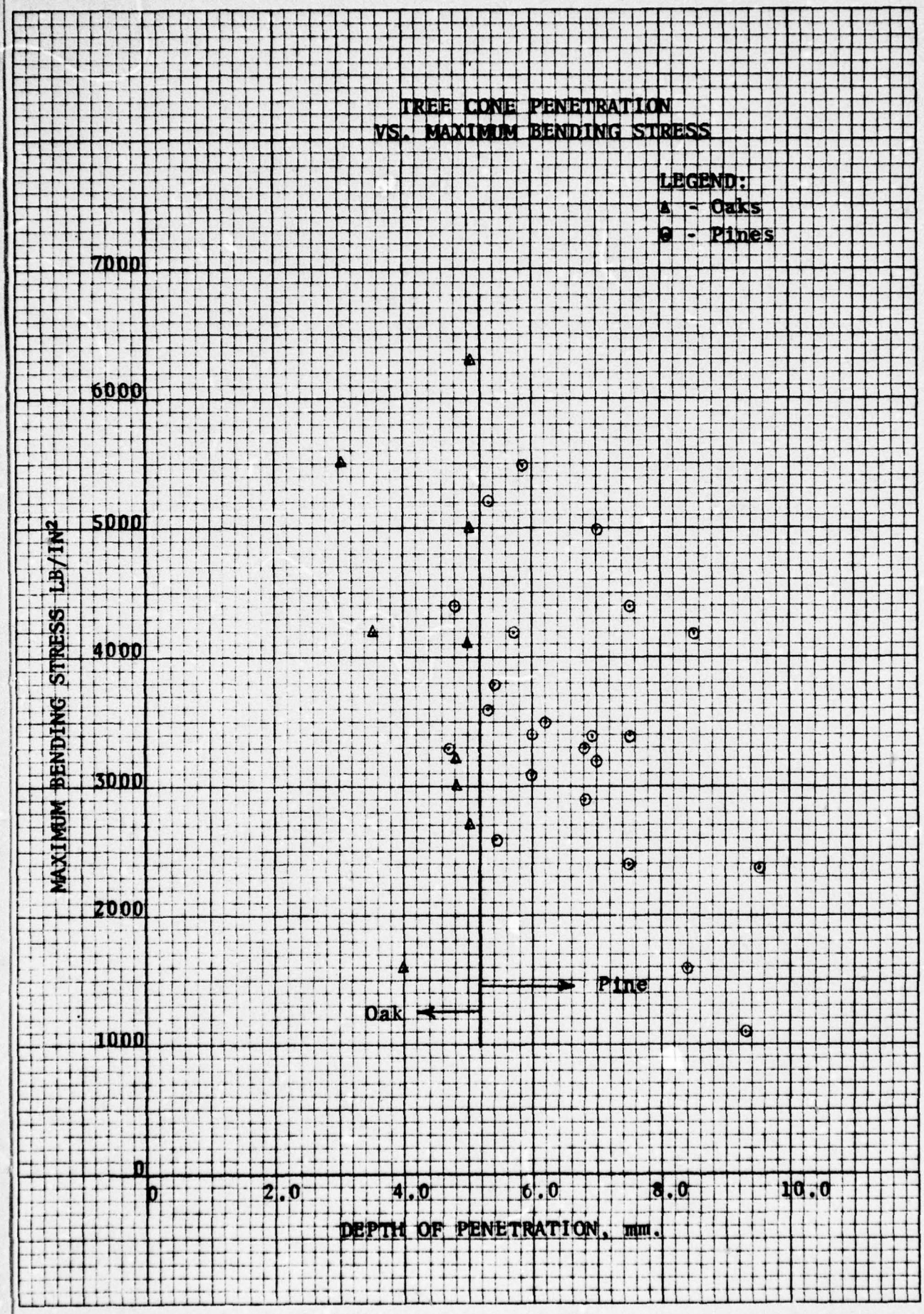
INFLUENCE OF SOIL MASS STRENGTH
ON TREE FAILURE MODE
Single Tree Overturning Tests, M37
LEGEND:
1.0 - Test Number
- Stem Failure
- Soil-Root Failure
NOTES:
(a) Stem diameters range from 3.5 in. to 6.0 in.; stems were elliptic below 3.5 in.
(b) Only a small number of roots failed in tension near the ground surface. Classified as type four failure.
Soil-Root Failures
Stem Failures
Root Failure(a)
Root Failure(b)
HORIZONTAL PUSHPAR FORCE (LBS)
AVG. CONE INDEX (0-18")
1000
2000
3000
4000
5000
6000
100
150
200
250
300
350
400
450
500
550

attention to these variables. Soil mass strength was held essentially constant also, and a wider range would be desirable. Tests with a larger vehicle, having more tractive effort, are indicated to permit consideration of a larger range of tree sizes. Improved instrumentation to provide a more dependable measure of distance is desirable.

Because the bending strength of different trees was believed to have an influence on the force required to push it over, a hand-operated tree penetrometer was employed in these tests. The device had been designed to indicate the depth of penetration of a right circular cone with an apex angle of 10° under a constant force. Samples 36 inches long were cut from test trees and subjected to laboratory bending tests (Appendix IV). Maximum bending stress was computed and plotted against the penetrometer readings (Figure 19). Under a constant force, the penetrometer went deeper in soft wood (Pine) than in harder Oak. More definitive trends could not be reliably stated since there was no apparent correlation between depth of penetration and bending failure stress. The next step would have been to correlate penetrometer readings with override force or work. It could not be done since a correlation between cone penetration and bending stress was not established.

All things considered, this segment of the test program succeeded in indicating the nature of some very fundamental questions regarding the impedance to vehicular movement offered by vegetation, With these data, first-order approximations of speed losses from longitudinal obstacles are now theoretically possible. Also, limiting tree sizes may now be estimated from the shearing strength of the soil, and practical no-effect tree sizes can be defined.

Figure 19


TREE CONE PENETRATION
VS. MAXIMUM BENDING STRESS
LEGEND:
▲ - Oaks
⊙ - Pines
MAXIMUM BENDING STRESS LB/IN²
7000
6000
5000
4000
3000
2000
1000
0
Pine
Oak
0
2.0
4.0
6.0
8.0
10.0
DEPTH OF PENETRATION, mm.

SUMMARY OF RESULTS

1. The maximum tree size which the M37 truck could push over was 5.3 inches, and this immobilization size could be computed with soil shearing strength and simple vehicle parameters:

$$d_{max} = \frac{[P_{max}]^{0.323}}{2.75}$$

where

$$P_{max} = a_{ur} A + W\tan\alpha_{ur}$$

and

d_{max} = Largest tree diameter, inches

P = Drawbar Pull = Pushbar Force

A = Total ground contact area of tires, sq. in.

W = Gross vehicle weight, lbs.

a_{ur} = Ultimate soil-to-rubber-adhesion, psi

α_{ur} = Ultimate soil-to-rubber-friction angle, degrees

2. The work expended in overriding trees of various sizes was found to be conveniently expressed by:

$$w = 27.2\ (d)^{3.63}$$

where

w = Work per tree, lb.-ft.

d = Tree diameter, inches

3. Maximum override force and override work were found to vary with a power of the tree diameter and a definite separation could not be made between Oaks and Pines.

4. Trees less than 3.5 inches in diameter usually bent elastically

in override tests with the pushbar 26 inches from the ground surface.

5. Stem fractures and root failures occurred on trees greater than 3.5 inches in diameter in these tests.

6. Tree penetrometer data indicated only that the depth of penetration is somewhat related to species but not to bending failure stress as determined by simple beam bending tests.

LONGITUDINAL OBSTACLE (MULTIPLE TREE OVERRIDE) TESTS

OBJECTIVE

The objective of these tests was to determine the additional force required to override trees in multiple array. The crowns of neighboring trees interfere with the crown of the tree which is pushed over into them. It was anticipated that a factor could be determined which would relate the spacing and size of the vegetation to the increase in override force (over that of an equivlent tree standing alone) produced by crown interference. This additional force must be defined before rational predictions of vehicle speed through these "longitudinal" obstacles can be made.

SCOPE

Five sites were selected for Multiple Tree Override Tests in Hancock County, Mississippi (Appendix II). The M37, equipped with the same pushbar used in the single tree override tests, was used as a test vehicle.

Test plans, data analysis procedures, summary data tables, and sample measurements are included in Appendix V.

DISCUSSION OF RESULTS

Of the five multiple override sites selected, the data from only two were ultimately useful because of vehicle immobilizations and excessive wheel slippage. The data were analyzed by constructing pushbar force - distance travelled curves from the oscillograms and determining the work expended (area under the curve) in negotiating the course (Measured Work, Table 2). Next, the diameters of each tree pushed over were listed and the work to push over

equivalent trees standing alone were taken from Figure 14, summed and divided by the distance travelled (Computed Work per ft., Table 2). Test site No. 2 contained nominally larger trees more closely spaced in comparison to test site No. 3, and this is reflected in the Work per Foot columns. Mean spacings (3.6 ft., 3.1 ft.) and average tree diameters (1.6 in., and 1.8 in.) were so nearly the same that no satisfactory fit of computed interference factors could be made. It can be noted, however, that the larger trees more closely spaced produced proportionally more interference (Percentage Increase, Table 2). The relative influence of spacings and size distributions on interference can be stated intuitively but the equation constants necessary to make it a useful prediction tool can not be determined until the tests covering a wider range of variables have been completed. At present, all that can be said is that trees in multiple array offered about 40 per cent additional override work than when standing alone.

TABLE 2. A COMPARISON OF THE INFLUENCE OF OVERRIDE WORK FOR MULTIPLE AND SINGLE TREE TESTS

Test No.	Measured Work, lb.-ft.	Feet Travelled	Measured Work/ft. (lb.-ft./ft.)	Computed Work/ft. (lb.-ft./ft.)	Percentage Increase
2	24,030	44	548	382	43.5%
3	25,616	77	334	243	37.5%

Even in the present absence of an interference factor, methods for treatment of longitudinal obstacle impedance appear not only possible but practicable. Of course, prediction accuracy needs improvement, but the framework within which this may be accomplished

has been established by the override tests.

SUMMARY OF RESULTS

1. A comparison of measured work per foot from the multiple override tests and computed work per foot from single tree override tests indicates a nominal increase of 40 per cent from interference of adjacent trees.

2. The exact nature of the interference factor could not be specified because of the small variations in mean tree spacings (3.6 ft., 3.1 ft.) and average stem diameters (1.6 in., 1.8 in.).

VERTICAL OBSTACLE (SURFACE GEOMETRY) TESTS

OBJECTIVES

The several objectives of this program have been included in the detailed test plans, Appendix V. Briefly, single non-deforming obstacles of varying size and shape were crossed at a wide range of speeds to determine their individual and comparable effects on driver "comfort". Deformable obstacles of varying heights and strengths were constructed to determine the effects of obstacle deformation on their severity and maximum negotiable height. Static and dynamic traction requirements for the various obstacles were also to be determined.

A series of spacings for a multiple, non-deforming obstacle test series was selected to indicate whether or not accelerations of the driver's seat varied significantly from those of similar single obstacles. An empirical expression for terrain roughness was also sought.

The test data indicated significant trends for all objectives except the latter which were so closely related to vehicle suspension characteristics, that it was not possible to derive a satisfactory factor independent of the vehicle itself. This is a complex problem far beyond the scope of this exploratory study; however, computer techniques recently evolved by FMC Corp., under related WES studies appear to have made considerable progress toward a first-order solution.

SCOPE

A total of 89 vertical obstacle tests were conducted with the M37, 3/4-ton truck, and M29C Weasel. Twenty-four tests on

the 4" square, 8" square and 8" sloped, single non-deforming, vertical obstacles were conducted with the M37 at speeds ranging from 0-32.5 mph; twenty tests were conducted with the M29C at speeds ranging from 0-20 mph. Sixteen tests on the 4" square, multiple, non-deforming vertical obstacles with spacings of 69", 138", and 207" were conducted with the M37 at speeds ranging from 2-43 mph; seven tests were conducted with the M29C at speeds ranging from 2.3-20 mph. Twenty tests on the 4", 8", 18", 20", and 22" slope-faced, single, deforming, vertical obstacles with average Cone Indexes ranging from 54 to 475 were conducted with the M37 at speeds ranging from 0.7-12.6 mph; two tests on the 8" obstacles were conducted with the M29C at speeds of 8.1 and 9.5 mph. Figures 20 thru 26 show the various vertical obstacles used in the tests.

Test plans, data analysis procedures, summary data tables, and sample measurements are included in Appendix VI.

DISCUSSION OF RESULTS

Driver Tolerance to Accelerations

Driver comfort (or discomfort) was difficult to specify simply. Quantitative definition has been achieved for one individual. This definition is still subject to the interpretation of accelerations measured on the vehicle body just below the driver's seat in terms of those the driver's body actually experienced. The effects of the interposed 4 inch cushion could not be specified.

After each test run was completed, the driver was asked to subjectively evaluate his "discomfort" in one of the following



Figure 20 - Four Inch, Square-Faced, Non-deformable, Vertical Obstacle.

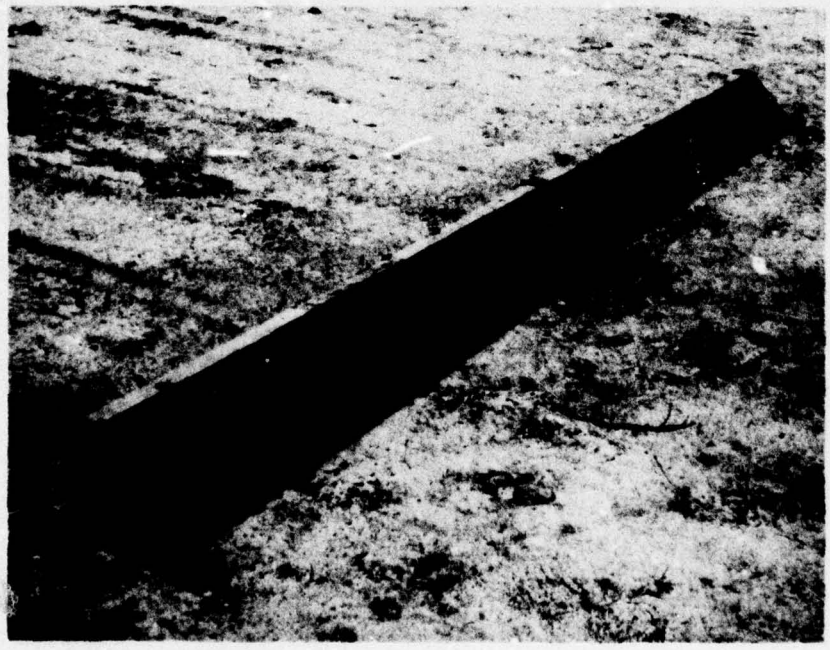


Figure 21 - Eight Inch, Square-Faced, Non-deformable, Vertical Obstacle.

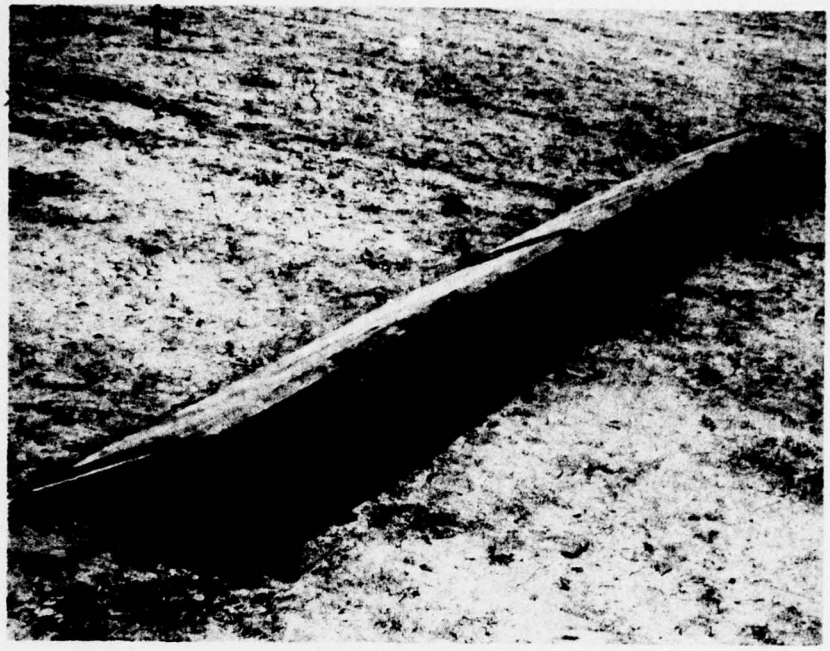


Figure 22 - Eight Inch, 30° Face Angle, Non-deformable, Vertical Obstacle.

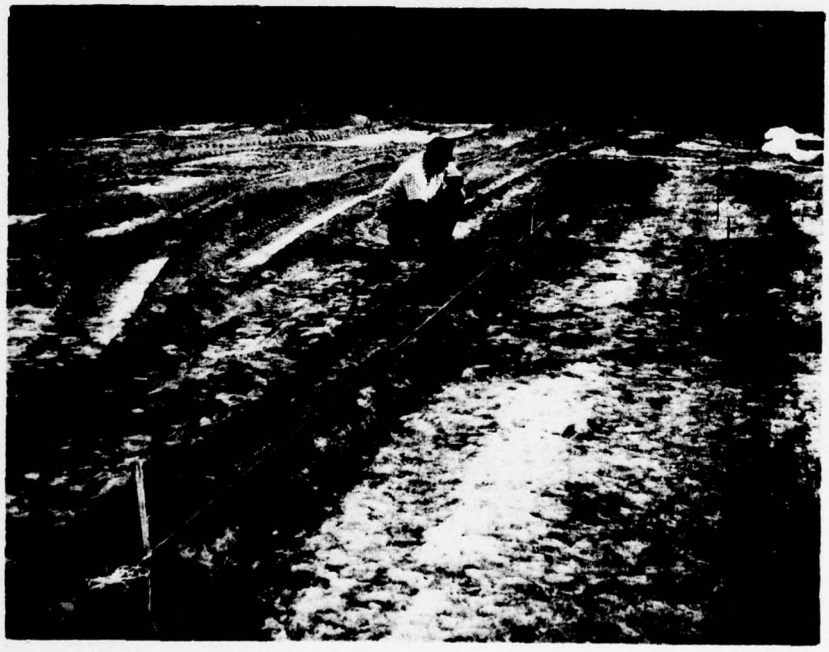


Figure 23 - Four Inch, 30° Face Angle, Deformable, Vertical Obstacle.



Figure 24 - Eight Inch, 30° Face Angle, Deformable, Vertical Obstacle.



Figure 25 - Twenty Inch, 30° Face Angle, Deformable, Vertical Obstacle.



Figure 26 - 18", 20", 22", and 24", 30° Face Angle, Deformable Vertical Obstacles.

discomfort levels:

0. Imperceptible
1. Barely perceptible
2. Distinctly perceptible
3. Slightly disagreeable
4. Disagreeable
5. Unbearable

(after Reiher and Meister, 1931)

From the driver's subjective evaluation, it was found that the human response to shock-impact accelerations could be broken down into segmented curves (Figure 27) very similar to Reiher and Meister's zones of comfort, although the latter comfort levels were approximately 1/10 of the magnitude of the curves

Figure 27

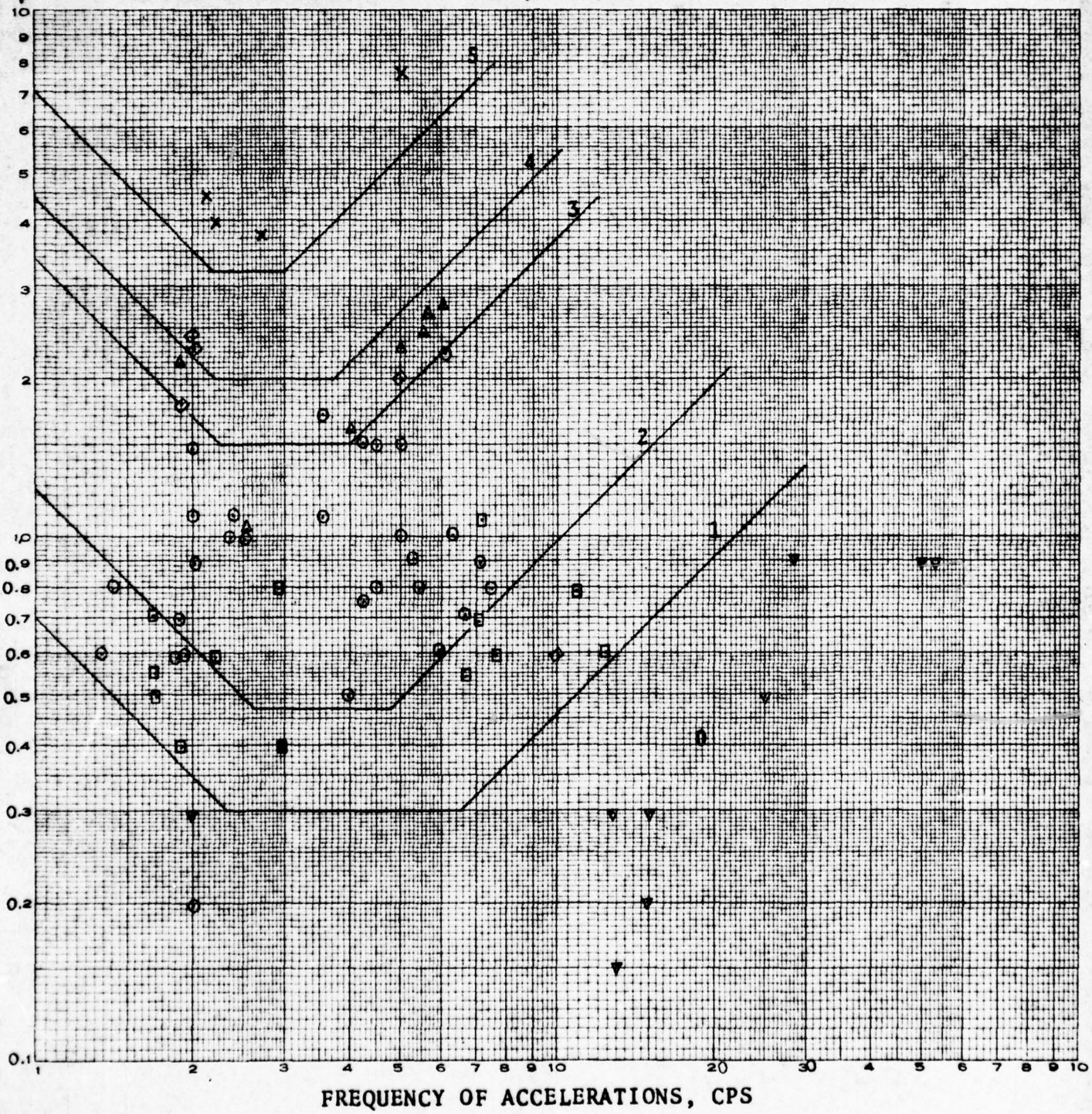
DRIVER RESPONSE

- 0 - Imperceptible -
- 1 - Barely Perceptible -
- 2 - Distinctly Perceptible -
- 3 - Slightly Disagreeable -
- 4 - Disagreeable -
- 5 - Unbearable -

DRIVER TOLERANCE TO VERTICAL ACCELERATION

M37 Truck

All Vertical Obstacle Tests



developed in this test program. This would be expected because they were dealing with low accelerations and low frequencies applied to the subject for an extended length of time (one to three minutes), while this test program dealt with high accelerations and low frequencies applied for a very short period of time (fractions of a second). The lower tolerance levels specified by Reiher and Meister (in comparison to those of this study) indicate that the human tolerance to vertical accelerations decreases as the duration of the accelerations increase.[3]

Vertical accelerations at the driver's seat appeared to be the most useful criterion for driver comfort since neither horizontal accelerations nor jerk (rate of acceleration increase) showed consistent trends. Acceleration alone was relatively meaningless without specification of frequency.

The comfort levels indicated in Figure 27 certainly do not indicate the comfort levels for all drivers. Rather wide deviations were noted for two other drivers. A test program with many individual drivers would be needed to completely substantiate the general comfort levels of most humans for shock-impact accelerations. Figure 27 will serve, though, in giving an appreciation for obstacle severity in the remainder of the discussion. "Safe" acceleration levels have been specified from the valleys of the curves.

Single Non-Deformable Vertical Obstacles

Maximum vertical accelerations varied with the height of the single, non-deformable obstacles and with the speed of the vehicle, but not with the shape of the obstacles used in this study. The latter fact could be attributed to tire deflection.

[3] Reference 16, Bibliography.

Wheel geometry indicated that the rate of change in vertical wheel velocity (acceleration) had to be greater when the vehicle's tire began to move over a larger obstacle at any particular ground speed. An increase in obstacle size from 4 to 8 inches indicates a 90 per cent increase in the initial rate of change of vertical velocity (acceleration) due to rotational and translational motion (Figure 28).

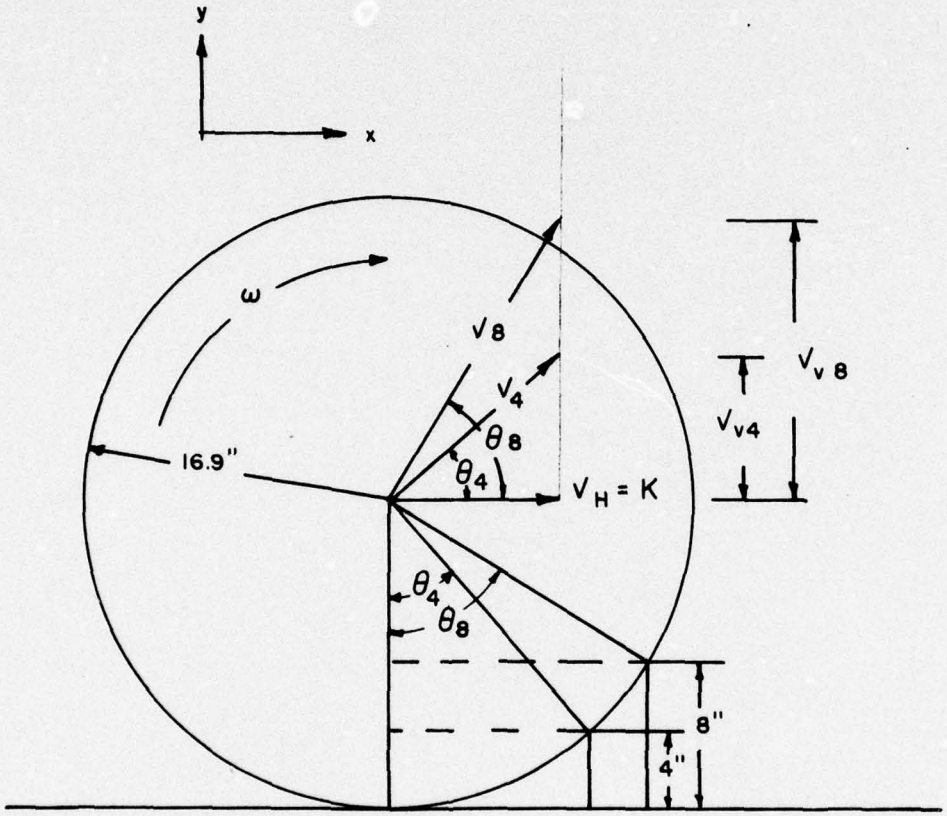


Figure 28. Vertical Wheel Velocity - Obstacle Model

$$\theta_4 = \cos^{-1} \frac{(16.9-4)}{16.9} = 40.4°$$

$$\theta_8 = \cos^{-1} \frac{(16.9-8)}{16.9} = 58.3°$$

$\text{Tan}\theta_4 = 0.851$

$\text{Tan}\theta_8 = 1.62$

$$V_{V4} = V_H \tan \theta_4$$

$$V_{V8} = V_H \tan \theta 8$$

Rate of Increase of Vertical Velocity (8 inch to 4 inch) $= \frac{V_{V8} - V_{V4} \times 100}{V_{V4}} = \frac{\text{Tan}\theta 8 - \text{Tan}\theta 4}{\tan \theta 4} \times 100$

$$= \frac{1.62 - 0.851}{0.851} \times 100 = 90\%$$

where

V_H = Horizontal velocity component of the wheel center of rotation, assumed to be constant.

V_4 and V_8 = The resultant velocity of the wheel center with the top leading edge of the 4 inch and 8 inch obstacle, respectively, taken as the instantaneous center of rotation.

V_{V4} and V_{V8} = Vertical velocity component of the resultant velocity for the 4 inch and 8 inch obstacle, respectively.

This indicates that the force acting upward on the axle should be about 90 per cent greater on the 8 inch obstacle. If tire deflection effects are assumed to be constant, the results (Figure 29) tend to bear this out.

The face length and angle of the slope-faced obstacle was designed such that the face would contain the entire contact surface of the deflected tire, thereby producing the highest possible tire "spring rate". The slope-faced obstacle was 8 inches high with a 30° (from horizontal) face angle which approximates many naturally-occurring surface angles. A corresponding 8 inch vertical-face ("square") obstacle was constructed to produce near-minimum tire "spring rates" by the penetration of the sharp corner into the tire carcass. Statically, tire

Figure 29

VARIATION OF VERTICAL ACCELERATION
WITH SPEED AND OBSTACLE HEIGHT
M37 Truck - Seat
Single Non-Deformable Obstacles
● - 4 inch, square-faced
▲ - 8 inch, 30° sloped-face
x - 8 inch, square-faced
8 inch Obstacles (Square and Sloped)
4 inch Square Obstacle
VERTICAL ACCELERATION (SEAT), G's
VEHICLE VELOCITY, MILES PER HOUR
0
1
2
3
4
5
10
15
20
25
30
35

deflection on a 90° point loading surface is about five times that on a flat surface for a given load. The net result was that tire and spring deflection modulated the severity of the 8 inch square-faced obstacle to the extent that there was no separation in the vertical acceleration data on the basis of shape of the 8 inch obstacles (Figure 29).

Maximum longitudinal accelerations at the driver's seat told a different story. Here, the accelerations on the inch slope-faced obstacle were about four times as great as they were on the 8 inch square obstacle (Figure 30). To the eye, the sloped obstacle appeared to be less critical -- and the results were mysterious. There was, however, an explanation. All the vertical components of accelerations were absorbed through both tire deflection and the suspension system of the vehicle. Longitudinal accelerations, therefore, reflect the effects of tire deflection only, and tire deflection on the square obstacle should be about five times as great as on the slope-faced obstacle. The additional tire deflection on the square obstacle apparently modulated longitudinal accelerations by something near this amount.

Tire deflections were small on the sloped 8 inch obstacle, and the slope replaced tire deflection as a modulator of vertical accelerations (to be substantiated later). Therefore, the unmodulated longitudinal forces were transmitted through the longitudinally rigid suspension system to the vehicle frame without benefit of appreciable tire deflection. Longitudinal accelerations of the axle were less for the 8 inch square obstacle than for the 8 inch sloped one. The difference between the seat longitudinal acceleration curves (about 4:1) as a matter of fact, was of the same order of magnitude as the computed difference in equal-load tire deflection on flat and 90° pointed surfaces, (about 5:1) indicating little modulation from the suspension system.

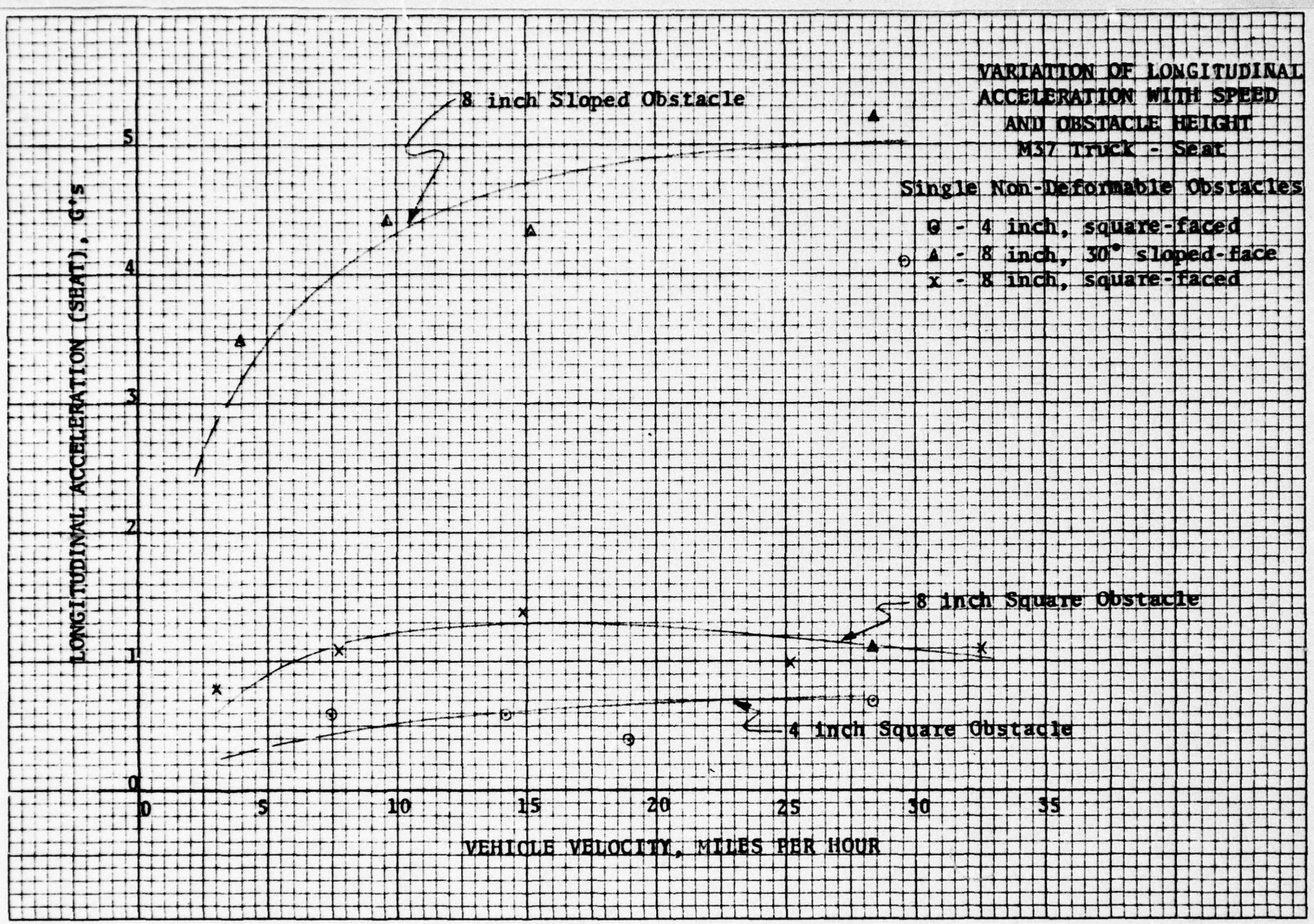

VARIATION OF LONGITUDINAL ACCELERATION WITH SPEED AND OBSTACLE HEIGHT
M37 Truck - Seat
Single Non-Deformable Obstacles
⊙ - 4 inch, square-faced
▲ - 8 inch, 30° sloped-face
x - 8 inch, square-faced
8 inch Sloped Obstacle
8 inch Square Obstacle
4 inch Square Obstacle
LONGITUDINAL ACCELERATION (SEAT), G's
VEHICLE VELOCITY, MILES PER HOUR
0
1
2
3
4
5
0
5
10
15
20
25
30
35

Figure 30

By examination of the attenuation of accelerations between those felt by the axle and corresponding accelerations at the driver's seat, (Ratio of Seat Acceleration to Axle Acceleration) the effects of longitudinal suspension system rigidity can be seen again. Figure 31B (lower curve) indicates that vertical accelerations were modulated by the suspension system which absorbed over half the acceleration received by the axle. This curve further verifies the fact that the 30° face slope was a satisfactory substitute for tire deflection on the square obstacle. It has been shown that the absolute magnitudes of the seat accelerations must be proportional, making them independent of shape as well.

Figure 31A is more difficult to understand since longitudinal accelerations were reduced somewhere between the axle and the seat when crossing the 8 inch square obstacle, but were magnified by the 8 inch slope-faced obstacle. Longitudinal accelerations at the axle were some 20-30 per cent higher on the sloped obstacle. There are too many unknowns to be certain whether or not the increased axle accelerations on the slope-faced obstacle were the sole cause of the magnified seat accelerations. This magnification must go unexplained for the time being. At any rate, it seemed reasonable that longitudinal stiffness of the suspension system contributed significantly to the recorded accelerations when crossing the slope-faced obstacles.

As would be expected, longitudinal accelerations between 4 and 8 inch square obstacles (Figure 30) exhibited about the same order of difference as the vertical accelerations. The similarities of tire and suspension behavior modes are evident.

It would be hazardous, at this point, to attempt to generalize the wheeled vehicle results. Broadly, however, for vertical-

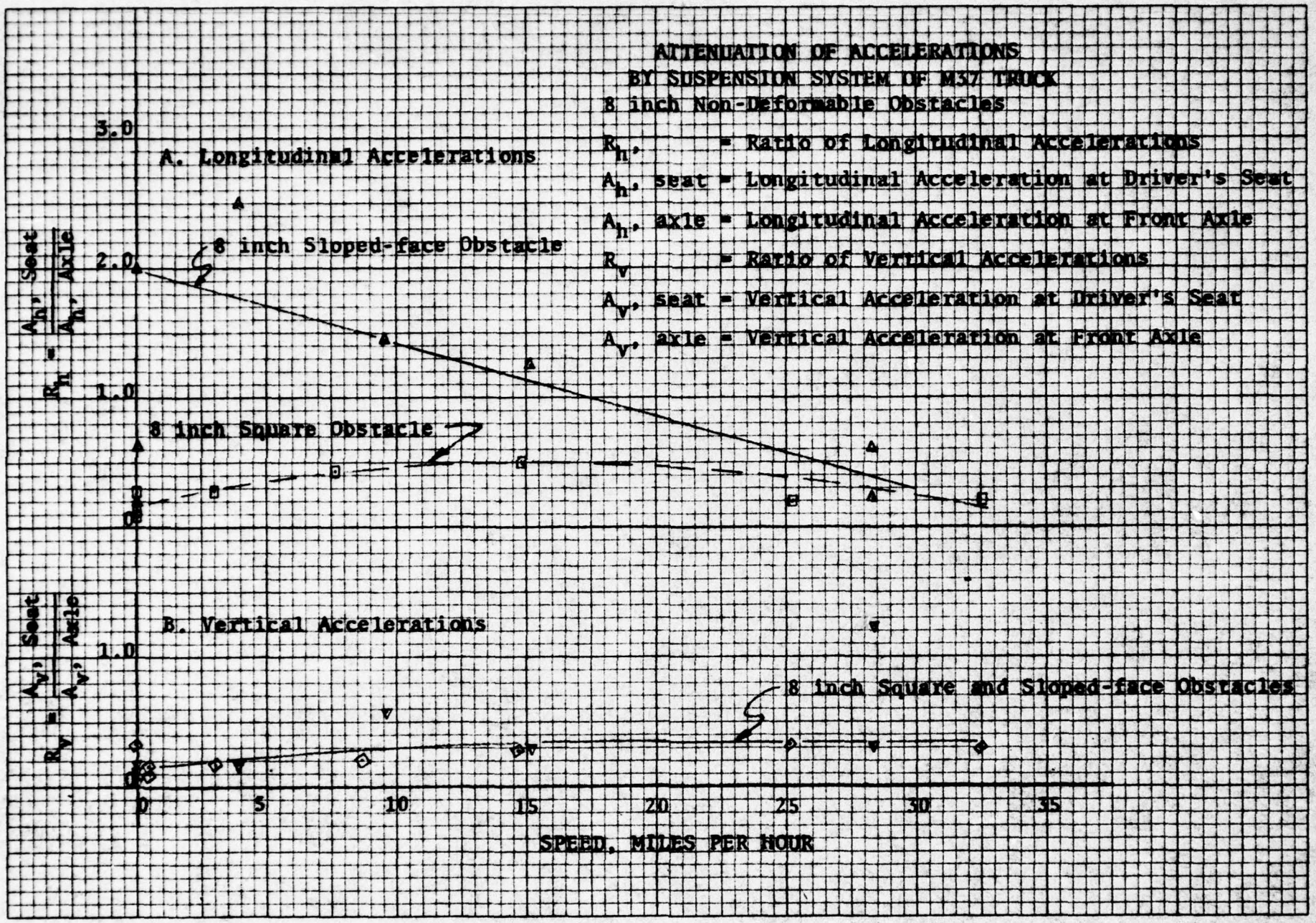

ATTENUATION OF ACCELERATIONS
BY SUSPENSION SYSTEM OF M37 TRUCK
8 inch Non-Deformable Obstacles
R_h, = Ratio of Longitudinal Accelerations
A_h, seat = Longitudinal Acceleration at Driver's Seat
A_h, axle = Longitudinal Acceleration at Front Axle
R_v = Ratio of Vertical Accelerations
A_v, seat = Vertical Acceleration at Driver's Seat
A_v, axle = Vertical Acceleration at Front Axle
A. Longitudinal Accelerations
8 inch Sloped-face Obstacle
8 inch Square Obstacle
$R_h = \frac{A_h, \text{Seat}}{A_h, \text{Axle}}$
3.0
2.0
1.0
B. Vertical Accelerations
8 inch Square and Sloped-face Obstacles
$R_v = \frac{A_v, \text{Seat}}{A_v, \text{Axle}}$
1.0
0
5
10
15
20
25
30
35
SPEED, MILES PER HOUR

Figure 31

faced obstacles, any vehicle/obstacle combination whose wheel diameter to obstacle height ratio were the same and whose suspension system, mass, and speed constitute a dimensionally-correct scaled model system (either larger or smaller) should experience the same accelerations. Slope-faced obstacles will not produce accelerations in proportion to their height unless the face angle is large enough to appear to the tire as a square obstacle, and will be a function of face angle below the critical angle.

A limited number of tests were also conducted on the M29C Weasel in which accelerations were measured only at the driver's seat. Both vertical and longitudinal accelerations on the 4 inch "square" obstacles corresponded closely to those of the M37. Vertical accelerations from crossing the 8 inch obstacles, though, showed significant differences. Both the square-faced and sloped-face 8 inch obstacles were contacted on the top corner first and there was a slight interference with the front idler. It is about 7-1/4 inches from the ground to the bottom of grousers on the track beneath the idler. Initial contact with both the larger obstacles produced an immediate uplift of the vehicle. Maximum accelerations were recorded at this point. Thus no inference concerning the effect of obstacle shape on induced vehicle accelerations could be made for the M29C (Figure 32).

Vertical accelerations were distinctly different for the 4 and 8 inch obstacles. Those recorded for the larger obstacles were significantly higher than those for the M37 at similar speeds, reflecting the relative "hardness" of the front idler in the vertical plane. The Weasel also pitched more violently at least partially because of its relatively shorter "wheelbase", further aggravating the vertical accelerations.

Figure 32

VARIATION OF VERTICAL ACCELERATION
WITH SPEED AND OBSTACLE HEIGHT
M29C Weasel - Seat
Single Non-Deformable Obstacles
● - 4 inch, square-faced
▲ - 8 inch, 30° sloped-face
x - 8 inch, square-faced
4 inch Square Obstacle
VERTICAL ACCELERATION (SEAT), G's
VEHICLE VELOCITY, MILES PER HOUR
0
1
2
3
4
0
5
10
15
20
25

The unsupported length of track between the front idler and the front road wheel modulated the longitudinal acceleration (Figure 33) in much the same manner as it did the vertical acceleration. The longitudinal acceleration from the 8 inch obstacles also reflect - to some unknown degree - the front idler interference discussed previously.

Multiple Non-Deformable Vertical Obstacles

The multiple-obstacle test courses consisted of 4 of the 4 inch square-faced obstacles. The vehicles were run at a wide range of speeds at each of the three different obstacle spacings. The spacings were chosen so that no two obstacles would be contacted by front and rear wheels (M37) at the same time, and thus the test courses were specifically designed to be pitch-inducing (thought to be the most frequent-occurring disturbance mode). Figure 34 (all 4 inch square obstacles) indicates that there was no appreciable difference in recorded vertical accelerations at any of the spacings. Single obstacle accelerations have been included for reference and fall within the scatter band of the multiple obstacle accelerations. Some accelerations were definitely more disconcerting to the driver, however, depending upon their frequency. The critical range appeared to be about 2 to 5 cycles per second (Figure 27) for the vertical acceleration range 0.5 to 1.0 G's. This was apparently the second harmonic of the resonant pitch frequency of the vehicle (approximately 1.7 cps[4]),[5]

[4] Assuming

(1) Pitch motion occurs about a line midway between the axles
(2) Weight uniformly distributed throughout vehicle length
(3) Spring rate to be 325 lb. per inch
(4) Radius of gyration about center of rotation to be 54.2 inches
(5) Vehicle weight = 7800 pounds.

[5] Reference 28, Bibliography.

Figure 33

VARIATION OF LONGITUDINAL ACCELERATION
WITH SPEED AND OBSTACLE HEIGHT
M29C Weasel - Seat
Single Non-Deformable Obstacles
⊖ - 4 inch, square-faced
▲ - 8 inch, 30° sloped-face
x - 8 inch, square-faced
LONGITUDINAL ACCELERATION (SEAT), g's
VEHICLE VELOCITY, MILES PER HOUR
8 inch Obstacles (Square and Sloped)
4 inch Square Obstacle
0
1
2
3
4
5
0
5
10
15
20
25

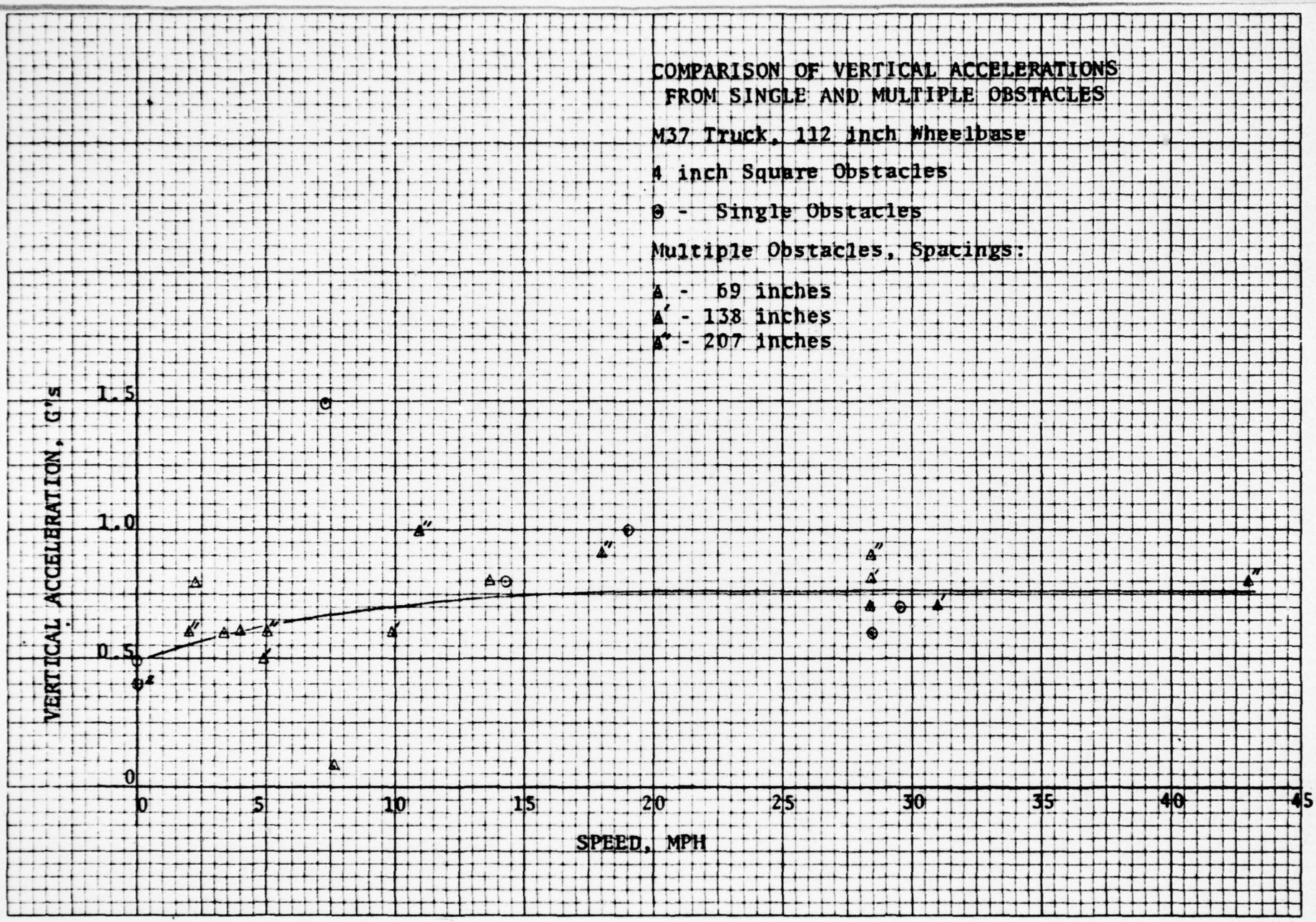

COMPARISON OF VERTICAL ACCELERATIONS
FROM SINGLE AND MULTIPLE OBSTACLES
M37 Truck, 112 inch Wheelbase
4 inch Square Obstacles
⊖ - Single Obstacles
Multiple Obstacles, Spacings:
Δ - 69 inches
Δ' - 138 inches
Δ'' - 207 inches
VERTICAL ACCELERATION, G's
1.5
1.0
0.5
0
0
5
10
15
20
25
30
35
40
45
SPEED, MPH

Figure 34

which just happens to be near vertical resonance of human abdominal organs (visceral resonance).

Vibrations in the vertical plane were induced by single obstacles as well as multiple obstacles. Unless the encounter frequency of multiple obstacles happened to match one of the fundamentals of the apparent M37 resonant pitch frequency, there was little change from the "single obstacle" driver reaction. A critical reaction occurred once during the M37 tests when crossing the 138 inch-spaced obstacles at 9.8 miles per hour, indicating an acceleration frequency of 10 cycles per second (cps) at the driver's seat from an induced frequency of bump encounter of 2.0 cps (an approximate harmonic of 10 cps). A similar condition was encountered when the M29C Weasel crossed the same obstacle spacing at 8.4 miles per hour. This produced a vertical acceleration frequency at the driver's seat (2.7 cps) which nearly matched that of the induced frequency (2.2 cps).

Single Deformable Vertical Obstacles

The vertical acceleration at the driver's seat of the M37 were also found to vary with the strength of single deformable obstacles. A series of obstacles were constructed of soil at various strengths. Heights selected were 4, 8 and 20 inches and Cone Indexes (mass strength) varied from 55 to 475. All had a 30° face angle, were 12 inches across the top and had 45° departure angles. By acceptance of some scatter, all data could be collapsed to a single curve (Figure 35) by dividing A_V by hV, where

A_V = Maximum vertical acceleration at driver's seat, G's

h = Obstacle height, ft.

V = Velocity of vehicle, ft. per second

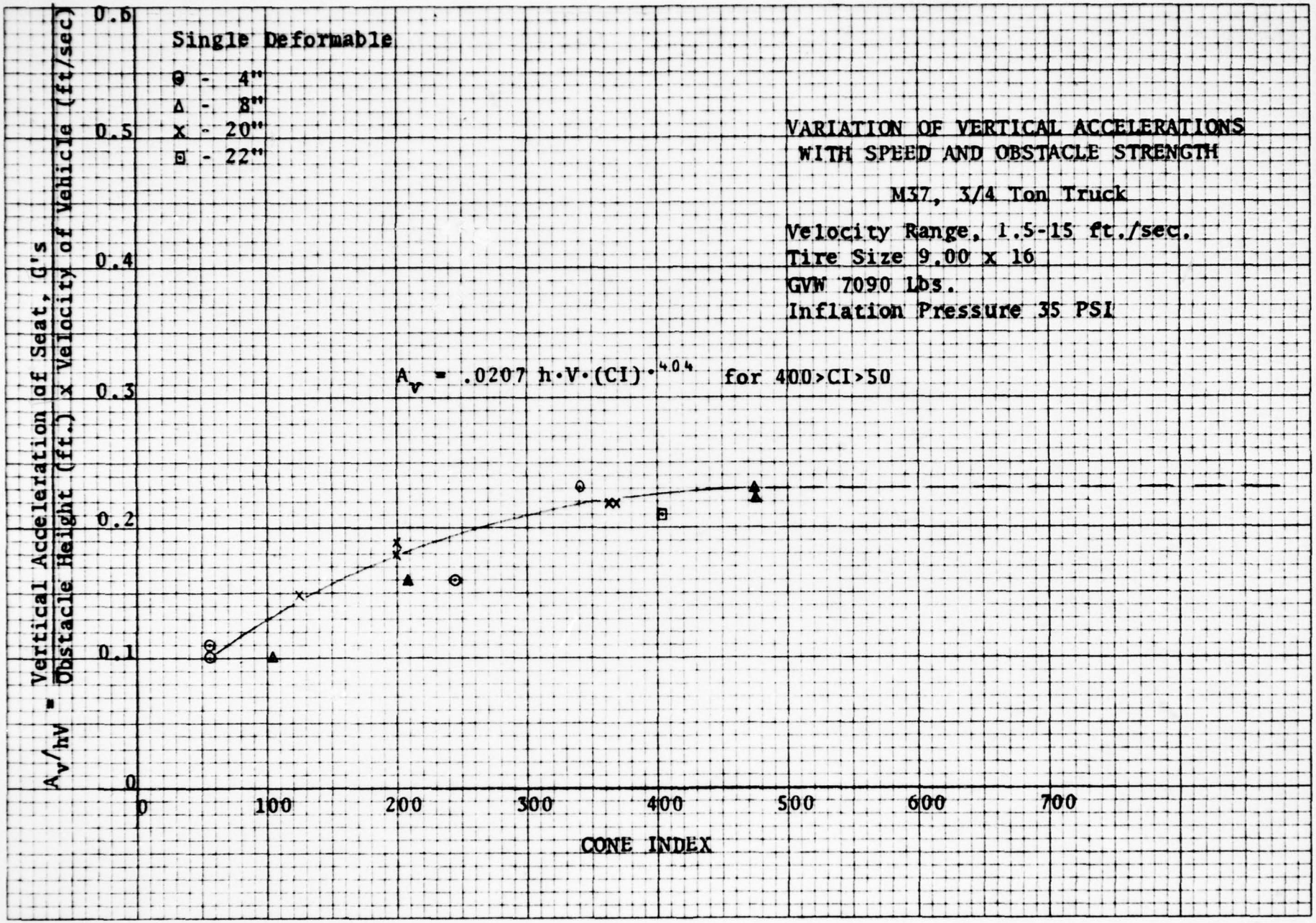

Single Deformable
Θ - 4"
Δ - 8"
X - 20"
E - 22"
VARIATION OF VERTICAL ACCELERATIONS
WITH SPEED AND OBSTACLE STRENGTH
M37, 3/4 Ton Truck
Velocity Range, 1.5-15 ft./sec.
Tire Size 9.00 x 16
GVW 7090 Lbs.
Inflation Pressure 35 PSI
$A_v = .0207\ h \cdot V \cdot (CI)^{.404}$ for 400>CI>50
A_v/hV = Vertical Acceleration of Seat, G's / Obstacle Height (ft.) x Velocity of Vehicle (ft/sec)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
700
CONE INDEX

Figure 35

For the M37 vehicle, therefore, A_V can be computed in terms of the strength (Cone Index) and height of the obstacle and the speed of the vehicle:

for $400 > CI > 50$; $15 > V > 1.5$ fps; h in ft.; A_V in G's

$$A_V = 0.0207\ hV\ (CI)^{0.404} \qquad \text{Eqn. (6)}$$

The equation is highly restrictive, serving merely to order the influence of only those variables included in these tests. The speed of the vehicle was varied only from 1 to 10 miles per hour, and the developed relation is not necessarily valid at higher speeds. Different face angles of the obstacle could affect obstacle deformation, and thus the energy absorbed by the obstacle, though shape has been shown to be a second-order influence.

The strength of the obstacle was no longer of importance to the M37 truck at rated cross-country payload and tire inflation pressure (7090 GVW and 35 psi -- 9.00 x 16 tires) once the Cone Index reached 400. If such a curve could be defined in terms of all vehicle parameters which influence vertical accelerations, it would be extremely useful since Cone Index data has been compiled from many geographic areas and supplementary data could be readily collected.

Vertical obstacle strength definitely has an influence on the maximum size which can be negotiated by a wheeled vehicle. The M37 truck crossed a high strength obstacle with little undercarriage interference, (obstacle height-vehicle ground clearance) but could not cross somewhat softer obstacles having more interference (Figure 36). A trend in negotiable size/strength was apparent, but the exact relationship could not be well defined in a general sense. However, the critical obstacle height and

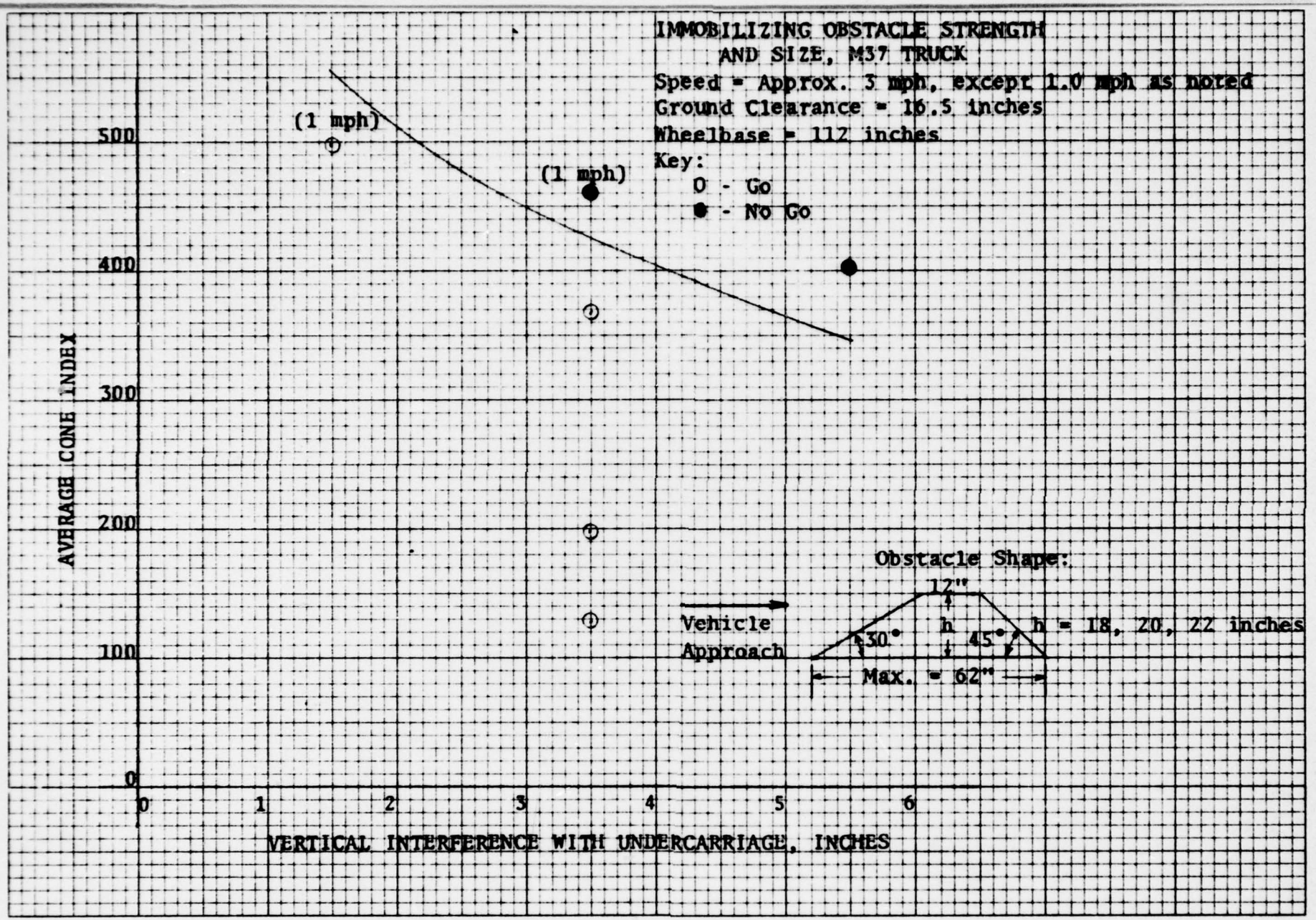

IMMOBILIZING OBSTACLE STRENGTH AND SIZE, M37 TRUCK
Speed = Approx. 5 mph, except 1.0 mph as noted
Ground Clearance = 16.5 inches
Wheelbase = 112 inches
Key:
O - Go
● - No Go
(1 mph)
(1 mph)
AVERAGE CONE INDEX
500
400
300
200
100
0
0
1
2
3
4
5
6
VERTICAL INTERFERENCE WITH UNDERCARRIAGE, INCHES
Obstacle Shape:
12"
Vehicle Approach
30°
h
45°
h = 18, 20, 22 inches
Max. = 62"

Figure 36

strength for the M37 may be estimated from Figure 36 for similarly-shaped obstacles.

A theory could be developed relating the maximum negotiable obstacle size to vehicle speed and physical characteristics, obstacle height and shearing strength of the obstacle material and surrounding soil. The assumptions required to produce a solution, appear to be conducive to misleading inaccuracies. However, a series of tests could be designed around these assumptions which would give some insight into the nature of the failure mechanism and would have reasonable hope of success. The limited data and time frame of this program did not permit such an analysis to be made.

Tractive Effort Requirements - Vertical Obstacles

Average tractive effort required, at essentially zero speed, to surmount all vertical obstacles used in these tests proved to be essentially independent of obstacle size and shape (Figure 37). At speeds greater than 0 mph, the tractive effort recorded was the tractive effort necessary to maintain speed (See VIII A3, page VI-25). For the M37, the tractive effort fell off rapidly from about 1400 to about 250 pounds as speed increased from 0 to 3 miles per hour. Tractive effort requirements to cross vertical obstacles were apparently replaced with vehicle momentum by increasing vehicle speed some unknown amount. The time-duration of peak tractive effort requirements would have to be evaluated before a rationale could be established. The nature of the data is such that this must remain merely an undefined postulate for the moment. Had it been possible to sensibly integrate the wildly varying torque oscillograms over the course, more definitive relations might have been obtained. The trend toward higher tractive effort at higher speeds reflected the greater tractive effort required to

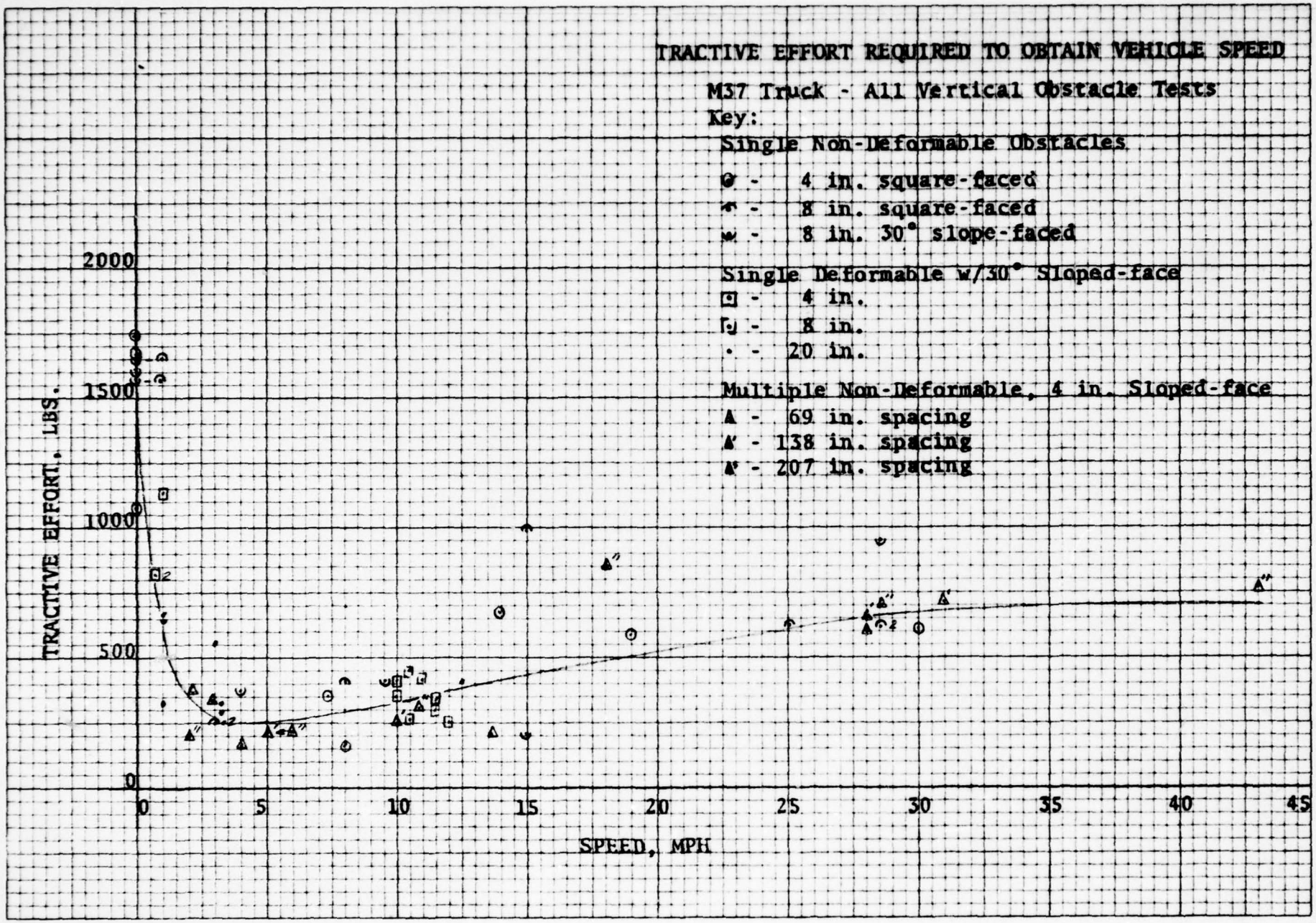

TRACTIVE EFFORT REQUIRED TO OBTAIN VEHICLE SPEED
M37 Truck - All Vertical Obstacle Tests
Key:
Single Non-Deformable Obstacles
- 4 in. square-faced
- 8 in. square-faced
- 8 in. 30° slope-faced
Single Deformable w/30° Sloped-face
- 4 in.
- 8 in.
- 20 in.
Multiple Non-Deformable, 4 in. Sloped-face
- 69 in. spacing
- 138 in. spacing
- 207 in. spacing
TRACTIVE EFFORT, LBS.
2000
1500
1000
500
0
0
5
10
15
20
25
30
35
40
45
SPEED, MPH

Figure 37

maintain vehicle speed.

The M29C Weasel showed the same central tendency toward a reduction in tractive effort as speed increased, but continued this trend, uninterrupted, to 700 pounds at the top speed of 20 miles per hour (Figure 38). The Weasel data did not show the abrupt drop in tractive effort at lower speeds as was observed for the M37. There was no separation of data for obstacle shape, though the 8 inch non-deformable obstacles displayed a slight tendency toward higher tractive effort requirements at near zero speeds for larger obstacles.

In the case of both vehicles, tractive effort requirements were highest when the obstacles were crossed from a standing start. Average tractive efforts at zero speed were 1390 lbs. for the M37 and 1360 lbs. for the Weasel. Had the strength of the soil been less than these values, any of the obstacles would have immobilized the vehicles unless the obstacles could have been approached at speed.

Maximum tractive effort can be computed with reasonable accuracy with easily obtained soil surface shearing strength measurements. The critical strength level appears now to be that required to permit acceleration of the vehicle since nominal speeds replace rather large amount of tractive effort required to negotiate vertical obstacles.

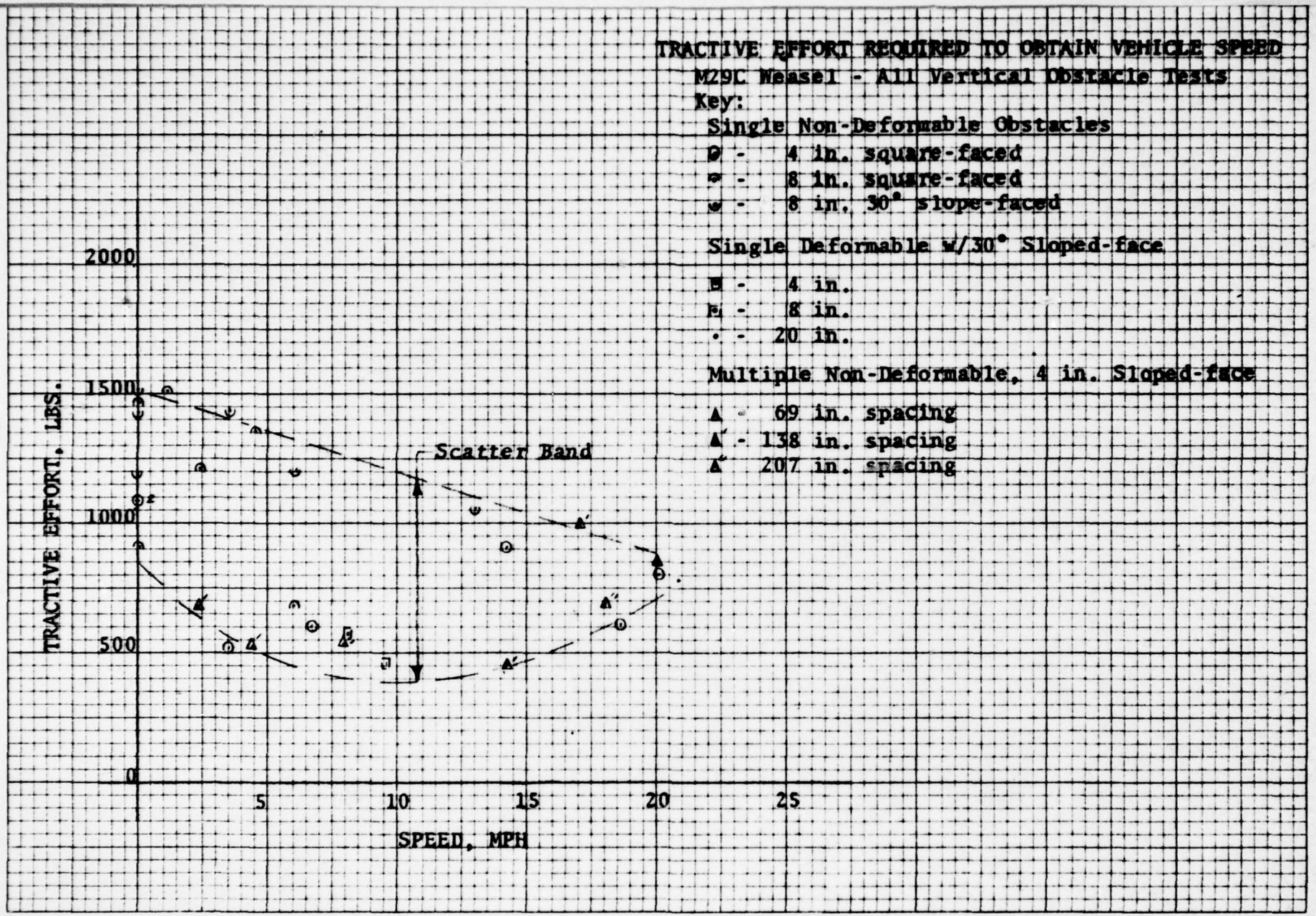

TRACTIVE EFFORT REQUIRED TO OBTAIN VEHICLE SPEED
M29C Weasel - All Vertical Obstacle Tests
Key:
Single Non-Deformable Obstacles
- 4 in. square-faced
- 8 in. square-faced
- 8 in. 30° slope-faced
Single Deformable w/30° Sloped-face
- 4 in.
- 8 in.
- 20 in.
Multiple Non-Deformable, 4 in. Sloped-face
- 69 in. spacing
- 138 in. spacing
- 207 in. spacing
Scatter Band
TRACTIVE EFFORT, LBS.
2000
1500
1000
500
0
5
10
15
20
25
SPEED, MPH

Figure 38

General Remarks

An obstacle of less-than-critical height with a face angle less than 90° can be negotiated by both vehicles, M37 and M29C, by disregarding possible destruction of truck and driver and by striking an obstacle at a high rate of speed. The vehicle will tend to "launch" itself over the obstacle as illustrated in Figure 39. Obstacles with a face angle of 90° can be negotiated by both vehicles, M37 and M29C, as long as the height is less than one-half the diameter of the tire or the height of the center of the front idler providing an adequate traction surface is present.

If the criterion for maximum speed is the approach of the minimum threshold of "slightly disagreeable" vertical accelerations, as defined by Figure 27, the limiting speeds for the test vehicles can be determined as in Table 3, page 76.

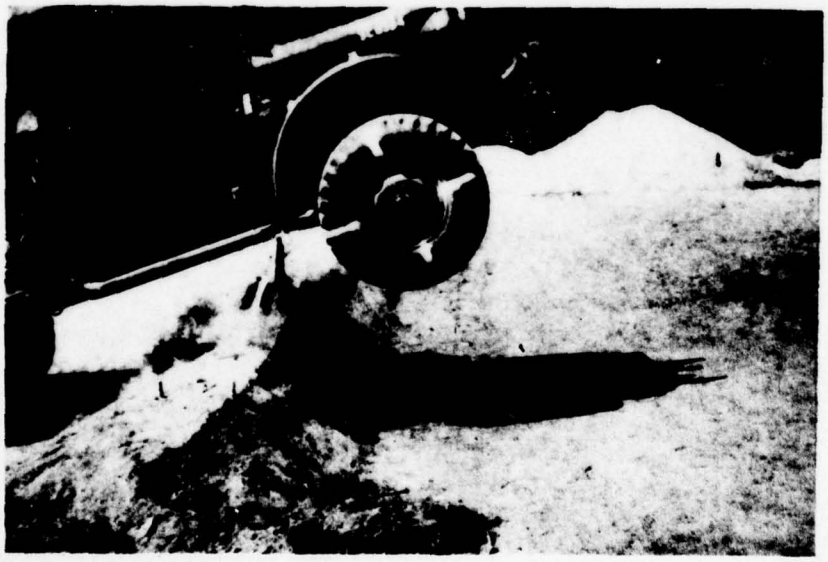


Figure 39 - M37 "launching" Itself Over a 20 Inch, 30° Face Angle, Obstacle at 10 mph.

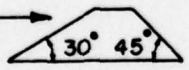
The limit was not exceeded by either vehicle in crossing the 4 inch single obstacle.

It appears, then, that sub-critical vertical obstacle sizes and strengths present no particular difficulties to the vehicles unless the dominant obstacle encounter frequency happens to coincide with the resonant frequency (or harmonic thereof) of a mode of vehicle motion or unless traction is critically low.

TABLE 3 - ESTIMATED MAXIMUM VEHICLE SPEEDS AT A MAXIMUM VERTICAL ACCELERATION OF 1.5 G's

Obstacle Size Obstacle Shape[2]	4 B	8 A	8 B	20[1] A	4 B[3]
Est. Max. Speed @ A_V[4] = 1.5 G					
M37	>30[5]	8	8	3	>43[5]
M29C	>20[5]	2	2	2[6]	--

(1) Computed from equation 6 at Cone Index = 400.

(2) A: →  B: →  Arrows indicate direction of vehicle motion.

(3) Multiple obstacles.

(4) Maximum vertical acceleration = 1.5 G's, taken at threshold of "Slightly Disagreeable", Figure 27.

(5) Limit not exceeded at highest speed.

(6) Implied

Attempts to collapse all acceleration data fron non-deformable obstacles to a function of obstacle size and vehicle velocity failed, probably because of the neglect of vehicle suspension parameters. The vertical acceleration numeric was most nearly constant, when acceleration was divided by obstacle height to the first power and vehicle velocity to the 0.404 power. This indicates that increases in velocity are most critical at slower speeds and the shapes of almost all acceleration/speed curves support this general hypothesis.

Vertical accelerations were usually incurred from pitch rather than bounce (by observation of vehicle motions). Therefore, driver comfort could be enhanced by locating him (passengers and/or cargo as well) as near the center of the vehicle's wheelbase and as low in the vehicle as practical considerations will allow, isolating him from pitch-induced vertical accelerations.

SUMMARY OF RESULTS

Driver Tolerance to Accelerations

1. Driver tolerance to vertical accelerations (short time-duration of exposure) took the form of classical curves (applicable to longer time-durations) but indicated accelerations some 10 times higher for "equal" comfort levels.

2. Minimum tolerance to vertical accelerations occurred in 2-6 cycle per second range, near human visceral resonance.

3. The minimum "disagreeable" vertical acceleration, as measured below the driver's seat and cushion, was 1.5 G's, and tolerance to acceleration at the same comfort level increased as frequency was reduced below 2.3 cycles per second or increased above 4 cycles per second.

Single Non-Deformable Vertical Obstacles

1. When obstacle height was increased from 4 to 8 inches, M37 truck vertical accelerations measured beneath the driver's seat increased by a factor of about two, but the relationship will not necessarily be true for other obstacle or vehicle sizes.

2. Increase in vertical acceleration at the M37 driver's seat when crossing the 8" obstacle was calculated to be a 90 per cent increase because of the obstacle height increase and the effects of wheel rotation and translation.

3. It was surmised that tire deflection incurred when crossing the 8 inch square-faced obstacle had the same effect on modulation of maximum vertical accelerations at the driver's seat as did the 30° slope of the sloped-face 8 inch obstacle which allowed minimal tire deflection.

4. Maximum longitudinal accelerations at the driver's seat of the M37 were about 4 times as large on the 8 inch sloped-face obstacle as on the 8 inch square obstacle and probably reflected the longitudinal stiffness of the suspension system.

5. Maximum longitudinal accelerations at the M37 driver's seat showed the same order of difference between 4 and 8 inch square obstacles as did the vertical accelerations.

6. The front idler of the M29C Weasel contacted the top corner of both the sloped and square obstacles first; thus, no inference concerning the effect of obstacle shape on induced vehicle accelerations could be made for this vehicle.

7. Increasing obstacle height from 4 to 8 inches produced about a 2 to 1 increase in longitudinal acceleration of the Weasel driver's seat, and as much as 9 to 1 increase in vertical accelerations (see 6, above).

Multiple Non-Deformable Vertical Obstacles

1. Vertical acceleration of the M37 driver's seat (below cushion) varied between 0.5 and 1.0 G's between speeds of 0 and 43 mph when crossing the 4 inch obstacles at all spacings.

2. Induced frequencies of 2.6 cps for the M37 and 2.2 cps for the M29C evoked critical driver reactions.

Single Deformable Vertical Obstacles

1. The deformable vertical obstacle used in the tests which was 3.5 inches higher than the M37 ground clearance (center of the vehicle) became immobilizing at a Cone Index of just over 400.

2. The vertical acceleration of the M37 seat for deformable obstacles can be predicted with the following equation:

$$A_v = 0.0207\, h\, V\, (CI)^{0.404} \qquad \text{Eqn. (6)}$$

for $400 > CI > 50$ and $15 \text{ fps} > V > 1.5 \text{ fps}$

where

A_v = Vertical acceleration at seat, G's

h = Obstacle height, ft.

V = Vehicle velocity, ft. per sec.

CI = Average Cone Index

Tractive Effort Requirements - Vertical Obstacles

1. Average tractive effort required at near zero speeds for the M37 truck to negotiate the vertical obstacles was independent of obstacle size or shape. The average tractive effort required at near zero speeds for the M37 truck to negotiate the vertical obstacles was 1390 pounds.

2. Average tractive effort required at near zero speeds for the M29C Weasel to negotiate the vertical obstacles in these tests was 1360 pounds.

CONCLUSIONS

LATERAL OBSTACLE (MANEUVER) TESTS

1. The maximum permissible speed of the test vehicles coursing through lateral obstacle arrays was accurately defined in terms of the ratio of mean obstacle spacing and vehicle width.

2. "Immobilizing" lateral obstacle spacing was specified in terms of vehicle width, but the "no-effect" spacing could not be defined simply.

3. The statistical sampling technique for mean obstacle spacing was found to be practicable in the field.

4. Mean spacing of the vegetation, in relation to vehicle width, was found to be a sensitive indicator of permissible vehicle speed.

5. Relative steering power requirements became more critical in closely-spaced lateral obstacle arrays in spite of the necessarily reduced vehicle speeds.

LONGITUDINAL OBSTACLE (SINGLE TREE OVERRIDE) TESTS

1. Maximum override force and override work could be approximated in terms of diameters of Pine and Oak trees pushed over in these tests.

2. The maximum tree size which was pushed over could be estimated in terms of the available tractive effort.

3. Maximum tractive effort predictions made with the Sheargraph agreed well with measured tractive efforts at immobilization.

4. Tree penetrometer readings did not correlate with bending strength of trees.

5. It appeared possible to develop relations between tree size (height and/or diameter) and the motion resistance imposed upon vehicles, allowing speed predictions to be made.

LONGITUDINAL OBSTACLE (MULTIPLE OVERRIDE) TESTS

1. The resistance to overriding multiple stems is greater than the sum of the overriding resistance of individual stems.

2. The exact nature of the interference factor relating override resistance of trees in single and multiple array could not be specified from these tests.

VERTICAL OBSTACLE (SURFACE GEOMETRY) TESTS

Driver Tolerance

1. Driver response in terms of comfort levels could be specified for the test driver, for all vertical obstacles, in terms of the magnitude and frequency of vertical accelerations measured under the driver's seat.

2. Minimal tolerance to vertical acceleration occurred near the human visceral resonant frequency (about 7 cps).

3. Vertical acceleration at the driver's seat appeared to be a better criterion of comfort than longitudinal acceleration or jerk.

4. The results obtained for a single driver's tolerance to acceleration should not be applied to all drivers.

Single Non-Deformable Vertical Obstacles

1. Maximum vertical acceleration varied with the height of single, non-deformable vertical obstacles and with the speed of the vehicle, but not with the shape of the obstacles used in this study.

2. Maximum longitudinal accelerations exhibited generally lower magnitudes and about the same proportionality as vertical accelerations with respect to obstacle size, but were hypersensitive to obstacle shape.

3. It was surmised that tire deflection modulated vertical accelerations on the square-faced vertical obstacles to nearly the same extent as did the slope of the slope-faced obstacle.

4. The lack of suspension flexibility in the longitudinal plane led to extremely high longitudinal accelerations from the slope-faced vertical obstacle.

5. There were no discernible differences in vertical accelerations of the Weasel on either the sloped or square large obstacles, apparently because the front idler contacted the top corner of the obstacle first.

6. Increasing obstacle height produced marked increases in both vertical and longitudinal accelerations at the Weasel driver's seat.

7. Vertical accelerations of the Weasel were distinctly larger than those of the M37.

8. Obstacles contacting the Weasel track in the unsupported length between the front idler and the first road wheel were cushioned by the resiliency of the track.

9. As a general rule incremental increases in speed of either vehicle produced smaller relative increases in the recorded accelerations.

Multiple Non-Deformable Vertical Obstacles

1. Variations in obstacle spacings produced no appreciable differences in recorded vertical accelerations of the M37 truck.

2. Vertical accelerations over the multiple obstacle course were similar in magnitude to those for the same obstacle alone when crossed at the same speed.

3. Those obstacle spacing/vehicle speed combinations which produced pitch resonance of the vehicle caused the greatest driver discomfort.

Single Deformable Vertical Obstacles

1. Maximum vertical accelerations at the M37 driver's seat increased linearly with obstacle height and with the 0.404

power of obstacle strength (Cone Index).

2. Maximum negotiable vertical obstacle size increased when obstacle strength decreased.

3. It appears possible to write a tentative equation to relate the maximum negotiable obstacle to vehicle speed and physical characteristics, obstacle height and shearing strength of the obstacle material and surrounding soil.

Tractive Effort Requirements - Vertical Obstacles

1. Tractive effort required, at near zero speeds, to negotiate the vertical obstacles was essentially independent of the sizes and shapes used.

RECOMMENDATIONS

LATERAL OBSTACLE (MANEUVER) TESTS

1. There is a wealth of data presently available from this and other tests which are applicable to performance predictions in multiple terrain factors. These predictions should be made.

2. Subsequent data have indicated that the relation developed herein between vehicle speed and obstacle spacing doesn't apply to all vehicles; therefore, additional tests should be conducted to account for vehicle specific power, steering response time, and swept width.

3. Analytical relations regarding the possible interaction of vehicle variables with lateral obstacle spacing should be defined immediately in order to assess other MERS-acquired terrain data.

LONGITUDINAL OBSTACLE (SINGLE TREE OVERRIDE) TESTS

1. Additional override tests should be conducted in order to determine a more explicit definition of the relation between override work and tree diameter because override work can take on large variations with small variations in tree diameter measurements.

2. Additional override tests should be conducted on a wider variety of tree species to determine the dependence (or independence) of species and override work and force.

3. In combination with spacing and size distribution hypotheses and soil and vehicle parameters, the framework should be established for prediction of vehicle speed through longitudinal obstacles.

4. A special study should be undertaken to thoroughly investigate the effects of soil strength on the force required to override trees.

5. Any future override test program should include a variable-height pushbar to determine its effect on maximum override force.

LONGITUDINAL OBSTACLE (MULTIPLE OVERRIDE) TESTS

1. Additional tests which would consider a wider range of mean tree spacings and stem diameters are required for definition of the interference factor.

VERTICAL OBSTACLE (SURFACE GEOMETRY) TESTS

Driver Tolerance

1. Additional study is needed on human tolerance to accelerations, (immediate and long-term) both vertical and longitudinal, when magnitude, duration, frequency and time of exposure can be varied within wide limits.

Single Non-Deformable Vertical Obstacles

1. Since the dynamics of tire deflection are not well known, supplementary information is needed for any further tests and/or evolution of theory.

2. Single non-deformable vertical obstacles are instructive in understanding the interaction of obstacles with vehicular ground contacting elements, but should not be used for the dynamics studies where driver response is the limit criterion.

Multiple Non-Deformable Vertical Obstacles

1. Since multiple non-deforming vertical obstacle tests are to become the sounding board for mathematical models of actual rough terrain-vehicle systems, further efforts should be directed toward the substantiation of theory currently evolving in numerous other studies.

Single Deformable Vertical Obstacles

1. Tests to develop more explicit definition of those vehicle and obstacle shape/size parameters which determine the maximum negotiable deformable vertical obstacle should be undertaken.

2. Further tests of deformable vertical obstacle shapes should be conducted only after basic relationships have been derived from non-deforming obstacle tests.

3. Computer techniques should be employed for general solutions for all vertical obstacle/vehicle performance relationships, supplemented with meaningful terrain data and soil mechanics analyses.

Tractive Effort Requirements - Vertical Obstacles

1. Further research toward the definition of tractive effort required for obstacle negotiation should be conducted.

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APPENDIX I

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PARTICIPATING PERSONNEL

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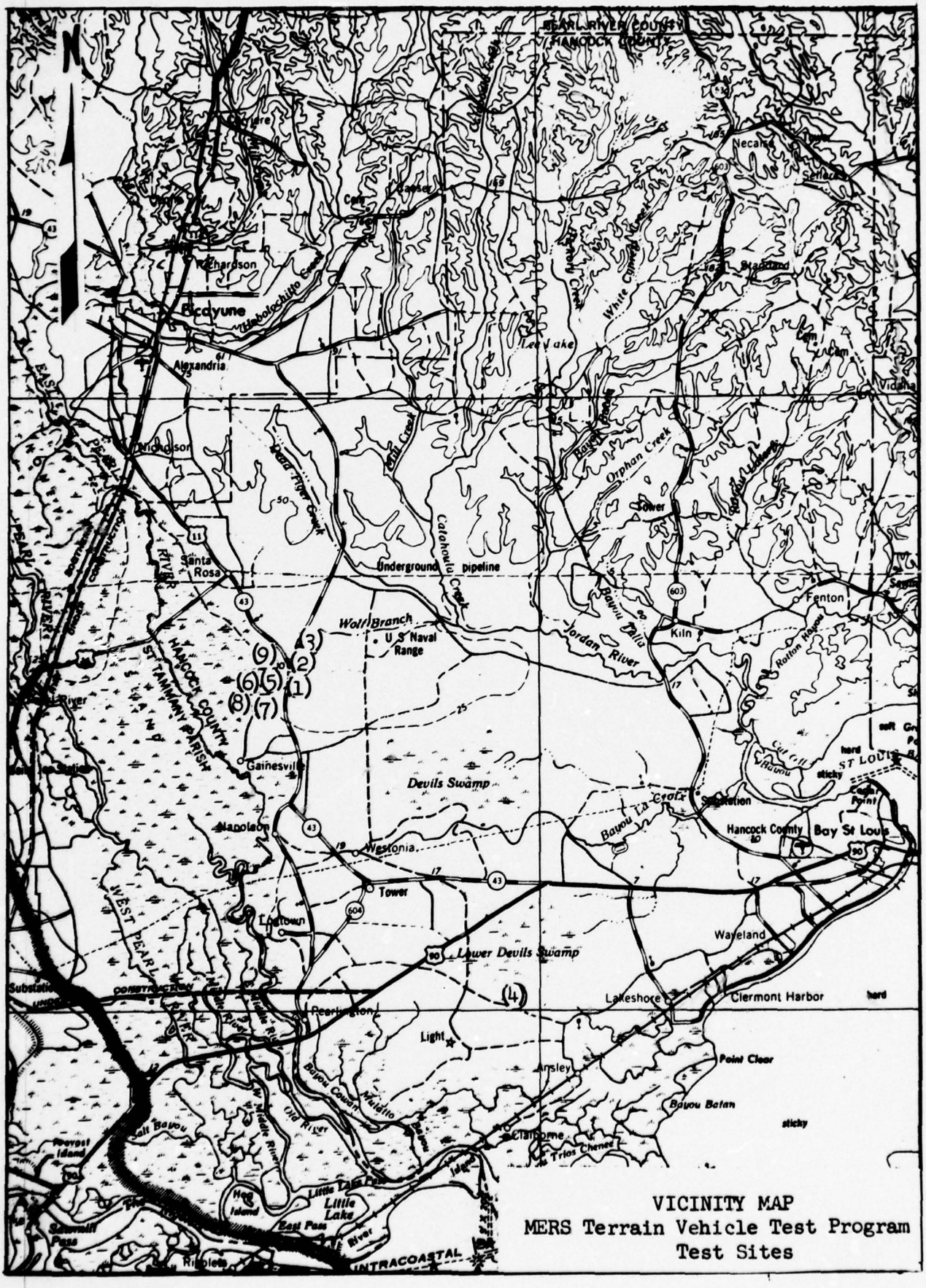
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APPENDIX II

VICINITY MAP AND SITE USAGE



VICINITY MAP
MERS Terrain Vehicle Test Program
Test Sites

SITE LOCATION AND USAGE

George C. Marshall Space Center, Mississippi

Site Number	Site Usage
1	Lateral Obstacle Tests
2	Lateral Obstacle Tests
3	Lateral Obstacle Tests
5	Single and Multiple Longitudinal Obstacle Tests
6	Single and Multiple Longitudinal Obstacle Tests
7	Single and Multiple Longitudinal Obstacle Tests
8	Single and Multiple Longitudinal Obstacle Tests
9	Single and Multiple Longitudinal Obstacle Tests

International Paper Co., Gulf Region, Headquarters, Mobile, Alabama

Site Number	Site Usage
4	Lateral Obstacle Tests

APPENDIX III

TEST PLAN

LATERAL OBSTACLE STUDIES

G. T. Cohron
R A. Werner

24 July 1964

LATERAL OBSTACLE STUDIES

I. Objective

The objectives of this exploratory study fall into three major categories. The first is related to the determination of vegetation spacings which cause immobilization and those which have no effect on the first pass performance of vehicles operating within them.

A second objective is to make first-order approximations of vehicle speed capabilities within vegetation spacings which have values between the two extremes. During investigations toward these two objectives, various auxiliary measurements will be acquired in order to approximate other limits imposed on vehicular speed within each vegetation array -- such as soil strength, surface roughness, visibility, horsepower expended, etc. The influence of the particular test vehicles will be removed from the results wherever possible and appropriate through a consideration of "independent" variables on a scale ratio -- or dimensionless -- basis.

Another major objective will be to evaluate the quantification of terrain parameters in terms which have meaning to vehicle performance determinations and in the specification of test procedures through which these relationships may be adequately studied. These will be established on a continual-modification basis, starting with the proposed plan of tests and building upon experience gained. (This plan is evidence of this activity.)

II. Scope

These tests will be performed in a minimum of three, preferably four, sites having vegetation stem spacings which vary from near-immobilizing to no-effect. Two vehicles will be used -- one wheeled and one tracked -- as indicators of the vegetation influence on vehicle performance. Three courses will be selected for each vehicle in each site. Two tests for each vehicle will be run at maximum speed. One test per vehicle will be run at a slower speed to get some indication of the torque required at slower speeds.

These tests will be conducted in sites which have as few critical secondary variables as possible. The analysis of the single factor can thus be approached with confidence, and the selection of suitable sites becomes a significant part of the activity.

III. Determination Sought

The dependence of vehicle speed on the mean stem spacing to vehicle width ratio will be plotted; hopefully, the mean stem spacing which results in immobilization of the vehicle and those which have no effect on the vehicle speed will be simultaneously defined.

From experimental path length increases determined in this test program, Randolph's model experiment for theoretical path length increase can be verified for all mean stem spacings. If the experimental and theoretical path length increase can be correlated, this would be an invaluable tool for relating stem spacing to distance travelled and then to speed of the vehicle.

Average or maximum front wheel angle can be related to path length increase and mean stem spacings. From this relation, the front wheel angle (severity of maneuver) can be related to speed.

Also a relationship between the traction requirements and average front wheel angle for various speeds will be sought. Data from the one-pass trafficability program can ultimately be used to supplement the data furnished by this program to develop a relation between the critical soil strength and front wheel angle or severity of maneuver.

IV. Test Site Requirements

Four test sites will be located which incorporate the following requirements:

A. Level

B. Firm Soil

C. Homogeneous mean stem spacings

D. Preferably, no microgeometry impediments

E. Very slight understory, if any

F. Free of logs or other vertical obstacles

G. Preferably, no stumps or holes

H. Each area shall be approximately 7 cell diameters long x 3 cell diameters wide for optimum speed data.

The four sites will be picked on the basis of having different mean stem spacings which vary from near-immobilizing to near-no-effect.

V. Measurements Required

A. Field Measurements

1. Plan view of lateral obstacle areas

   a. In selected areas, plot each significant stem including holes and stumps on a 1:100 map.

   b. Count significant holes and stumps and mark with a 6' stake.

   c. WES vegetation data forms will be filled out, giving complete information on the significant vegetation.

   d. A representative cell of the ground cover vegetation (secondary) will be made for each site and noted in the vegetation forms.

   e. After a test has been completed, the actual path of the vehicle, microgeometry sample sites, soil sites, and five second balls shall be plotted on the plan view of the area. The actual path of the vehicle shall be marked half-way between the tracks.

2. Visibility determinations will be made for each site. A dot-distance count system will be used to determine the visibility. A 4' x 8' target which incorporates 75 dots, divided into three equal-sized areas classified as low, medium, and high, will be used at 50 foot increments on the four points of the compass to determine the visibility. Dot counts are to be made using a surveyor's level with the lens 4.5' above the ground.

3. Microgeometry samples will be made in areas of significant irregularities. Changes of deviations, irregularities, are to be measured in both left and right vehicle tracks.

4. Cone Index to 30 inches (0, 3, 6, 9, 12, 18, 24, 30 inches) for each test lane approximately every 100 foot or at a significant soil change along the path of the vehicle.

5. Remolding index for 0"-6" and 6"-12" using the standard 100 blow method for all soil sites.

6. Moisture content and grain size analysis samples for 0-6, 6-12, and 12-18 inch layers for all soil sites.

7. Soil shear strength (Sheargraph) for soil to soil, soil to rubber, and rubber on grass or forest litter for all soil sites.

8. Rut depths where ruts are significant.

9. Stop watch time for the vehicle to traverse the test lane.

B. <u>Recorded on Magnetic Tape and Oscillograph</u>

1. Torque

2. Lateral acceleration at the driver's seat

3. Vertical acceleration at the driver's seat

4. Drive line revolutions outside the transmission and transfer case.

5. Time

6. Event marker

7. Voice

8. Front wheel angle measured with a linear potentiometer

9. Displacement of the front and rear axles with respect to the frame measured with linear potentiometer.

VI. Conduct of Tests

A. Advance

1. After an adequate site has been located, the area will be cleared of significant understory and mapped as outlined in Section V, Measurements Required.

2. After completion of the plan view of the area, test courses will be selected, taking into consideration any unwanted factor of the area.

3. Sufficient space will be allowed for the vehicle to accelerate to speed before entering the timed section of the course and decelerate from speed after passing the end marker, all to be done within the same vegetative spacing so that end effects are minimized.

B. Pre-Test

1. The driver will be given a chance to walk through the test site to familiarize himself with the site.

2. The start and finish points of the test course will be marked at preselected map points with orange markers approximately 8 feet high, and will be clearly visible to the driver before starting the vehicle.

3. Instrumentation will be checked to make sure the transducers and recorders are operational.

4. The vehicle will be placed behind the starting marker so sufficient distance is available to get the vehicle up to speed before entering the test course.

C. Test

1. Upon signal from the Test Engineer, the recording instrumentation will be started and calibrated with the vehicle in neutral gear and the vehicle wheels straight ahead.

2. Upon signal to start the test, the driver will negotiate the test course, maneuvering around the lateral obstacles, at the absolute maximum controllable speed.

3. The Test Engineer will be the "voice". Upon reaching the starting stake, he shall mark the oscillograph by pressing the event marker and indicate on the voice channel of the tape recorder the start of the course. The Test Engineer shall mark the start, finish, and any significant happenings on the oscillograph and recorder. Visual observations are also to be made on the tape recorder for future reference during analysis.

4. The Instrumentation Engineer shall time the test using the start and finish markers as reference points. He shall also be required to drop a polystyrene ball "overboard" every 5 seconds.

5. Upon completion of the test, the oscillograph tape will be developed immediately to determine if all instrumentation was working properly. From the oscillograph record, the Test Engineer shall determine whether the test needs to be repeated because of some critical instrumentation failure.

D. Post Test

1. Soil sites are to be slected about every 100 feet along the path or at any point of significant change in soil conditions.

2. For each soil site, the following measurements will be taken in the tracks of the vehicle:

   a. Cone Index profiles to 30 inches.

   b. Remolding indexes, 0"-6", 6"-12", using the standard 100 blow method.

   c. Moisture content and grain size analysis samples for 0-6, 6-12, and 12-18 inch layers.

   d. Sheargraph readings for soil to soil, soil to rubber, and rubber to grass or forest litter.

3. Rut depth will be measured where ruts are of significant depth.

4. Microgeometry samples will be made in areas of significant irregularities. These measurements will be made in both tracks of the vehicle.

5. Visibility measurements will be taken as outlined in Section V, Measurements Required.

6. The actual path of the vehicle, (and) soil sites, microgeometry sample sites, and five second balls shall be plotted on the plan view of the area. The

actual path of the vehicle shall be marked half-way between the tracks.

7. Ask the driver to evaluate the "ride" of the vehicle during test as best described by one of the following:

Imperceptible
Barely perceptible
Distinctly perceptible
Slightly disagreeable
Disagreeable
Unbearable

VII. Analysis Procedure

A. From the completed plan view of the site, the following measurements will be taken:

1. Straight line distance of the test course.

2. The actual vehicle path length and the number and distance of vehicle backups.

3. The vegetation cell diameter, the diameter of a circle enclosing 20 lateral obstacles, every 0.67 x average cell diameter (for the entire site) along the actual vehicle path length.

B. From the permanent record of the magnetic tape, the following measurements will be taken:

1. The total time required to traverse the test course using the event markers as references for the start and finish points.

2. From the timer, five second intervals may be marked and the distance travelled in five seconds determined from the drive line revolutions.

3. For each five second interval, the average, maximum and minimum torque will be determined, using the calibration steps for defining the torque/inch of the trace displacement from the zero line.

4. For each five second interval, the maximum positive and negative vertical and lateral accelerations will

be measured, using the calibration steps to determine the "g" force/inch of the trace displacement from the zero line.

5. For each five second interval, the average and maximum steering angle will be measured, using the calibration steps to determine the degrees of turn/inch of the trace displacement from the zero line.

C. Soils data will be summarized for each test course by soil sites.

D. Upon summarization, all data will be averaged for an entire test course.

E. The "speed made good" will be figured from the straight-line course distance and the total time required to negotiate the test course.

F. The Mean Lateral Obstacle Spacing is (.224) Cell Diameter. (From "The Physiognomy of Vegetation", Marshall University, May 1964.)

G. Visibility (Ft./dot loss) is determined by interpolation of the average dot count at 100 feet from a plot of dot count vs. distance from observer, using the center 1/3 of the 4 ft. x 8 ft. board.

VIII. Data Forms

A. Field Data Form

1. Course No.
2. Test No.
3. Vehicle
4. Engine RPM
5. Tire Pressure
6. Gear Used/Transfer Used
7. Course Length
8. Path Length
9. Elapsed Time
10. "Speed Made Good"
11. Speed Decretion
12. Driveshaft RPM
13. Torque
14. Ave. Front Wheel Angle
15. Veg. Cell Diameter
16. Tree Spacing
17. Remarks

B. Oscillogram Data Form

1. Time (Sec.)
2. Shaft Revolutions
3. Distance Travelled (Ft.)
4. Cumulative Distance (Ft.)
5. Average Speed (MPH)
6. Average Cell Diameter
7. Mean Tree Spacing/Vehicle Width
8. Driveshaft Torque (Ft.-Lbs.)
   Average
   Maximum
   Minimum

9. Average Tractive Effort (Lbs.)
10. Vertical Acceleration (G's)
    Up
    Down
11. Lateral Acceleration (G's)
    Right
    Left
12. Remarks

C. Summary Data Form

1. Site No.
2. Test No.
3. Vehicle
4. Speed Made Good (MPH)
5. Average Torque (Ft.-Lbs.)
6. Maximum Torque (Ft.-Lbs.)
7. Average Tractive Effort (Lbs.)
8. Average Steering Angle
9. Maximum Steering Angle
10. Mapped Course Length (Ft.)
11. Mapped Path Length (Ft.)
12. Path Elongation
13. Vegetative Cell Diameter (Ft.)
14. Mean Stem Spacing (Ft.)
15. Mean Stem Spacing/Vehicle Width
16. Visibility (Ft./Dot)
    0-100' (Center Target)

17. Remarks

D. Data From Plan View

1. Course No.

2. Vehicle
3. Course Length
4. Path Length
5. Path Elongation
6. No. of Backups
7. Distance of Backups
8. Veg. Cell Diameter
9. Tree Spacing

E. Soils Data Form

WES No. 1424, July 1964

F. Visibility Data Form

WES No. 1369, February 1964

G. Vegetation Structure Data Form

WES No. 1374, February 1964

H. Soils Summary Data Form

1. Vehicle
2. Test No.
3. Distance From Starting Stake, Ft.
4. Cone Index at Depths
   a. SFC
   b. 3 In.
   c. 6 In.
   d. 9 In.
   e. 12 In.

5. Average Cone Index by Layers
   a. 0-6 In.
   b. 3-9 In.
   c. 6-12 In.
6. Average Remolding Index by Layers
   a. 0-6 In.
   b. 3-9 In.
   c. 6-12 In.
7. Rating Cone Index by Layers
   a. 0-6 In.
   b. 3-9 In.
   c. 6-12 In.
8. Moisture Context (% Dry Wt.)
   a. 0-6 In.
   b. 6-12 In.
9. Dry Density (Lbs./Ft.^{3})
   a. 0-6 In.
   b. 6-12 In.
10. Soil Shear Values (all ultimate -- or steady-state -- values)
   a. Soil to Soil
      1) c_u
      2) ϕ_u
      3) Inflection Pressure
      4) c_{u^2}
      5) ϕ_{u^2}
   b. Rubber to Soil
      1) a_{ur}
      2) α_{ur}
      3) Inflection Pressure
      4) a_{ur^2}
      5) α_{ur^2}

c. Rubber to Litter

1) a_{ul}

2) α_{ul}

3) Inflection Pressure

4) a_{ul^2}

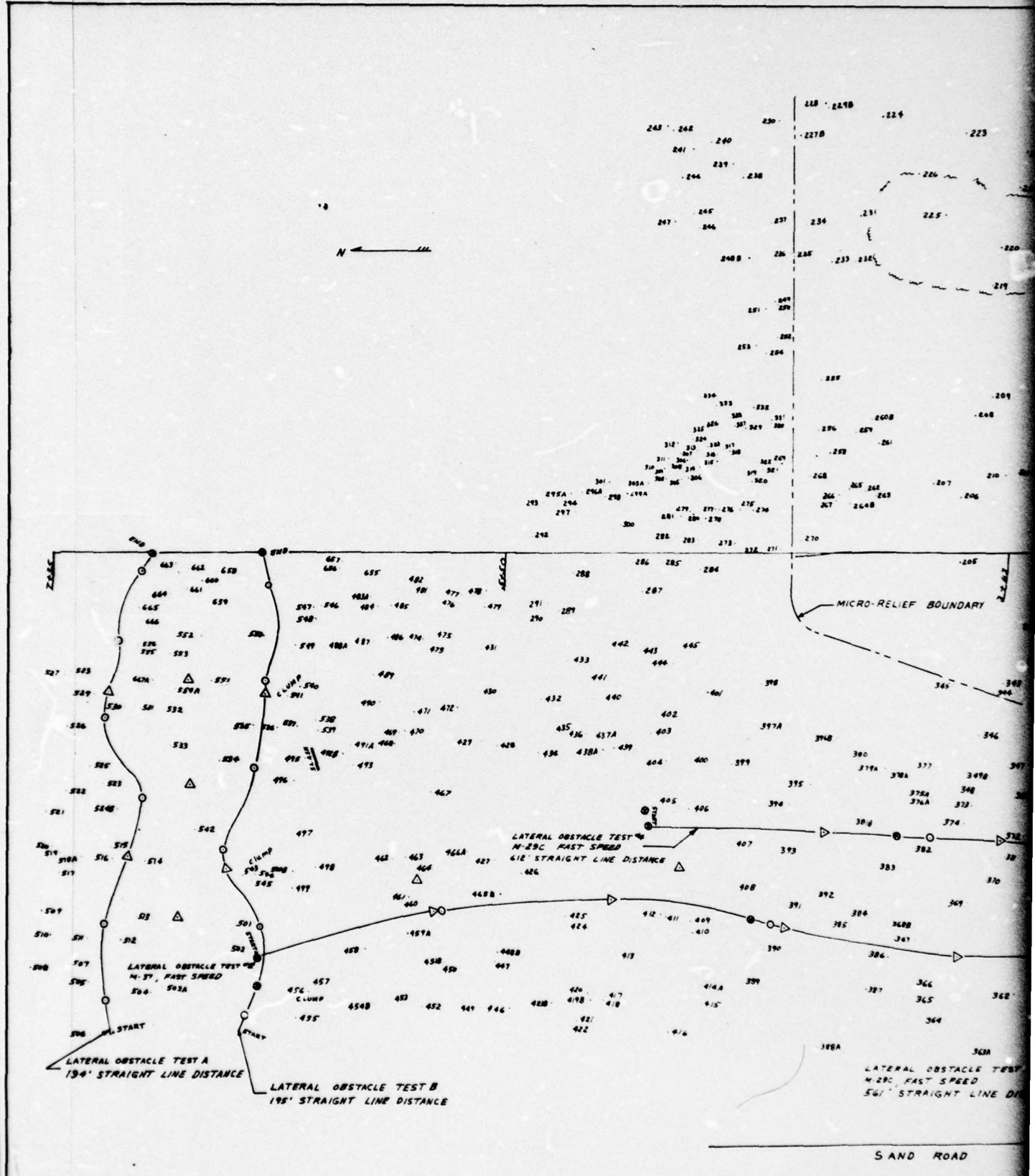
5) α_{ul^2}

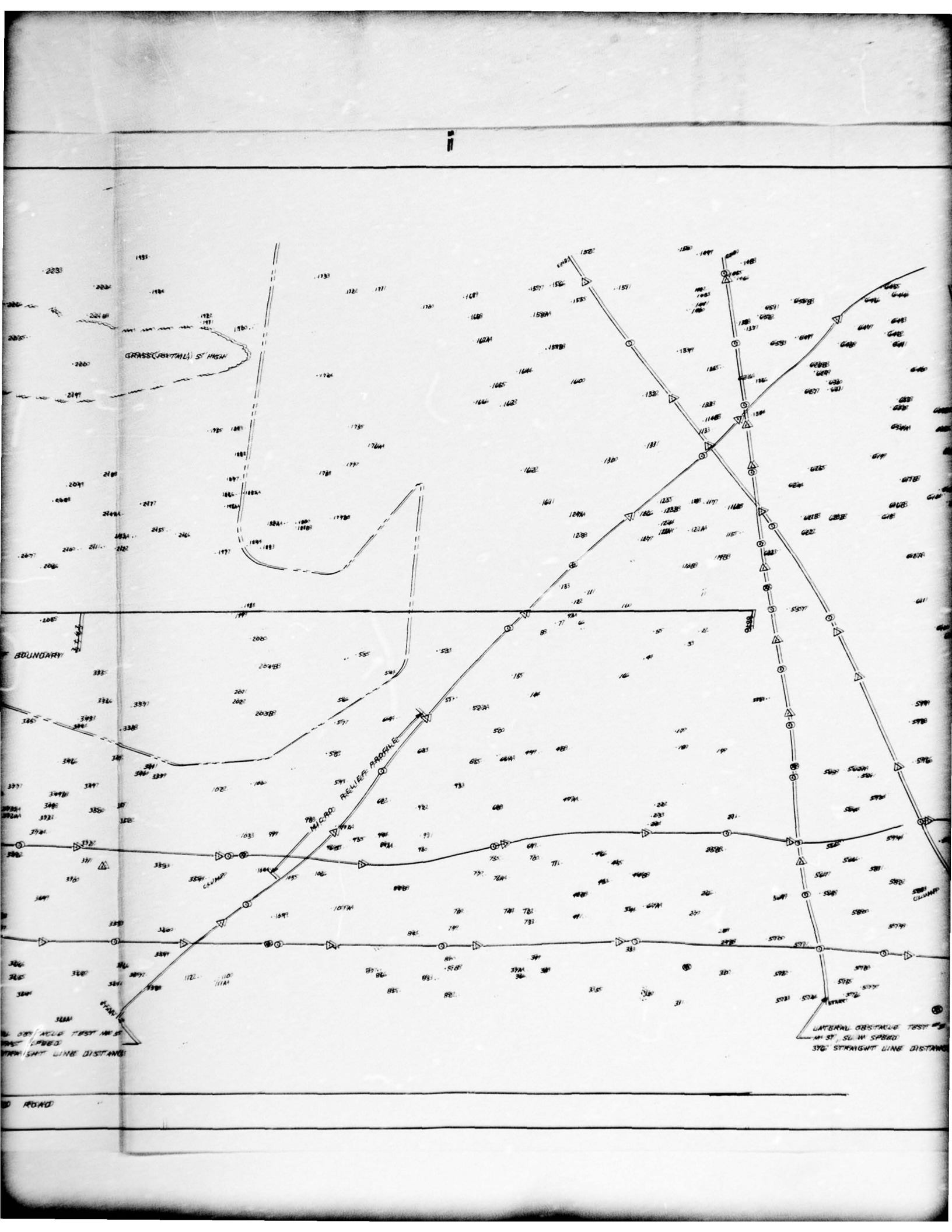
11. Computed Drawbar Pull

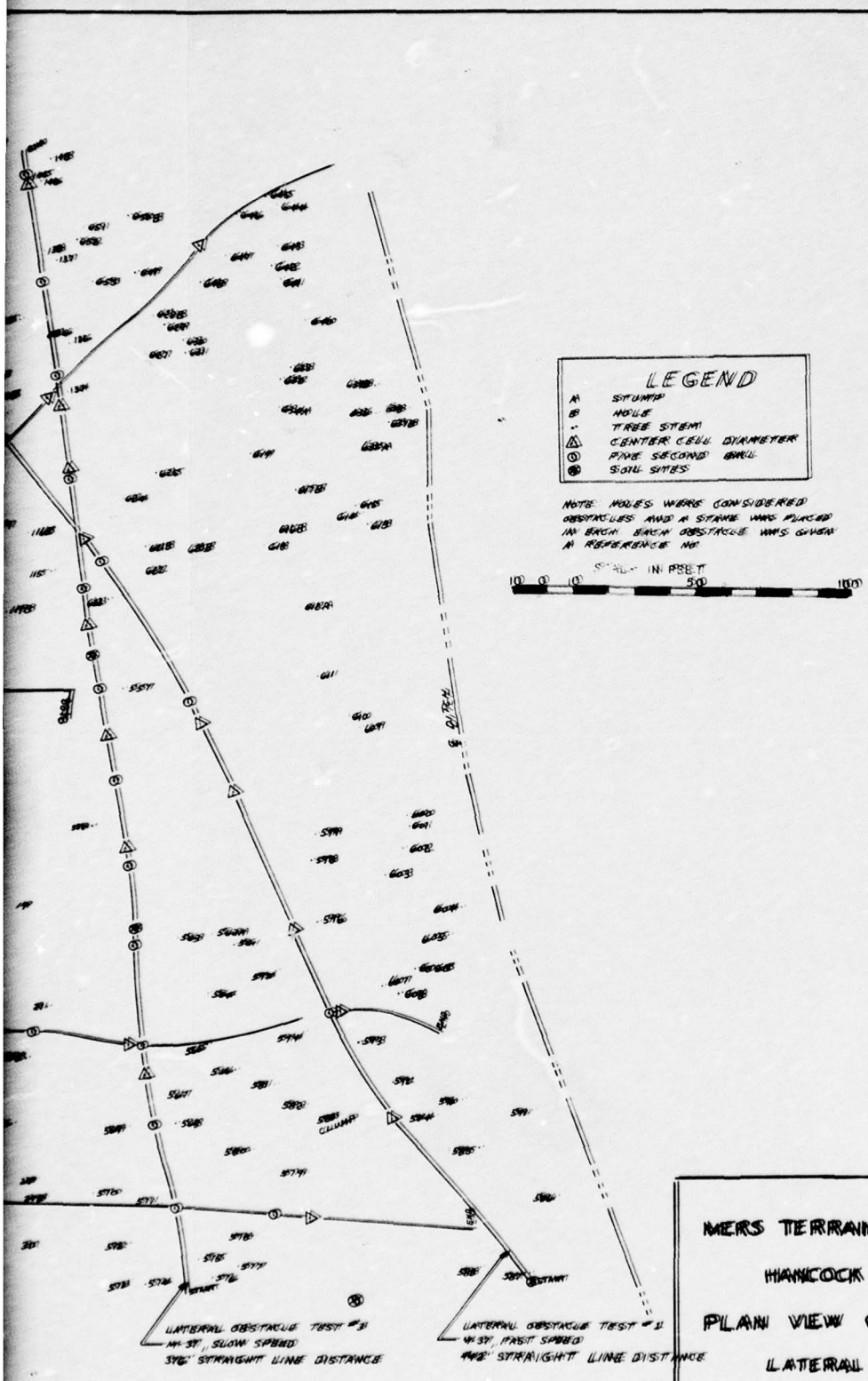
a. Soil to Soil

b. Rubber to Soil

c. Rubber to Litter


N
MICRO-RELIEF BOUNDARY
LATERAL OBSTACLE TEST A
194' STRAIGHT LINE DISTANCE
LATERAL OBSTACLE TEST B
195' STRAIGHT LINE DISTANCE
LATERAL OBSTACLE TEST
M-29C, FAST SPEED
612' STRAIGHT LINE DISTANCE
LATERAL OBSTACLE TEST
M-29C, FAST SPEED
561' STRAIGHT LINE DI
LATERAL OBSTACLE TEST
M-37, FAST SPEED
SAND ROAD
START
C. CLUMP


GRASS (RWY 14/32) ST HIGH
BOUNDARY
MICRO RELIEF PADDLE
CLIMAT
START
LATERAL OBSTACLE TEST
HIGH SPEED
STRAIGHT LINE DISTANCE
ROAD



MERS TERRAIN VEHICLE TEST PROGRAM

HANCOCK COUNTY MISSISSIPPI

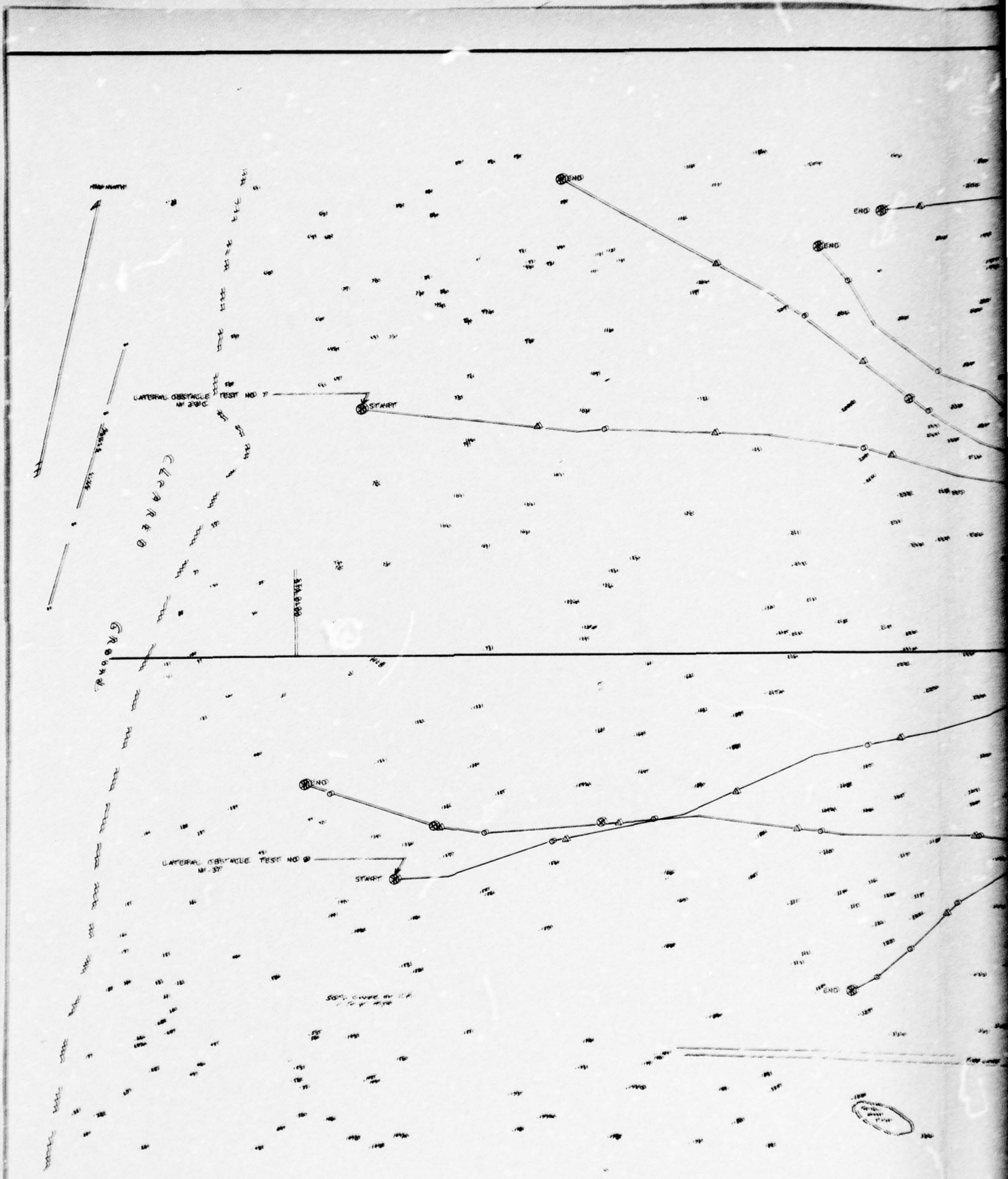
PLAN VIEW OF TEST SITE NO 1

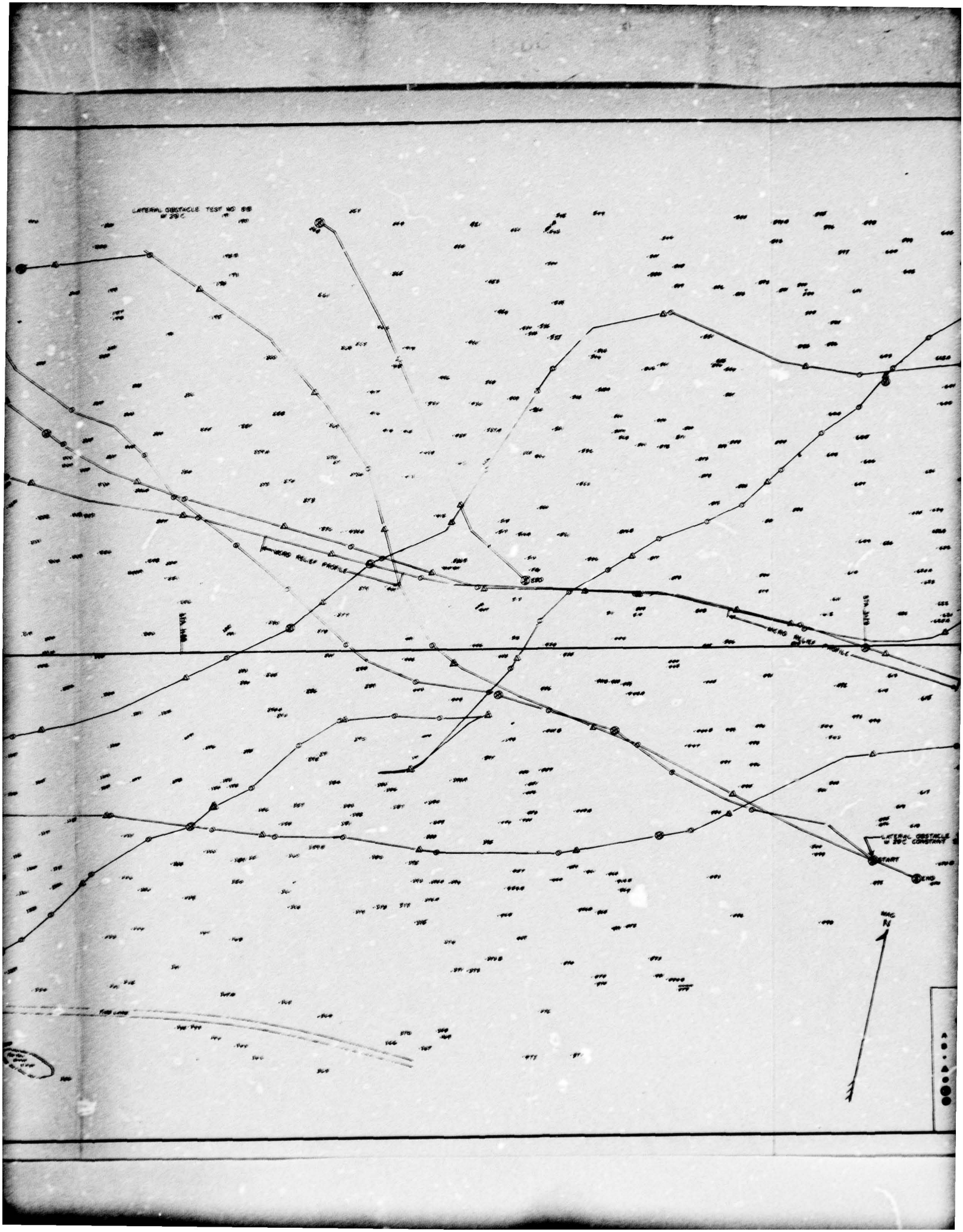
LATERAL OBSTACLE COURSE

GEO. COORDINATES LAT. 30°22'59" LON. 89°37'06"

MAPPED BY G.L. BLAIR JULY 24 1964

Figure III-1


END
END
END
LATERAL OBSTACLE TEST NO 7
START
LATERAL OBSTACLE TEST NO 8
START
END
END


LATERAL OBSTACLE TEST NO 8B
W 20C
LATERAL OBSTACLE
W 20C CONSTANT
START
END
N

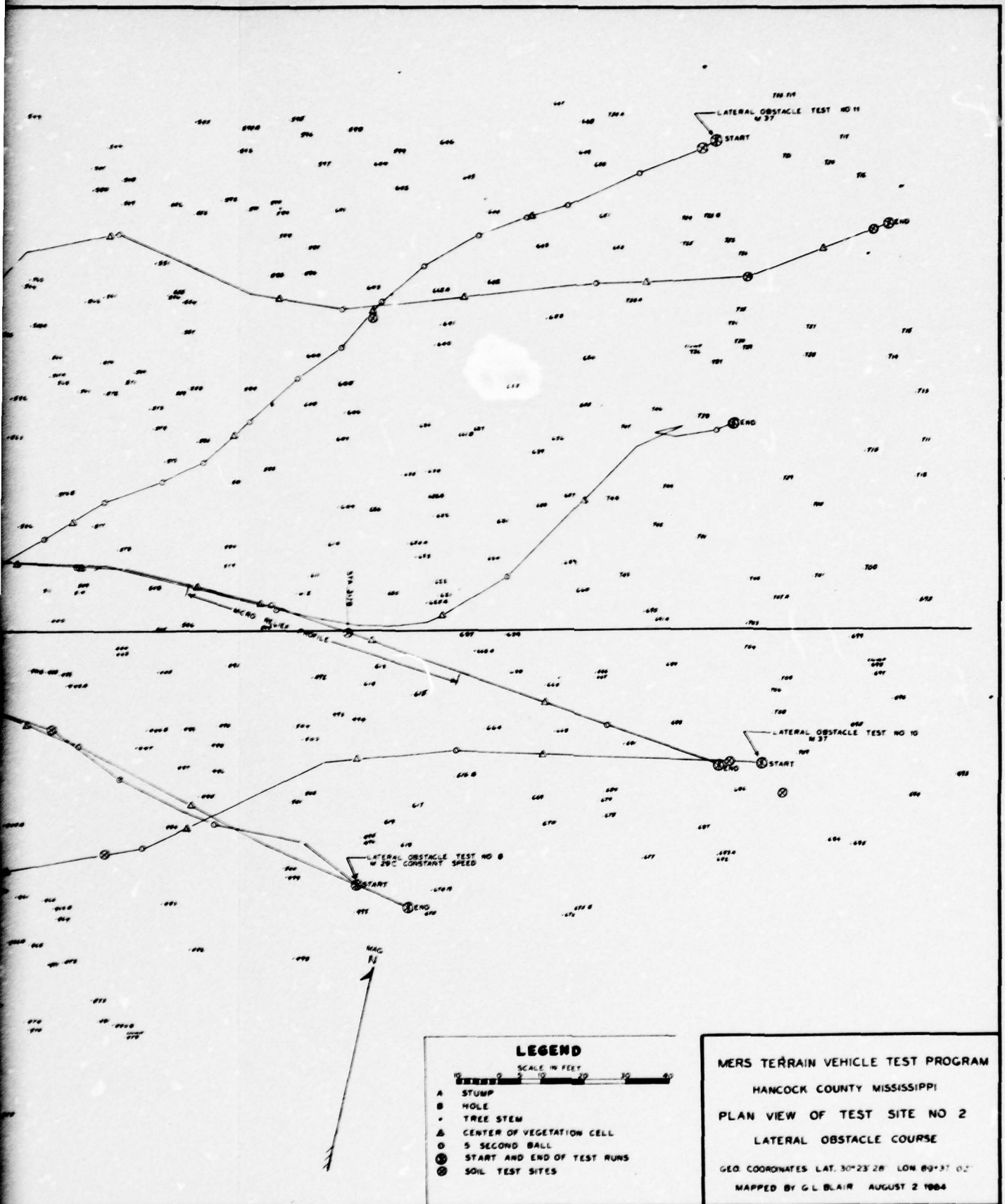
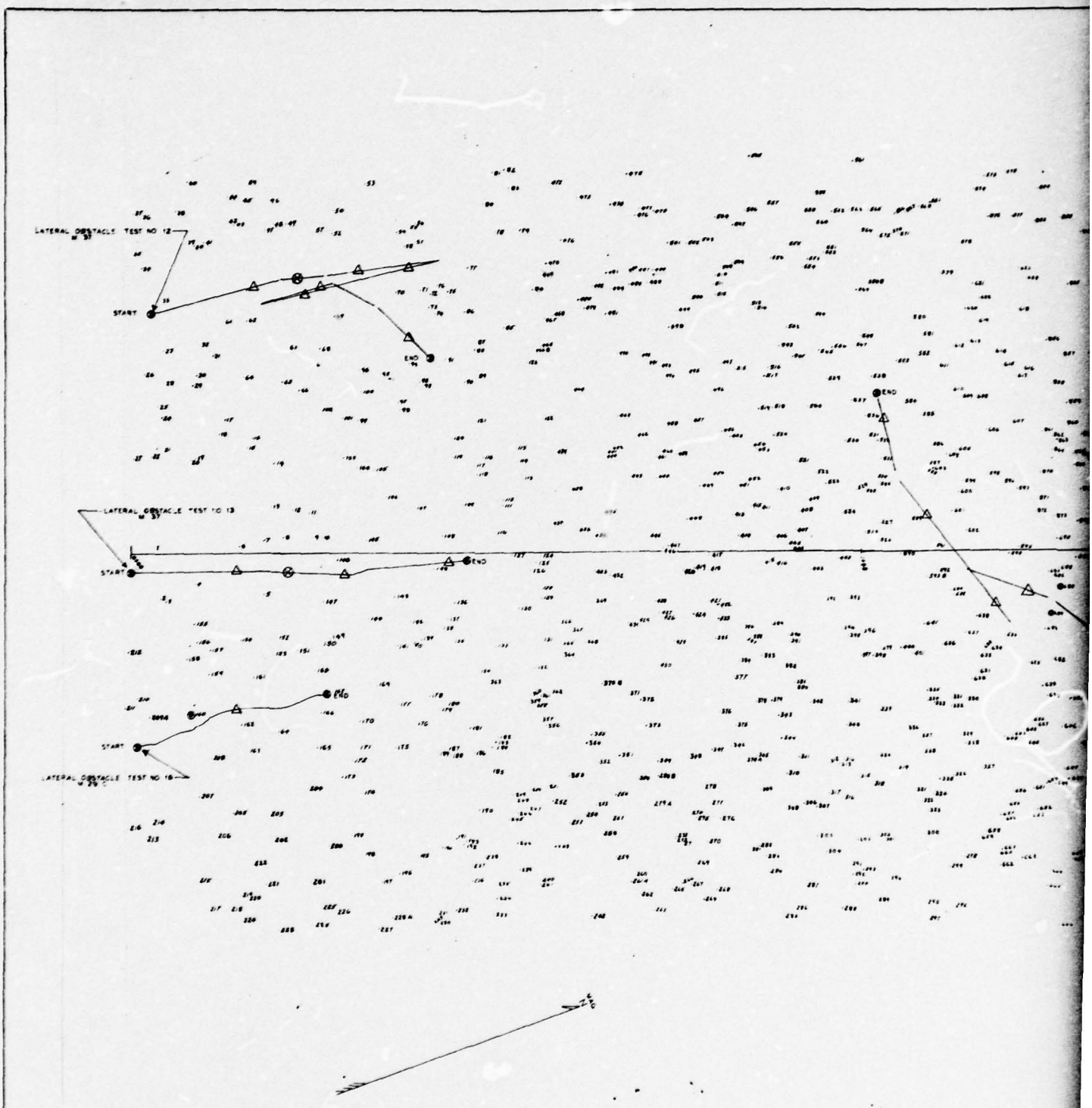

LATERAL OBSTACLE TEST NO 11
W 37
START
END
END
LATERAL OBSTACLE TEST NO 10
W 37
START
END
LATERAL OBSTACLE TEST NO 8
W 29 C CONSTANT SPEED
START
END
MAG N
LEGEND
SCALE IN FEET
0 5 10 20 30 40
A STUMP
B HOLE
• TREE STEM
△ CENTER OF VEGETATION CELL
○ 5 SECOND BALL
START AND END OF TEST RUNS
SOIL TEST SITES
MERS TERRAIN VEHICLE TEST PROGRAM
HANCOCK COUNTY MISSISSIPPI
PLAN VIEW OF TEST SITE NO 2
LATERAL OBSTACLE COURSE
GEO COORDINATES LAT. 30°23'28" LON 89°37'02"
MAPPED BY G L BLAIR AUGUST 2 1984

Figure III - 2


LATERAL OBSTACLE TEST NO 12
START
END
LATERAL OBSTACLE TEST NO 13
START
END
END
START
LATERAL OBSTACLE TEST NO 16

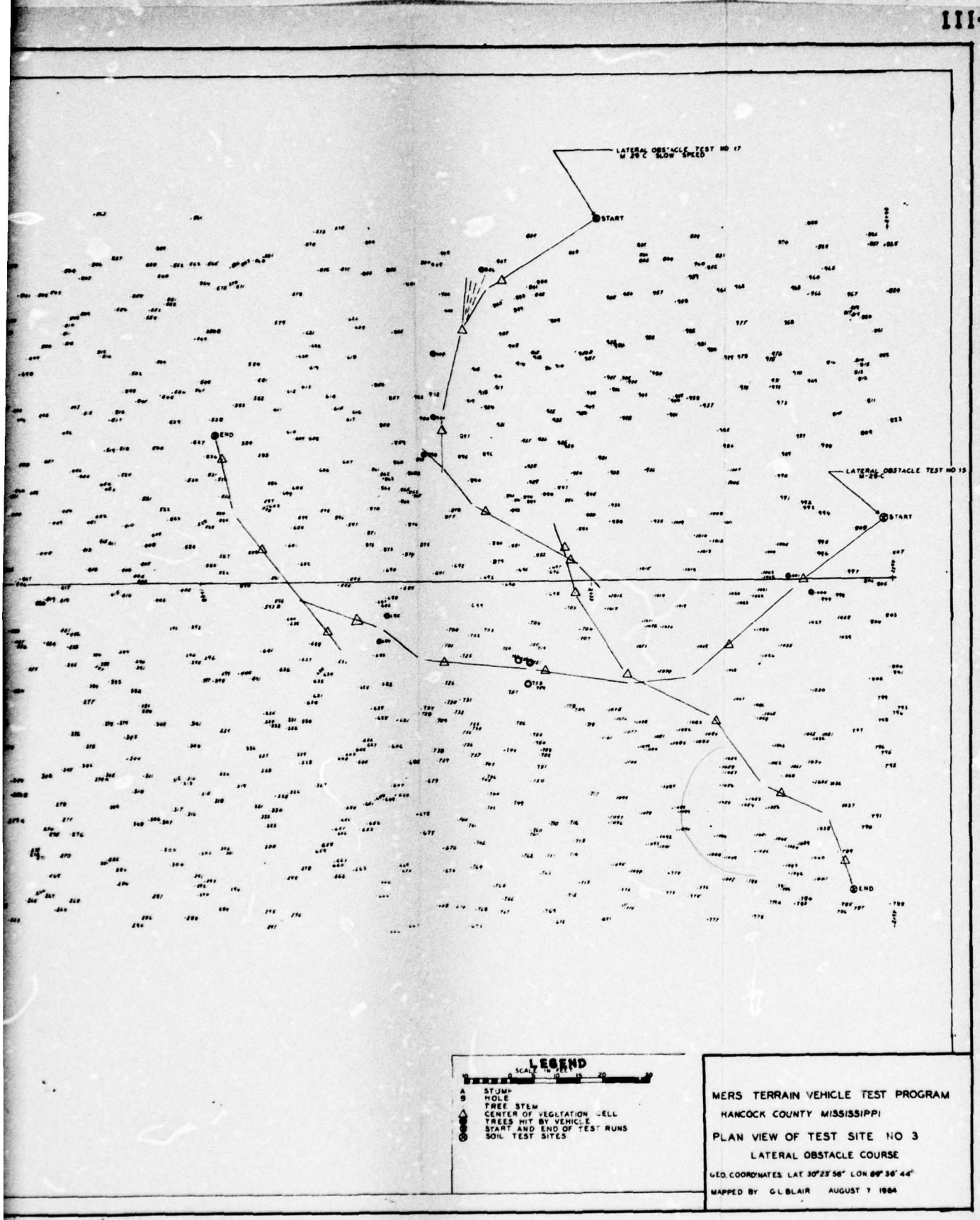
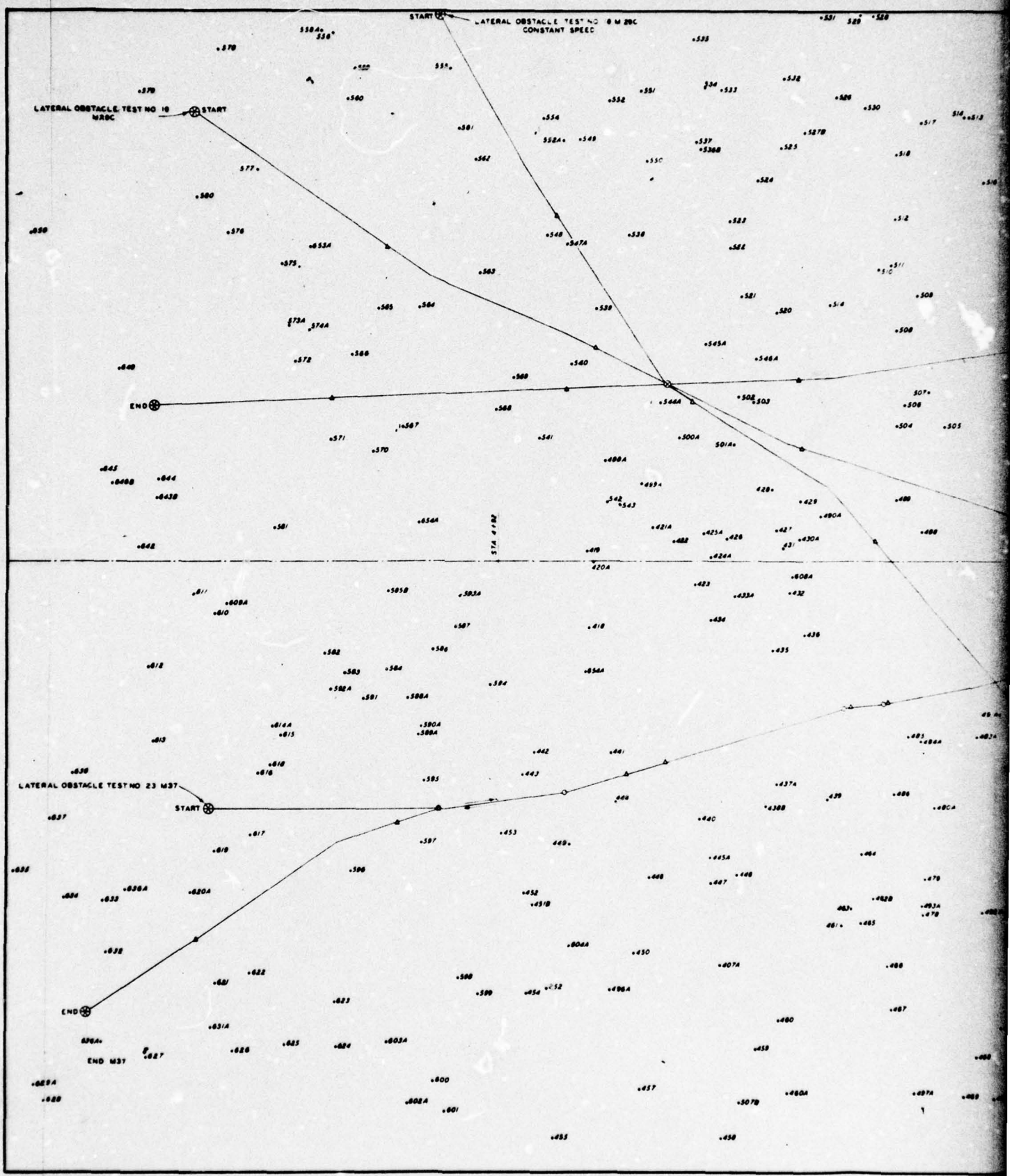
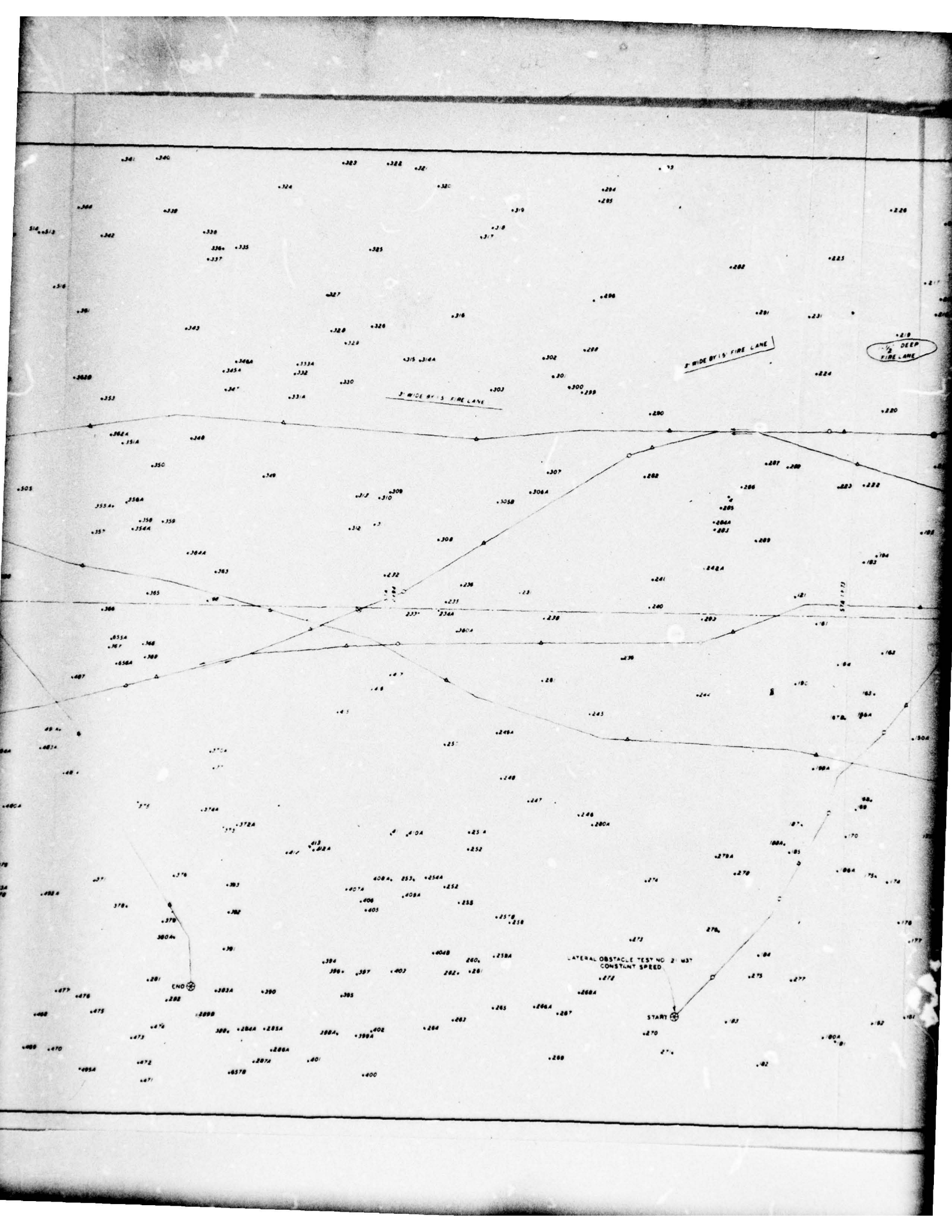
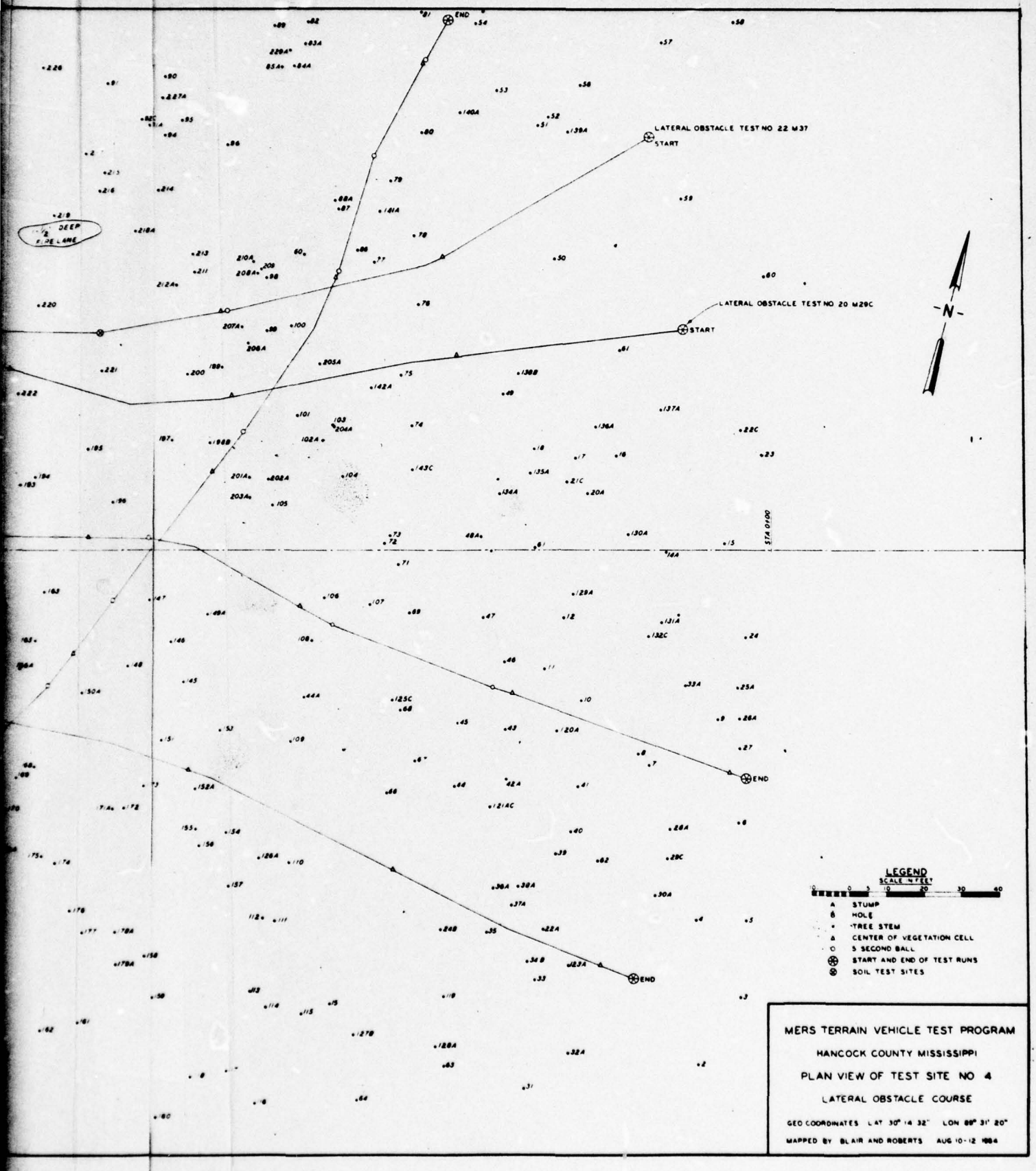

LATERAL OBSTACLE TEST NO 17
W 26°C SLOW SPEED
START
END
LATERAL OBSTACLE TEST NO 15
S-26-C
START
END
LEGEND
SCALE IN FEET
0 5 10 15 20 30
A STUMP
B HOLE
TREE STEM
CENTER OF VEGETATION CELL
TREES HIT BY VEHICLE
START AND END OF TEST RUNS
SOIL TEST SITES
MERS TERRAIN VEHICLE TEST PROGRAM
HANCOCK COUNTY MISSISSIPPI
PLAN VIEW OF TEST SITE NO 3
LATERAL OBSTACLE COURSE
GEO. COORDINATES LAT 30°23'58" LON 89°36'44"
MAPPED BY G.L.BLAIR AUGUST 7 1984

Figure III-3


START
LATERAL OBSTACLE TEST NO 8 M 28C
CONSTANT SPEED
LATERAL OBSTACLE TEST NO 10
M 28C
START
END
STA 418Z
LATERAL OBSTACLE TEST NO 23 M37
START
END
END M37


3' WIDE BY 15' FIRE LANE
3' WIDE BY 15' FIRE LANE
1½' DEEP FIRE LANE
LATERAL OBSTACLE TEST NO 2 M37
CONSTANT SPEED
START
END



MERS TERRAIN VEHICLE TEST PROGRAM

HANCOCK COUNTY MISSISSIPPI

PLAN VIEW OF TEST SITE NO 4

LATERAL OBSTACLE COURSE

GEO COORDINATES LAT 30° 14 32" LON 89° 31' 20"

MAPPED BY BLAIR AND ROBERTS AUG 10-12 1984

Figure III-4

M37, 3/4-Ton Truck Site No. 1 Test No. 1 29 July 1964

Time (Sec.)	Shaft Revs.	Distance Traveled (Ft.)	Cumulative Distance (Ft.)	Avg. Speed (MPH)	Avg. Cell Dia.	Mean Tree Spacing/Veh. Width	Driveshaft Torque (Ft.-Lbs.) Avg.	Max.	Min.	Average Tractive Effort (Lbs.)	Vertical Acceleration (G's) UP	DOWN	Lateral Acceleration (G's) RIGHT	LEFT
0-3	37.0	56.2	56.2	12.8	115	4.20	205	238	183	851	.29	.44	.21	.18
3-6	46.2	70.2	126.4	15.9	115	4.20	205	233	188	851	.44	.15	.14	.46
6-9	47.0	71.4	197.8	16.2	127	4.64	166	249	50	689	.73	.29	.28	.32
9-12	43.5	66.1	263.9	15.0	122	4.46	155	332	199	643	.44	.29	.30	.27
12-15	38.7	58.8	327.7	13.4	112	4.09	211	249	183	876	.58	.29	.30	.27
15-18	40.7	61.9	384.6	14.1	116	4.24	216	277	177	896	.58	.15	.30	.27
18-21	38.8	59.0	443.6	13.4	118	4.31	222	244	211	921	.58	.44	.33	.23
21-22.2	13.3	20.2	463.8	11.5	120	4.38	211	266	172	876	.87	.29	.16	.19
Total	305.2	463.8	463.8	----	---	----	---	---	---	---	---	---	---	---
Average	-----	-----	-----	14.0	118	4.31	199	261	108	825	.56	.29	.25	.27

M37, 3/4-Ton Truck Site No. 1 Test No. 2 29 July 1964

0-5	52.0	79.0	79.0	10.8	90	3.29	288	355	238	1195	.73	.29	.25	.21
5-10	72.6	110.4	189.4	15.1	101	3.69	166	338	-94	689	.73	.58	.19	.39
10-15	85.0	129.2	318.6	17.7	101	3.69	227	266	194	942	.58	.29	.25	.42
15-20	67.4	102.4	421.0	14.0	114	4.17	205	371	-388	851	.87	.29	.16	.35
20-25	45.2	68.7	489.7	9.4	113	4.13	321	371	288	1332	.73	.29	.14	.14
25-30	69.0	104.9	594.6	14.4	95	3.47	183	355	-28	759	.87	.29	.28	.18
30-35	70.6	107.3	701.9	14.7	118	4.31	222	355	161	921	.87	.29	.35	.32
35-39.7	69.9	106.2	808.1	14.6	119	4.39	211	255	183	876	.73	.15	.33	.35
Total	531.7	808.1	808.1	----	----	----	---	---	---	----	---	---	---	---
Average	-----	-----	-----	13.8	106	3.89	228	333	69	946	.76	.31	.24	.30

M37, 3/4-Ton Truck Site No. 1 Test No. 3 29 July 1964

0-5	16.6	25.2	25.2	3.5	108	3.95	150	211	94	623	.73	.15	.07	.07
5-10	17.8	27.1	52.3	3.7	108	3.95	161	199	122	668	.58	.15	.05	.09
10-15	19.6	29.8	82.1	4.1	110	4.02	127	183	94	527	.58	0	.07	.05
15-20	16.8	25.5	107.6	3.5	124	4.53	183	238	122	759	.58	0	.05	.09
20-25	18.2	27.7	135.3	3.8	136	4.97	211	283	122	876	.44	0	.04	.12
25-30	18.1	27.5	162.8	3.8	137	5.01	233	288	172	967	.44	.15	.04	.09
30-35	19.8	30.1	192.9	4.1	129	4.71	244	283	205	1013	.44	0	.09	.11
35-40	22.0	33.4	226.3	4.6	118	4.31	277	327	216	1150	.29	.29	.04	.11
40-45	24.6	37.4	263.7	5.1	109	3.98	238	294	199	988	.44	.15	.18	.09
45-50	23.4	35.6	299.3	4.9	102	3.73	233	271	194	967	.29	.44	.05	.11
50-55	23.4	35.6	334.9	4.9	94	3.43	233	305	177	967	.44	.15	.04	.19
55-60	21.5	32.7	367.6	4.5	87	3.18	260	310	233	1079	.44	.15	.04	.11
60-62.8	13.1	19.9	387.5	4.9	84	3.07	260	294	222	1079	.44	.29	.05	.19
Total	254.9	387.5	387.5	----	---	----	---	---	---	----	---	---	---	---
Average	-----	-----	-----	4.2	111	4.06	216	268	167	898	.47	.15	.06	.11

TABLE III-1 (CONTINUED) LATERAL OBSTACLE TESTS

BASIC DATA TABLES

M37, 3/4-Ton Truck Site No. 2 Test No. 9 5 August 1964

Time (Sec.)	Shaft Revs.	Distance Traveled (Ft.)	Cumulative Distance (Ft.)	Avg. Speed (MPH)	Avg. Cell Dia.	Mean Tree Spacing/Veh. Width	Driveshaft Torque (Ft.-Lbs.) Avg.	Max.	Min.	Average Tractive Effort (Lbs.)	Vertical Acceleration (G's) UP	DOWN	Lateral Acceleration (G's) RIGHT	LEFT
0-5	45.4	69.0	69.0	9.5	84	3.07	150	277	-11	621	.40	.56	.24	.39
5-10	45.0	68.4	137.4	9.4	67	2.45	105	210	116	435	.30	.51	.27	.43
10-15	38.4	58.4	195.8	8.0	60	2.19	127	260	116	536	.40	.30	.23	.20
15-20	35.4	53.8	249.6	7.4	65	2.38	138	260	-11	571	.30	.35	.16	.36
20-25	23.6	35.9	285.5	4.9	52	1.90	94	250	-5	389	.15	.25	.13	.36
25-30	22.1	33.6	319.1	4.6	47	1.72	122	293	-188	505	.30	.15	.17	.16
30-35	25.4	38.6	357.7	5.3	51	1.86	177	271	61	733	.25	.20	.30	.04
35-40	30.8	46.8	404.5	6.4	59	2.16	144	233	-50	596	.15	.30	.23	.22
40-45	40.0	60.8	465.3	8.3	71	2.60	171	277	83	708	.30	.40	.29	.24
45-47.3	38.0	57.8	523.1	17.2	65	----	127	266	-404	526	.30	.51	.36	.55
Total	344.1	523.1	523.1	----	--	----	---	---	---	---	---	---	---	---
Average	-----	-----	-----	8.1	62	2.26	136	260	0	562	.29	.35	.24	.30

M37, 3/4-Ton Truck Site No. 2 Test No. 10 5 August 1964

0-5	43.3	65.8	65.8	9.0	67	2.45	210	315	66	870	.30	.35	.23	.30
5-10	38.2	58.1	123.9	8.0	68	2.48	166	271	55	690	.30	.30	.20	.34
10-15	39.7	60.3	184.2	8.3	62	2.27	188	310	17	782	.30	.35	.29	.32
15-20	25.9	38.5	222.7	5.3	48	1.75	188	310	-11	782	.25	.45	.14	.32
20-25	23.2	35.3	258.0	4.8	49	1.79	116	194	28	482	.10	.35	.20	.11
25-30	11.8	17.9	275.9	2.5	52	1.90	105	355	-150	437	.10	.25	.16	.09
30-35	15.7	23.9	299.8	3.3	57	2.08	194	388	28	808	.30	.25	.32	.22
35-40	29.0	44.1	343.9	6.0	61	2.23	188	354	-122	782	.30	.35	.14	.23
40-45	35.0	53.2	397.1	7.3	74	2.70	144	354	11	598	.30	.45	.20	.33
45-50	59.3	89.7	486.8	12.3	71	2.59	222	300	161	923	.40	.76	.62	.32
Total	321.1	486.8	486.8	----	----	----	---	---	---	---	---	---	---	---
Average	-----	-----	-----	6.7	60.9	2.22	172	315	8.0	715	.27	.39	.25	.26

TABLE III-1 - LATERAL OBSTACLE TESTS

BASIC DATA TABLES

TABLE III-1 (CONTINUED) LATERAL OBSTACLE TESTS

BASIC DATA TABLES

M37, 3/4-Ton Truck Site No. 2 Test No. 11 5 August 1964

Time (Sec.)	Shaft Revs.	Distance Traveled (Ft.)	Cumulative Distance (Ft.)	Avg. Speed (MPH)	Avg. Cell Dia.	Mean Tree Spacing/Veh. Width	Driveshaft Torque (Ft.-Lbs.) Avg.	Max.	Min.	Average Tractive Effort (Lbs.)	Vertical Acceleration (G's) UP	DOWN	Lateral Acceleration (G's) RIGHT	LEFT
0-5	10.0	15.2	15.2	2.1	71	2.59	88	144	50	365	.05	.15	.09	.06
5-10	9.5	14.4	29.6	2.0	71	2.59	116	183	66	482	.05	.20	.06	.01
10-15	9.0	13.7	43.3	1.9	71	2.59	116	188	55	482	.05	.05	.13	.01
15-20	8.6	13.1	56.4	1.8	71	2.59	127	194	66	528	.05	.05	.10	.01
20-25	8.3	12.6	69.0	1.7	71	2.59	111	194	11	461	.05	.25	.16	.13
25-30	8.4	12.8	81.8	1.8	70	2.56	144	205	72	598	.05	.05	.09	.06
30-35	8.4	12.8	94.6	1.8	69	2.52	138	232	88	574	.05	.05	.07	.06
35-40	8.6	13.1	107.7	1.8	66	2.41	138	205	88	574	.05	.05	.07	.04
40-45	8.3	12.6	120.3	1.7	63	2.30	116	194	39	482	.05	.05	.09	.03
45-50	8.7	13.2	133.5	1.8	62	2.27	116	177	17	482	.05	.05	.09	.03
50-55	8.7	13.2	146.7	1.8	62	2.27	116	171	44	482	.05	.05	.09	.01
55-60	8.5	12.9	159.6	1.8	62	2.27	127	216	72	528	.05	.05	.07	.03
60-65	8.6	13.1	172.7	1.8	63	2.30	127	210	33	528	.05	.05	.07	.04
65-70	8.4	12.8	185.5	1.8	63	2.30	122	227	55	507	.05	.05	.10	.01
70-75	8.6	13.1	198.6	1.8	61	2.23	111	194	39	461	.05	.05	.12	.03
75-80	8.1	12.3	210.9	1.7	60	2.19	105	188	55	437	.05	.05	.10	.03
80-85	8.0	12.2	223.1	1.7	58	2.12	127	194	72	528	.05	.05	.10	.03
85-90	7.7	11.7	234.8	1.6	56	2.05	133	177	89	552	.05	.05	.10	.04
90-95	6.5	9.9	244.7	1.4	55	2.01	155	282	72	644	.10	.10	.07	.06
95-100	6.5	9.9	254.6	1.4	54	1.97	133	210	33	552	.05	.05	.07	.01
100-118	Vehicle Stopped													
118-138	-20.0	-30.4	285.0	-1.0	54	1.97	243	5	-630	1010	.05	.05	.07	.09
138-145	9.4	14.3	299.3	1.4	54	1.97	144	250	-17	598	.05	.05	.09	.01
145-150	8.1	12.3	311.6	1.7	53	1.94	138	210	33	574	.05	.05	.07	.01
150-155	8.9	13.5	325.1	1.8	52	1.90	160	216	98	665	.05	.05	.07	.06
155-160	9.0	13.7	338.8	1.9	51	1.86	150	200	60	623	.05	.05	.06	.06
160-165	9.3	14.1	352.9	1.9	51	1.86	144	205	103	598	.10	.10	.06	.04
165-170	9.7	14.7	367.6	2.0	52	1.90	188	205	-526	782	.10	.10	.14	.04
170-175	10.8	16.4	384.0	2.2	54	1.97	138	194	76	574	.10	.10	.16	.03
175-180	11.1	16.9	400.9	2.3	56	2.05	116	227	44	482	.10	.10	.09	.03
180-185	11.0	16.7	417.6	2.3	53	1.94	155	227	66	644	.10	.10	.10	.09
185-190	11.4	17.3	434.9	2.4	54	1.97	216	315	55	898	.10	.10	.16	.04
190-192.8	6.3	9.6	444.5	1.3	54	1.97	150	321	92	623	.05	.05	.16	.01
Total	252.4	383.7	444.5	---	----	----	---	---	---	----	---	----	---	---
Average	-----	-----	-----	1.8	59.7	2.18	138	205	18	572	.06	.075	.10	.04

TABLE III-1 (CONTINUED) LATERAL OBSTACLE TESTS

BASIC DATA TABLES

M37, 3/4-Ton Truck Site No. 4 Test No. 21 17 August 1964

Time (Sec.)	Shaft Revs.	Distance Traveled (Ft.)	Cumulative Distance (Ft.)	Avg. Speed (MPH)	Avg. Cell Dia.	Mean Tree Spacing/Veh. Width	Driveshaft Torque (Ft.-Lbs.) Avg.	Max.	Min.	Average Tractive Effort (Lbs.)	Vertical Acceleration (G's) UP	DOWN	Lateral Acceleration (G's) RIGHT	LEFT
0-5	17.5	26.6	26.6	3.6	80	2.92	172	233	122	715	.20	.20	.09	.15
5-10	16.2	24.6	51.2	3.4	80	2.92	183	222	133	760	.20	.15	.10	.08
10-15	16.0	24.3	75.5	3.3	78	2.85	183	227	127	760	.15	.20	.10	.08
15-20	16.3	24.8	100.3	3.4	74	2.70	172	261	94	714	.15	.30	.24	.17
20-25	17.0	25.8	126.1	3.5	71	2.59	161	227	100	670	.15	.15	.10	.10
25-30	17.7	26.9	153.0	3.7	68	2.48	150	250	100	624	.35	.25	.21	.13
30-35	14.9	22.7	175.7	3.1	66	2.41	205	310	78	851	.35	.30	.31	.21
35-40	22.9	34.8	210.5	4.8	64	2.34	194	272	133	807	.25	.45	.19	.13
40-45	20.3	30.9	241.4	4.2	64	2.34	183	261	105	760	.35	.45	.21	.12
45-50	17.5	26.6	268.0	3.6	67	2.45	188	238	161	781	.25	.25	.16	.17
50-50.6	2.0	3.0	271.0	3.4	69	2.53	188	261	150	781	.25	.25	.12	.09
Total	178.3	271.0	271.0	---	--	----	---	---	---	---	---	---	--	---
Average	-----	-----	-----	3.6	71	2.59	180	251	119	748	.24	.27	.16	.13

M37, 3/4-Ton Truck Site No. 4 Test No. 22 18 August 1964

Time (Sec.)	Shaft Revs.	Distance Traveled (Ft.)	Cumulative Distance (Ft.)	Avg. Speed (MPH)	Avg. Cell Dia.	Mean Tree Spacing/Veh. Width	Driveshaft Torque (Ft.-Lbs.) Avg.	Max.	Min.	Average Tractive Effort (Lbs.)	Vertical Acceleration (G's) UP	DOWN	Lateral Acceleration (G's) RIGHT	LEFT
0-5	49.0	74.5	74.5	10.2	75	2.74	179	306	121	744	.74	1.24	.37	.39
5-10	52.0	79.0	153.5	10.8	68	2.48	173	225	-225	718	.62	.62	.42	.27
10-15	41.0	62.3	215.8	8.5	84	3.07	127	410	-121	527	.50	.50	.11	.22
15-20	57.0	86.6	302.4	11.9	89	3.25	317	317	214	1315	.74	.74	.32	.22
20-25	65.0	98.8	401.2	13.5	88	3.22	173	329	-156	718	.87	.62	.27	.17
25-30	65.0	98.8	500.0	13.5	76	2.78	185	271	-248	769	1.24	1.24	.50	.29
30-35	61.0	92.7	592.7	12.7	77	2.81	167	352	-138	702	1.36	1.24	.62	.50
Total	390.0	592.7	592.7	----	----	----	---	---	---	----	----	----	---	---
Average	-----	-----	----	11.6	79.6	2.90	189	316	0	785	.87	.89	.37	.29

M37, 3/4-Ton Truck Site No. 4 Test No. 23 18 August 1964

Time (Sec.)	Shaft Revs.	Distance Traveled (Ft.)	Cumulative Distance (Ft.)	Avg. Speed (MPH)	Avg. Cell Dia.	Mean Tree Spacing/Veh. Width	Driveshaft Torque (Ft.-Lbs.) Avg.	Max.	Min.	Average Tractive Effort (Lbs.)	Vertical Acceleration (G's) UP	DOWN	Lateral Acceleration (G's) RIGHT	LEFT
0-5	50.6	76.9	76.9	10.5	76	2.78	242	351	-24	1005	.60	1.25	.21	.32
5-10	56.4	85.7	162.6	11.7	80	2.92	236	267	188	980	.40	.70	.17	.31
10-15	63.5	96.5	259.1	13.2	84	3.07	230	249	200	955	.35	.35	.10	.22
15-20	56.2	85.4	344.5	11.7	86	3.14	157	345	-315	652	.60	.75	.35	.35
20-25	49.9	75.8	420.3	10.4	79	2.89	224	303	170	930	.65	.80	.44	.31
25-30	47.7	72.5	492.8	9.9	67	2.45	230	321	115	955	.65	1.40	.45	.25
30-35	49.2	74.8	567.6	10.2	67	2.45	224	345	109	930	.90	1.25	---	---
Total	373.5	567.6	567.6	----	----	----	---	---	---	----	---	----	---	---
Average	-----	-----	-----	11.1	77.0	2.81	220	311	63	915	.59	.93	.29	.29

TABLE III-2 - LATERAL OBSTACLE TESTS

BASIC DATA TABLES

M29C, WEASEL Site No. 1 Test No. 4 31 July 1964

Time (Sec.)	Drive Wheel Revs. RIGHT	LEFT	AVG.	Drive-haft Revs.	Distance Traveled (Ft.)	Cumulative Distance (Ft.)	Avg. Speed (MPH)	Avg. Cell Dia. (Ft.)	Mean Tree Spacing/Veh. Width	Driveshaft Torque (Ft.-Lbs.) AVG.	MAX.	MIN.	Average Tractive Effort (Lbs.)	Vertical Acceleration (G's) UP	DOWN	Lateral Acceleration (G's) RIGHT	LEFT
0-5	29.1	29.8	29.4	124.1	102	102	13.9	94	3.76	104	178	21	790	.29	.22	.13	.10
5-10	33.4	33.5	33.4	140.9	116	218	15.8	103	4.12	108	191	15	821	.44	.29	.17	.21
10-15	31.2	30.0	3.06	129.1	106	324	14.4	106	4.24	104	197	17	790	.22	.51	.21	.37
15-20	28.9	29.2	29.0	122.4	101	425	13.8	105	4.20	104	195	-4	790	.44	.37	.37	.54
20-25	33.5	33.0	33.2	140.1	115	540	15.7	107	4.28	104	185	13	790	.59	.29	.15	.27
25-27.5	15.6	17.1	16.4	69.2	57	597	15.5	---	----	81	193	-25	616	.15	.15	.37	.10
Total	171.7	172.6	172.0	725.8	597	597	----	---	---	---	---	---	---	---	---	---	---
Average	-----	-----	-----	-----	---	---	14.8	103	4.1	101	190	4	768	.36	.31	.24	.29

M29C, WEASEL Site No. 1 Test No. 5 31 July 1964

Time (Sec.)	Drive Wheel Revs. RIGHT	LEFT	AVG.	Drive-haft Revs.	Distance Traveled (Ft.)	Cumulative Distance (Ft.)	Avg. Speed (MPH)	Avg. Cell Dia. (Ft.)	Mean Tree Spacing/Veh. Width	Driveshaft Torque (Ft.-Lbs.) AVG.	MAX.	MIN.	Average Tractive Effort (Lbs.)	Vertical Acceleration (G's) UP	DOWN	Lateral Acceleration (G's) RIGHT	LEFT
0-5	24.3	24.3	24.3	102.5	84	84	11.4	110	4.00	116	187	55	882	.15	.37	.12	.10
5-10	27.3	26.1	26.7	112.7	93	177	12.7	100	4.40	120	196	33	912	.29	.59	.25	.85
10-15	30.0	30.3	30.2	127.4	105	282	14.3	118	4.72	114	196	22	866	.15	.29	.10	.00
15-20	34.1	34.0	34.0	143.5	118	400	16.1	112	4.48	118	214	2	897	.15	.81	.15	.13
20-25	33.0	33.0	33.0	139.3	114	514	15.5	97	3.88	106	202	-6	806	.15	.44	.25	.27
25-27.5	13.0	14.0	13.5	57.0	47	561	12.8	---	----	63	186	-80	479	.22	.15	.40	.08
Total	161.7	161.7	161.7	682.4	561	561	----	---	---	---	---	---	---	---	---	---	---
Average	-----	-----	-----	-----	---	---	13.8	107	4.3	106	197	4	806	.19	.44	.21	.25

M29C, WEASEL Site No. 2 Test No. 6 3 August 1964

Time (Sec.)	Drive Wheel Revs. RIGHT	LEFT	AVG.	Drive-haft Revs.	Distance Traveled (Ft.)	Cumulative Distance (Ft.)	Avg. Speed (MPH)	Avg. Cell Dia. (Ft.)	Mean Tree Spacing/Veh. Width	Driveshaft Torque (Ft.-Lbs.) AVG.	MAX.	MIN.	Average Tractive Effort (Lbs.)	Vertical Acceleration (G's) UP	DOWN	Lateral Acceleration (G's) RIGHT	LEFT
0-5	15.4	15.8	15.6	65.8	54	54	7.4	89	3.56	105	159	0	798	.29	.21	.12	.12
5-10	13.8	14.1	14.0	59.1	48	102	6.5	65	2.60	81	153	-42	616	.07	.14	.14	.12
10-15	11.3	10.7	11.0	46.4	38	140	5.2	51	2.04	125	185	61	950	.43	.36	.65	.55
15-20	13.1	13.2	13.2	55.7	46	186	6.3	64	2.56	106	193	-53	806	.14	.29	.06	.14
20-25	10.5	9.9	10.2	43.0	35	221	4.6	57	2.28	74	193	-110	562	.29	.64	.31	.14
25-30	10.1	10.2	10.2	43.0	35	256	4.6	53	2.12	106	153	49	806	.21	.14	.10	.16
30-35	14.4	15.0	14.7	62.0	51	307	6.9	61	2.44	98	165	40	745	.43	.29	.12	.10
35-40	18.0	18.0	18.0	76.0	62	369	8.4	59	2.36	113	178	64	859	.43	.50	.18	.10
40-43.4	17.5	17.0	17.2	72.6	60	429	12.0	---	----	106	189	40	806	.29	.21	.16	.22
Total	124.1	123.9	124.1	523.6	429	429	----	---	---	---	---	---	---	---	---	---	---
Average	-----	-----	-----	-----	---	---	6.9	62.4	2.5	102	174	5	775	.29	.31	.20	.18

TABLE III-2 (CONTINUED) LATERAL OBSTACLE TESTS

BASIC DATA TABLES

M29C, WEASEL Site No. 2 Test No. 7 3 August 1964

Time (Sec.)	Drive Wheel Revs. RIGHT	Drive Wheel Revs. LEFT	Revs. AVG.	Driveshaft Revs.	Distance Traveled (Ft.)	Cumulative Distance (Ft.)	Avg. Speed (MPH)	Avg. Cell Dia. (Ft.)	Mean Tree Spacing/Veh. Width	Driveshaft Torque (Ft.-Lbs.) AVG.	MAX.	MIN.	Average Tractive Effort (Lbs.)	Vertical Acceleration (G's) UP	Vertical Acceleration (G's) DOWN	Lateral Acceleration (G's) RIGHT	Lateral Acceleration (G's) LEFT
0-5	16.3	----	16.3	68.8	56.6	56.6	7.7	78	3.12	117	185	45	889	.37	.51	.14	.16
5-10	17.3	----	17.3	73.0	60.0	116.6	8.2	83	3.32	88	154	88	669	.29	.07	.18	.06
10-15	15.5	----	15.5	65.4	53.8	170.4	7.3	64	2.56	110	182	37	836	.29	.21	.20	.08
15-20	19.2	----	19.2	81.0	66.6	237.0	9.1	63	2.52	70	180	-74	532	.37	.21	.27	.08
20-25	15.5	----	15.5	65.4	53.8	290.8	7.3	55	2.20	110	164	14	836	.29	.29	.12	.22
25-30	11.8	----	11.8	49.8	40.9	331.7	5.6	61	2.44	72	180	-117	547	.51	.66	.20	.18
30-35	13.0	11.0	12.0	50.6	41.6	373.3	5.7	60	2.40	125	199	60	950	.21	.15	.22	.18
35-40	12.9	13.2	13.0	54.9	45.1	418.4	6.1	--	----	113	204	17	859	.29	.15	.18	.06
Total	121.7	----	120.6	508.9	418.4	418.4	---	--	----	---	---	---	---	---	---	---	---
Average	-----	----	-----	------	-----	-----	7.1	66	2.64	101	181	9	768	.33	.22	.18	.08

M29C, WEASEL Site No. 2 Test No. 8A 21 August 1964

0-5	----	----	18.7	91	64.9	64.9	8.8	71	2.84	129	242	-59	980	.91	.25	.27	.96
5-10	----	----	13.8	67	47.7	112.6	6.5	60	3.40	79	244	-53	600	.51	.51	.35	.28
10-15	----	----	12.2	59	42.2	154.8	5.7	57	2.28	136	243	-41	1034	.51	.35	.33	.16
15-20	----	----	19.9	97	69.1	223.9	9.4	61	2.44	125	243	-41	950	1.42	.86	.51	.50
20-23.78	----	----	10.7	52	37.1	261.0	6.7	67	2.68	129	231	-61	980	.61	.61	.70	.44
Total	----	----	75.3	366	261.0	817.2	---	--	----	---	---	---	----	----	---	---	---
Average	----	----	----	---	-----	-----	7.4	63	2.53	120	241	-51	909	.79	.52	.43	.47

M29C, WEASEL Site No. 2 Test No. 8B 21 August 1964

0-5	----	----	6.2	30	21.4	21.4	2.9	60	2.40	97	119	45	737	.15	.20	.06	.13
5-10	----	----	5.3	26	18.5	39.9	2.5	60	2.40	108	148	62	821	.10	.25	.03	.15
10-15	----	----	5.3	26	18.5	58.4	2.5	59	2.36	105	136	51	798	.20	.15	.08	.06
15-20	----	----	5.5	27	19.2	77.6	2.6	55	2.20	114	182	45	866	.30	.35	.04	.13
20-25	----	----	5.1	25	17.8	95.4	2.4	52	2.08	114	213	6	866	.40	.30	.13	.32
25-26.05	----	----	1.0	5	3.6	99.0	2.3	52	2.08	45	88	31	342	---	---	.04	.03
Total	----	----	28.4	139	99.0	391.7	---	--	----	---	---	---	---	---	---	---	---
Average	----	----	----	---	----	-----	2.5	56	2.24	97	148	40	738	.23	.25	.06	.14

TABLE III-2 (CONTINUED) LATERAL OBSTACLE TESTS

BASIC DATA TABLES

M29C, WEASEL Site No. 4 Test No. 18 20 August 1964

Time (Sec.)	Drive Wheel Revs. RIGHT	LEFT	AVG.	Drive-shaft Revs.	Distance Traveled (Ft.)	Cumulative Distance (Ft.)	Avg. Speed (MPH)	Avg. Cell Dia. (Ft.)	Mean Tree Spacing/Veh. Width	Driveshaft Torque (Ft.-Lbs.) AVG.	MAX.	MIN.	Average Tractive Effort (Lbs.)	Vertical Acceleration (G's) UP	DOWN	Lateral Acceleration (G's) RIGHT	LEFT
0-5	7.4	7.2	7.3	30.8	25.7	25.7	3.50	78	3.12	101	143	39	768	.15	.15	.09	.09
5-10	5.7	5.3	5.5	23.2	19.8	45.5	2.70	78	3.12	114	154	-8	866	.15	.15	.04	.13
10-15	7.1	7.7	7.4	31.2	26.7	72.2	3.64	76	3.04	101	143	12	768	.20	.10	.20	.09
15-20	7.8	6.5	7.2	30.4	27.1	99.3	3.69	68	2.72	108	154	36	821	.66	.46	.07	.13
20-25	7.9	7.1	7.5	31.6	27.4	126.7	3.37	67	2.68	97	154	42	737	.40	.30	.06	.07
25-30	6.9	7.3	7.1	30.0	25.3	152.0	3.45	72	2.88	106	147	59	806	.10	.10	.06	.08
30-35	6.6	7.6	7.1	30.0	26.4	178.4	3.60	75	3.00	91	152	27	692	.05	.10	.02	.08
35-40	6.8	7.6	7.2	30.4	26.4	204.8	3.60	75	3.00	103	147	36	783	.20	.05	.06	.07
40-45	7.2	6.8	7.0	29.5	25.0	229.8	3.41	76	3.04	91	147	34	692	.05	.10	.06	.10
45-50	7.0	6.7	6.8	28.7	24.3	254.1	3.31	71	2.84	97	142	46	737	.10	.10	.02	.03
50-54.8	6.1	7.0	6.6	27.8	24.3	278.4	3.31	68	2.72	103	142	59	783	.35	.15	.13	.20
Total	76.5	76.8	76.7	323.6	278.4	278.4	----	--	----	---	---	---	---	---	---	---	---
Average	----	----	----	-----	-----	-----	3.42	73	2.92	101	148	35	768	.21	.16	.07	.10

M29C, WEASEL Site No. 4 Test No. 19 20 August 1964

0-5	18.2	18.1	18.2	76.8	63.2	63.2	8.61	82	3.28	105	344	-57	798	.76	1.37	.61	.29
5-10	20.1	19.7	19.9	84.0	70.0	133.2	9.54	73	2.92	140	206	45	1064	.81	.81	.43	.27
10-15	22.4	21.2	21.8	92.0	77.7	210.9	10.59	65	2.60	126	218	20	958	.46	.96	.56	.67
15-20	23.2	23.7	23.4	98.7	82.2	293.1	11.20	80	3.20	122	212	24	927	.40	.76	.57	.43
20-25	26.0	25.6	25.8	108.9	90.2	383.3	12.29	72	2.88	122	218	10	927	.76	.76	.49	.34
25-30	25.0	26.0	25.5	107.6	90.2	473.5	12.29	75	3.00	122	234	8	927	.66	.86	1.06	.25
30-34.9	26.3	25.2	25.8	108.9	91.3	564.8	12.44	70	2.80	117	231	12	889	.46	.46	.60	.46
Total	161.2	159.5	160.4	676.9	564.8	564.8	-----	--	----	---	---	---	----	---	---	---	---
Average	-----	-----	-----	-----	-----	-----	10.99	74	2.96	122	238	9	927	.62	.85	.62	.39

M29C, WEASEL Site No. 4 Test No. 20 20 August 1964

0-5	18.2	16.8	17.5	73.8	63.2	63.2	8.61	72	2.88	101	312	0	768	.81	1.01	.42	.42
5-10	18.2	19.2	18.7	78.9	66.6	129.8	9.07	62	2.48	156	275	8	1185	.51	.40	.31	.21
10-15	22.5	21.8	22.2	93.7	78.1	207.9	10.64	78	3.12	142	243	36	1079	.76	.66	.37	.53
15-20	26.4	26.5	26.4	111.4	92.0	299.9	12.53	76	3.04	138	280	16	1049	1.01	.96	.31	.50
20-25	29.4	28.4	28.9	122.0	102.0	401.9	13.90	70	2.80	122	230	4	927	.81	.81	.27	.47
25-30	22.1	22.1	22.1	93.3	76.7	478.6	10.45	72	2.88	81	183	-61	616	1.01	2.02	.88	.79
30-35	15.9	15.8	15.8	66.7	55.2	533.8	7.52	86	3.44	146	263	30	1110	.91	.91	.88	.40
35-36.8	6.6	6.8	6.7	28.3	23.6	557.4	3.22	--	----	122	249	32	927	.81	.61	.76	.57
Total	159.3	157.4	158.3	668.1	557.4	557.4	-----	--	----	---	---	---	----	----	----	---	---
Average	-----	-----	-----	-----	-----	-----	9.49	74	2.96	126	267	8	958	.83	.92	.53	.49

TABLE III-3 - LATERAL OBSTACLE TESTS

SUMMARY TABLE

Site No.	Test No.	Veh.	Speed Made Good (MPH)	Average Torque (Ft.-Lbs.)	Maximum Torque (Ft.-Lbs.)	Average Tractive Effort (Lbs.)	Maximum Tractive Effort (Lbs.)	Average Steering Angle	Maximum Steering Angle	Mapped Course Length (Ft.)	Mapped Path Length (Ft.)	Path Elongation	Veg. Cell Dia. (Ft.)	Mean Stem Spacing (Ft.)	Mean Stem Spacing/Veh. Width	Visibility (0-100')	Ft./Dot (Center Target)	Remarks
1	A	M37	4.11	---	---	---	----	----	----	194.0	206	1.06	-----	----	---	56.0		Driver said he could have gone
1	B	M37	4.75	---	---	---	----	----	----	195.0	203	1.04	-----	----	---	56.0		faster these two runs (Tests A&B)
1	1	M37	13.60	199	261	825	1080	5.3	8.6	442.0	446	1.005	118.1	26.5	4.3	56.0		
1	2	M37	13.40	228	333	946	1380	12.4	26.6	782.0	789	1.009	106.4	23.8	3.9	56.0		
1	3	M37	4.08	216	268	898	1110	4.1	9.1	376.0	379	1.007	111	24.9	4.1	56.0		Slow speed
1	4	M29C	15.10	101	190	768	1440	----	----	612.0	618	1.010	103.0	23.1	4.1	56.0		
1	5	M29C	13.90	106	197	806	1370	----	----	558.0	560	1.002	107.0	24.0	4.3	56.0		
2	6	M29C	6.35	102	174	775	1320	----	----	405.0	407.5	1.006	62.4	14.0	2.5	6.8		
2	7	M29C	6.65	101	181	768	1370	----	----	452.9	483.4	1.066	66	14.8	2.6	6.8		
2	8	M29C	-----	---	---	---	----	----	----	-----	---	-----	-----	----	---	6.8		Instrument failure
2	9	M37	7.48	136	260	562	1080	16.0	23.6	520.0	530.6	1.021	62	13.9	2.3	6.8		
2	10	M37	6.41	172	315	715	1310	13.9	20.6	470.8	478.8	1.014	60.9	13.6	2.2	6.8		
2	11	M37	1.35	138	205	572	820	14.1	22.7	381.0	392.5	1.028	59.7	13.4	2.2	6.8		Slow speed
2	8A	M29C	7.40	120	241	909	1830	----	----	292.0	316.0	1.080	63	14.1	2.5	6.8		Track speed (Avg.) 7.4 MPH
2	8B	M29C	2.50	97	148	738	1120	----	----	113.0	115.0	1.018	56	12.5	2.3	6.8		Slow speed
3	12	M37	-----	---	Mobile	---	----	----	----	290.0	---	-----	39.0	8.7	1.40	5.5		
3	12	M37	-----	---	Immobilized	---	----	----	----	290.0	---	-----	30.0	6.8	1.10	5.5		Immobilized
3	13	M37	-----	---	Mobile	---	----	----	----	294.0	---	-----	38.0	8.51	1.39	5.5		
3	13	M37	-----	---	Immobilized	---	----	----	----	294.0	---	-----	36.0	8.01	1.31	5.5		Immobilized
3	14	M37	-----	---	Immobilized	---	----	----	----	148.1	---	-----	-----	-----	---	5.5		Immobilized before "Start" Position
3	15	M29C	-----	---	Mobile	---	----	----	----	295.0	---	-----	33.7	7.55	1.35	5.5		
3	15	M29C	-----	---	Immobilized	---	----	----	----	295.0	---	-----	31.0	6.94	1.24	5.5		Immobilized
3	16	M29C	-----	---	Mobile	---	----	----	----	294.5	---	-----	-----	----	---	5.5		
3	16	M29C	-----	---	Immobilized	---	----	----	----	294.5	---	-----	40.0	8.96	1.60	5.5		Immobilized
3	17	M29C	-----	---	Mobile	---	----	----	----	147.9	---	-----	28.0	6.27	1.12	---		Non-immobilized, but path did not close with end stake. By 100', straight line distance. Slow speed
4	18	M29C	3.38	101	148	768	1120	----	----	272.0	279.0	1.026	73	16.1	2.9	5.99		
4	19	M29C	10.90	122	238	927	1810	----	----	562.0	570.0	1.014	74	16.6	3.0	5.99		
4	20	M29C	10.42	126	267	958	2030	----	----	549.0	556.0	1.013	74	16.6	3.0	5.99		Slow speed
4	21	M37	3.54	180	251	748	1040	7.8	15.0	264.0	267.0	1.011	71	15.9	2.6	5.99		
4	22	M37	11.40	189	316	785	1310	7.5	12.5	587.0	597.0	1.017	79.6	17.8	2.9	5.99		
4	23	M37	10.10	220	311	915	1290	9.7	14.2	552.0	570.0	1.033	77.0	17.2	2.8	5.99		

TABLE III-4

LATERAL OBSTACLE TESTS

A Summary of Soils Data

Veh.	Test No.	Distance From Start Stake (Ft.)	Cone Index at Depths				Average Cone Index by Layers			Average Remolding Index by Layers			Rating Cone Index by Layers			Moisture Content In % Of Dry Mat		Dry Density In Lb./Ft.³		Shear Values Soil to Soil					Shear Values Rubber to Soil					Shear Values Rubber to Litter					Computed Drawbar Pull		
			SFC	3"	6"	9"	12"	0-6"	3-9"	6-12"	0-6"	3-9"	6-12"	0-6"	3-9"	6-12"	0-6"	6-12"	0-6"	6-12"	c_u	ϕ_u	Taff. PSI	σ_{u1}^2	σ_{u2}^2	c_{ur}	ϕ_{ur}	Taff. PSI	σ_{ur1}^2	σ_{ur2}^2	c_{ul}	ϕ_{ul}	Taff. PSI	σ_{ul1}^2	σ_{ul2}^2	Soil to Soil	Rubber to Soil	Rubber to Litter
M37	1	1+00	67	150	140	--	68	119	--	104	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
M37	2	7+15	82	175	138	138	140	132	147	137	--	--	--	--	--	--	28.6	25.0	84.0	81.8	0	48.5	2.8	1.4	33.0	0	46.5	2.2	1.5	24.0	0	58.0	2.8	2.4	32.0	--	3444	4896
M37	2	6+15	32	59	94	90	90	62	81	91	.27	.22	.16	17	18	15	41.4	24.6	72.6	94.4	1.8	19.5	--	--	--	0	61.0	1.0	1.6	22.0	0	49.5	3.5	1.3	38.0	--	3174	5778
M37	2	4+10	16	60	63	52	63	46	58	59	.40	.44	.47	18	26	28	41.5	24.5	74.0	93.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
M37	2	2+04	62	154	138	142	162	118	144	147	.25	.24	.24	30	34	35	34.9	24.0	75.5	90.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
M37	3	1+00	83	135	136	110	110	118	127	119	.29	.35	.42	33	44	50	33.2	26.1	79.4	89.7	1.6	13.5	--	--	--	1.4	28.0	--	--	--	0	49.0	4.0	2.0	34.0	-	4039	5182
M37	3	1+75	32	70	84	78	118	52	67	83	.22	.23	.24	11	15	20	47.0	28.2	88.0	87.4	0	49.0	1.8	2.0	7.0	0	50.0	2.0	1.8	22.0	--	--	--	--	--	--	3214	--
M29C	4	1+00	70	138	141	121	118	116	133	126	.44	.36	.28	51	48	35	31.2	25.2	83.3	91.5	--	--	--	--	--	0	43.0	4.3	1.6	27.0	0	49.0	3.8	2.1	33.5	--	--	--
M29C	4	2+00	32	47	58	62	76	45	55	65	.35	.42	.49	16	23	32	42.6	28.6	73.6	87.4	0	58.5	1.0	1.8	13.5	--	--	--	--	--	--	--	--	--	--	7050	--	--
M29C	5	1+75	46	113	104	101	88	87	106	97	.35	.40	.45	30	42	44	30.1	26.3	85.0	91.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
M29C	5	1+00	32	47	58	62	76	45	55	65	.35	.42	.49	16	23	32	42.6	28.6	73.6	87.4	0	58.5	1.0	1.8	13.5	--	--	--	--	--	--	--	--	--	--	7050	--	--
M29C	6	1+00	108	204	183	176	164	165	187	174	.58	.53	.48	94	99	84	14.8	18.4	85.6	104.0	0	49.0	3.8	1.8	40.0	0	36.0	--	--	--	0	33.5	--	--	--	6854	--	--
M29C	6	2+00	165	225	265	265	257	218	249	263	--	--	--	--	--	--	24.6	17.9	81.1	98.9	0	46.0	3.8	1.8	43.5	0	35.0	--	--	--	0	40.5	2.4	0.7	29.5	6175	--	--
M29C	6	3+20	135	265	250	240	248	215	251	246	--	--	--	--	--	--	21.6	21.6	89.4	95.2	1.0	43.0	--	--	--	0	36.5	--	--	--	--	--	--	--	--	8675	--	--
M29C	6	End	40	92	108	120	118	78	108	114	.28	.29	.30	22	31	34	35.2	23.3	79.9	94.5	--	--	--	--	--	--	--	--	--	--	0	40.5	2.4	0.7	29.5	6175	--	--
M29C	7	2+00	165	225	265	265	257	218	251	263	--	--	--	--	--	--	24.6	17.9	81.1	98.9	0	46.0	3.8	1.8	43.5	0	35.0	--	--	--	0	40.5	2.4	0.7	29.5	6175	--	--
M29C	7	3+20	135	265	250	240	248	215	251	246	--	--	--	--	--	--	21.6	21.6	89.4	95.2	1.0	43.0	--	--	--	0	36.5	--	--	--	--	--	--	--	--	8675	--	--
M29C	7	End	164	298	300	300	300	254	299	300	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
M29C	8A	Start	61	41	60	100	112	39	67	91	.17	.16	.15	6.6	10.7	13.6	34.2	28.4	82.2	89.7	2.0	14.0	--	--	--	0.8	28.0	--	--	--	1.2	46.0	5.2	4.6	36.5	--	3919	4438
M29C	8A	2+00	60	158	103	141	182	107	134	142	.37	.40	.42	39.6	53.6	59.6	23.5	21.5	93.4	100.0	1.2	35.0	4.4	3.2	14.5	0.9	32.0	--	--	--	0.8	40.5	8.0	5.0	17.5	--	4396	3226
M29C	8A	End	68	86	72	65	60	75	74	66	.29	.47	.65	21.8	34.8	42.9	24.1	20.0	90.7	103.3	2.4	41.5	6.4	6.6	14.5	2.2	39.0	4.8	1.1	35.5	1.6	44.5	--	--	--	5257	7265
M37	9	0+48	80	242	224	210	298	182	225	244	•	--	--	--	--	--	--	--	--	--	0	47.0	4.2	2.5	28.0	0	51.0	1.0	0.7	36.0	--	--	--	--	--	--	5269	--
M37	9	2+00	155	238	170	167	145	188	191	160	•	--	--	--	--	--	--	--	0.5	44.0	--	--	--	--	--	0.3	34.0	--	--	--	--	--	--	--	--	--	4822	--
M37	9	4+25	124	244	182	162	146	183	196	163	•	--	--	--	--	--	--	--	0	49.0	1.4	0.3	42.5	0.5	33.5	--	--	--	--	--	--	--	--	--	--	4777	--
M37	10	1+50	47	57	126	121	109	77	101	118	.34	.28	.22	26	28	26	34.4	28.9	84.4	90.2	1.0	43.0	2.5	2.2	23.5	0	54.0	1.6	1.5	25.0	--	--	--	--	--	--	3382	--
M37	10	3+00	118	230	161	184	158	169	191	167	•	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
M37	10	End-70'	80	242	224	210	298	182	225	244	•	--	--	--	--	--	--	--	0	47.0	4.2	2.5	28.0	0	51.0	1.0	0.7	36.0	--	--	--	--	--	--	--	--	5269	--
M37	11	0+80	124	244	182	162	146	183	196	163	•	--	--	--	--	--	--	--	0	49.0	1.4	0.3	42.5	0.5	33.5	--	--	--	--	--	--	--	--	--	--	4777	--
M37	11	2+00	150	272	268	253	264	230	264	261	•	--	--	--	--	--	--	--	0	50.0	1.6	1.9	35.0	0	45.0	1.5	0.7	32.0	--	--	--	--	--	--	--	--	4556	--
M37	11	3+00	118	230	161	184	153	77	191	118	•	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
M37	12	Entire Lane	125	209	219	250	264	184	192	244	•	--	--	--	--	--	21.0	19.1	88.7	100.4	0.3	43.5	--	--	--	0	37.0	--	--	--	0.2	35.7	--	--	--	5327	5113
M37	13	Entire Lane	187	342	418	379	327	315	378	374	•	--	--	--	--	--	22.9	18.5	81.8	104.3	0.3	43.5	--	--	--	0	37.0	--	--	--	0.2	35.7	--	--	--	5327	5113
M29C	15	Center of Course	136	183	191	144	146	170	173	162	•	--	--	--	--	--	23.5	20.0	85.3	100.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
M29C	16	0+20	190	223	280	280	282	231	294	347	•	--	--	--	--	--	17.7	17.6	94.1	107.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
M29C	17	Entire Lane	91	256	210	226	256	186	231	231	•	--	--	--	--	--	24.0	19.8	89.0	101.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
M29C	18	1+00	66	148	202	216	252	130	189	223	•	--	--	--	--	--	14.8	15.0	91.8	93.2	0.7	47.0	4.7	2.8	32.5	1.2	36.5	4.5	2.7	23.0	0.7	43.0	2.4	1.9	24.5	8583	--	--
M29C	18	2+00	44	144	166	360	274	118	223	267	•	--	--	--	--	--	18.7	13.3	89.0	96.7	0	39.0	2.3	2.1	38.5	0.1	45.0	8.5	3.2	32.2	1.4	33.5	--	--	--	9917	--	--
M29C	19	1+20	66	148	202	216	252	130	189	223	•	--	--	--	--	--	14.8	15.0	91.8	93.2	0.7	47.0	4.7	2.8	32.5	1.2	36.5	4.5	2.7	23.0	0.7	43.0	2.4	1.9	24.5	8583	--	--
M29C	19	2+80	57	186	360	398	318	201	315	350	•	--	--	--	--	--	16.1	15.0	85.9	95.6	1.6	47.0	5.5	4.8	26.5	0.8	44.0	3.3	2.4	27.0	1.1	32.0	--	--	--	11480	--	--
M29C	19	4+00	90	186	328	328	266	201	247	273	•	--	--	--	--	--	19.7	15.0	89.1	97.7	1.7	43.3	8.0	4.7	29.0	0.8	27.0	--	--	--	0.9	44.0	7.8	5.2	22.0	10018	--	--
M29C	20	1+00	78	182	212	244	260	157	213	230	•	--	--	--	--	--	20.6	20.7	88.8	91.2	1.5	47.5	4.9	4.7	24.5	1.3	40.5	5.7	4.8	32.2	0.9	35.0	--	--	--	11182	--	--
M29C	20	2+00	70	156	236	248	242	154	213	242	•	--	--	--	--	--	21.6	18.0	87.0	100.6	1.8	41.5	--	--	--	1.2	44.0	6.9	4.8	34.0	1.3	33.5	--	--	--	10891	--	--
M37	21	1+00	38	150	206	236	300	131	197	247	•	--	--	--	--	--	--	--	--	--	0.1	42.5	--	--	--	--	44.0	2.3	1.0	31.0	--	--	--	--	--	4446	--
M37	22	1+00	52	158	250	266	316	153	231	284	•	--	--	--	--	--	17.9	15.0	93.1	103.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
M37	22	2+40	31	106	250	394	408	196	250	356	•	--	--	--	--	--	17.9	12.2	88.6	106.8	--	--	--	--	--	--	--	--	--	--	0	35.0	--	--	--	--	4981
M37	22	4+30	34	246	400	482	554	333	376	478	•	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	35.0	--	--	--	--	4981
M37	23	0+30	34	246	400	482	554	333	376	478	•	--	--	--	--	--	23.8	12.1	84.0	99.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
M37	23	End	70	198	230	226	214	166	218	223	•	--	--	--	--	--	23.5	12.8	85.2	104.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

• Soil too hard to take remolding data.

TABLE III-5 - SAMPLE SOIL MEASUREMENTS

ONE PASS PERFORMANCE

WES FORM NO. JULY 1963 1424 Site No. 1 D. B. S. P.

TEST NO. #4 - STA. 1+00 LOCATION NASA DATE 31 JULY 1964

VEHICLE M29C, WEASEL TEST WT. _____ WATER TABLE _____

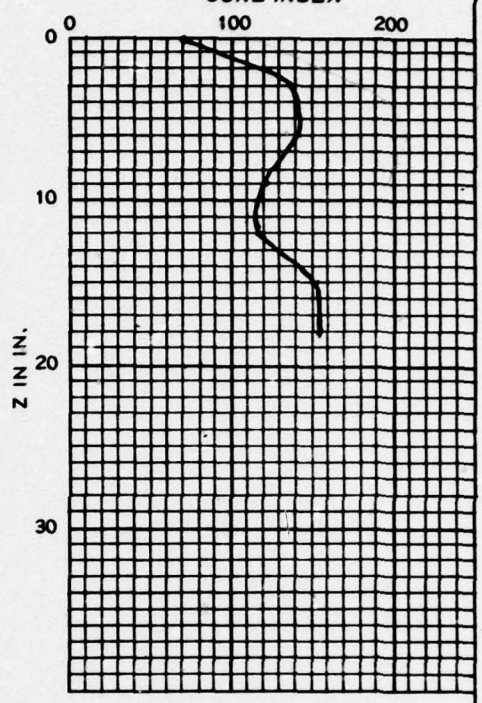
TIRE SIZE _____ INFL. PRESS. _____ IMMOB. PASS _____

EST. D. B. _____ D/W _____ TORQUE _____

CONE SIZE _____ SHAFT SIZE _____

CONE INDEX

SFC	3"	6"	9"	12"	15"	18"							
70	210	280	90	100	115	200							
70	140	160	145	125	115	130							
50	185	80	75	60	300	300							
110	80	75	155	160	145	80							
50	105	110	140	145	85	60							
350													
70													
TOT	690	705	605	590	760	770							
AVG	138	141	121	118	152	154							
CI	116		126										
RI	44		.28										
RCI	51		35										



REMOLDING INDEX

STA.	1+00		1+00		1+00		1+00											
DEPTH	0"-6"		0"-6"		6"-12"		6"-12"											
	0	100	0	100	0	100	0	100	0		0		0		0		0	
SFC.	60	40	80	25	50	30	35	10										
1	130	30	180	55	180	50	65	10										
2	150	60	215	55	170	50	105	30										
3	155	75	200	70	170	60	180	20										
4	135	120	205	105	280	120	100	20										
TOTAL	630	325	850	320	850	310	455	90										
R. I.	.52		.36		.36		.20											

MOISTURE CONTENT & DENSITY

STA.	1+00	1+00	1+00	1+00						
DEPTH	0"-6"	6"-12"	0"-6"	6"-12"						
CAN. NO.	514C	1072C	604C	973C						
WET & CAN	369.2	383.4	379.5	389.8						
DRY & CAN	306.0	326.5	310.5	331.0						
WATER	63.2	56.9	67.0	58.8						
CAN	100	100	100	100						
DRY SOIL	206.0	226.5	210.5	231.0						
% MOISTURE	30.7	25.1	31.8	25.4						
DRY DENSITY	82.4	90.6	84.2	92.4						

TABLE III-6 - SAMPLE SOIL MEASUREMENTS

ONE PASS PERFORMANCE

WES FORM NO. 1424
JULY 1964

Site No. 4 D. B. S. P.

TEST NO. #22-STA. 1+00 LOCATION NASA DATE 18 Aug. 1964

VEHICLE M37 TEST WT. _____ WATER TABLE _____

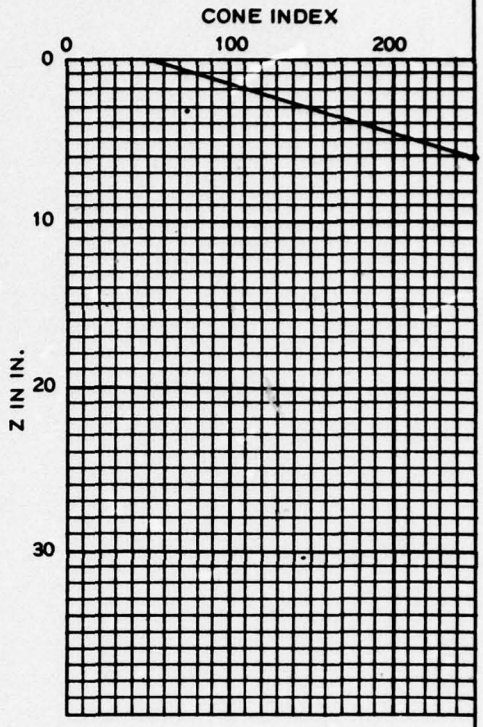
TIRE SIZE 9:00-14 INFL. PRESS. 35 psi IMMOB. PASS _____

EST. D. B. _____ D/W _____ TORQUE _____

CONE SIZE .2 SHAFT SIZE _____

CONE INDEX

	3	6	9	12	15	18							
SFC													
30	100	200	250	300	300	320							
70	150	250	260	280	340	400							
50	230	300	340	380	380	370							
40	110	200	300	350	460	360							
70	200	300	280	300	330	370							
-													
260													
62													
TOT	790	1250	1430	1580	1800	1810							
AVG	158	250	286	316	360	362							
CI													
RI													
RCI													

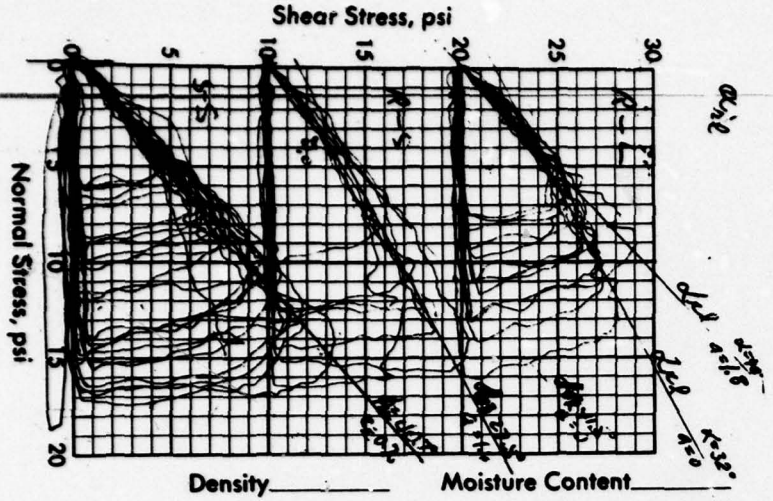


REMOLDING INDEX

DEPTH	0		0		0		0		0		0		0		0		0		0	
SFC.																				
1																				
2																				
3																				
4																				
TOTAL																				
R. I.																				

MOISTURE CONTENT & DENSITY

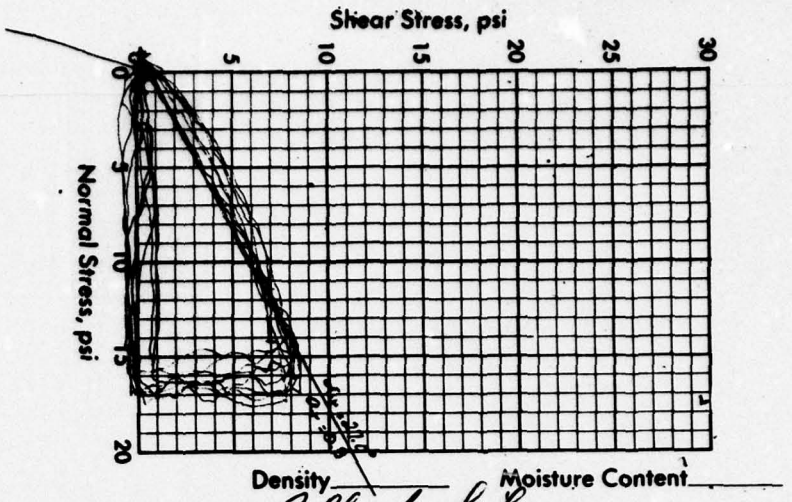
STA.	1+00	1+00	1+00	1+00						
DEPTH	0-6	6-12	0-6	6-12						
CAN. NO.	453c	619c	906c	874c						
WET & CAN	374.4	396.3	364.4	402.2						
DRY & CAN	332.7	357.7	326.0	387.0						
WATER	41.7	38.6	38.4	36.2						
CAN	100	100	100	100						
DRY SOIL	232.7	257.7	226.0	287.0						
% MOISTURE	17.9	15.0	17.0	12.3						
DRY DENSITY	93.1	103.1	90.4	114.8						



Soil THIS TEST IS VALID FOR TESTS 12-17

Location NASA Test No. 0.R 17 Date 25 AUG 64

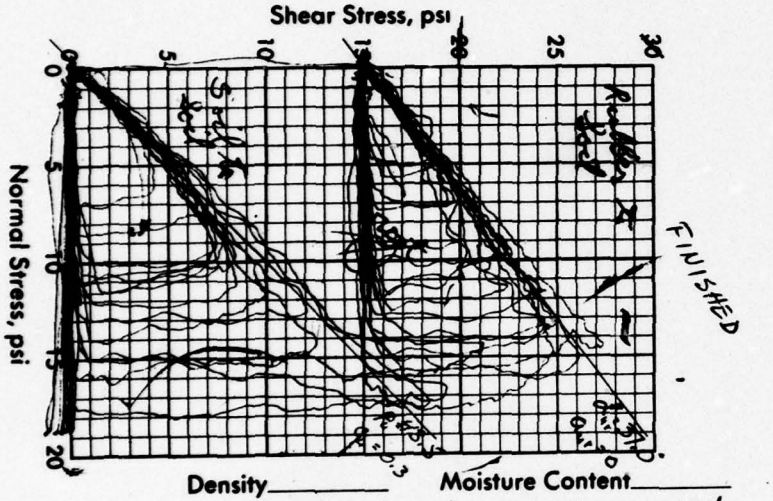
PRINTED ■ GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK No. TC



Soil Rubber to Soil

Location Sta 4 Sta 4+00 Test No. 19 Date 8-20-64

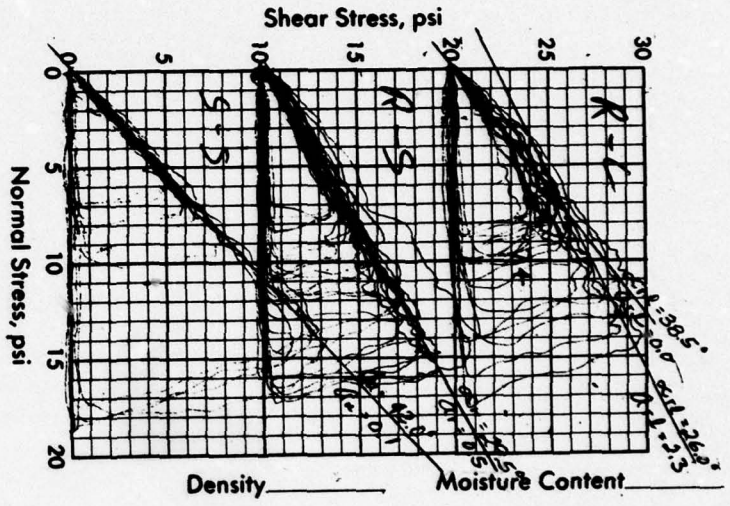
PRINTED IN U.S.A. ■ GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK No. TCI 9971



Soil Average of Entire Testtime

Location SITE 3 ~~0 to 30~~ Test No. 12-13 Date 14AUG64

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Soil

Location NASA M.O.R. Course 5 Test No. M.O.R.2 Date

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WES FORM NO. 1369
FEBRUARY 1964

VISIBILITY DATA FORM

MAP REFERENCE: 1 + 48 SITE NO.: 3

GEOGRAPHIC COORDINATES:

MEASURED BY: Grenke and Batchelor DATE: 10 August 1964

UNIT MEASURE: Feet INSTRUMENT HEIGHT: 4.5 Ft. PHOTO NO.:

AZIMUTH OF SIGHT LINE	TIME	WEATHER	SUN AZIMUTH	LIGHT INTENSITY	TARGET HEIGHT	DOT COUNT AT DISTANCE ⊡ SUN ON TARGET ⊠ SUN NOT ON TARGET 25	50	100	150			NOTES
℄ 0° N	1100	Clear			T	15	11	1	0			
					M	14	13	3	0			
					B	14	7	3	0			
45°	1115	Clear			T	25	11	5	5			
					M	24	9	1	1			
					B	16	10	0	0			
90°	1130	Clear			T	18	20	10	10			
					M	20	20	11	10			
					B	20	19	3	4			
135°	1145	Clear			T	25	25	5	4			
					M	25	23	5	5			
					B	24	11	0	1			
℄ 180° S	1200	Clear			T	24	10	14	0			
					M	20	10	10	0			
					B	20	10	9	0			
225°	1300	Light Rain			T	20 X	15 X	9 X	0 X			
					M	20 X	14 X	4 X	0 X			
					B	20 X	13 X	0 X	0 X			
270°	1315	Light Rain			T	20 X	23 X	10 X	Out X			
					M	20 X	18 X	10 X	Of X			
					B	14 X	15 X	6 X	Test X	Course		
315°	1330	Light Rain			T	25 X	20 X	10 X	8 X			
					M	20 X	20 X	6 X	1 X			
					B	20 X	8 X	0 X	0 X			

NOTES:

TABLE III-8 - SAMPLE VISIBILITY MEASUREMENT

APPENDIX IV

TEST PLAN

SINGLE LONGITUDINAL OBSTACLES

B. O. Benn
G. T. Cohron
R. A. Werner

20 August 1964

VEHICLE OVERRIDE OF SINGLE LONGITUDINAL OBSTACLES

I. OBJECTIVE

This study has three objectives. All can be accomplished through the analysis of data, separate tests not being required. They are as follows:

A. The determination of the maximum tree size which can be pushed over with a given amount of tractive effort. The corollary determination will be that of the "no-effect" tree size, considering their individual effects on probable vehicle speed.

B. The support of the multi-tree override study in supplying basic data on the work expended in overriding single stems so that the effects of crown interference may be computed.

C. The delineation of simple, expeditious procedures involving only important variables to facilitate more comprehensive tests.

II. SCOPE

These tests will include studies of thirty trees ranging in stem diameter size from 2.54 cm (1 in.) to the maximum size the M37 truck can push over -- about 14 cm (5-1/2 in.) in diameter. Three trees of each of 10 different sizes (about 1.3 cm (1/2 in.) diameter increments) will be sought to furnish both an adequate range in sizes and an evaluation of variability within each size.

All tests will be conducted statically so these fundamental data will not be clouded with the unknowns imposed through dynamic tree contacts. This will allow "safe" estimates of vehicle speed, based upon the energy expended, to be made since inertia loading will not be involved.

III. DETERMINATIONS SOUGHT

The data to be collected lend themselves to various analyses, but the following are considered to be the most pertinent to the object of this study:

A. The relationship which characterizes the resistance of single trees to overriding moment plotted against override distance for a wide range of tree sizes (Figure IV-1).

B. The tree strength parameters which are sufficient to describe its reaction to override moment.

C. The maximum tree size which can be overriden in terms of available tractive effort.

D. In combination with multi-override tests, an estimate of speed through various mean spacings of tree stems of less-than-immobilizing sizes and spacings.

E. An attempt to devise a single override factor from the type, size, and spacing of the vegetation and strength of the soil.

F. A determination of the desirable instrumentation for more comprehensive tests.

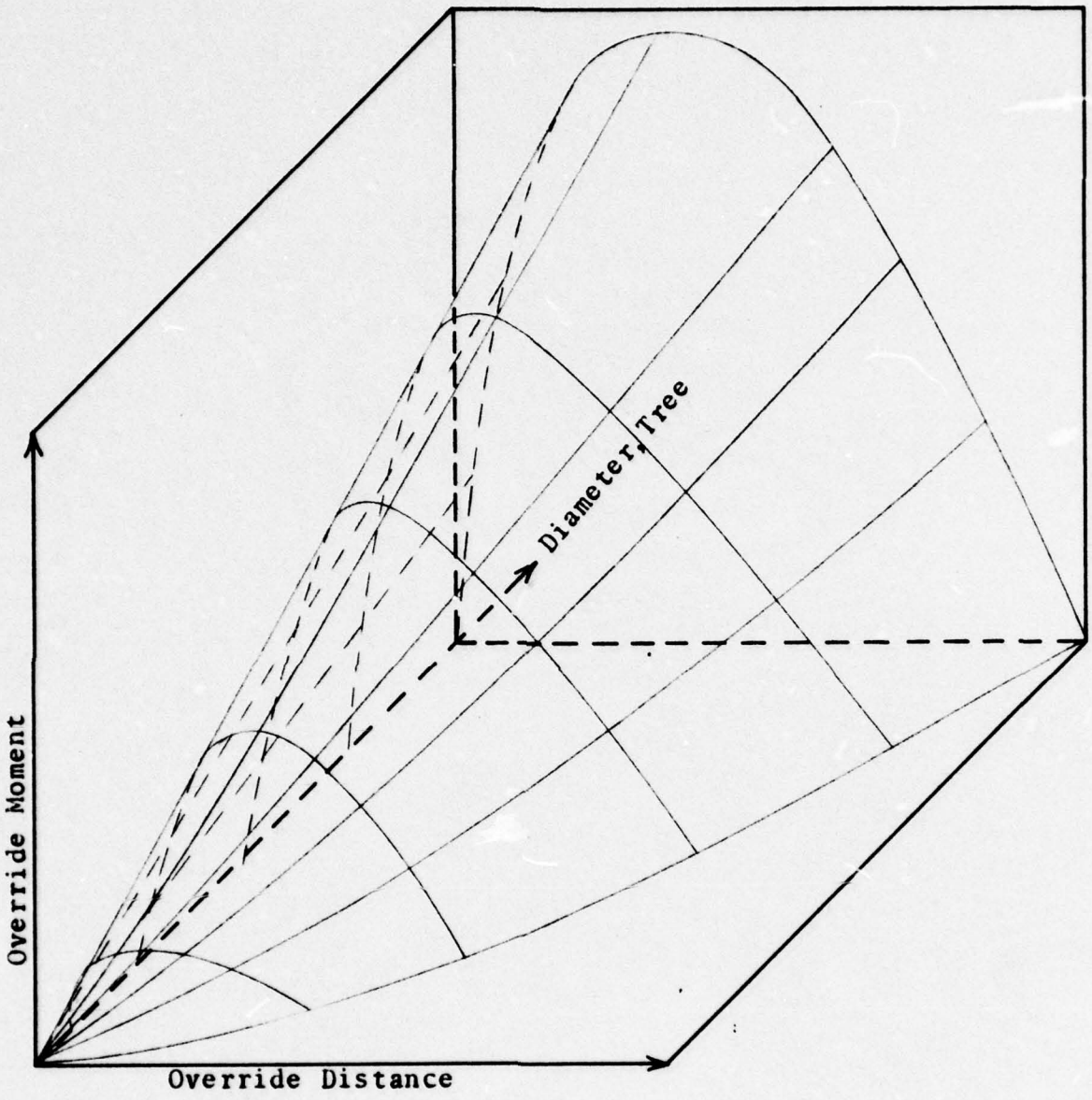


Figure IV-1 - Relationships Sought From Single Longitudinal Override Study.

IV. TEST SITE REQUIREMENTS

The area onto which the overriden tree is to fall must be free of other trees which would interfere with the felled tree reaching the ground. Single-standing trees are the most desirable to minimize site preparation. The area will also be cleared sufficiently to allow motion picture coverage of each override test. Trees are to range in size from 2.54 cm (1 in.) in diameter to about 14 cm (5-1/2 in.) in diameter, preferably in 1.3 cm (1/2 in.) increments. At least 30 trees will be required, three each of the 10 sizes.

The trees will be prepared for testing by painting horizontal bands about the half of the trunk facing the camera at one foot intervals, beginning one foot above the soil surface. Cone index readings will be made immediately prior to test according to the procedures outlined under "Conduct of Tests". Every effort will be made to select test sites whose soils are firm and level. It is desirable that a minimum amount of potential tractive effort is lost due to soft soils. Sheargraph readings may be used for this pre-test screening if felt to be necessary.

V. MEASUREMENTS REQUIRED

A. Advance

1. Tree location
2. Tree species
3. Tree diameter
4. Tree height
5. Crown diameter
6. Branching height

B. Pre-Test

1. Date
2. Location
3. Test number
4. Type of test
5. Vehicle, weight and tire pressure
6. Cone Index around tree
7. Remolding index
8. Moisture content/grain size analysis sample

C. Test

1. On oscillogram and magnetic tape
   a. Time
   b. Driveshaft RPM
   c. Pushbar horizontal force
   d. Torque
   e. Horizontal (transverse -- fore and aft) acceleration
   f. Event marker from start till tree hits ground
   g. Verbal notes on magnetic tape

2. By engineer
   a. Stopwatch times
      (1) Till tree hits ground
      (2) Till vehicle rear bumper leaves crown
   b. Pertinent observations

3. Photography: Motion-pictures - 16 frames per second

D. Post-Test

1. Mode of failure (see Figure V-3, Multiple-Stem Override Plan).

2. Tree rooting habits, tap root, fibrous root, etc.
3. Size and shape of hole when tree uproots with relative position of root bulb.
4. Distance traveled by the vehicle
   a. Till tree hit ground
   b. Till vehicle left crown
5. Sheargraph readings in vehicle tracks
6. Tree penetration resistance
7. Photograph failure
8. Collect a 76 cm (30 in.) sample of the tree trunk

E. Laboratory

1. Tree bending strength from trunk sample
2. Grain size analysis

VI. Conduct of Tests

A. Advance

1. Record required data on "Vegetation Structure Data" form and make forms available to test crew when tests are to start (see corrected sample with Multiple-Stem Override Plan).

B. Pre-Test

1. Record pertinent location, test number, test type and vehicle data.

2. Cone Index around the tree
   a. Take 4 samples spaced 90° apart on a radius equal to 3 tree diameters.

b. Take 4 samples 90° apart, 45° out of phase with the first readings, on a radius equal to 5 tree diameters.

c. Cone Index readings to be taken in the usual form to a depth of 76 cm (30 in.).

3. Collect two Hvorslev samples for 0- to 15-cm (0- to 6-in.) and 15- to 30.5-cm (6- to 12-in.) layers for record.

4. Collect single composite soils moisture/bulk density samples from the 0- to 15-cm, 15- to 30.5-cm, and 30.5- to 45.5-cm (0- to 6-in., 6- to 12-in., and 12- to 18-in.) layers, at locations 5 tree diameters from the trunk. Record samples for grain size analysis will be collected as required to characterize the area.

C. Test

1. Driver Instruction
   a. Low gear, low range, 4-wheel drive.
   b. Bring bumper within 1.3 cm (1/2 in.) of the tree before engaging clutch to start test.
   c. Keep engine RPM over 1200.

2. Record listed data on magnetic tape and small oscillogram.

3. Engineer (in vehicle)
   a. Event marker to indicate
      (1) Start test

(2) Tree hits ground
(3) Vehicle over tree crown

b. Record notes verbally on magentic tape

4. Take stopwatch time of events under 3.a.

5. Photography
Motion pictures of the sequence of events at 16 frames per second. Use telephoto lenses on one of each tree size to "flatten" the picture for easier analysis (reduces parallex).

Camera to be level and lens to be on a plane with horizontal tape on the side of the vehicle. Camera location to be perpendicular to the path of the vehicle and aimed directly at the tree.

Panning will be required to cover the motion of the truck over the tree, but none will be done until after the tree has completely fallen.

D. Post-Test

1. Record mode of failure.

a. Use the definitions given in the Multi-Stem Vegetation Plan (Type 1 through Type 5).

b. Give pertinent dimensions relating to the:
(1) Height of the failure
(2) Degree of complete failure
(3) Dimensions of the root bulb of soil in a Type 3 failure (Figure IV-2).

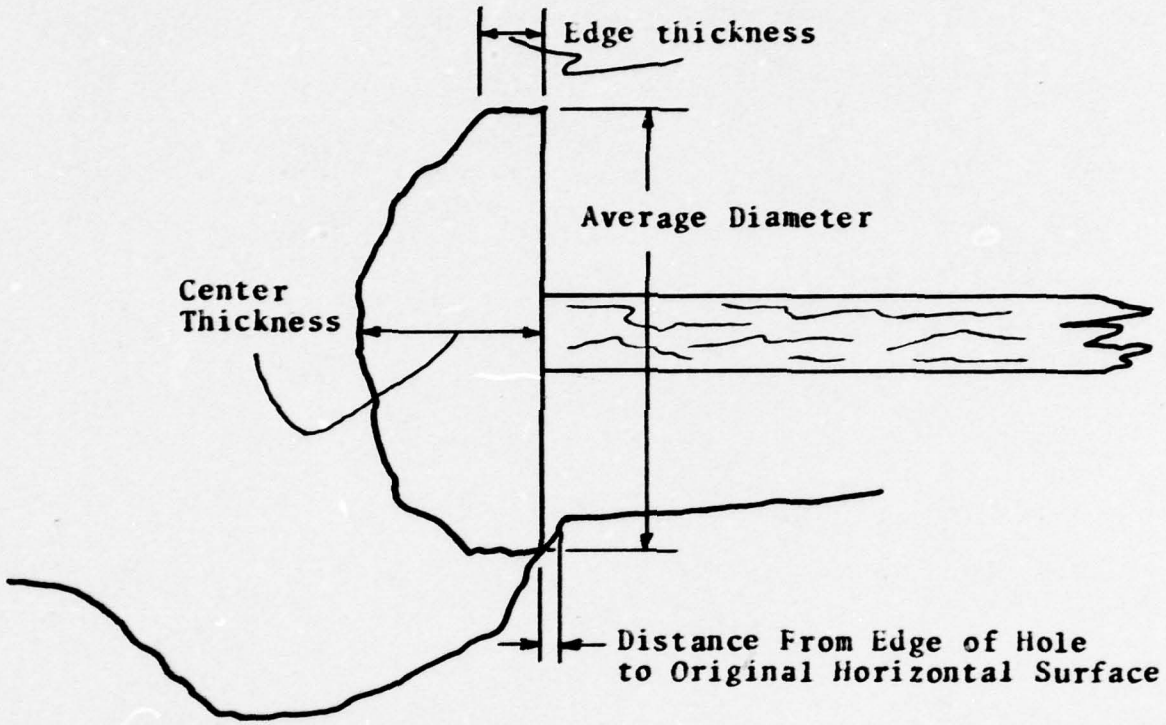


Figure IV-2 - Dimensions of the Root Bulb of Soil in a Type 3 Failure.

c. Tree rooting habits:
   (1) Fibrous
   (2) Tap root
   (3) Branched roots

2. Measure distance traveled

   a. From start till tree hit ground
   b. To end of run after vehicle pass over crown

3. Record soil shearing strength in approach tracks of M37 truck.

   a. Get as close to the tree as possible without getting in highly disturbed area.

   b. Collect the following shearing stress - normal stress curves:
      (1) Soil-to-soil, ultimate
      (2) Rubber-to-soil, ultimate
      (3) Rubber-to-litter

4. Saw out a 76 cm (30 in.) sample of the tree trunk immediately above the failed area. Seal the ends to prevent undue loss of sap.

5. Collect tree penetration resistance with the 10° cone penetrometer (Figure IV-3).

6. Before failed tree is disturbed, take photographs (black-and-white). Place a scale and a card with test number in the frame.
   a. Overall view of the tree

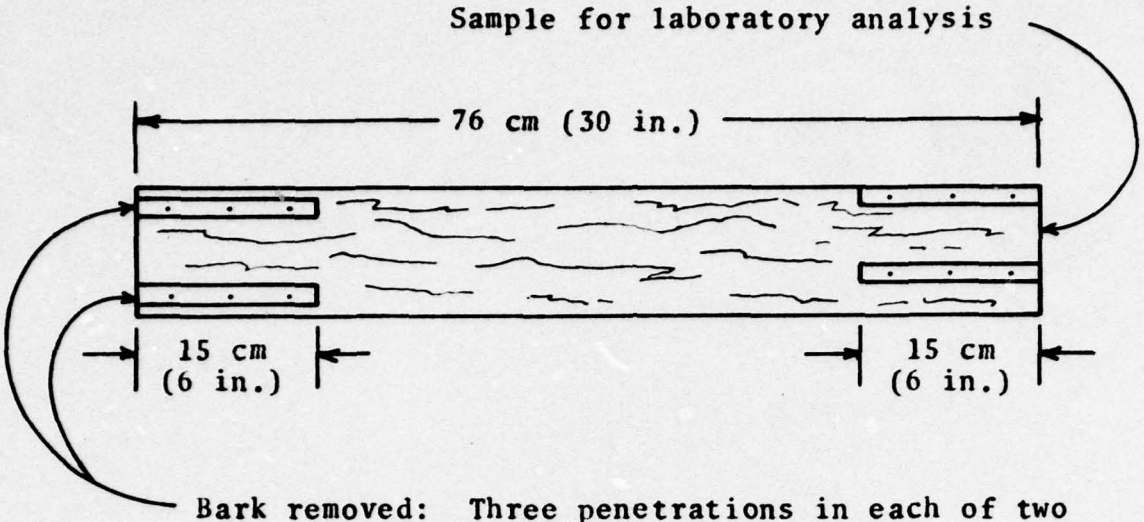


Figure IV-3 - Tree penetration resistance measurements.

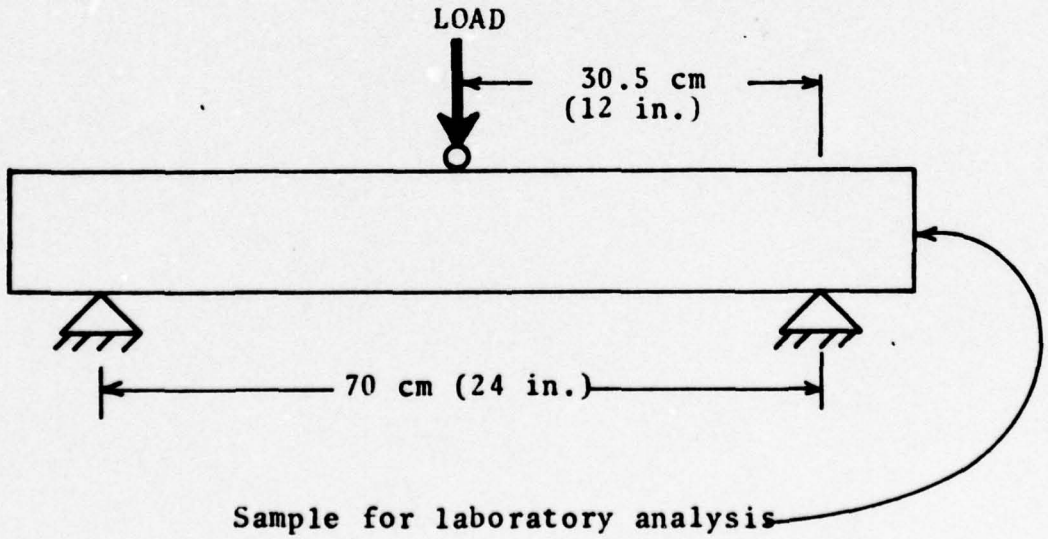


Figure IV-4 - Bending test.

b. Close-up of failure. Hold camera on a horizontal line through the center of interest so that scalar analysis can be made.

c. Tree rooting habits

E. Laboratory Analysis

1. Determine maximum bending stress of the 30 in. sample (Figure IV-4).

2. Perform grain size analysis on record soil samples according to standard procedures.

VII. DATA FORMS

A. Field Data Form

1. Test No.
2. Tree No.
3. Tree Species
4. Tree Diameters at
   a. Surface
   b. 6"
   c. 12"
   d. 24"
   e. 42"
5. Tree Height

B. Soils Data Form

1. WES Form No. 1424, July 1964
2. Sheargraph Form

C. Summary Data Form

1. Test No.
2. Tree No.
3. Tree Species
4. Tree Diameter at 42"
5. Maximum Pushbar Force, Lbs.
6. Total Work (Ft.-Lbs.)
7. Maximum Torque (Ft.-Lbs.)
8. Mode of Failure
9. Maximum Stress for Three Point Loading
10. Average Cone Index
    a. SFC-6"
    b. 6"-12"
    c. 12"-18"
    d. 18"-24"
    e. 24"-30"
11. Average Cone Index
    a. SFC-18"
12. Moisture Content in % of Dry Weight
    a. SFC-6"
    b. 6"-12"
    c. 12"-18"
13. Shear Values
    a. Soil to Soil
        1) c_u
        2) ϕ_u
        3) Inflection Pressure
        4) c_{u^2}
        5) ϕ_{u^2}

b. Rubber to Soil
   1) a_{ur}
   2) α_{ur}
   3) Inflection Pressure
   4) a_{ur^2}
   5) α_{ur^2}

c. Rubber to Litter
   1) a_{ul}
   2) α_{ul}
   3) Inflection Pressure
   4) a_{ul^2}
   5) α_{ul^2}

14. Computed Drawbar Pull
   a. Rubber to Soil
   b. Rubber to Litter

VIII. ANALYSIS PROCEDURE

A. From the permanent record of the magnetic tape, the following measurements will be taken:

1. Determine the zero line for the torque and force trace, and the calibration for each trace.

2. Construct vertical lines through the driveshaft revolution trace at every 1/2 pip. Then, read the actual values of recorded torque for each 1/2 pip of the revolution counter. Continue to read the torque until it reaches equilibrium; this will be the end of the run.

3. Read the force trace similarily until it returns to zero, being sure to record the peak force and the pips (and fractions) at which it occurred.

4. Then plot force vs. distance (figured from the drive line revolutions) and measure the area beneath the curve. This area is the work required to override the tree.

TABLE IV-1

SINGLE LONGITUDINAL OBSTACLE T

Summary of Data and Test Resu

Override Test No.	Tree No.	Tree Species	Tree Diam. at 42"	Tree Height	Tree Cone Penetrometer Depth	Maximum Pushbar Force (Lbs.)	Total Work (Ft./Lbs.)	Maximum Torque (Ft./Lbs.)	Mode Of Failure	Maximum Stress For Three Point Loading	Average Cone Index				
											SFC-6"	6-12"	12-18"	18-24"	24-30"
1	1	Pine	1.8	12	7.5	150	306	--	EY	3400	201	202	192	222	334
2	2	Pine	1.5	9	7.0	70	230	200	EY	3200	202	192	192	282	474
3	3	Pine	5.5	32	6.0	--	--	--	TC	3100	232	182	190	237	309
4	4	Pine	5.3	37	5.0	4620	9940	320	TB	4100	398	433	421	452	454
5	5	Pine	4.1	38	3.5	2020	3740	266	SR	3100	404	418	341	389	435
6	6	Pine	2.7	20	7.0	680	1780	119	CP	5000	370	470	482	521	575
7	7	Pine	4.0	31	5.6	1440	--	221	SR	4800	136	140	144	172	281
8	8	Pine	4.5	39	5.3	4560	11,100	362	TC	5500	206	365	393	426	461
9	9	Pine	3.5	34	5.3	1500	2460	258	TB	5200	136	174	184	261	352
10	35	Pine	1.0	7	9.3	0	0	114	EY	1100	250	240	210	270	520
11	37	Long-Leaf Pine	4.5	28	6.8	2030	4250	270	TB	3300	165	179	163	183	215
12	12	Pine	4.1	23	5.4	1500	3590	221	TB	3800	165	180	166	210	376
13	13	Pine	3.9	24	5.7	1180	2610	203	SR	4200	154	194	214	243	362
14	14	Pine	4.8	23	6.9	2060	4725	280	TB	3400	151	155	144	217	420
15	16	Pine	3.0	14	6.0	1290	2780	172	EY	3400	161	195	159	132	147
16	18	Pine	3.5	13	6.2	910	1800	240	EY	3500	185	226	181	157	130
17	15	Pine	3.6	19	4.7	1250	2940	259	TB	3300	206	241	182	150	175
18	34	Pine	1.1	6	8.4	180	--	--	EY	1600	150	190	240	360	490
19	45	Pine	2.3	13	9.5	180	286	179	EY	2400	240	330	280	380	520
20	38	Pine	2.7	15	5.3	510	857	143	EY	3600	140	150	240	330	500
21	32	Long-Leaf Pine	5.0	27	8.5	3920	11,250	310	TB	4200	210	220	200	260	390
22	31	Long-Leaf Pine	3.2	19	7.5	640	1470	196	EY	4400	160	120	130	180	260
23	28	Pine	5.3	22	7.3	2990	5050	291	SR	3400	190	200	160	200	280
24	44	Pine	2.0	13	7.5	110	204	96	EY	2400	330	720	750	750	750
25	43	Pine	1.2	7	5.4	80	163	123	EY	2600	420	640	650	700	750
26	40	Pine	2.2	14	5.0	270	368	112	TB	4100	200	260	230	220	560
27	41	Pine	3.4	22	4.8	1290	2940	193	TB	4400	160	190	280	370	530
28	42	Pine	1.6	11	6.8	60	38	160	EY	2900	200	220	300	340	460
29	39	Pine	6.0	36	5.0	4350	--	315	SR	4100	150	150	170	240	420
30	46	White Oak	1.5	13	5.0	63	1680	225	EY	2700	190	220	210	300	500
31	47	White Oak	1.7	12	5.0	200	3840	90	EY	5000	290	480	490	540	620
32	48	White Oak	1.3	11	4.8	60	896	115	EY	3000	200	240	240	290	380
33	49	White Oak	2.7	--	5.0	800	1856	180	CP	4100	250	320	330	400	590
34	51	White Oak	2.3	15	4.8	350	5490	115	EY	3200	170	220	210	280	370
35	50	White Oak	4.8	--	5.0	3700	--	320	SR	4100	310	550	540	540	610
36	52	White Oak	6.4	--	5.0	4900	--	345	No Go	6300	130	150	140	180	410
37	53	White Oak	5.7	--	--	4800	--	320	No Go	--	120	140	170	210	350
38	55	White Oak	3.7	25	--	1600	3550	210	SR	5200	150	160	130	190	320
39	56	White Oak	5.2	26	--	3710	3250	310	SR	5700	200	220	210	200	190
40	57	White Oak	5.0	27	--	2920	7760	314	SR	4000	130	150	210	260	340
41	58	White Oak	3.9	--	--	2570	6235	--	TB	5800	80	120	160	230	310
42	59	Pin Oak	2.5	15	3.5	740	1600	116	TB	4200	210	310	260	290	420
43	60	Pin Oak	5.3	20	3.0	4200	12,600	295	SR	5900	190	210	200	260	450
44	61	Pin Oak	4.0	16	3.0	2900	8150	278	TB	5500	160	220	270	330	440
45	62	Pin Oak	0.8	6	4.0	0	0	140	EY	1600	230	330	340	420	580
46	63	Pin Oak	5.5	25	3.5	5550	--	338	SR	6600	260	310	300	400	530

Mode of Failure: EY - Elastic Yield
CP - Compression
TB - Tension Brake
TC - A Combination of Tension Brake and Compression
SR - Soil and Root Failure

TABLE IV-1

INGLE LONGITUDINAL OBSTACLE TESTS

ummary of Data and Test Results

rage Cone Index			Average	Moisture Content In % Of Dry Weight			Shear Values Soil To				Shear Values Rubber To Soil					Shear Values Rubber To Litter					Computed Drawbar Pull	
2"	12-18"	18-24"	24-30"	SFC-18"	SFC-6"	6-12"	12-18"	c_u	ϕ_u	Infl. PSI	c_u^2	ϕ_u^2	a_{ur}	ϕ_{ur}	Infl. PSI	a_{ur}^2	ϕ_{ur}^2	a_{ul}	ϕ_{ul}	Infl. PSI	a_{ul}^2	ϕ_{ul}^2	Rubber to Soil	Rubber to Litter
	192	222	334	198	15.9	14.8	15.5	.4	45.0	--	--	--	.4	33.5	--	--	--	0	35.0	5.9	1.6	32.0	4912	4892
	192	282	474	195	1).2	15.2	16.6	.2	42.5	--	--	--	.2	34.0	--	--	--	.2	44.0	3.5	1.8	36.5	4958	5773
	190	237	309	201	14.2	18.3	19.6	.2	42.0	5.8	1.8	38.5	.1	36.0	--	--	--	.1	35.0	--	--	--	5317	5127
	421	452	454	417	16.0	16.1	16.7	0	42.5	--	---	--	.2	34.0	--	--	--	.2	37.0	6.0	2.0	33.0	4958	5151
	341	389	435	388	18.7	16.1	16.9	0	42.5	--	--	--	.2	34.0	--	--	--	.2	37.0	6.0	2.0	33.0	4958	5151
	482	521	575	441	14.9	15.8	16.9	.4	40.0	--	--	--	.2	33.0	--	--	--	.2	46.0	3.6	1.4	35.0	4776	5398
	144	172	281	140	22.2	20.1	21.0	.2	45.0	5.3	1.4	38.0	0	37.0	--	--	--	.2	51.0	2.3	1.8	33.0	5500	5109
	393	426	461	321	23.0	19.3	20.2	.2	42.0	--	--	--	0	32.5	--	--	--	0	39.5	3.4	1.6	27.0	4647	4053
	184	261	352	165	22.0	18.3	19.1	.2	42.0	--	--	--	0	32.5	--	--	--	0	39.5	3.4	1.6	27.0	4647	4053
	210	270	520	233	17.7	17.1	16.9	--	--		--	--	--	--	--	--	--	--	--	--	--	--	--	--
	163	183	215	169	16.9	14.3	14.1	--	--	--	--	--	0	36.0	--	--	--	0	47.5	2.3	1.4	39.0	5296	6200
	166	210	376	170	28.6	20.0	21.2	.2	40.7	--	--	--	0	41.5	4.0	1.6	27.5	0	40.0	4.0	1.8	32.0	4126	4794
	214	243	362	187	33.5	21.0	20.6	.2	40.7	--	--	--	0	41.5	4.0	1.6	27.5	0	40.0	4.0	1.8	32.0	4126	4794
	144	217	420	150	31.5	20.7	22.0	.2	40.7	--	--	--	0	41.5	4.0	1.6	27.5	0	40.0	4.0	1.8	32.0	4126	4794
	159	132	147	172	28.3	19.5	21.1	.2	40.7	--	--	--	0	41.5	4.0	1.6	27.5	0	40.0	4.0	1.8	32.0	4126	4794
	181	157	130	197	29.5	19.8	22.4	.2	40.7	--	--	--	0	41.5	4.0	1.6	27.5	0	40.0	4.0	1.8	32.0	4126	4794
	182	150	175	210	31.6	19.6	19.6	.2	40.7	--	--	--	0	41.5	4.0	1.6	27.5	0	40.0	4.0	1.8	32.0	4126	4794
	240	360	490	160	14.4	16.4	16.8	.6	40.7	--	--	--	.3	32.0	--	--	--	.3	46.5	3.4	2.0	29.5	4622	4545
	280	380	520	283	17.6	15.0	14.9	.6	40.7	--	--	--	.3	32.0	--	--	--	.3	46.5	3.4	2.0	29.5	4622	4545
	240	330	500	177	31.2	23.6	25.2	.5	40.5	5.4	1.9	31.4	.3	32.5	5.8	2.0	21.0	.5	4.0	3.4	1.4	34.2	3217	5230
	400	260	390	210	13.7	12.9	14.2	.3	40.0	--	--	--	.2	33.5	--	--	--	.3	47.0	4.9	2.8	30.0	4871	4792
	130	180	260	137	25.5	21.8	20.9	.3	42.0	--	--	--	.7	32.2	--	--	--	.5	45.0	4.7	2.3	30.8	4734	4826
	160	200	280	183	21.0	18.8	19.9	.4	43.2	--	--	--	.6	34.7	--	--	--	.7	45.0	7.2	3.1	31.5	5173	5117
	750	750	750	600	24.5	18.4	21.1	.4	43.2	--	--	--	.6	34.7	--	--	--	.7	45.0	7.2	3.1	31.5	5173	5117
	650	700	750	570	22.1	18.2	26.9	.4	43.2	--	--	--	.6	34.7	--	--	--	.7	45.0	7.2	3.1	31.5	5173	5117
	230	220	560	230	25.6	21.0	21.4	.6	38.5	5.8	2.3	26.5	.7	32.0	--	--	--	.6	46.0	4.9	3.3	24.3	4705	3830
	280	370	530	210	23.9	20.2	19.6	.6	38.5	5.8	2.3	26.5	.7	32.0	--	--	--	.6	46.0	4.9	3.3	24.3	4705	3830
	300	340	460	240	22.9	179.0	18.1	.6	38.5	5.8	2.3	26.5	.7	32.0	--	--	--	.6	46.0	4.9	3.3	24.3	4705	3830
	170	240	420	186	34.5	23.6	22.6	.6	38.5	5.8	2.3	26.5	.7	32.0	--	--	--	.6	46.0	4.9	3.3	24.3	4705	3830
	210	300	500	206	19.9	14.7	14.3	.2	46.6	3.2	1.2	38.0	.1	48.5	1.7	.9	33.0	.6	50.0	5.0	3.9	27.0	4922	4532
	490	540	620	420	13.5	13.8	14.1	0	50.5	2.2	1.0	39.0	0	38.0	5.4	1.1	30.0	.3	42.5	2.3	.9	31.5	4438	4659
	240	290	380	226	17.6	13.1	13.0	0	50.5	2.2	1.0	39.0	0	38.0	5.4	1.1	30.0	.3	42.5	2.3	.9	31.5	4438	4659
	330	400	590	300	15.3	13.6	14.5	0	50.5	2.2	1.0	39.0	0	38.0	5.4	1.1	30.0	.3	42.5	2.3	.9	31.5	4438	4659
	210	280	370	200	12.4	14.8	16.3	0	42.5	7.0	1.6	35.5	.2	35.6	6.7	1.4	28.2	.2	43.0	3.6	1.8	27.0	3748	4095
	540	540	610	467	12.8	12.1	13.6	0	42.5	7.0	1.6	35.5	.2	35.6	6.7	1.4	28.2	.2	43.0	3.6	1.8	27.0	3748	4095
	140	180	410	140	17.5	12.3	13.3	.7	49.5	3.4	2.9	27.0	.2	37.0	4.3	1.9	20.5	.2	50.0	3.5	2.3	29.5	2948	4607
	170	210	350	143	21.6	15.5	14.6	.7	49.5	3.4	2.9	27.0	.2	37.0	4.3	1.9	20.5	.2	50.0	3.5	2.3	29.5	2948	4607
	130	190	320	147	19.0	17.5	17.6	.2	48.0	2.9	1.1	41.5	.2	36.5	8.0	1.8	28.0	.3	48.0	1.8	1.2	31.8	4248	4785
	210	200	190	210	17.0	19.2	24.1	.2	48.0	2.9	1.1	41.5	.2	36.5	8.0	1.8	28.0	.3	48.0	1.8	1.2	31.8	4248	4785
	210	260	340	163	17.3	12.9	14.7	.2	48.0	2.9	1.1	41.5	.2	36.5	8.0	1.8	28.0	.3	48.0	1.8	1.2	31.8	4248	4785
	160	230	310	120	13.9	12.5	13.8	.2	48.0	2.9	1.1	41.5	.2	36.5	8.0	1.8	28.0	.3	48.0	1.8	1.2	31.8	4248	4785
	260	290	420	260	11.0	10.0	12.5	.3	46.0	--	--	--	.3	33.6	--	--	--	.4	44.5	5.3	2.7	29.2	4906	4472
	200	260	450	200	21.2	18.3	18.8	1.9	38.0	--	--	--	1.0	41.5	2.1	1.7	29.0	1.2	36.5	--	--	--	4395	5660
	270	330	440	217	12.0	10.0	9.4	1.6	41.0	--	--	--	.8	32.0	6.8	3.1	15.0	1.0	39.5	3.0	2.2	25.0	2600	3879
	340	420	580	300	11.7	9.7	11.8	1.6	42.5	--	--	--	.9	37.0	2.3	1.8	22.5	.8	40.0	2.9	1.7	29.0	3394	4395
	300	400	530	290	21.3	14.3	15.2	--	--	--	--	--	--	--	--	--	---	--	--	--	--	--	--	--
																					Total		195,045	207,739
																					Avg.		4432	4722
																					Max.		5500	6200
																					Min.		2600	3830

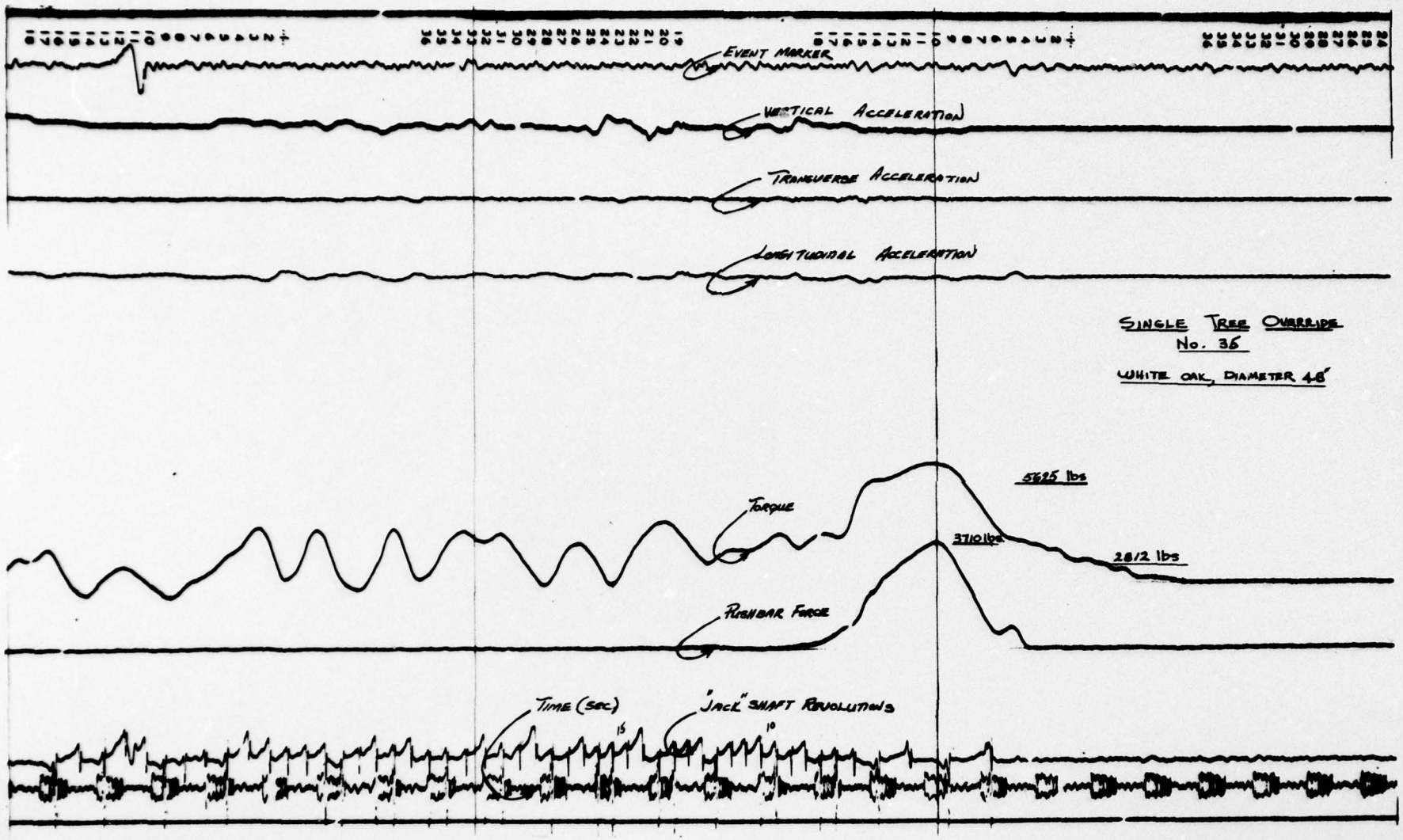


Figure IV-5 - Sample Oscillogram

APPENDIX V

TEST PLAN

MULTIPLE LONGITUDINAL OBSTACLES

G. T. Cohron
R. A. Werner

20 August 1964

VEHICLE OVERRIDE OF MULTIPLE LONGITUDINAL OBSTACLES

I. OBJECTIVE

To determine a first-order approximation of the amount of physical impedance to vehicular movement that is caused by a vegetation stand so arranged that several plants are in contact with the vehicle at a given time; also, to order the significance of this physical impedance in the spectrum of all environmental resistances to vehicular movement.

II. SCOPE

The scope of this study includes performing a limited number of vehicle tests in selected vegetation plots that have varying stem sizes and stem densities, and deriving vegetation characteristic work required relations therefrom. These results, in conjunction with the results obtained from the single tree override study, will be analyzed to determine sound test techniques to be recommended for studying the forces imposed by these segments of the vegetation population.

III. DETERMINATIONS SOUGHT

A group of trees acting in concert is expected to require more work to override than the summation of energies from the same trees acting alone. It is anticipated that this additional work will be caused by crown intermingling, additional frictional drag due to the stacking of a number of stems under the vehicles at a given time, and other factors. Comparison of the results of the single stem override tests and the multiple override tests is expected to yield the weighted significance of these characteristics. A graphical portrayal of the desired information could be plotted as shown in Figure V-1.

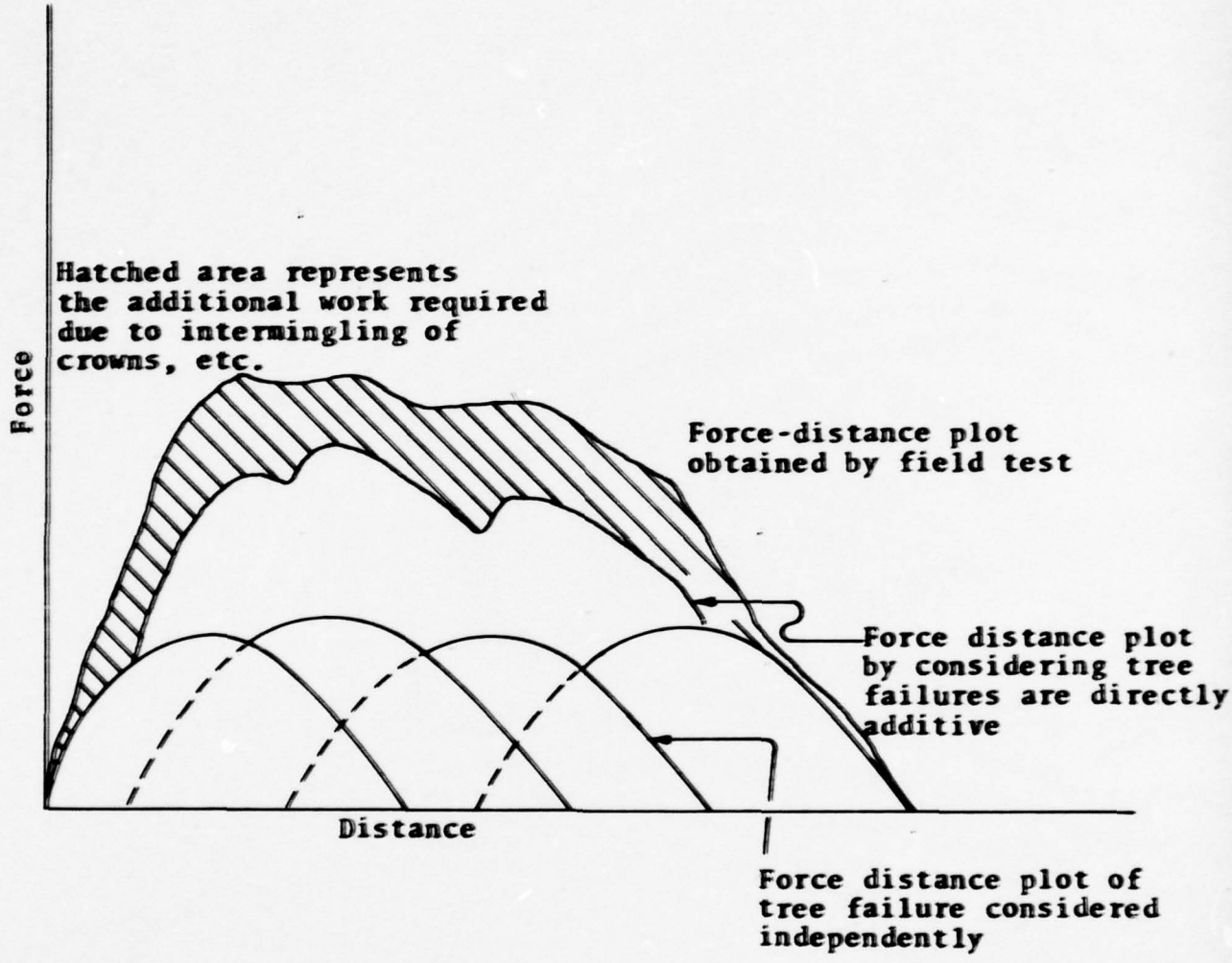


Figure V-1 - Effect of Intermingling of Crowns on Work Required for Vehicle Override

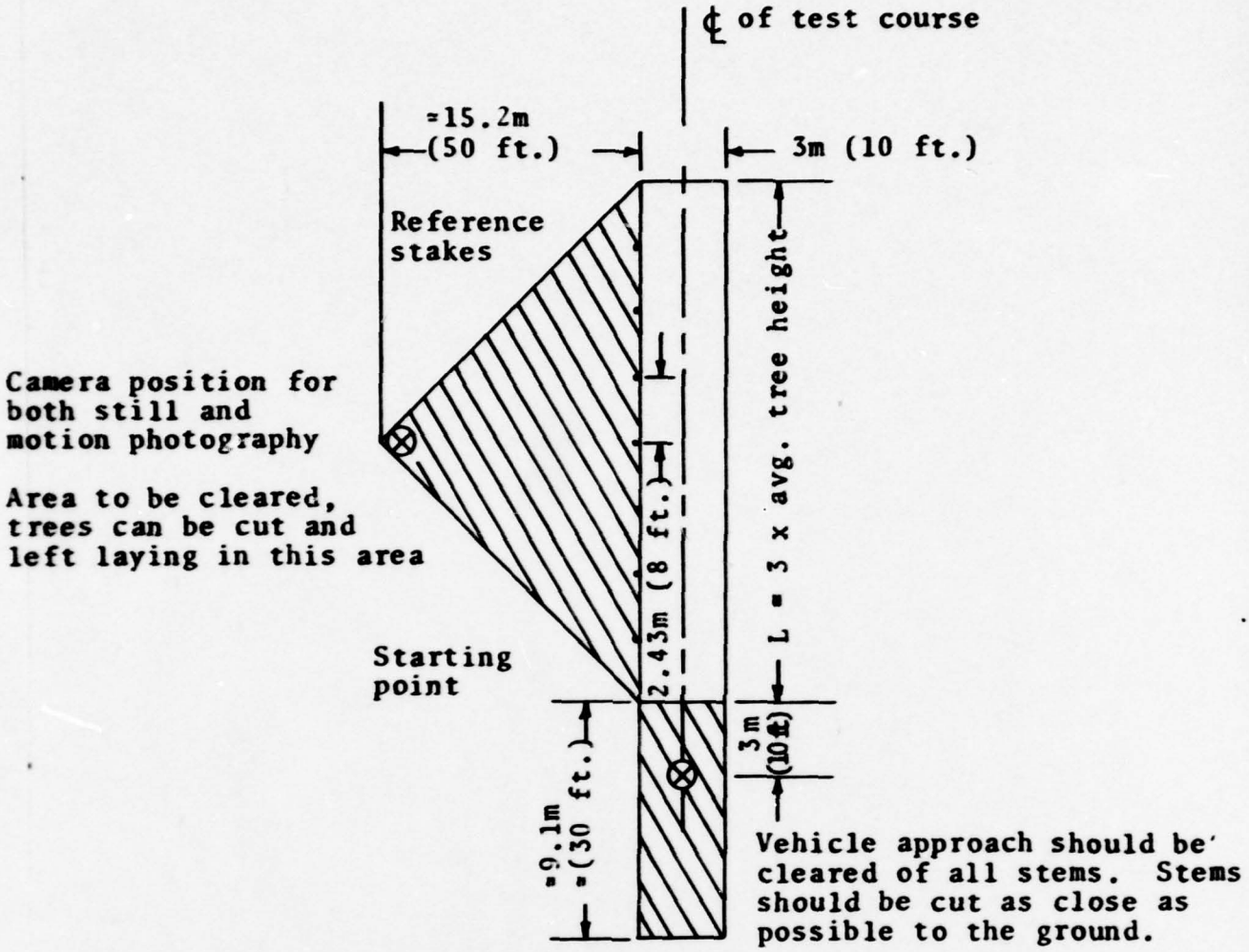
Intuitively- the interference factor established by the difference between the recorded curve and the computed curve has to be a direct function of tree diameter, height, and crown interlacing (which, in turn, is a function of crown diameter and mean stem spacing). These relationships are also desired in order to relate readily collected environmental data to vehicle performance. Ultimately, a single interference factor is desired which, added to the size and strength term, will describe the behavior of any tree being overridden, regardless of its location with respect to other trees.

Yet another object, somewhat incidental to the vegetation, will be the determination of the ability of soil surface shear measurements to predict the adequacy of the soil to supply the tractive effort required to override both single- and multi-tree stands. These data will be applicable to any vehicle.

IV. TEST SITE REQUIREMENTS

Tests will be conducted in vegetation stands that the M37 is capable of overriding without maneuvering. Sites will be selected in five uniform stands and these stands will exhibit a range of stem sizes and stem densities. This range should include stem sizes of approximately 2.54 cm (1 in.) with average spacing of 0.6 m (2 ft.) to stem sizes of 10 cm (4 in.) with average spacing of 1.2 m (4 ft.). The site should be located on firm, level terrain.

The size of the test course will be dictated by the average height of the trees in the course. As a rule of thumb, the length of the course should be at least three times the average height of the trees in the course. The width of the course will be 10 ft. (see Figure V-2).



Note: Reference stakes will be marked at 1-ft. intervals along their length. Core will be taken to ensure the top of the stakes are in the same horizontal plane as the motion picture camera lens.

Figure V-2 - Test Site Requirements

V. MEASUREMENTS REQUIRED

A. Advance

1. Map of tree stems in the test course
2. Plant characteristics
3. Tree hardness
4. Course location and dimensions

B. Pre-Test

1. No additional measurements required
2. Take black-and-white stereo pair perpendicular to direction of vehicle motion

C. Test

1. Record the following:
   a. Pushbar force
   b. Drive-line torque
   c. Horizontal transverse (fore-and-aft) acceleration
   d. Driveshaft RPM
   e. Event marker
   f. Voice on magnetic tape
2. Collect the following additional information:
   a. Stopwatch time
   b. Pertinent observations
3. Photography - Make color movies of the entire test run

D. Post-Test

1. Soils
   a. Cone Index

b. Remolded Cone Index
c. Moisture content/density samples
d. Sample for grain-size analysis
e. Sheargraph for surface traction parameters

2. Photos - Stereo pairs of the course along -- and perpendicular to -- the longitudinal axis of the course.

E. Laboratory - Soil grain size analyses

VI. CONDUCT OF TESTS

A. Advance

The location of the stems of all plants that could possibly come in contact with the pushbar will be plotted on a plan sheet. The plant characteristics will be recorded on the vegetation data sheet as outlined in Part VII of the MEGA Data Collection Manual. Ground cover information will be recorded in the standard manner.

In addition to this data, penetration depth of the 10° cone under an 18-lb. load will be measured and recorded in the hardness column. These readings will be collected in the following manner:

1. Select a location on the stem approximately 1.2m (4 ft.) from the earth's surface.
2. Remove outer bark, but leave cambrium layer.
3. Insert penetrometer until spring deflection indicator reaches the last graduation on the shaft and record the depth of penetration.

Clearings will be prepared for the approach of the vehicle and for adequate photo coverage (see Figure V-2). Trees within the test course which are "outsized" will be removed if they would either lead to an immobilization or if its size is inconsistent with other trees in the array.

B. Pre-Test

A long piece of light-colored tape will be attached to the side of the vehicle along a horizontal line on a level plane through the camera lens. Suitably scaled vertical tapes will also be attached to permit scaling of frames from the motion picture. Reference stakes will be placed at 2.4 m (8 in.) intervals along the "camera" side of the test course (see Figure V-2).

C. Test

1. Conduct

a. Bring the front wheels of the vehicle to rest inside the vehicle approach area.

b. Turn recording instruments on (calibration, etc.) and place vehicle in 4 x 4 low range low gear.

c. Start the vehicle and allow it to proceed down the centerline of the course at approximately 0.67 m/sec (1.5 m.p.h.). When the pushbar crosses the starting point, record this event with the event marker. Start the stopwatch.

d. When the vehicle is approximately halfway down the approach lane, start the motion picture camera. The camera will be set in the location designated in Figure V-2. A continuous motion-picture record will be made of the test.

e. When the pushbar reaches the end of the test course, record this event with the event marker. Stop the stopwatch.

D. Post-Test

1. Soils

A minimum of 10 cone index profiles will be taken in the test course. Enough information to compute the remolded cone index (RCI) of the area will be collected. In addition, sufficient sheargraph measurements will be taken to permit the computation of maximum tractive effort.

2. Photographs

Stereo black-and-white photographs will be taken after the test has been conducted. These photographs should be taken both perpendicular to -- and along the longitudinal axis of -- the test plot. To facilitate taking these photographs, an area adjacent to the test course will be cleared as illustrated in Figure V-2.

3. Observations

After the test has been run, observe the failure mode of each plant in the plot. Record this data in the remarks column of the Vegetation Data Form. For a description of the failure modes see Figure V-3.

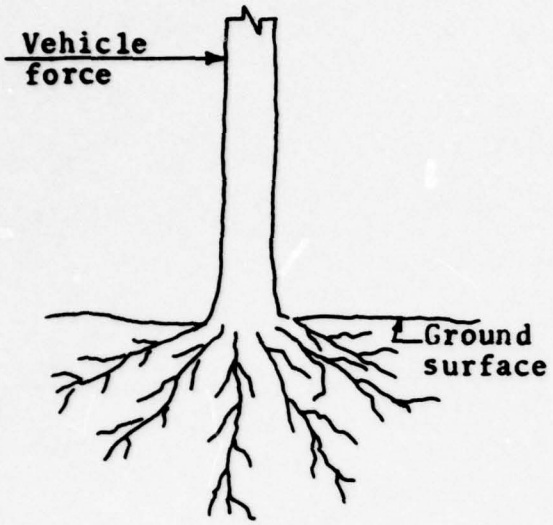
VII. ANALYSIS PROCEDURE

A. From the permanent record of the magnetic tape, the following measurements will be taken:

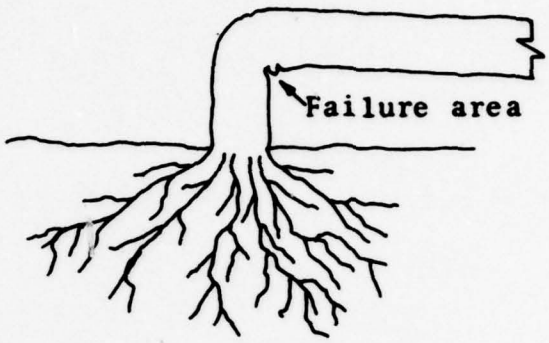
1. The force will be measured, every 1/2 revolution of the drive shaft, using the calibration steps to determine the pounds of force per inch of the force trace displacement from the zero line.

2. Then, using the plan view and the force measurements, a force distance plot can be made from which the total work required can be determined.

B. Then by summing the work required for each individual tree on the basis of the single tree work curve, a comparison of the total work for the multiple and single longitudinal obstacles can be made.

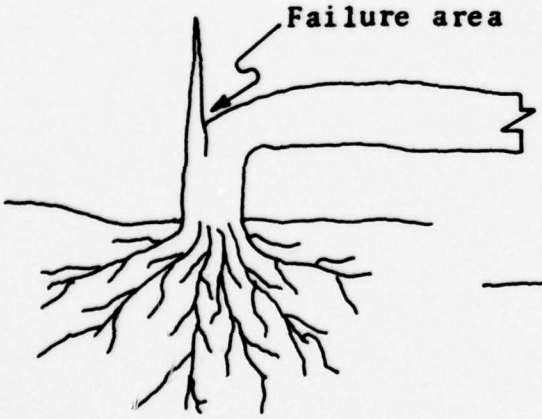


Before failure



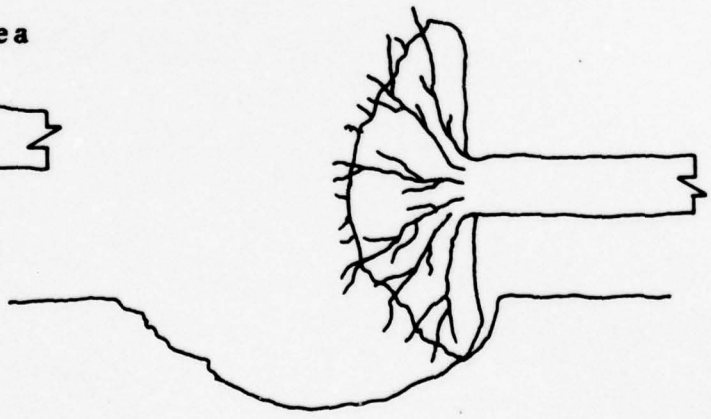
Type 1

Root-soil system stronger than stem (stem fails in compression).



Type 2

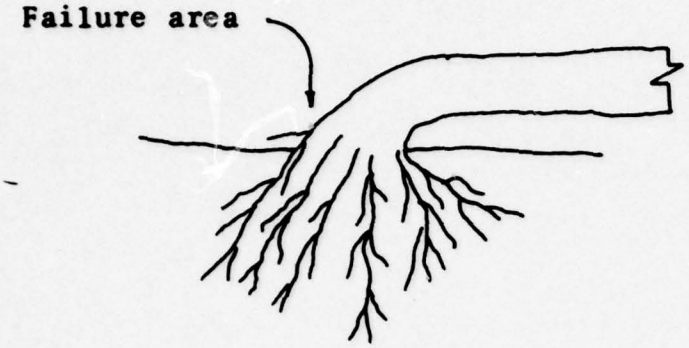
Root-soil system stronger than stem (stem fails in tension).



Type 3

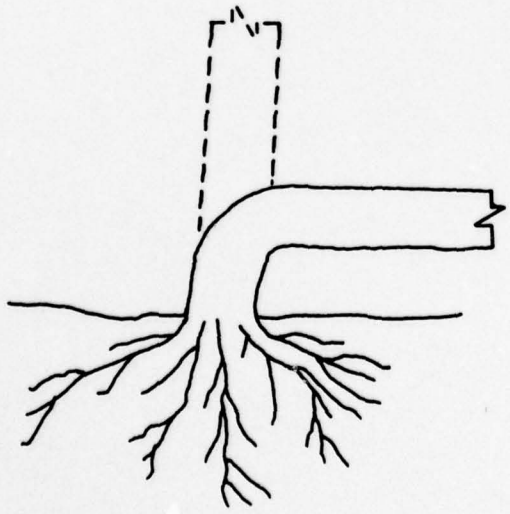
Stem stronger than root-soil system (roots fail in tension, soil in shear).

Figure V-3 - Tree Failure Modes



Type 4

Stem stronger than root-soil system (roots pull out of soil, but shear failure of soil is not pronounced).



Type 5

Root-soil system stronger than stem (stem deforms elastically).

Figure V-3 (con.)

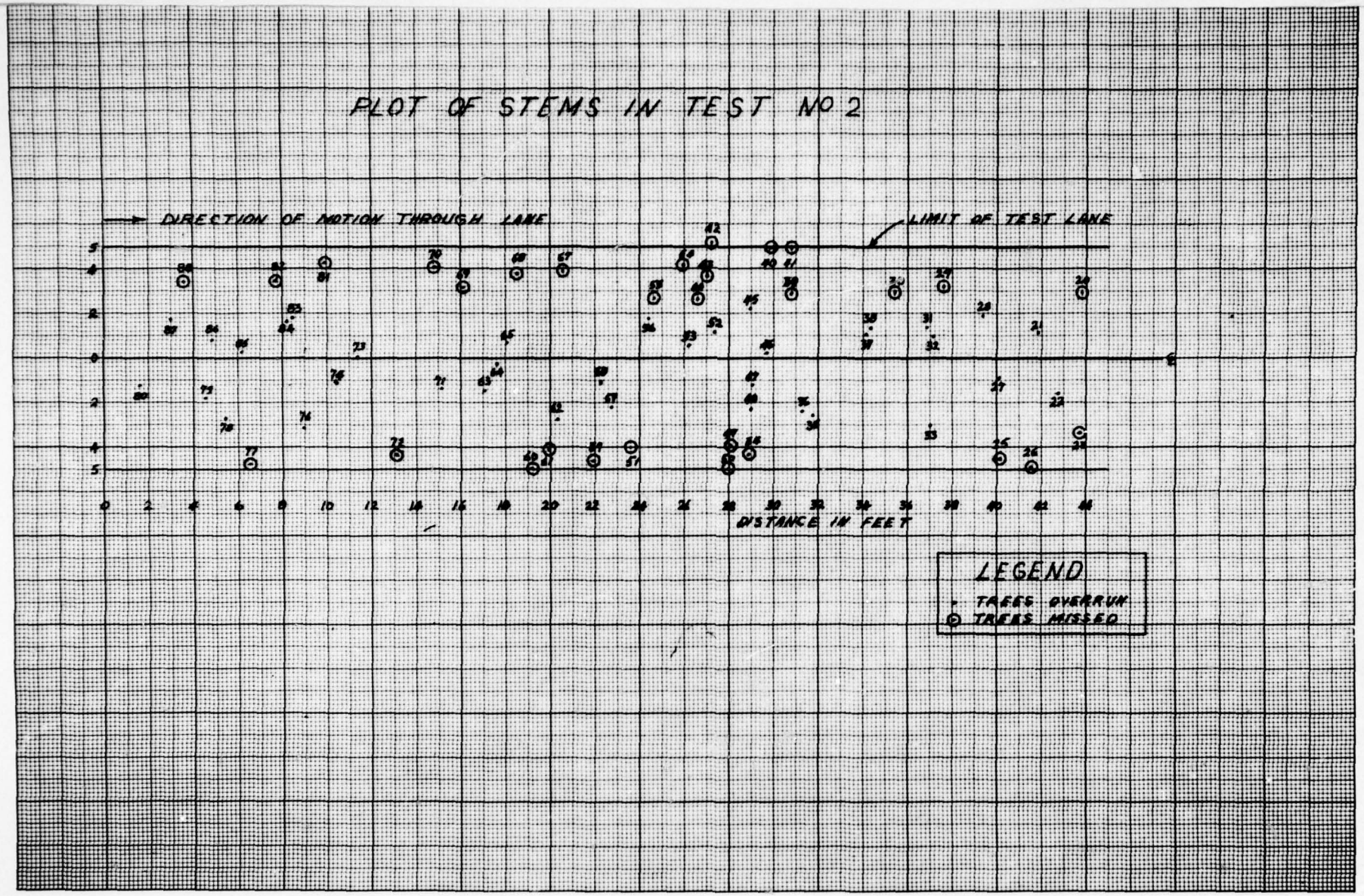


Figure V-4 Plan View, Site No. 5

TABLE V-1 - VEGETATION STRUCTURE DATA FOR TEST NO. 2*

Country: U. S. A. **Site No.:** 5 (Pine Trees)
State: Hancock County, Mississippi **Date:** 13 August 1964

Plant Number	Height (Ft.)	Crown Diameter (Ft.)	Distance From Plot Center	Diameter @ 42" (In.)	Hardness Tree Penetrometer (MM.)
1	9	5	26.5	1.3	10
2	10	3	22.5	1.2	6
3	12	5	21.0	1.6	9
4	16	7	19.0	2.6	9
5	12	5	19.0	1.9	8
6	24	10	18.5	4.2	10
7	10	4	21.5	1.3	9
8	9	4	20.5	1.2	8
9	24	7	16.5	4.2	10
10	9	2	14.0	0.9	7
11	13	4	14.0	1.7	10
12	15	6	11.5	2.4	10
13	8	3	11.5	1.1	9
14	10	3	12.5	1.2	8
15	24	10	9.5	4.2	10
16	14	6	12.0	2.3	9
17	15	6	13.5	2.0	8
18	9	3	15.5	0.8	8
19	16	6	16.5	1.7	7
20	18	8	13.5	2.8	9
21	10	6	11.5	1.7	8
22	16	8	9.0	2.3	11
23	12	5	7.5	1.8	8
24	14	5	8.5	1.9	8
25	24	11	6.0	4.8	10
26	17	4	5.5	2.2	9
27	20	7	9.5	3.8	9
28	12	3	12.5	1.3	6
29	20	6	14.0	3.2	8
30	22	8	14.5	3.5	10
31	12	3	12.5	1.3	7
32	14	5	12.0	1.7	7
33	15	5	8.5	2.2	11
34	18	6	12.5	2.9	9
35	16	5	12.0	2.4	8
36	18	7	12.5	2.9	9

* Abstracted from WES Form #1374

TABLE V-1 (CONTINUED) VEGETATION STRUCTURE DATA FOR TEST NO. 2*

Plant Number	Height (Ft.)	Crown Diameter (Ft.)	Distance From Plot Center	Diameter @ 42" (In.)	Hardness Tree Penetrometer (MM.)
37	11	3	13.5	1.3	9
38	15	5	13.5	1.5	8
39	15	5	17.0	1.4	9
40	14	3	19.0	1.6	9
41	7	2	18.5	0.8	8
42	9	5	21.0	1.9	10
43	18	6	20.0	3.4	8
44	17	6	19.5	4.1	10
45	15	4	17.5	2.1	8
46	16	4	15.5	2.0	7
47	16	4	15.0	2.2	9
48	12	3	14.5	1.6	8
49	14	5	14.5	2.0	8
50	11	4	13.5	1.9	8
51	14	5	18.5	2.4	9
52	7	2	18.0	1.1	11
53	8	2	18.5	1.2	11
54	8	3	21.0	1.1	10
55	7	2	21.0	0.9	7
56	8	2	20.5	1.0	10
57	13	4	20.0	1.4	7
58	16	5	21.0	2.0	8
59	8	2	20.0	0.8	9
60	7	2	22.5	0.8	10
61	6	2	22.0	0.8	9
62	17	6	22.0	3.0	9
63	9	2	25.5	0.9	11
64	15	4	25.5	2.0	10
65	11	3	25.5	1.2	8
66	7	3	25.5	0.9	10
67	16	9	25.0	3.2	9
68	11	4	26.5	1.6	6
69	10	3	28.5	1.2	10
70	8	2	30.0	0.8	11
71	15	5	27.5	2.2	8
72	14	3	28.5	2.0	8
73	15	6	31.5	2.9	8
74	8	2	32.0	0.9	7
75	--	--	----	---	--
76	8	2	33.0	1.2	10
77	14	4	35.0	2.0	7

* Abstracted from WES Form #1374

TABLE V-1 (CONTINUED) VEGETATION STRUCTURE DATA FOR TEST NO. 2*

Plant Number	Height (Ft.)	Crown Diameter (Ft.)	Distance From Plot Center	Diameter @ 42" (In.)	Hardness Tree Penetrometer (MM.)
78	14	5	36.5	2.4	9
79	10	3	37.5	1.3	8
80	9	1	40.5	1.4	9
81	9	2	34.5	1.1	10
82	7	2	36.0	1.0	10
83	9	2	35.0	0.9	9
84	10	3	35.0	1.2	7
85	15	5	36.5	2.1	7
86	14	5	38.0	2.3	8
87	14	5	40.0	2.4	7
88	8	2	40.0	1.1	9

Note: 10% Cover - Pine Straw 1/2" Deep

* Abstracted from WES Form #1374

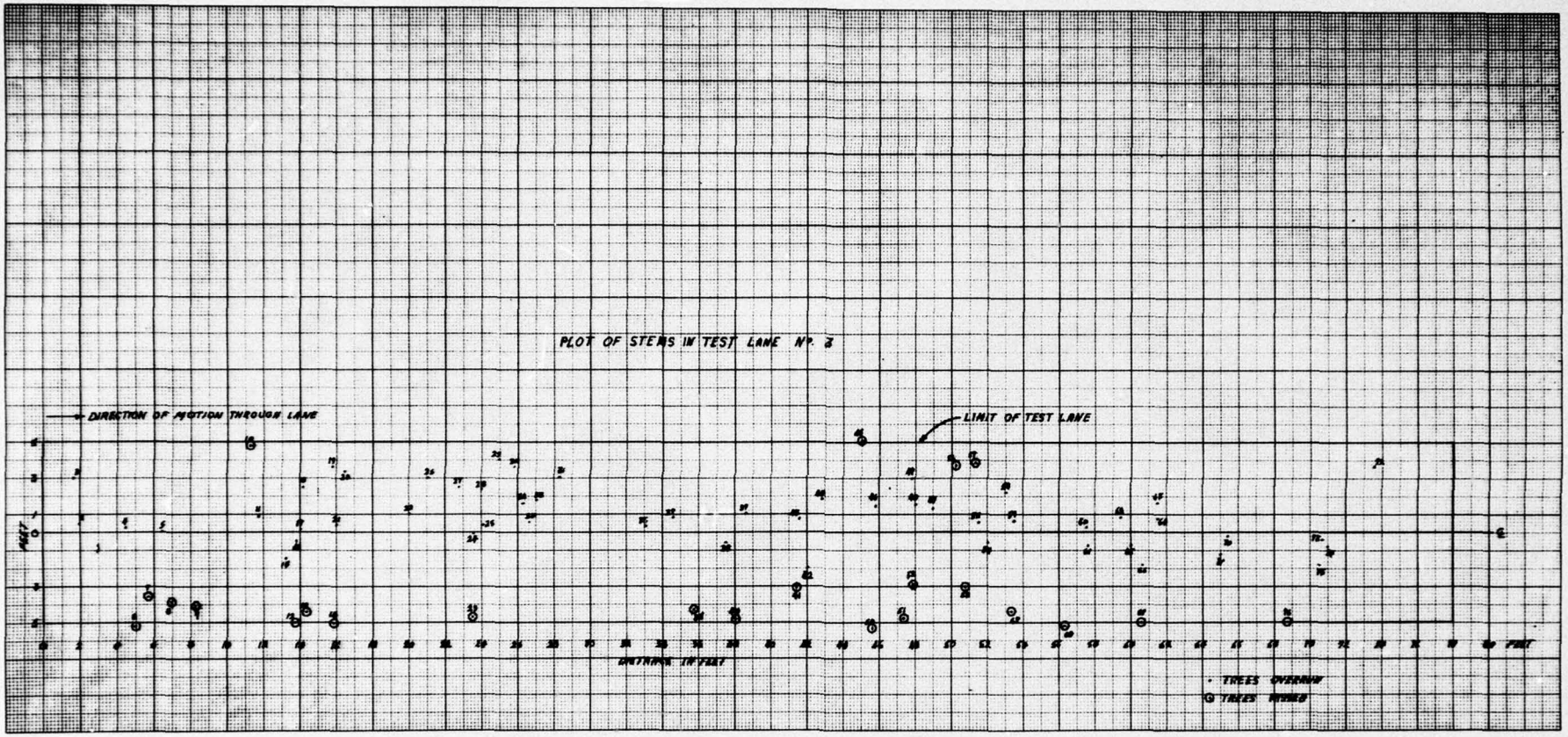


Figure V-5 - Plan View, Site No. 6

TABLE V-2 - VEGETATION STRUCTURE DATA FOR TEST NO. 3*

Country: U. S. A. Site No.: 6

State: Hancock County, Mississippi Date: 14 August 1964

Plant Number	Height (Ft.)	Crown Diameter (Ft.)	Distance From Plot Center	Diameter @ 42" (In.)	Hardness Tree Penetrometer (MM.)
1	13	4	27.0	1.9	7
2	7	2	28.0	1.0	11
3	9	2	28.5	1.3	9
4	12	5	25.5	1.7	8
5	13	6	23.5	2.3	9
6	14	6	25.5	2.2	8
7	12	3	24.5	1.6	9
8	10	2	28.5	1.2	6
9	10	3	22.0	1.4	8
10	13	5	19.5	2.3	10
11	8	2	18.5	1.0	9
12	13	5	17.0	2.0	8
13	8	2	16.5	0.9	8
14	10	3	15.0	1.2	7
15	10	5	17.0	1.4	8
16	9	4	16.5	1.3	7
17	14	5	16.0	2.4	8
18	7	2	16.0	0.7	11
19	9	3	14.5	0.8	9
20	9	2	14.0	1.1	8
21	14	4	14.0	1.9	8
22	19	5	10.0	3.5	11
23	13	3	8.0	1.5	6
24	16	4	6.5	1.7	7
25	16	6	6.0	2.4	8
26	8	1	9.5	0.7	7
27	9	2	1.5	0.8	7
28	12	3	6.5	1.7	8
29	10	2	6.5	1.0	8
30	14	4	5.5	1.7	7
31	15	4	3.5	1.7	7
32	17	5	4.0	2.3	6
33	9	3	3.5	1.1	7
34	7	1	3.5	0.8	8
35	19	9	7.0	3.7	9
36	12	4	3.0	1.6	8
37	15	6	4.5	1.8	8
38	18	6	7.5	2.2	9

* Abstracted from WES Form #1374

TABLE V-2 (CONTINUED) VEGETATION STRUCTURE DATA FOR TEST NO. 3*

Plant Number	Height (Ft.)	Crown Diameter (Ft.)	Distance Front Plot Center	Diameter @ 42" (In.)	Hardness Tree Penetrometer (MM.)
39	7	1	8.5	0.7	12
40	10	2	9.5	1.1	7
41	11	2	12.0	1.1	9
42	9	2	12.0	0.8	8
43	15	5	11.5	1.9	8
44	16	5	13.0	2.1	7
45	9	2	16.0	0.9	8
46	17	7	16.0	2.5	9
47	16	2	18.0	1.6	7
48	18	4	18.0	2.0	8
49	15	1	19.0	0.7	8
50	11	2	16.5	1.2	8
51	7	1	18.0	.6	10
52	8	1	18.0	.8	9
53	18	5	21.0	2.8	10
54	15	2	22.0	2.5	8
55	20	6	21.5	2.9	8
56	18	5	20.5	1.7	8
57	16	3	21.5	1.6	8
58	13	3	25.0	1.2	8
59	13	4	24.5	1.4	8
60	17	5	20.5	2.1	8
61	16	4	20.5	2.0	9
62	16	4	18.5	1.8	7
63	7	1	16.5	0.8	9
64	18	9	16.5	3.1	10
65	8	1	18.0	0.9	10
66	9	2	17.5	1.1	9
67	19	6	25.0	3.4	10
68	16	5	22.5	2.0	9
69	16	4	18.0	2.1	9
70	7	1	12.5	0.7	11
71	8	1	13.0	0.8	9
72	15	6	6.0	2.7	10
73	17	4	7.0	2.1	8
74	13	3	7.0	1.7	8
75	17	4	7.5	2.5	9
76	15	3	10.5	1.8	9

* Abstracted from WES Form #1374

TABLE V-3 - MULTIPLE TREE OVERRIDE TEST NO. 2
SUMMARY OF TEST RESULTS AND DATA

Site No. 5

Tree No.	Diameter @ 42" (In.)	Height (Ft.)	Branching Height (Ft.)	Crown Diameter (Ft.)	Predicted Work (Ft.-Lbs.)
21	1.7	10	5	6	210
22	2.3	16	7	8	610
27	3.8	20	9	7	3800
28	1.3	12	8	3	75
31	1.3	12	6	3	75
32	1.7	14	7	5	210
33	2.2	15	7	5	520
35	2.4	16	9	5	720
36	2.9	18	10	7	1450
37	1.3	11	7	3	75
38	1.5	15	10	5	145
45	2.1	15	9	4	440
46	2.0	16	11	4	370
47	2.2	16	9	4	520
48	1.6	12	7	3	170
52	1.1	7	6	2	40
53	1.2	8	6	2	55
56	1.0	8	6	2	28
57	1.4	13	7	4	100
58	2.0	16	8	5	370
62	3.0	17	6	6	1600
63	0.9	9	6	2	20
64	2.0	15	7	4	370
65	1.2	11	6	3	55
71	2.2	15	7	5	520
73	2.9	15	6	6	1450
74	0.9	8	4	2	20
76	1.2	8	6	2	55
78	2.4	14	9	5	720
79	1.3	10	8	3	75
80	1.4	9	8	1	100
83	0.9	9	5	2	20

TABLE V-3 (CONTINUED) MULTIPLE TREE OVERRIDE TEST NO. 2

SUMMARY OF TEST RESULTS AND DATA

Tree No.	Diameter @ 42" (In.)	Height (Ft.)	Branching Height (Ft.)	Crown Diameter (Ft.)	Predicted Work (Ft.-Lbs.)
84	1.2	10	5	3	55
85	2.1	15	7	5	440
86	2.3	14	8	5	610
87	2.4	14	8	5	720
				Total Predicted Work	16,813

Predicted Average Work/Ft. = $\frac{16,813}{44}$ = 382#

Cone Index

SFC - 132

Avg. 3"-18" - 663

Shear Values

Soil to Soil

ϕ_u = 42.0° A_u = 0.1

Rubber to Soil

α_r = 29.5° A_r = 0.5

TABLE V-4 - MULTIPLE TREE OVERRIDE TEST NO. 3
SUMMARY OF TEST RESULTS AND DATA

Site No. 6

Tree No.	Diameter @ 42" (In.)	Height (Ft.)	Branching Height (Ft.)	Crown Diameter (Ft.)	Predicted Work (Ft.-Lbs.)
1	1.9	13	6	4	310
2	1.0	7	5	2	28
3	1.3	9	5	2	75
4	1.7	12	6	5	210
5	2.3	13	6	6	610
11	1.0	8	6	2	28
15	1.4	10	5	5	100
16	1.3	9	6	4	75
17	2.4	14	5	5	720
18	0.7	7	4	2	10
19	0.8	9	6	3	13
20	1.1	9	5	2	40
21	1.9	14	6	4	310
22	3.5	19	7	5	2800
24	1.7	16	7	4	210
25	2.4	16	6	6	720
26	0.7	8	6	1	10
27	0.8	9	7	2	13
28	1.7	12	6	3	210
29	1.0	10	6	2	28
30	1.7	14	7	4	210
31	1.7	15	7	4	210
32	2.3	17	7	5	610
33	1.1	9	6	3	40
34	0.8	7	5	1	13
36	1.6	12	7	4	170
37	1.8	15	5	6	260
38	2.2	18	8	6	520
39	0.7	7	5	1	10
42	0.8	9	6	2	13
43	1.9	15	6	5	310
44	2.1	16	8	5	440
46	2.5	17	6	7	840
47	1.6	16	7	2	170
48	2.0	18	7	4	370
49	0.7	15	6	1	10
54	2.5	15	6	2	840
55	2.9	20	7	6	1450

TABLE V-4 (CONTINUED) MULTIPLE TREE OVERRIDE TEST NO. 3

SUMMARY OF TEST RESULTS AND DATA

Tree No.	Diameter @ 42" (In.)	Height (Ft.)	Branching Height (Ft.)	Crown Diameter (Ft.)	Predicted Work (Ft.-Lbs.)
58	1.2	13	6	3	55
59	1.4	13	6	4	100
60	2.1	17	7	5	440
61	2.0	16	7	4	370
62	1.8	16	6	4	260
63	0.8	7	3	1	13
64	3.1	18	7	9	1800
65	0.9	8	6	1	20
66	1.1	9	6	2	40
70	0.7	7	5	1	10
71	0.8	8	6	1	13
72	2.7	15	7	6	1100
73	2.1	17	8	4	440
74	1.7	13	6	3	210
75	2.5	17	9	4	840
				Total Predicted Work	18,717

Predicted Average Work/Ft. = $\frac{18,717}{77}$ = 243#

Cone Index

SFC - 115

Avg. 3"-18" - 671

Shear Values

Soil to Soil

ϕ_u = 41.2° A_u = 0.5

Rubber to Soil

α_r = 31.5° A_r = 0.1

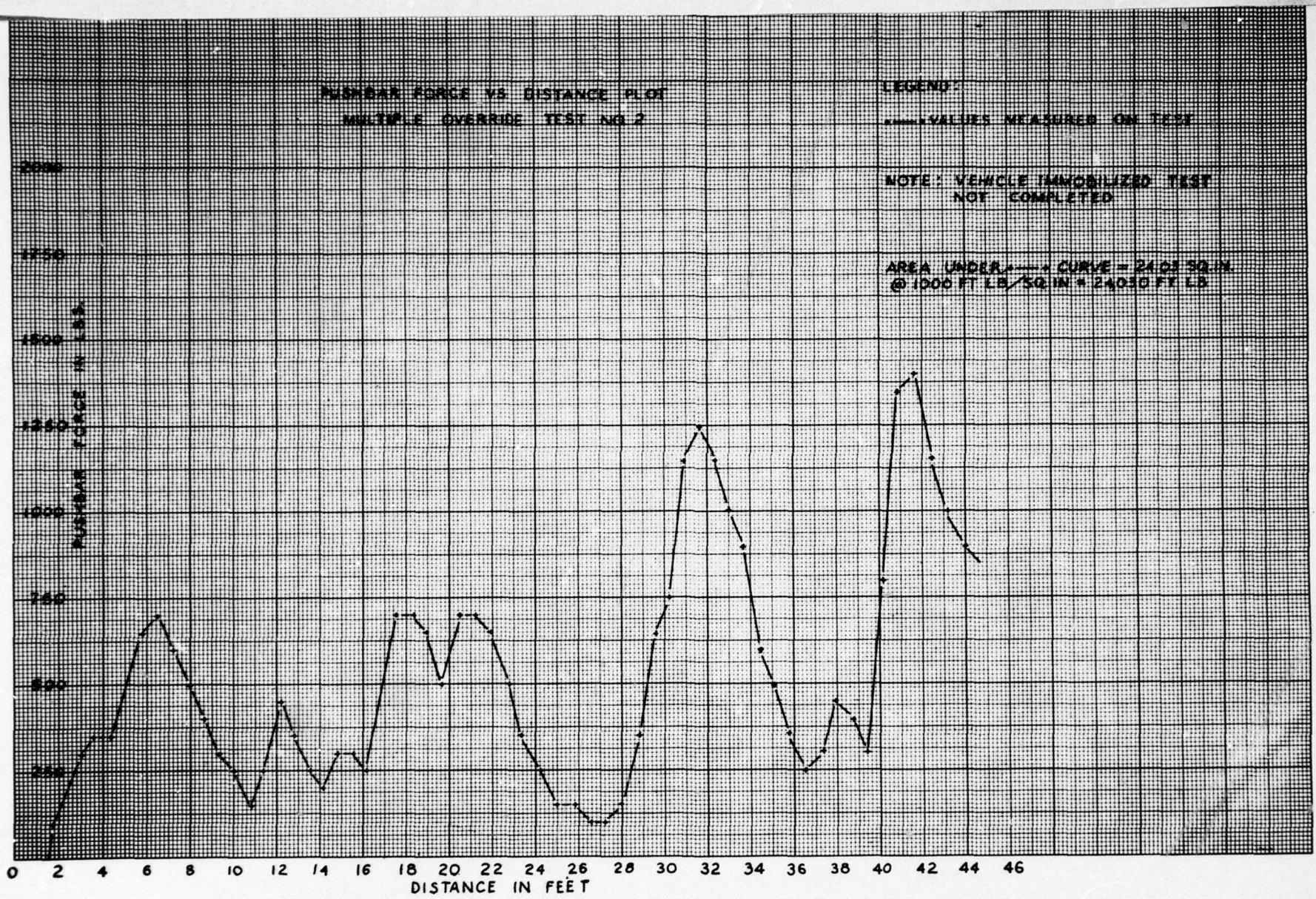

PUSHBAR FORCE VS DISTANCE PLOT
MULTIPLE OVERRIDE TEST NO 2
LEGEND:
•——• VALUES MEASURED ON TEST
NOTE: VEHICLE IMMOBILIZED TEST NOT COMPLETED
AREA UNDER •——• CURVE = 24.03 SQ.IN.
@ 1000 FT LB/SQ IN = 24,030 FT LB
PUSHBAR FORCE IN LBS
2000
1750
1500
1250
1000
750
500
250
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46
DISTANCE IN FEET

Figure V-6

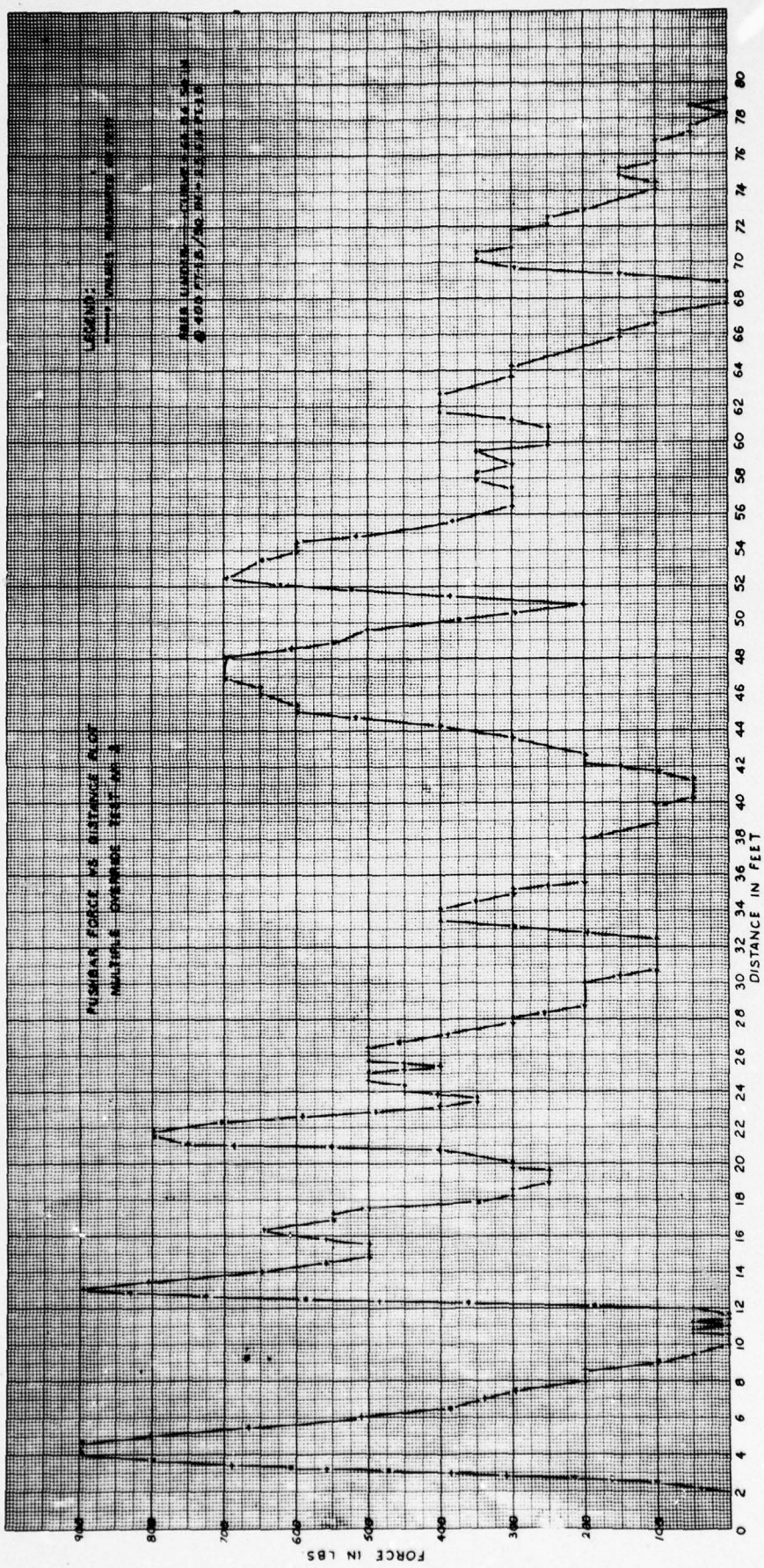

PUSHBAR FORCE VS. STROKE PLOT
NEUTRAL DYNAMIC SET UP
FORCE IN LBS
DISTANCE IN FEET

Figure V-7

APPENDIX VI

TEST PLANS
VERTICAL OBSTACLES

G. T. Cohron

31 August 1964

RIDGID WHEEL - VERTICAL OBSTACLE MODEL

Another one of the many restrictions placed on the cross-country speed of a vehicle is the geometry of the terrain upon which it must operate. This geometry can assume several forms, each having a different kind of influence on the performance of a vehicle. Relief having low amplitude and high frequency (relative to the vehicle size) will usually cause the limiting speed to be determined by the degree of discomfort to the driver, the actual speed reflecting the adequacy of the suspension system to isolate him from the geometry of the terrain as slused by the wheels. Larger obstacles occurring somewhat independently -- rice paddy bunds, for example -- may also lead to a similar speed limit criterion; however, their size may easily be sufficient to cause structural damage to the vehicle if speeds exceed safe maximums, even with the best of suspension systems.

Studies are presently being made to determine analytical techniques for treatment of the surface geometry effect on vehicle speed. The surfaces used for input to vehicle suspension system models are non-yielding representations of naturally-occurring terrain cross-sectional surface profiles. Significant progress has been made in the development of an understanding of the problem, at least within the "mid-range" of terrain roughness values. The boundary conditions, however, are much less well-defined. When an obstacle reaches such a height that structural damage is impending or that surface traction becomes critical, the region becomes more-or-less undefined.

The major purpose of the studies outlined here is to treat vertical obstacles in essentially single array in order to better

define the upper limits of obstacle heights on a dimensionless basis and the dependence of the maximum negotiable size on surface conditions. The maximum negotiable size is obviously a function of obstacle strength. While size-speed and size-traction relationships will be explored using non-deforming obstacles -- for the sake of test set-up simplicity -- obstacles having different strengths will be constructed of soil for the "obstacle strength-immobilization size" study.

A better understanding of the influence of vertical obstacles on vehicular cross-country performance should be obtained through this simple test series. They have been designed to define the limits and order the degree of influence of those factors which are believed to have the greatest influence on vehicular performance.

Some theoretical background studies were necessary to properly design test procedures. These covered the selection of suitable shapes and sizes. They are presented in the introduction to assist in the understanding of the nature of the problem.

If we consider the fact that vertical accelerations of a wheel overriding an obstacle arise from changes in velocity in the vertical plane, certain deductions can be drawn regarding the possible influence of obstacle sizes and shapes. The proper selection of obstacle shapes and sizes can then be made in order to produce consistent test results which can be intelligently interpreted.

The basic premise of the tests outlined herein is to present the test vehicle with an array of obstacles which minimize the influence of its peculiar characteristics with a view toward

obtaining generalized deductions applicable to any machine of the same general type. To satisfy this requirement means that the entire range of obstacle sizes must produce vertical accelerations on the vehicle through a similar mode, though obviously of differing magnitudes of the dependent variable.

Consider first the case of an ideally rigid system in which a non-slipping wheel travelling on a perfectly smooth horizontal surface contacts a "square" obstacle and determine the equation which relates the forward velocity of its center and the height of the obstacle to the vertical accelerations produced. The assumptions require that the V_v vs. t (see definitions below) function be discontinuous at $t = t_o = 0$. That is, at $t_o - \Delta t$ there will be no vertical velocity, and at $t_o + \Delta t$ there will be some finite value of vertical velocity, regardless of how small Δt is taken to be in either case. (This is the definition of a step function.) Because V_v increases from zero to a finite value in a step, the acceleration at that step therefore must be infinite, though mathematically indeterminate.

The shape of the vertical acceleration-time curve at $t>o$ will be dependent upon the <u>height</u> and <u>shape</u> of the obstacle and longitudinal velocity (or vehicle speed). For a square obstacle which is less than the height of the wheel center, the instantaneous vertical velocity is the vertical component of the resultant velocity whose direction is tangent to the surface of the wheel at the point of contact with the obstace. As the wheel rolls farther, onto the obstacle, the rate of vertical translation of its center reduces as the direction of the resultant velocity approaches the horizontal, reducing the vertical acceleration. This may be explored mathematically as follows:

<u>Definitions</u>:

θ = direction of the resultant velocity from the horizontal
h = obstacle height, ft.
r = wheel radius, ft.

d = distance travelled from point of contact with the obstacle during time, t, ft.

x = difference between total distance travelled to reach the top of the obstacle and elapsed distance, d

t = elapsed time, from the point of incipient wheel contact with the obstacle, sec.

t_o = time at the point of contact of the wheel with the obstacle, assumed to be zero for this analysis.

V_r = resultant velocity vector, ft./sec.

V_h = longitudinal velocity vector, ft./sec., assumed constant.

V_v = vertical velocity vector, ft./sec.

A_v = vertical acceleration, ft./sec.^{2}

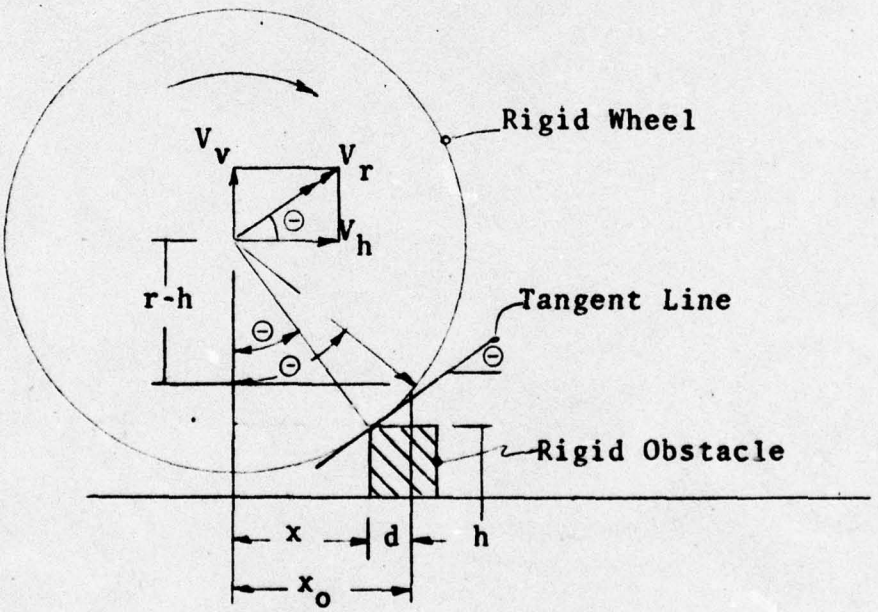


Figure VI-1 - Rigid Wheel Contacting a Solid Square Obstacle.

From vectoral summation,

$$V_v = V_h \tan \theta, \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (1)$$

where $\theta = 0°$ prior to contact. Then

$$A_v = \frac{\Delta V_v}{\Delta t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Since $\Delta t = t - t_o$, and $t_o = 0$,

$$\Delta t = t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Since V_h has been assumed to be a constant, the differential form of equation (1) reduces to

$$\Delta V_v = V_h \cdot \Delta \tan \theta.$$

By substitution into equation (2) for cases where $t>0$,

$$A_v = \frac{V_h}{t} (\tan \theta - \tan \theta_o), \; t>0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

At $t = 0$, $\theta_o = \cos^{-1} (\frac{r - h}{r})$ $\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$ (5)

and at $t>0$, $\theta = \sin^{-1} \frac{x}{r}$ $\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$ (6)

Only x remains to be determined:

$$\left.\begin{aligned} x &= x_o - d \\ x_o &= r \sin \theta_o \text{ or, from (5), } = r \sin [\cos^{-1} (\tfrac{r - h}{r})] \\ d &= V_h t \end{aligned}\right\} \ldots\ldots (7)$$

Substituting values of x_o and d from equations (7) into (6),

$$\theta = \sin^{-1} \left\{ \frac{r \sin [\cos^{-1} (\frac{r - h}{r})] - V_h t}{r} \right\} \ldots\ldots\ldots\ldots (8)$$

Finally, combining (5) and (8) with (4)

$$A_v = \frac{V_h}{t} \left\{ \tan [\sin^{-1} \left\{ \frac{r \sin [\cos^{-1} (\frac{r - h}{r})] - V_h t}{r} \right\}] - \tan [\cos^{-1} (\frac{r - h}{r})] \right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

It may be seen from equation (9) that as t is taken smaller and smaller, A_v increases, approaching the point of discontinuity where it

is infinitely large. In reality, the rigid system postulated here cannot exist. In particular, tire and/or obstacle deformation will alter the absolute values radically, though the practical results should show the same trends as the theoretical. To determine A_v as a function of independent, determinant variables, only θ needs to be defined.

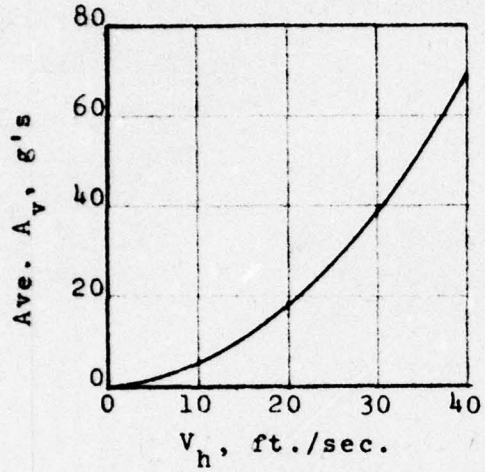
Therefore, at $t>0$, but infinitely small, A_v would be nearly infinite, regardless of obstacle size or vehicle velocity, if the system were rigid. Practically, tire deformation will be the greatest single modifier of this impossible situation. Other deductions can also be made.

IA. At a constant obstacle height and t = a constant >0, increasing velocity produces increases in both the ($\tan \theta - \tan \theta_o$) term and in V_h/t, making incremental increases in speed produce proportionately larger increases in average vertical acceleration with speed (see Figure VI-1a).

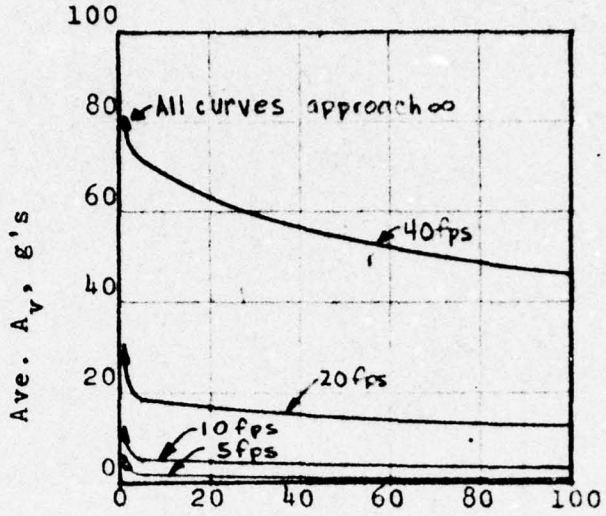
IB. At a constant vehicle speed and t = constant >0, A_v approaches infinity as the obstacle height approaches the radius of the wheel (see Figure VI-1c). Tire deflection will do little to modify this effect since larger square-faced obstacles allow more tire contact area, reducing the amount of deflection at any particular speed. In reality, then, A_v would be expected to reach a higher peak much sooner with a large obstacle than with a smaller one. These peaks will likely be more severe than with smaller obstacles and higher speeds because of proportionately greater tire deflections in the latter. As before, the A_v - t curve should decay rapidly.

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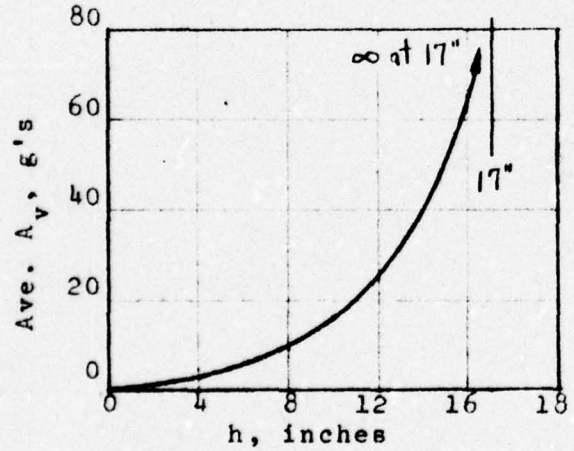
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a. Variation of Average A_v with Vehicle Velocity (t = .0023 sec., h = 4 inches).



b. Relationship Between Acceleration-Time Curves for Different Speeds (h = 4 inches).



c. Variation in Average A_v with Obstacle Height (V_v = 10 fps, t = 20% of total).

Figure VI-1A - Theoretical Average Vertical Accelerations for a Rigid Wheel (radius = 17 inches) Operating on a Horizontal Surface with no Slip, over Rigid, Vertical-Faced Obstacles.

Consider secondly the case of a rigid wheel contacting an obstacle whose approach surface is inclined at such an angle to prevent point contact with the rim of the wheel as follows:

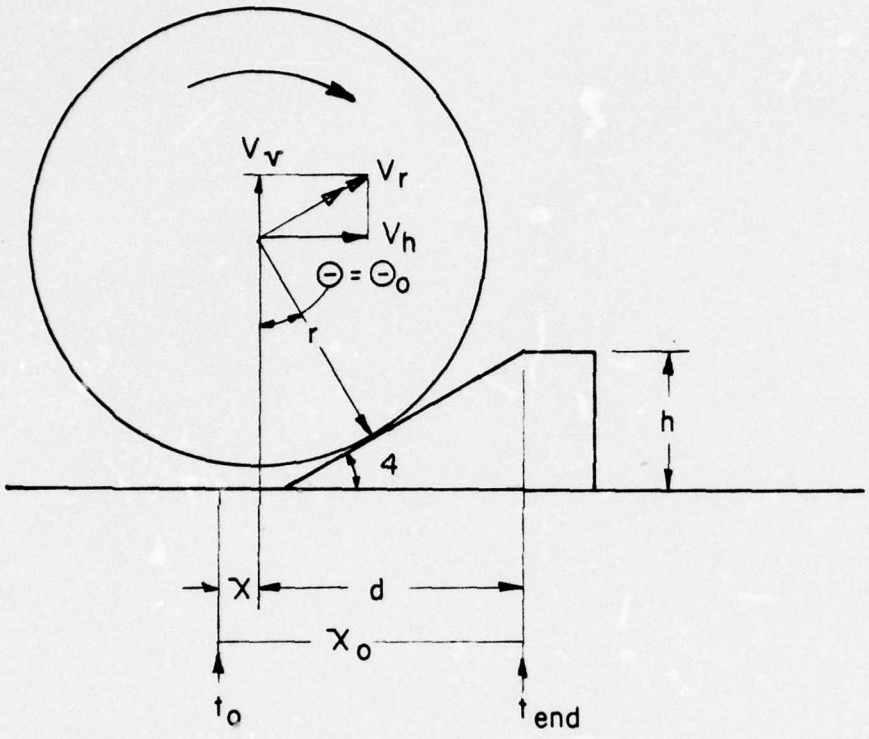


Figure VI-2 - Rigid Wheel Contacting a Solid Obstacle with Sloping Face

New definition: ϕ = slope of the obstacle face with the horizontal.

Again $V_v = V_h \tan \theta$ . . . . . (1)

but $\theta = \phi$ . . . . . (10)

after contact between the wheel and the obstacle has been made.

Generally, $A_v = \frac{V_v}{t} = \frac{V_h \tan \theta}{t}$ . . . . . (11)

at the instant of contact of the wheel with the obstacle, $t = t_o$ and $\theta = \theta_o$.

So $V_h \tan \theta$ becomes finite instantaneously at the moment of contact while t is yet small. Therefore $A_v \longrightarrow \infty$.

After the wheel moves up the obstacle an infinitesimal amount, there is no further change in the vertical velocity ($A_v = 0$) until it begins to approach zero as the point of contact reaches the top edge of the obstacle and the contact point passes under the center of the wheel. This is a period of negative acceleration and is not thought to be significant.

During the critical period at the moment the wheel contacts the obstacle, tire deflection will help to ameliorate the situation to some extent, though to a markedly lesser degree than in the case of the square obstacles with sharp corners. The sloping surfaces allow more of the tire to be in contact with the obstacle and deflection is reduced accordingly at any level of dynamic force. These surfaces must, then, transfer more energy into the suspension system of the vehicle than do the sharp obstacles. Since the suspension system has a lower rebound rate than a highly deflected, highly overloaded tire, the overall effect of tire and suspension interaction may tend to equalize the reactions to the two types of obstacles.

Important deductions may be stated:

IIA. Obstacle height will have little or no influence on either the magnitude or the time-duration of vertical

acceleration over the leading side, provided the leading face of the obstacle is large enough to contain the deflected tire's contact area without overlap onto the top of the obstacle.

IIB. At a constant vehicle speed (V_h), and t = constant > 0, maximum vertical acceleration will vary with the tangent of the slope of the obstacle face up to the point that the face angle is large enough to produce a sharp-cornered obstacle.

IIC. With a fixed obstacle face slope greater than zero and less than the value which would produce point loading (a geometric relation between wheel diameter and obstacle height), maximum vertical acceleration, ideally, will vary linearly with vehicle speed.

IID. The time during which A_v will reach a maximum and return to zero is primarily a function of tire-suspension deflection rate.

IIE. The decay of A_v should be very rapid since it equals zero as soon as equilibrium resultant velocity parallel to the face of the obstacle is established.

It may well be that the longitudinal component of the acceleration vector (deceleration) will be equally as critical -- or even more so -- as the vertical component. This is particularly true of square -- or sharp edged -- obstacles in general and large square obstacles in particular. The driver is considerably less well-restrained to effectively cope with horizontal decelerations than with vertical accelerations upward through the seat. He certainly responds to both, or to their vectorial summation,

through entirely different body reactions and will unwittingly choose the most uncomfortable reaction mode as an acceleration limit determinant. This situation is certainly deserving of careful consideration and will only be touched lightly in this particular study.

Another nuance to the conditions outlined here is a determination of the severity of upward vertical acceleration produced on the "rebound" after the obstacle has been crossed. Conceivably an obstacle with a gentle approach slope and a vertical departure slope could drop a vehicle onto a hard surface from such a height that tolerable acceleration limits would be surpassed in leaving the obstacle. This situation is amenable to mathematical treatment -- at least within the same confines of lack of rigorism portrayed here -- and will be investigated as time and project goals permit. All obstacles in this project will have a 45° departure slope to help prevent undue clouding of the first-approximation results for these entrance-slope studies.

A vehicle is required to produce more tractive effort in crossing a large obstacle than is needed for a smaller one. The relationship most certainly will not be linear within the obstacle height range being considered (up to approx. 1/4 wheel diameter). Statically (approach speed = 0), tractive effort increases with the sine of the angle θ defined earlier. Dynamically, the momentum of the vehicle should be able to get the vehicle across small obstacles at high speeds (high momentum) with little further tractive effort required beyond that necessary to maintain motion. Large obstacles will have to be approached at slower speeds, reducing momentum by the square of velocity, providing disproportionately less assistance for a more demanding (in terms of tractive effort) obstacle. The dynamic effect will be estimated from differences noted between static and dynamic tests.

TEST PLAN

SINGLE NONDEFORMABLE VERTICAL OBSTACLES

G. T. Cohron
R. A. Werner

1 September 1964

TEST PLAN FOR SINGLE NONDEFORMABLE VERTICAL OBSTACLES

I. OBJECTIVE

These tests are fundamental in that the data gained here will be used not only for these tests, but also in the interpretation of results from the subsequent more complex tests. Since human variability among individuals is not a topic of investigation during this early stage of development, the tolerance of a single driver to accelerations will be estimated on the basis of these tests. This level can be reached by crossing small obstacles at high speed or by crossing larger obstacles at slower speeds. The interdependency will be studied.

Another object will be to study both static and dynamic traction requirements for crossing vertical obstacles. This segment of the study will assist the resolution of minimum soil strength requirements when various sizes of obstacles are known to exist in an area of interest.

II. SCOPE

This series of tests encompasses the forty-eight individual tests specified in Table VI-1. Zero-speed tests will be used to determine the static tractive effort required to negotiate the different obstacles. Other runs will be used to determine the maximum speed at which the various obstacles can be crossed.

One driver will be used to hold the driver variable as nearly constant as possible. Exposure to maximum accelerations have been spread apart (except for the last three runs) in hopes of controlling driver-influenced bias for obstacle size or shape.

TABLE VI-1 - OUTLINE OF SINGLE NONDEFORMING VERTICAL OBSTACLE TEST CONDITIONS

Run Number	Vehicle	Obstacle Height, Type*	Speed**	Number Of Runs
1-3	M37	4 Sq.	O	3
4	M37	4 Sq.	I_1	1
5	M37	4 Sq.	I_2	1
6	M37	4 Sq.	I_3	1
7	M37	4 Sq.	M	1
8-10	M37	8 Sl.	O	3
11	M37	8 Sl.	I_1	1
12	M37	8 Sl.	I_2	1
13	M37	8 Sl.	I_3	1
14	M37	8 Sl.	M	1
15-17	M37	8 Sq.	O	3
18	M37	8 Sq.	I_1	1
19	M37	8 Sq.	I_2	1
20	M37	8 Sq.	I_3	1
21	M37	8 Sq.	M	1
22	M37	8 Sl.	M	1
23	M37	4 Sq.	M	1
24	M37	8 Sq.	M	1
25-27	M29C	4 Sq.	O	3
28	M29C	4 Sq.	I_1	1
29	M29C	4 Sq.	I_2	1
30	M29C	4 Sq.	I_3	1
31	M29C	4 Sq.	M	1
32-34	M29C	8 Sl.	O	3
35	M29C	8 Sl.	I_1	1
36	M29C	8 Sl.	I_2	1
37	M29C	8 Sl.	I_3	1
38	M29C	8 Sl.	M	1
39-41	M29C	8 Sq.	O	3
42	M29C	8 Sq.	I_1	1
43	M29C	8 Sq.	I_2	1
44	M29C	8 Sq.	I_3	1
45	M29C	8 Sq.	M	1
46	M29C	8 Sl.	M	1
47	M29C	4 Sq.	M	1
48	M29C	8 Sq.	M	1

* Key: Sq. = Square approach face (vertical)
Sl. = Sloping approach face (30° from horizontal)

** I_1 is well below the maximum speed to provide a greater range of data for dynamic condition analysis. I_2 and I_3 are intermediate speeds used to "home-in" on the maximum (M). Zero speeds are used for static traction determinations.

Part of the intermediate speeds for each obstacle size will be run purposely slow in order that checks can be made on the influence of momentum. These will provide data necessary to approximate the "required tractive effort-speed" relationships.

Obstacle sizes and shapes have been chosen consistent with the theories to be checked. They consist of 14-foot timbers, suitably anchored to a graded surface of hard soil, shaped and sized as follows:

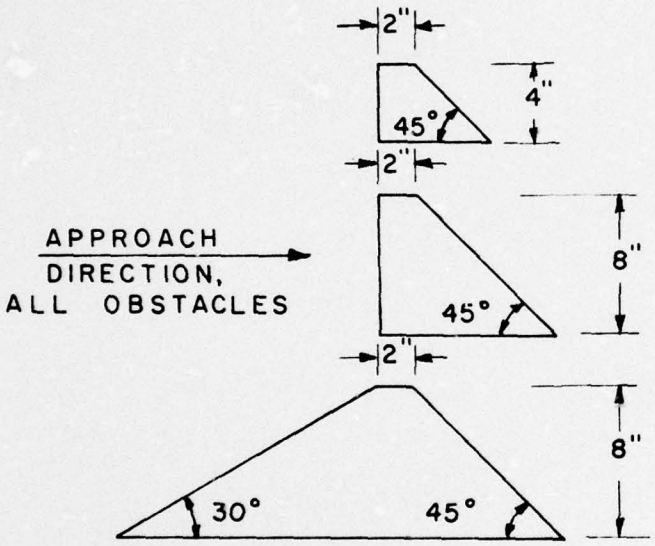


Figure VI-3

The major part of these tests will be conducted with the M37 3/4-ton truck. The Weasel will be used for specific cases where the influence of tractive element form must be estimated.

III. DETERMINATIONS SOUGHT

The vertical shapes and sizes have been chosen to produce data consistent with specific needs outlined in the introduction.

A. Four-inch high square-faced obstacle

1. Test hypothesis 1A; that is, the constancy of vertical acceleration with a range of speeds and an estimate of the probable influence of tire deflection using the Weasel results.

2. Measure the static traction required to overcome the obstacle as a function of obstacle height (with B below).

B. Eight-inch high square-faced obstacle

1. Test hypothesis IB; the relationship between:
   a. Maximum acclerations and speeds compared to the smaller obstacle of like shape and
   b. The shapes of the vertical acceleration curves compared to the smaller obstacle of like shape.

2. Determine the static traction required to negotiate obstacles of differing heights (with A, above) to check predictions based on soil surface shear measurements and the geometrics of the vehicle and obstacle.

C. Eight-inch high obstacle with a 30° approach face angle

1. Test hypothesis IIC: Maximum vertical acceleration is linearly proportional to speed.

2. Compare the shape of the vertical acceleration-distance curve with that of an equi-height, square-faced obstable.

3. Check static traction requirements as in B.2. above.

D. All obstacles

1. From recorded data determine the extent to which dynamic force (from vehicle momentum) replaces required static tractive effort.

2. Check the agreement -- or lack thereof -- between simplified theory and field results wherever possible.

3. Determine the modifying influence of tire and suspension deflection on vertical acceleration.

IV. TEST SITE REQUIREMENTS

A suitable site will be located which incorporates the following requirements:

A. Nearly level (up to 2% slope permissable)

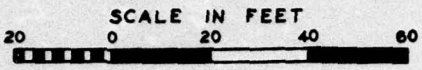
B. Firm soil: 0-6 Cone Index over 300

C. Course dimensions 160.0 ft. by 232.0 ft., according to Figure VI-4. This area covers the requirements for all vertical obstacle tests.

D. No trees can be situated on a potential location for the test course because their removal would damage the soil surface strength.

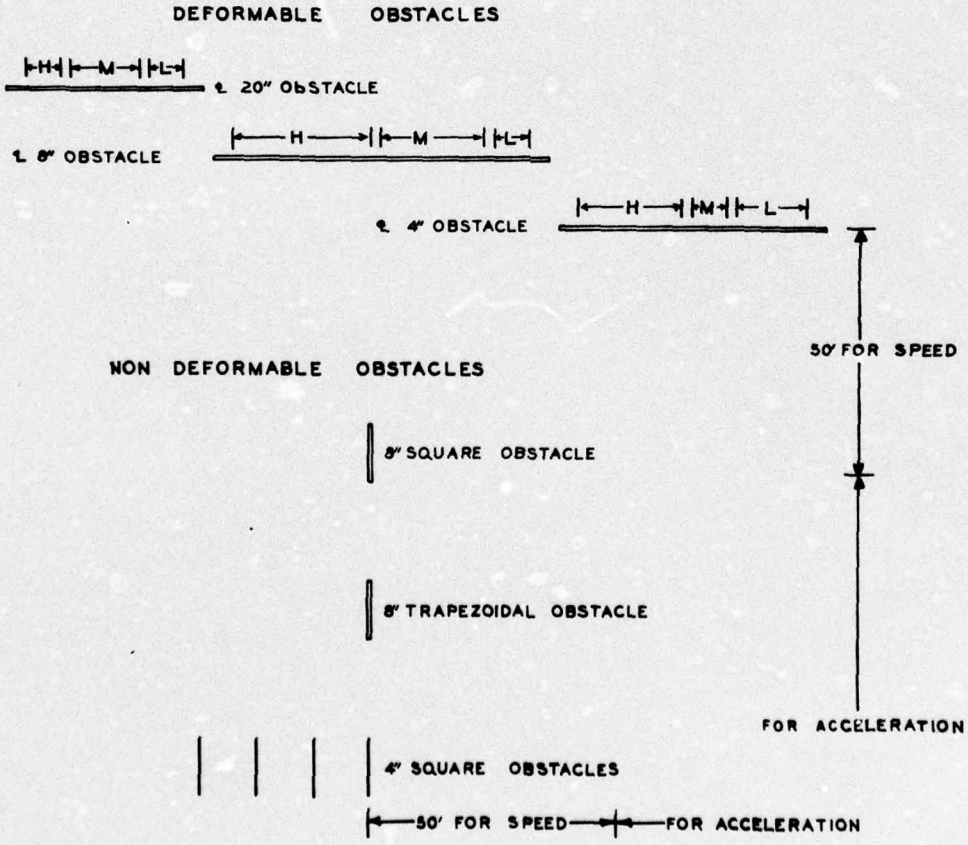
FIGURE VI - 4

VERTICAL OBSTACLE LAYOUT



STRENGTH CLASS

H — HIGH
M — MEDIUM
L — LOW



E. An adjacent area must be available for borrow-soil with which to construct the deformable obstacles (for another test in the series).

F. Area must be accessible to heavy equipment used in course preparation.

V. MEASUREMENTS REQUIRED

A. Recorded (magnetic tape and oscillogram)

1. Drive line torque between transmission and transfer case.

2. Vertical acceleration
   a. At driver's seat
   b. At front axle (optional)

3. Longitudinal acceleration
   a. At driver's seat
   b. At front axle (optional)

4. Drive line revolution counter giving two sharp counts per revolution on the M37, one count per revolution on the M29C.

B. Field measurements

1. Obstacle Type
2. Obstacle Height
3. Time for 50 ft.
4. Driver Reaction

C. Sheargraph measurements of soil surface shearing strength.

D. Cone Index measurements of soil "hardness" as a control measure since sinkage cannot be tolerated.

E. Background Data Needed

1. Load-deflection curve for a 9.00 x 16 military tire at 35 psi inflation on a flat surface.

2. Load-deflection curve for a 9.00 x 16 military tire on a 45° right triangular knife edge whose 18-inch hypotenuse is laid on the surface (6.36 inches high).

3. Accurate vehicle weights and load distribution.

4. Accurate instrumentation calibration data.

VI. CONDUCT OF TESTS

The course for these tests will be prepared before that for the two other obstacle studies. Once the surface has been graded level and free of low areas where water could stand, the three solid obstacles will be placed as in Figure VI-4. Tests will then be conducted in the numerical order of Table VI-1.

A. Static Tests

1. Collect Cone Index readings for the immediate test site before test to insure adequate soil bearing capacity. The readings will be collected in the test lane along the particular obstacle within an

area as long as the vehicle wheelbase so they will apply directly to the specific test involved. Three profiles per test lane will be ample.

2. Bring the front wheels of the vehicle in contact with the obstacle.

3. Instruct the driver to make as smooth a start as possible since we do not want unnecessary torque peaks in the data.

4. Turn on instruments for a zero reading with the test vehicle out of gear.

5. Cross the obstacle with the front wheels only for record purposes.

6. Take Sheargraph record of ultimate soil-soil and soil-rubber shear failures in the test lane. Make one composite graph for each test.

B. Intermediate-speed Dynamic Runs

1. Preparation of test
   a. Repeat Cone Index survey as above.
   b. Specify driver's use of hard hat and seat belt throughout all tests. Do not permit shoulder harness use.
   c. Set 4-foot to 6-foot stakes along the edge of the path(s) to be followed to carefully adhere to lane locations.

2. Sequence of Runs

   a. The first run of the dynamic series will be slow -- of the order of 1 mph.
   b. Subsequent runs (up to 3 more) will be used to "home in" on the maximum tolerable speed. In all cases, be sure the driver has achieved this maximum speed.

3. Instruct the driver to hold his speed constant during the last 50 feet (clearly marked) of his approach by watching either a tachometer (preferred) or speedometer.

4. For a field check on speed, time the vehicle through the 50 foot measured distance (marked with tapes on the ground so they are easily visible by one test engineer) just prior to obstacle contact.

5. After the obstacle has been crossed, solicit driver's opinion of the obstacle severity from the following list:
   a. Imperceptible
   b. Perceptible
   c. Distinctly perceptible
   d. Slightly disagreeable
   e. Disagreeable
   f. Unbearable

6. Instruct driver on the next speed to try.

C. Personnel Requirements

1. Field Test

a. Engineer
   (1) Site preparation
   (2) Driver instruction
   (3) Test Notes
b. Technician (2) - Soils data
c. Engineer or Technician - Instrumentation
d. Driver

2. Data Analysis
   a. Engineer-in-charge
   b. Engineer
   c. Engineers or Technicians - 2

VII. DATA FORMS

A. Field Data Form

1. Test Number
2. Vehicle
3. Obstacle Type
4. Obstacle Height
5. Time for 50 Feet
6. Speed, MPH
7. Sheargraph Test Numbers
8. Cone Index Test Numbers
9. Driver Reaction
10. Remarks

B. Soils Data Form

WES No. 1424, July 1964

C. Summary Table

1. Test Number
2. Obstacle Height
3. Obstacle Face Angle
4. Driver Reaction
5. Speed, MPH
6. Average Torque (Ft.-Lbs.)
7. Tractive Effort (Lbs.)
8. Seat Jerk
   a. Vertical
   b. Longitudinal
9. Vertical Seat Acceleration/Velocity of Vehicle
10. Vertical Acceleration
    a. Seat
       1) Maximum, G's
       2) Frequency, cps
    b. Axle
       1) Maximum, G's
       2) Frequency, cps
       3) Initial Acceleration, G's
11. Longitudinal Acceleration
    a. Seat
       1) Maximum, G's
       2) Frequency, cps
    b. Axle
       1) Maximum, G's
       2) Frequency, cps
       3) Initial Acceleration, G's

VIII. ANALYSIS PROCEDURE

A. From the permanent record of the magnetic tape, the following measurements will be taken: (using the calibration steps to define the displacement from the zero line)

1. The maximum vertical and longitudinal acceleration of the seat and axle.
   a. The frequency of the accelerations will be determined for at least two cycles, using the timer pips as the time reference.

   b. The time for the vertical and longitudinal acceleration of the seat to go from zero to the maximum and back to zero again will be measured and converted to seat jerk (2 x maximum acceleration ÷ time, as measured).

2. The initial vertical and longitudinal acceleration of the axle.

3. The average torque will be measured at the time of the front wheel contact with the obstacle, since for these vehicles and obstacles the average in crossing the obstacles appeared to be near this value -- with the obvious exception of the zero-speed runs where the maximum torque is the significant measurement.

B. The soils measurements will be summarized for each test or test course.

TABLE VI-2 - VERTICAL OBSTACLE TESTS

SINGLE NONDEFORMABLE

SUMMARY OF DATA AND TEST RESULTS

M37, 3/4-TON TRUCK

Test No.	Obstacle Height (In.)	Face Angle	Driver Reaction	Speed (MPH)	Average Torque (Ft.-Lbs.)	Tractive Effort (Lbs.)	Seat Jerk		Vertical Seat Acceleration	Vertical Acceleration					Longitudinal Acceleration					
										Seat		Axle			Seat			Axle		
							Vertical	Horizontal	Velocity	Maximum (G's)	Frequency (Cycles/Sec.)	Maximum (G's)	Frequency (Cycles/Sec.)	Initial Acceleration (G's)	Maximum (G's)	Frequency (Cycles/Sec.)		Maximum (G's)	Frequency (Cycles/Sec.	Initial Acceleration (G's)
1B	4	90°	1	0	400	1656	2.9	4.0	----	0.4	3	1.8	8.7	1.8	0.5	2.0*		0.7	11.0	0.7
2B	4	90°	1	0	420	1739	2.7	3.3	----	0.4	1.9	2.4	8.3	2.4	0.25	4.0*		1.0	10.0	1.0
3B	4	90°	1	0	260	1074	1.8	6.0	----	0.5	1.7	2.0	9.0	2.0	0.24	6.0*		0.9	11.0	0.9
4	4	90°	2	7.34	85	352	33.3	15.0	.14	1.5	.5	3.9	5.4	3.9	0.6	7.4		1.5	6.7	1.2
5	4	90°	2	14.20	165	683	26.7	8.0	.032	0.8	5.5	5.5	8.7	5.5	0.6	7.4		2.7	14.2	2.0
6	4	90°	2	18.90	140	580	33.3	16.0	.037	1.0	6.3	5.7	9.0	5.7	0.4	11.0		4.5	14.2	0.7
7	4	90°	2	29.60	150	621	20.0	164.0	.017	0.7	6.7	6.8	14.3	6.8	4.1	14.0		2.2	18.0	1.8
8	8	30°	2	0	400	1656	2.2	5.2	----	0.2	2.0	7.8	9.0	7.8	1.3	----		2.1	11.0	2.1
9	8	30°	2	0	390	1615	11.0	1.5	----	1.1	2.0	6.0	8.7	6.0	0.3	12.5		1.7	10.0	1.7
10	8	30°	2	0	380	1573	10.0	114.3	----	2.0	2.4	6.7	8.3	6.7	4.0	7.0		2.0	11.0	2.0
11	8	30°	2	3.90	90	373	11.1	21.2	.173	1.0	2.5	5.5	8.0	0.5	3.5	8.6		1.3	10.0	1.3
12	8	30°	3	9.60	100	414	23.2	24.4	.153	2.2	1.9	3.4	9.0	3.2	4.4	1.3		3.0	12.5	1.8
13	8	30°	3	15.20	50	207	46.0	53.8	.100	2.3	5.0	7.6	11.0	7.6	4.3	4.0		3.4	----	3.2
14	8	30°	3	28.40	230	952	67.5	47.3	.067	2.7	5.6	7.6	12.5	7.6	5.2	2.0		9.0	6.0	4.0
15	8	90°	2	0	380	1573	5.4	5.7	----	0.7	1.9	6.0	8.7	6.0	0.2	10.0		2.0	10.0	2.0
16	8	90°	2	0	400	1656	12.0	6.2	----	1.5	2.0*	4.5	9.0	4.5	0.4	4.5		1.5	10.0	1.5
17	8	90°	2	0	380	----	11.1	8.6	----	1.0	5.0	7.0	8.0	7.0	0.3	14.0		2.0	10.0	2.0
18	8	90°	2	3.00	60	248	8.2	7.0	.207	0.9	2.0	5.0	8.0	1.5	0.8	1.5		2.0	10.0	0.8
19	8	90°	3	7.70	100	414	17.8	8.8	.140	1.6	4.0	7.6	9.0	4.4	1.1	2.0		2.6	11.0	1.6
20	8	90°	4	14.80	240	994	40.0	40.0	.093	2.0	5.0	7.0	5.5	7.0	1.4	8.0		2.8	11.0	2.8
21	8	90°	3	25.20	150	621	62.2	33.3	.073	2.8	6.0	7.7	12.0	7.0	1.0	14.0		5.0	20.0	5.0
22	8	30°	3	28.40	150	621	62.5	55.0	.060	2.5	5.5	2.0	14.0	2.0	1.1	14.0		5.0	20.0	4.5
23	4	90°	2	28.40	150	621	15.0	10.0	.013	0.6	6.0	2.0	14.2	2.0	0.7	6.0		3.0	20.0	2.0
24	8	90°	2	32.50	No Torque	----	51.1	44.0	.047	2.3	6.0	7.5	12.5	7.5	1.1	13.0		5.0	18.0	5.0

* Cycle Not Complete

TABLE VI-3 - VERTICAL OBSTACLE TESTS

SINGLE NON-DEFORMABLE

SUMMARY OF DATA AND TEST RESULTS

M29C, WEASEL

Test No.	Obstacle Height (In.)	Face Angle	Driver Reaction	Speed (MPH)	Average Torque (Ft.-Lbs.)	Tractive Effort (Lbs.)	Seat Jerk		Vertical Seat Acceleration		Horizontal Seat Acceleration	
							Vertical	Horizontal	Maximum (G's)	Frequency (Cycles/Sec.)	Maximum (G's)	Frequency (Cycles/Sec.)
1	4	90°	0	0	0	0	7.5	7.2	0.15	13	0.18	10
2	4	90°	0	0	157	1193	8.0	8.7	0.20	15	0.26	13
3	4	90°	0	0	158	1201	12.0	8.9	0.30	13	0.31	11
4	4	90°	0	3.5	70	532	12.0	7.0	0.30	15	0.21	13
5	4	90°	0	6.7	80	608	25.0	10.2	0.50	25	0.41	20
6	4	90°	0	14.2	120	912	60.0	40.0	0.90	50	0.60	22
7	4	90°	0	20.0	105	798	60.0	60.0	0.90	29	0.90	33
8	4	90°	0	18.8	80	608	60.0	63.3	0.90	50	0.95	30
9	8	30°	3	0	190	1444	103.0	16.2	3.10	21	1.05	25
10	8	30°	3	0	160	1216	35.6	22.0	1.60	28	0.77	22
11	8	30°	3	0	200	1520	55.0	17.6	2.20	20	0.88	20
12	8	30°	3	3.5	190	1444	77.1	23.1	2.70	25	1.04	40
13	8	30°	4	6.1	160	1216	91.4	31.4	3.20	33	1.10	20
14	8	30°	5+	13.1	140	1064	120.0	48.0	3.00	40	1.20	20
15	8	90°	0	0	200	1520	18.0	9.7	0.90	16	0.58	25
16	8	90°	1	0	190	1444	24.0	12.5	1.20	25	0.69	16
17	8	90°	1	0	120	912	26.7	12.6	1.20	25	0.63	15
18	8	90°	1	2.3	160	1216	33.3	13.5	1.50	20	0.74	22
19	8	90°	2	4.5	180	1368	90.0	23.1	2.70	22	1.04	17
20	8	90°	4	6.0	90	684	108.0	28.3	2.70	20	1.13	17

TEST PLAN

MULTIPLE NONDEFORMABLE VERTICAL OBSTACLES

G. T. Cohron
R. A. Werner

1 September 1964

TEST PLAN FOR MULTIPLE NONDEFORMABLE VERTICAL OBSTACLES

I. OBJECTIVE

This series of tests will add nother dimension to the basic understanding to be gained through tests on single nondeformable obstacles. Simply stated, a comparison will be made between the "mid-ship" vertical accelerations at the two subjectively defined limiting conditions. If there is a difference, inferences as to the possible cause(s) will be sought.

These tests will also provide three check points to determine the degree of agreement -- in principle only -- between the actual severity of the artificial surface roughness and that indicated by recent theory of Stone and Dugundji.

II. SCOPE

This series will be comprised of 23 tests in carefully selected test situations. The major emphasis will be placed on M37 tests with cross sections taken through the data with the M29C to permit estimates of trends peculiar to the different vehicle form.

Table VI-4 outlines the tests by number. Repetitions of runs were confined to only those necessary to provide an indication of the consistency of data so error bands could be estimated. Only two repetitions will be made of maximum speeds, and these delayed in the test sequence to minimize driver fatigue.

The three spacings were chosen such that the acceleration at the driver's seat would not reflect the combined effect of obstacles under both wheels at the same time. Specifically, they

TABLE VI-4 - OUTLINE OF MULTIPLE, NONDEFORMABLE VERTICAL OBSTACLE TEST CONDITIONS

Run No.	Spacing Inches	Speed Class*	Repetitions	Vehicle
1	207	I_1	1	M37
2-4	207	I_2	3	M37
5	207	M	1	M37
6-8	69	I_1	3	M37
9	66	I_2	1	M37
10	69	M	1	M37
11	138	I_1	1	M37
12	138	I_2	1	M37
13	138	M	1	M37
14	69	M	1	M37
15	207	M	1	M37
16	138	M	1	M37
17	138	I_1	1	M29C
18-20	138	I_2	3	M29C
21	138	M	1	M29C
22	69	M	1	M29C
23	207	M	1	M29C

* I_1 is purposely slow

I_2 is used to find the maximum tolerable speed, M.

were chosen so that each wheel would have the maximum available distance to reach equilibrium on the horizontal surface after having crossed an obstacle. In all three spacings the accelerations imposed on the front wheels -- and the resulting reaction at the driver's location -- will not be obscured by unwanted accelerations at the rear wheels.

III. DETERMINATIONS SOUGHT

The dependence of vertical acceleration on the speed of crossing multiple obstacles will be plotted and the subjective limits imposed. The intersection of these curves will be used to compare to similar data from the single-obstacle tests. If a significant difference is detected, the probable causes will be sought from among the test data.

Stone and Dugundji have recently proposed an ordering of influences of terrain factors which contribute to the "roughness". The index of roughness was found to vary directly (though not necessarily in direct proportion) with the maximum height of the obstacles and inversely as their dominant frequency -- or distance-period. The general form of the equation is as follows:

$$R = f\left(\frac{A}{p}\right)$$

where R = Roughness index, dimensionless
A = Maximum amplitude, ft.
p = Distance-based period, ft.

The three spacings used in these tests will permit the maximum speed for each to be plotted against the roughness index to explore its physical significance. Since the roughness index

(as grossly simplified here) does not include a speed term, any constant speed less than maximum could be treated in the same manner if a parameter other than speed -- such as vertical acceleration -- were chosen. However, this is little more than academic for the purpose of these tests, which is to define limits on vehicular performance.

IV. TEST SITE REQUIREMENTS

Figure VI-4 of the Single Nondeformable Obstacle Plan shows the location for the multiple-obstacle array. All other conditions of the site are identical. Since several runs are likely to be run in the tracks of previous runs, the course condition will be watched for signs of significant deterioration.

V. MEASUREMENTS REQUIRED

A. Instrumentation Records

1. Drive-line Torque
2. Drive-line RPM
3. Vertical Acceleration
   a. At axle
   b. At driver's seat
4. Horizontal Acceleration
   a. At axle
   b. At driver's seat
5. Time reference, preferably two pips per second

B. Field Measurements

1. Time elapse for course traversal
2. Sheargraph measurements
3. Cone Index measurements

VI. CONDUCT OF TESTS

A. Pre-test

1. Arrange the four obstacles according to the Table schedule.

2. Prepare vehicle and check instrument calibration.

3. Collect spot checks with the cone penetrometer to ensure satisfactory course bearing capacity. Take two 0- to 6-inch readings between each two obstacles (6 total readings) at least once each day, and more often as conditions indicate.

4. Use same driver as used in other vertical obstacle studies.

B. Test

1. Instruct the driver as to the purpose of the particular run and the approximate level of speed, if the run is to be made at less than the maximum.

2. Approach the first obstacle at the constant speed which will be maintained throughout the test run.

3. Time the vehicle with a stopwatch from the time the rear wheels leave the first obstacle until they leave the fourth obstacle, enter the value on the field data form, and determine average speed.

C. Post-Test

1. Examine oscillograms for acceptability of recorded data and pick of peak g's as required above, if possible.

2. Collect two composite Sheargraph curves along the test course:
   a. Soil-soil
   b. Soil-rubber

D. Personnel Requirements

1. Field Test
   a. Engineer
      (1) Site preparation
      (2) Driver instruction
      (3) Test notes
   b. Technician (2)
      (1) Soils data
      (2) Stopwatch time
   c. Engineer or Technician - Instrumentation
   d. Driver

2. Data Analysis
   a. Engineer-in-charge
   b. Engineer
   c. Technicians - 2

VII. DATA FORMS

A. The same data forms will be used in this test series, as used in the test series for single, nondeforming

vertical obstacles, except, obstacle type should be changed to obstacle spacing and the initial accelerations of the axle should be deleted.

VIII. ANALYSIS PROCEDURES

A. The same measurements will be taken from the permanent record of the magnetic tape, as taken in the single, nondeforming test series, except the initial axle accelerations will be deleted. Instead of taking the maximum longitudinal and vertical acceleration of the seat and axle, the average of the maximums will be taken. (In most cases, the average maximum acceleration turned out to be the second highest maximum.)

TABLE VI-5 - VERTICAL OBSTACLE TESTS

MULTIPLE NON-DEFORMING (4", 90° FACE ANGLE)

SUMMARY OF DATA AND TEST RESULTS

M37, 3/4-TON TRUCK

Test No.	Obstacle Spacing (In.)	Driver Reaction	Speed (MPH)	Average Torque (Ft.-Lbs.)	Tractive Effort (Lbs.)	Seat Jerk		Vertical Acceleration				Horizontal Acceleration			
								Seat		Axle		Seat		Axle	
						Vertical	Horizontal	Maximum (G's)	Frequency (Cycles/Sec.)	Maximum (G's)	Frequency (Cycles/Sec.)	Maximum (G's)	Frequency (Cycles/Sec.)	Maximum (G's)	Frequency (Cycles/Sec.)
11	69	1	28.4	150	621	35.0	70.0	0.70	7.00	6.50	10.0	0.70	30.00	4.70	25.00
12	69	3	8.1	40	162	1.5	28.0	0.08	7.00	3.50	6.0	1.40	6.00	1.50	9.00
13	138	2	4.9	50	207	20.0	20.0	0.50	4.00	3.20	8.0	0.60	16.00	1.20	14.00
14	138	4	9.8	60	248	24.0	25.0	0.60	10.00	4.00	6.0	0.50	20.00	2.70	10.00
15	138	1	28.4	160	662	32.0	46.7	0.80	11.00	6.70	10.0	0.70	25.00	3.70	30.00
16	138	1	31.0	150	621	24.0	70.0	0.60	12.50	6.60	13.0	0.70	25.00	6.00	17.00
1A	207	1	2.0	45	186	4.8	2.1	0.60	2.20	2.60	10.0	0.35	1.70	0.70	12.50
2A	207	2	5.0	50	207	4.8	8.3	0.60	1.90	2.50	7.0	0.50	5.00	1.40	5.00
3A	207	3	10.8	75	311	6.7	17.1	1.00	2.50	4.40	7.0	0.60	8.50	2.60	7.50
4A	207	2	18.0	205	849	15.0	22.0	0.90	5.30	5.90	7.1	0.55	12.50	3.90	16.70
5A	207	2	43.0	185	766	22.9	25.0	0.80	7.50	6.60	14.3	0.50	12.50	4.30	16.70
6A	207	2	28.4	170	704	25.7	22.0	0.90	7.10	6.40	11.1	0.55	9.10	3.70	14.30
7A	69	2	2.2	90	373	5.3	3.1	0.80	1.41	2.70	9.1	0.65	1.19	0.87	1.28
8A	69	2	3.3	80	331	4.8	4.0	0.60	1.90	3.10	9.1	0.70	1.50	1.30	10.00
9A	69	2	4.0	40	166	3.2	9.6	0.60	1.32	3.25	7.7	0.53	4.50	1.00	2.30
10A	69	2	13.6	50	207	12.3	17.7	0.80	4.50	6.20	9.1	0.62	9.10	3.50	12.50
M29C, WEASEL															
21	207	1	18.0	90	684	6.25	356.0	1.0	1.6	----	----	8.90	14.3	----	-----
22	69	1	20.0	110	836	31.40	810.0	1.1	7.1	----	----	8.10	25.0	----	-----
23	138	0	2.3	90	684	1.30	1.1	0.1	2.9	----	----	0.18	2.0	----	-----
24	138	0	4.3	70	532	2.90	5.8	0.3	2.0	----	----	0.23	9.1	----	-----
25	138	5	8.4	70	532	78.00	6.0	3.9	2.7	----	----	1.02	2.2	----	-----
26	138	1	14.2	60	456	17.80	10.0	0.8	2.9	----	----	0.75	2.7	----	-----
27	138	1	17.1	130	988	20.00	56.0	0.9	7.2	----	----	0.84	25.0	----	-----

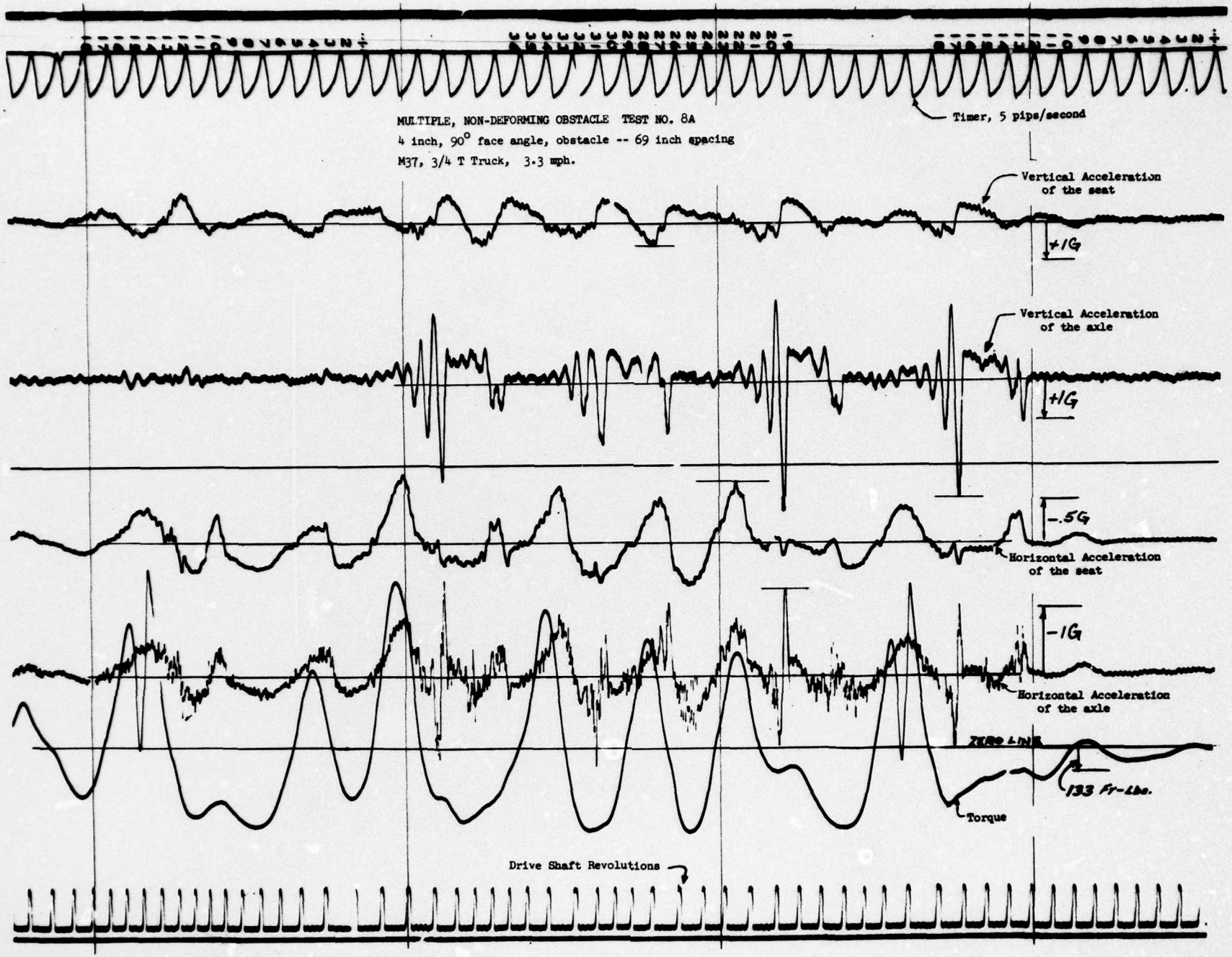


Figure VI-5 - Sample Oscillogram

TEST PLAN

SINGLE DEFORMABLE VERTICAL OBSTACLES

R. A. Werner

1 September 1964

TEST PLAN FOR SINGLE DEFORMABLE VERTICAL OBSTACLES

I. OBJECTIVE

An obstacle which will yield under the influence of externally applied force will create a less severe restriction on (a) the speed of advance of a vehicle crossing it or (b) the ability of the vehicle to negotiate an obstacle of given size and shape. This plan outlines tests through which an attempt will be made to discover the maximum negotiable obstacle size as a function of its strength and the speed at impact.

A second object will be to attempt to relate a modified form of the roughness index discussed in the "Multiple Nondeforming Vehicle Obstacle" plan. A third term will be added which will reflect the direction of new values the roughness index should take when obstacles are less than "hard".

A further object will be to attempt to relate accelerations at a constant speed for deformable and nondeforming obstacles. This would simplify future artificial obstacle tests and point the way to operate off-road.

II. SCOPE

This test series involves 18 tests conducted over obstacles of like shape but varying size and strength (See Table VI-6). The deformable obstacles have an approach face which is somewhat like naturally occurring topographic variations. These, then, should relate directly to the nondeformable obstacle of like shape, differences being attributable to the deformation produced in crossing it.

TABLE VI-6 - OUTLINE OF SINGLE DEFORMABLE VERTICAL OBSTACLE TEST CONDITIONS

Test No.	Height Inches	Strength Class*	Traction Cond.**	Vehicle
1	20	H	G	M37
2	20	M	G	M37
3	20	M	G	M37
4	20	S	G	M37
5	4	H	G	M37
6	4	M	G	M37
7	4	S	G	M37
8	4	S	G	M37
9	8	H	G	M37
10	8	H	G	M37
11	8	M	G	M37
12	8	S	G	M37
13	4	H	B	M37
14	4	H	B	M37
15	8	H	B	M37
16	8	H	B	M37
17	8	M	G	M29C
18	8	M	G	M29C

* H - hard
M - medium
S - soft

** G - good
B - bad

Although major emphasis will be placed on the M37 tests, a limited number of runs with the M29C will also be run. As before, these few tests will hopefully have inferences on the broader aspects of the performance of tracked vehicles. At least, they will permit the writing of meaningful procedure for tests of tracked vehicles in the future.

The spatial arrangement of the obstacles is indicated in Figure VI-4, contained in "Single Nondeformable Vertical Obstacle" plan, and they will be shaped as indicated in Figure VI-6.

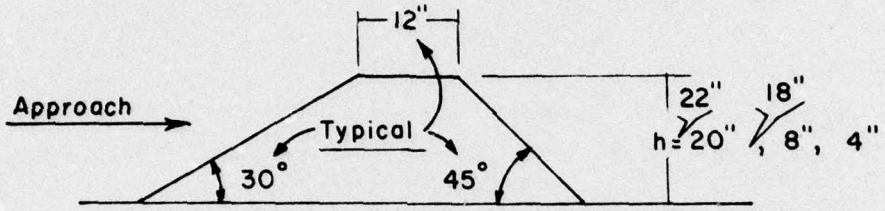


Figure VI-6

Various levels of compaction will be given each one-third of each size of obstacle during construction so that the strength influence can be determined. The 8-inch deformable obstacle is identical in shape to its nondeformable counterpart to further die the data together.

Maximum negotiable obstacle size will be a function of not only size but strength. Therefore, the 20-inch obstacle (with 3-1/2 inches interference with the M37 undercarriage) should produce an immobilization with at least one of its three strengths when operating at the expected maximum speed. Hopefully, the medium-strength will be the no-go condition. The latter is relatively certain and the former, being less certain, is hedged with the low-strength end.

III. DETERMINATIONS

A. Twenty-inch deformable obstacle

1. Determine the maximum negotiable obstacle size as a function of its strength and the vehicle's speed at impact.

2. Estimate the probably speed increase which can be sustained due to the modification of obstacle severity through deformation.

B. Eight-inch deformable obstacle

By comparison with the identical nondeforming obstacle, approximate the influence of deformation on speed of vehicle traverse.

C. Four-inch and eight-inch deformable obstacles considered together

1. Determine the influence of obstacle strength expressed by a modified roughness index (R^1)

$$R^1 = f\left(\frac{A}{p} \cdot \frac{CI_m}{CI_a}\right)$$

where R^1 = Modified roughness index, dimensions
A = Maximum vertical amplitude, ft.
p = Distance-based period, ft.
CI_m = Maximum soil strength required for obstacle to be essentially nondeformable
CI_a = Actual obstacle strength, Cone Index

2. Determine the relationship between accelerations on deformable and nondeformable obstacles (at various constant speeds), and see if it can be reasonably well approximated mathematically.

IV. TEST SITE REQUIREMENTS

A suitable site will be located which incorporates the following requirements:

A. Nearly level

B. Firm soil: 0-6 Cone Index over 300

C. Course dimension 160.0 ft. by 232.0 ft. according to Figure VI-4.

D. An adjacent area must be available for borrow soil with which to construct the deformable obstacles.

E. Area must be accessible to heavy equipment used in course preparation.

F. Course must be graded and cleared of top 3 inches to clear the vegetation.

G. Obstacle Construction

1. A scraper will be used to move friable soil from borrow pit to test site.

2. Scraper will put down 4- to 6-inch lifts of soil for 20-inch obstacle.

3. A roller will be used to develop the desired obstacle strengths.
   a. The roller will make one pass over the high strength section after the first layer is put down.

   b. One pass over the high and medium strengths after the second layer.

   c. One pass over the high strength after the third layer.

   d. One pass over the high and medium strengths after the fourth layer.

4. Repeat steps 2 and 3 for the 4- and 8-inch obstacles, only use 2.5- and 1.5-inch layers, respectively.

5. Obstacle centerline to be staggered 11 feet to facilitate maneuvering of the heavy equipment.

6. The grader will then shape the obstacles as illustrated in the previous text.

MEASUREMENTS REQUIRED

A. Field Measurements

1. Cone Index on the obstacle before the test

2. Cone Index in ruts on the obstacle after the test

3. Sheargraph on the obstacle before the test

4. Sheargraph in the tracks on the ground after the test (Rubber to Soil, and Soil to Soil in both cases).

5. Elapsed time for 50 feet

6. Deformation of the obstacle in places where the vehicle comes in contact with the obstacle.

B. Recorded on Magnetic Tape and Oscillograph

1. Torque
2. Vertical acceleration at the axle
3. Vertical acceleration at the driver's seat
4. Longitudinal acceleration at the axle
5. Longitudinal acceleration at the driver's seat
6. Drive line revolutions

NOTE: No pushbar measurements will be taken because the pushbar is 26 inches above the ground.

I. CONDUCT OF TESTS

A. Pre-Test

1. Determine the average obstacle height for each test with a transit and rod.

2. Eight 4- to 6-foot stakes will be set to define the approach lane and the portion of the obstacle which is to be included in the test.

3. Lay out two tapes on the ground 50 feet apart so one man can measure elapsed time during the approach (at constant speed) to the obstacle.

4. Take Cone Index profiles in 1-inch increments for the first 6 inches and in 3-inch increments thereafter, of the obstacle every foot along the centerline of that portion of the obstacle used for the test.

5. Take Sheargraph records of ultimate soil to soil and soil to rubber shear failures on the side of the obstacle. Make one composite graph for each test.

6. The driver will be instructed to drive at a speed selected as optimum from the single nondeforming vertical obstacle study.

B. Test

1. The driver will accelerate for 80 feet, at which time he should hold a constant speed until the front wheels have crossed the obstacle.

2. As the front wheels travel over the first tape, the stopwatch will be started by an observer. It will be stopped when the front wheels pass over the second tape.

3. Instrumentation will record:
   a. Drive line torque
   b. Drive line revolutions
   c. Vertical acceleration at the driver's seat and the front axle
   d. Longitudinal acceleration at the driver's seat and front axle
   e. Time base

C. Post Test

1. Conduct a Cone Index survey, taking two profiles in each rut and two between the ruts.

2. Take Sheargraph measurements as stated in the pre-test, only take the measurements in the tracks of the vehicles on the ground and on the top of the obstacle.

3. The height of the deformed obstacle will be measured in places where the vehicle frame comes in contact with the obstacle and in the wheel patch after deformation has taken place.

D. Personnel Requirements

1. Field Test
   a. Engineer
      (1) Site preparation
      (2) Driver instruction
      (3) Test notes
   b. Technician (2)
      (1) Soils data
      (2) Time
   c. Engineer or Technician - Instrumentation
   d. Driver
      (1) Drive
      (2) Help with site preparation

2. Data Analysis
   a. Engineer-in-charge
   b. Engineer
   c. Engineers or Technicians - 2

VII. DATA FORMS

A. Use the same as used for single, nondeforming vertical obstacles.

B. Include on the Field Data Form, in addition to above:

1. Deformation (inches) due to
   a. Left Track
   b. Right Track
   c. Frame

VIII. ANALYSIS PROCEDURE

A. Use the same as used for single, nondeforming vertical obstacles.

TABLE VI-7 - VERTICAL OBSTACLE TESTS

SINGLE DEFORMABLE

SUMMARY OF DATA AND TEST RESULTS

M37, 3/4-TON TRUCK

Test No.	Obstacle Height (In.)	Driver Reaction	Speed (MPH)	Average Torque (Ft.-Lbs.)	Tractive Effort (lbs.)	Vertical Seat Acceleration		Average Cone Index Of Obstacle	Seat Jerk		Vertical Acceleration				Initial Acceleration (G's)	Horizontal Acceleration				Initial Acceleration (G's)
						Obstacle Height	Vehicle X Velocity		Vertical	Horizontal	Seat Maximum (G's)	Seat Frequency (Cycles/Sec.)	Axle Maximum (G's)	Axle Frequency (Cycles/Sec.)		Seat Maximum (G's)	Seat Frequency (Cycles/Sec.)	Axle Maximum (G's)	Axle Frequency (Cycles/Sec.)	
1	4	2	10.0	100	414	.23		340	22.0	9.4	1.10	3.6	6.40	6.2	6.40	0.70	2.9	2.90	5.90	5.30
2	4	2	9.8	85	352	.16		244	15.0	5.2	0.75	4.2	4.80	5.3	4.80	0.42	2.9	1.80	5.90	0.95
3	4	1	11.7	60	248	.10		54	18.4	5.4	0.55	6.7	4.40	5.6	4.20	0.30	4.8	1.55	8.30	1.05
4	4	1	11.4	80	331	.11		54	20.0	4.6	0.60	7.7	3.70	6.1	3.70	0.35	4.5	1.60	7.70	0.55
5	8	4	10.3	65	269	.23		474	25.6	20.0	2.30	2.0	8.90	11.1	8.90	1.00	5.5	3.20	14.30	1.80
6	8	4	11.0	100	414	.22		474	28.2	10.0	2.40	2.0	9.00	11.2	9.00	0.70	5.9	2.40	8.30	1.70
7	8	4	11.4	90	373	.16		209	18.4	12.6	1.75	1.9	9.80	9.1	5.80	0.75	5.0	2.75	16.70	1.85
8	8	2	10.7	110	455	.10+		102	20.0	20.0	1.10	2.4	8.30	4.8	8.30	0.70	5.6	2.35	16.70	1.95
9	20	S-	12.6	100	414	.25/.21		129	38.5/46.4	41.4	7.7/6.5	5.0/2.2	9.20	8.3	3.70	1.45	3.2	8.90	14.30	3.40
10	20	1	3.1	60	248	.09		129	4.6	4.2	0.70	1.7	2.40	5.9	0.80	0.50	2.4	1.40	11.10	0.85
11	20	2	3.2	70	290	.19		200	18.8	11.6	1.50	4.5	6.70	7.7	0.80	0.75	4.8	2.70	12.50	0.50
12	20	2	3.1	80	331	.18		200	17.6	12.4	1.50	4.2	7.30	8.3	1.30	0.80	4.5	2.00	8.70	0.60
13	20	2	3.2	60	248	.22		367	21.2	13.0	1.70	3.8	6.30	8.3	1.30	0.85	5.6	2.00	7.10	0.45
14	20	1	1.0	40	324	.22		367	4.0	1.4	0.55	1.7	1.50	8.3	0.50	0.35	0.9	0.85	0.65	0.30
15	4	-	0.7	100	811	.30		---	1.4	0.4	0.10	3.3	0.30	9.1	0.10	0.15	0.9	0.30	0.60	0.30
16	4	-	0.7	100	811	.30		---	1.0	0.4	0.10	2.5	0.40	9.1	0.20	0.15	0.9	0.40	0.70	0.40
17	4	-	1.0	140	1135	.41		---	2.0	0.8	0.20	1.9	0.50	6.7	0.50	0.25	0.8	0.50	0.90	0.50
1R	18	0	1.0	85	690	.43		498	11.9	2.3	0.95	2.4	1.20	10.0	0.40	0.48	1.2	1.25	1.80	0.50
2R	20	0	1.0	80	648	.41		460	13.3	3.4	1.00	1.7	1.15	5.5	0.05	0.50	1.7	0.95	16.70	0.14
3R	22	1	3.0	70	568	.21		404	21.3	4.8	1.70	4.3	2.80	8.3	0.80	0.67	1.8	2.30	12.50	0.30
M29C, WEASEL																				
28	8	4.5	8.1	75	570	---		---	60.0	10.5	4.50	2.1	----	---	----	1.00	1.1	----	-----	----
29	8	4.5	9.5	60	456	---		---	55.3	7.1	4.00	2.2	----	---	----	1.03	1.1	----	-----	----

TABLE VI-8

VERTICAL OBSTACLES SOILS DATA

Test No.	Date	CI - OBSTACLE Before Traffic * SFC	1"	2"	3"	4"	5"	6"	12"	18"	CI - OBSTACLE After Traffic # SFC	1"	2"	3"	4"	5"	6"	12"	18"	SHEARGRAPH - OBSTACLE FACE Soil c_u	ϕ_u	Soil to Infl. PSIG	Soil c_u	Soil ϕ_u	Rubber a_{ur}	Rubber ϕ_{ur}	Rubber to Infl. PSIG	Soil a_{ur}	Soil ϕ_{ur}
M37, 3/4 Ton Truck																													
4" Deformable	23 Sept.																												
1	64	167	330	333	367	500	700+	--	--	--	125	300	337	362	437	700+	--	--	--	0	31°	--	--	--	0	31°	--	--	--
2	"	151	193	263	325	700+	--	--	--	--	190	300	282	475	700+	--	--	--	--	0	31°	--	--	--	0	31°	--	--	--
3	"	8	27	47	143	700+	--	--	--	--	100	175	290	700+	--	--	--	--	--	0	34°	--	--	--	0	33°	--	--	--
4	"	7	20	30	150	700+	--	--	--	--	150	260	370	700+	--	--	--	--	--	0	33°	--	--	--	0	36°	--	--	--
8" Deformable	24 Sept.																												
5	64	533	700+	--	--	--	--	--	--	--	460	700+	--	--	--	--	--	--	--	0	30°	--	--	--	0	28°	--	--	--
6	"	415	700+	--	--	--	--	--	--	--	442	675+	--	--	--	--	--	--	--	0	37°	--	--	--	0	37°	--	--	--
7	"	145	187	205	210	242	267	700+	--	--	202	425	397	400	420	410	700+	--	--	0	32°	--	--	--	0	34°	--	--	--
8	"	82	137	123	100	87	83	700+	--	--	45	120	230	290	350	700+	--	--	--	0	32°	--	--	--	0	34°	--	--	--
20" Deformable	24 Sept.																												
9 & 10	64	97	167	140	113	113	113	103	170	147	100	190	195	200	180	180	215	175	700+	0	36°	--	--	--	0	33°	--	--	--
11	"	87	163	187	207	193	193	190	363	700+	210	330	340	335	290	285	255	350	700+	0	32°	--	--	--	0	32°	--	--	--
12	"	77	103	133	183	213	257	210	397	700+	160	270	310	290	265	260	245	300	525+	0	32°	--	--	--	0	32°	--	--	--
13	"	237	317	370	423	383	387	413	403	700+	270	440	420	470	415	405	390	400	575+	0	28°	--	--	--	0	36°	--	--	--
Non Deformable Test Numbers 1 Thru 25	The Approaches for the Deformable and Non-Deformable Obstacles all had a Surface CI of 300+ and a 1" CI of 700+.																			0	41°				0	38°			
																				0	42°				0	39°			
																				0	39°	Average = 40.5°			0	38°	Average = 38°		
																				0	40°				0	37°			
Weasel Approaches for Deformable and Non-Deformable Obstacles	6 Oct. 64	180	290	345	385	450	475	425	125	--	--	--	--	--	--	--	--	--	--	0	46°	--	--	--	0	36°	--	--	--
8" Deformable	6 Oct.																												
28	64	60	80	120	80	40	20	200	500+	--	20	20	20	20	20	150	300+	--	--	--	--	--	--	--	--	--	--	--	--
29	"	20	50	40	30	20	20	300+	600+	--	20	20	20	20	20	100	300+	--	--	0.5	54°	5.6	6.4	28°	2.3	34.5°	7.0	4.8	18°
M37, 3/4 Ton Truck	9 Oct.																												
1-R Deformable 18"	64	270	450	500	515	520	580	650	< 12"-700+	--	320	475	510	530	530	600	680	<12"-700+	--	0	38°	--	--	--	0	41°	--	--	--
2-R Deformable 20"	"	355	460	450	475	465	445	570	< 12"-700+	--	380	470	440	480	470	440	600	<12"-700+	--	0	38°	--	--	--	0	41°	--	--	--
3-R Deformable 22"	"	390	445	370	340	395	460	425	< 12"-700+	--	430	450	375	310	360	425	400	<12"-700+	--	0	38°	--	--	--	0	41°	--	--	--

* Data is average of 3 Cone Penetrometer Readings with 0.2 sq. in. cone.

\# Data is average of Cone Penetrometer Readings taken in left and right wheel track at high point of obstacle (compaction accounts for readings fewer than original obstacle height).

NOTE: Some rutting and deformation of obstacles occurred. See original data file.