U. S. ARMY
TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

TRECOM TECHNICAL REPORT 64-19

INVESTIGATION OF TERRAIN ROUGHNESS

Task 1D021701A04902
(Formerly Task 9R97-01-005-02)
Contract DA 44-177-TC-846

May 1964

prepared by:

MIDWEST RESEARCH INSTITUTE
Kansas City, Missouri

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U S ARMY TRANSPORTATION RESEARCH COMMAND
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The U. S. Army Transportation Research Command concludes that terrain roughness data can be adequately determined by the profilometer system described in this report. These data can be utilized to design various types of military equipment with improved operational capabilities.

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Final Report

Prepared by
Midwest Research Institute
Kansas City, Missouri

for

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FORT EUSTIS, VIRGINIA

PREFACE

This report was prepared jointly by Mr. Frank Turner, Project Engineer, and Mr. A. J. Bossert of the Midwest Research Institute, Kansas City, Missouri. Mr. Bossert contributed the electronic design and wrote the computer program used. Mr. Lee Robertson assisted with the modification of the profilometer equipment.

Mr. C. J. Roma has been the technical monitor for the U. S. Army Transportation Research Command (USATRECOM), Fort Eustis, Virginia.

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INTRODUCTION

The purposes of the terrain roughness investigation were to provide field operation capabilities to the existing terrain profilometer system, to prove these capabilities under extreme terrain conditions, to develop and test a computer program to reduce terrain data to a continuous profile, and to obtain profiles of various representative typies of desert terrain. Operational environment included surveying up to 60-per cent grades and 30-per cent side slopes. The required accuracy of the profile readings over a 10-foot displacement is approximately 1/2 inch.

The principle of operation of the terrain profilometer is somewhat analogous to the rod and level used in conventional surveying methods. The light-source tube, mounted on the jeep, replaces the engineer's level by projecting a collimated beam of light over the surface to be surveyed (see Figure 1). This light beam is adjusted to level, as indicated by a standard surveyor's spirit level, to establish the required reference from which measurements can be made (see Figure 2). The terrain sensor (the measuring instrument which replaces the rod) is towed over the survey path and senses the vertical position of the light beam. The distance between the surface being surveyed and the centerline of the light beam is measured every 6 inches of travel and recorded in digital form on punched paper tape.

These objectives were accomplished in a four-phase program which included the design of specialized auxiliary equipment, preliminary field tests and field operations in the vicinity of the Yuma Proving Ground, analysis of the resulting data on digital computers, and post operational modification. Each phase is discussed separately.

Figure 1. Terrain Profilometer System

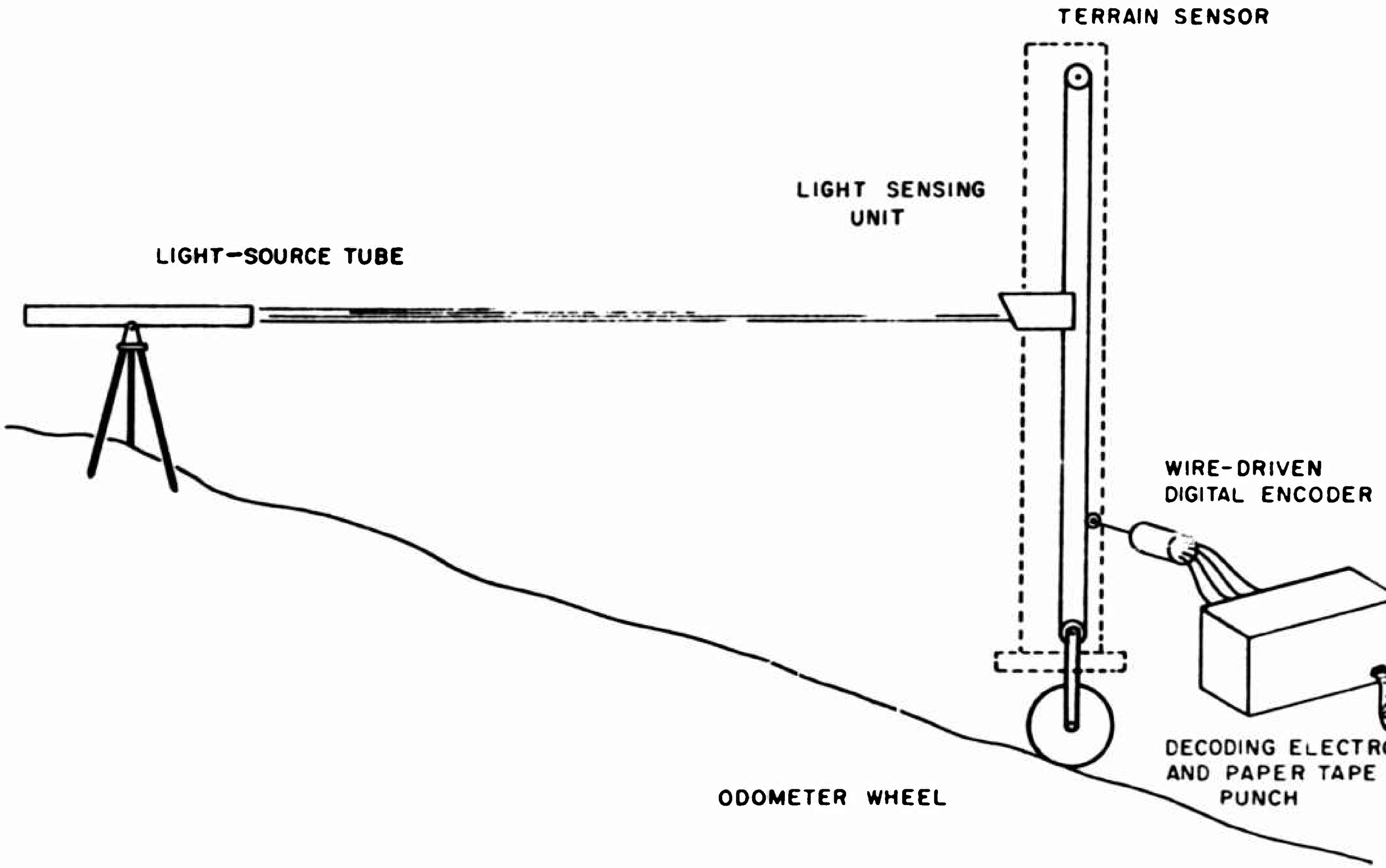

Figure 2. Schematic Drawing Showing Terrain Profilometer Operation

REDESIGN, MODIFICATION, AND REPAIR - PHASE I

Initial consideration of the general operational requirements of the terrain profilometer system led to the design of a special trailer to support the profile sensor (see Figure 3). The trailer-mounted design permitted positioning the odometer wheel between the weight-carrying wheels to reduce the possibility of exceeding its vertical travel while in rough terrain. A trailer-mounted system further permits greater flexibility in the selection of a (towing) vehicle.

Photographs of Yuma terrain were studied to determine the dynamic loads which could be expected during the survey. A consideration of areas containing fairly large exposed rocks led to the adoption of the low-pressure Goodyear "Terra-Tire." Each tire carries a load of 500 pounds with 4-6 psi pressure. The resulting isolation of the sensor frame aided materially in maintaining the desired vertical attitude and in reducing the difficulty of keeping the light beam centered on the sensing head.

To attain satisfactory accuracy on fairly steep slopes it was necessary to make terrain measurements with the sensor housing in a vertical position rather than perpendicular to the slope. The sensor housing was mounted in a gimbal to permit attitude control in both yaw (side to side) and pitch (fore and aft) (see Figure 4). The hydraulic cylinders which control the attitude of the sensor housing are operated from a control station mounted on the towing vehicle (see Figure 5). The operator actuates the hydraulic valves through direct-acting control linkages. Vertical attitude was indicated by a damped, two-plane bubble level mounted on the vertical surface of the sensor housing facing the operator. The bubble level consisted of a shallow glass dome partially filled with colored silicone oil (see Figure 6).

The relay servo incorporated in the original profilometer was replaced with a proportional servo. An error signal applied to the original relay servo applied full current to the servo motor. The design depended on drag within the system to prevent overrun of the correct position. Faulty adjustment reduces the size of the "no-error" zone and can permit a rapid oscillation back and forth across the beam. The resulting high dynamic loads caused early failure of the gear reducer. The new proportional system is much less critical in adjustment. Maintenance of the proportional servo is well within the capabilities of experienced electronics technicians.

Figure 3. Desert Survey Operation

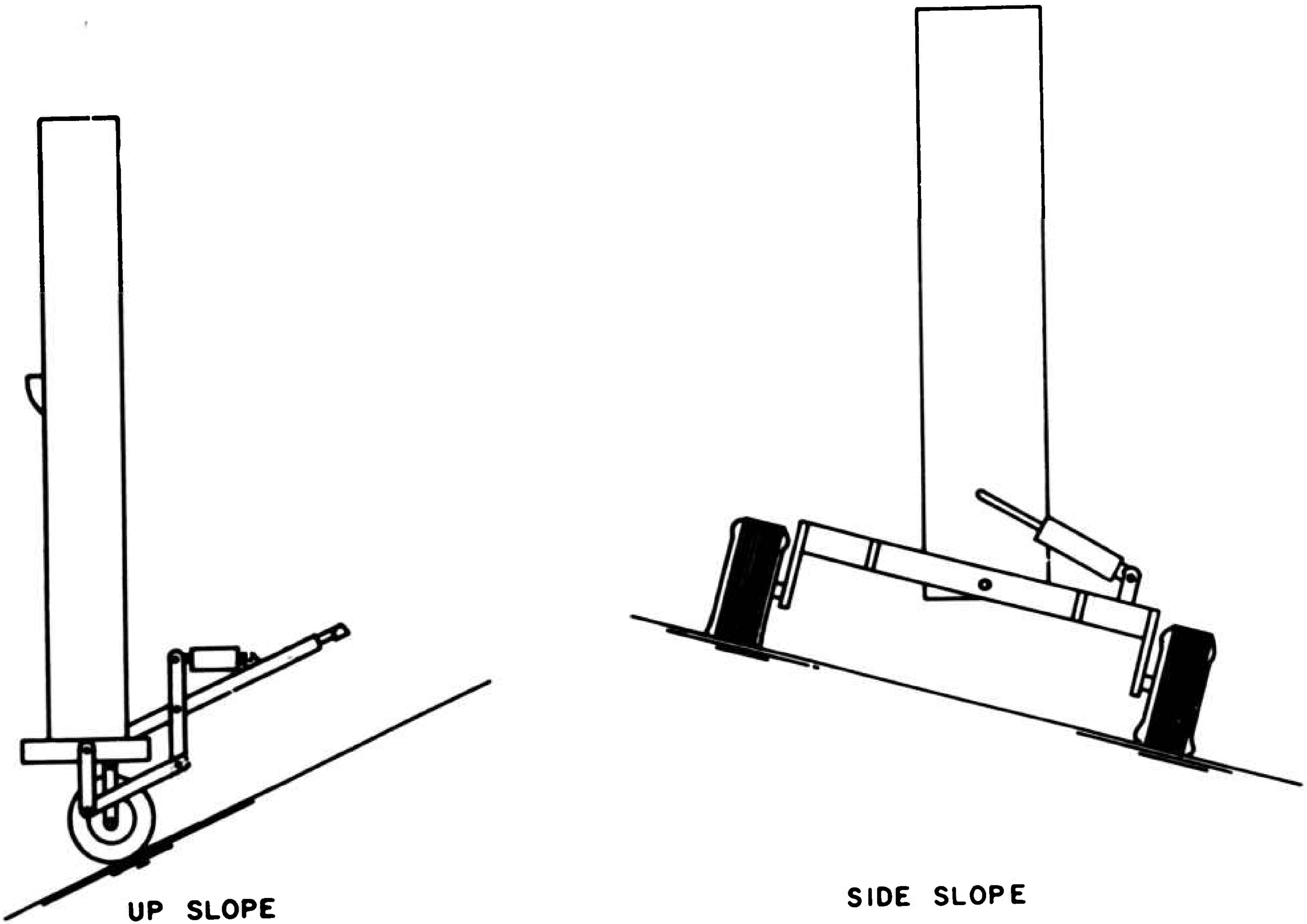

Figure 4. Attitude Control

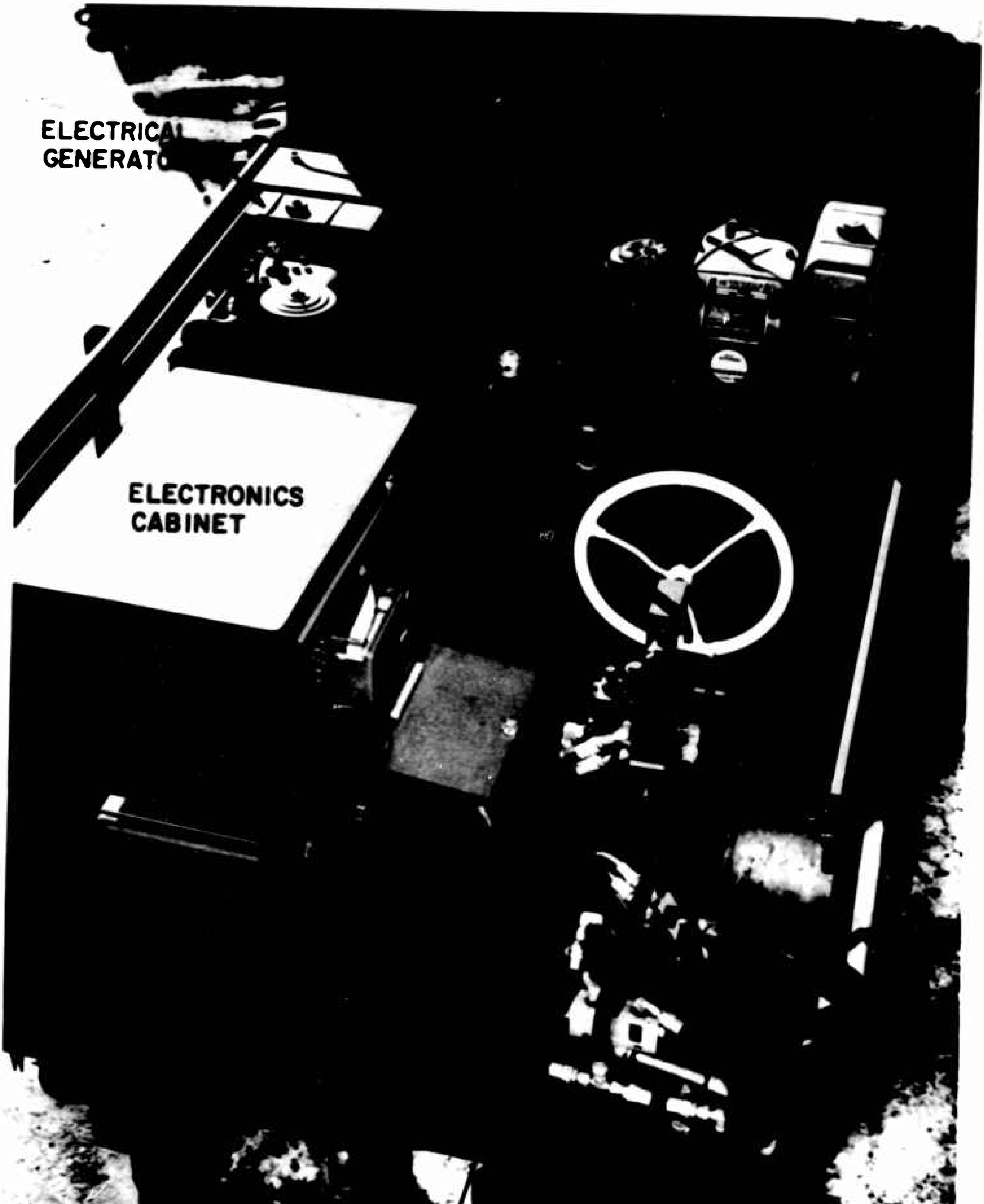

Figure 5. Equipment Mounted on Towing Vehicle

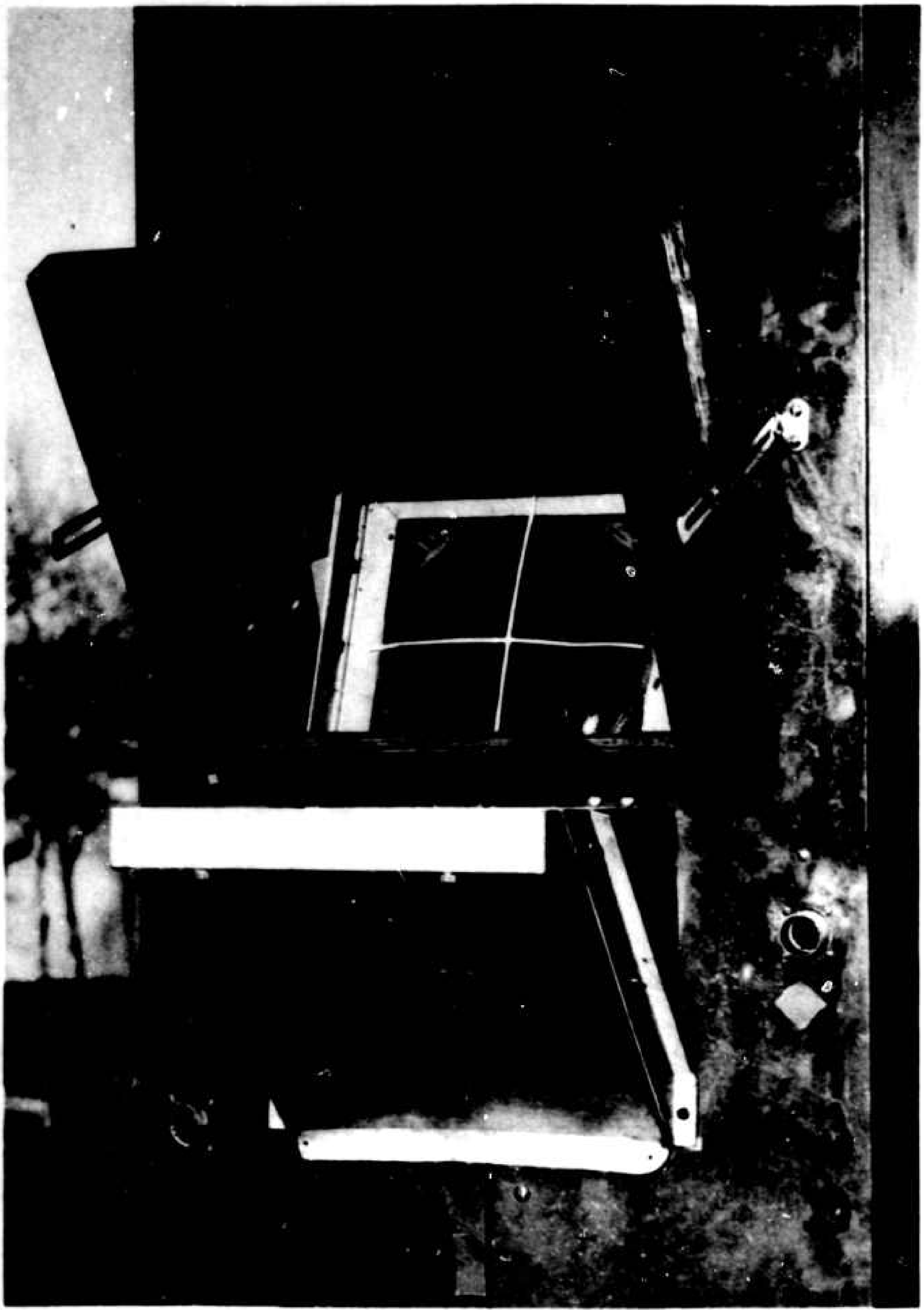

Figure 6. Attitude Indicator

Several features were incorporated into the profilometer system to increase the safety, reliability, and operating convenience. The light-projector system was made more mobile by mounting the electrical power supply on a jeep and by providing high and low adjustable mounting points for the light tube (see Figure 7). A retractable hitch stand was provided to permit easy removal of the towing vehicle. Adequate clearance for storage of the tall sensor housing has presented a problem in the past. Special wheels were mounted to the trailer frame which permit the unit to be rotated to a horizontal position for ease of maintenance and handling in storage (see Figure 8). A foot-operated locking valve, which must be held open to allow flow to the reservoir, was included in the hydraulic circuit. This safety device prevents accidental motion of the sensor housing in the event that the hydraulic control column is inadvertently operated. Two clamping block assemblies are provided to lock the housing in position and to permit safe removal of the hydraulic lines and cylinders.

Operational tests were conducted at the Midwest Research Institute (MRI) field station for a period of 30 days before the equipment was shipped to Yuma. These tests provided operational experience for the crew and an opportunity to alter the pitch control components to eliminate undesirable deflection. The accuracy of the entire system was tested by repeatedly surveying a four-sided course which started and stopped at the same point. The differences in elevation at each relocation of the light source were determined by manual reading from the paper tape and from the total accumulated error determined for the run. Even under poor test conditions, which included mud and a partial snow cover, the closing error did not exceed 1 foot.

Figure 7. Light-Projector System

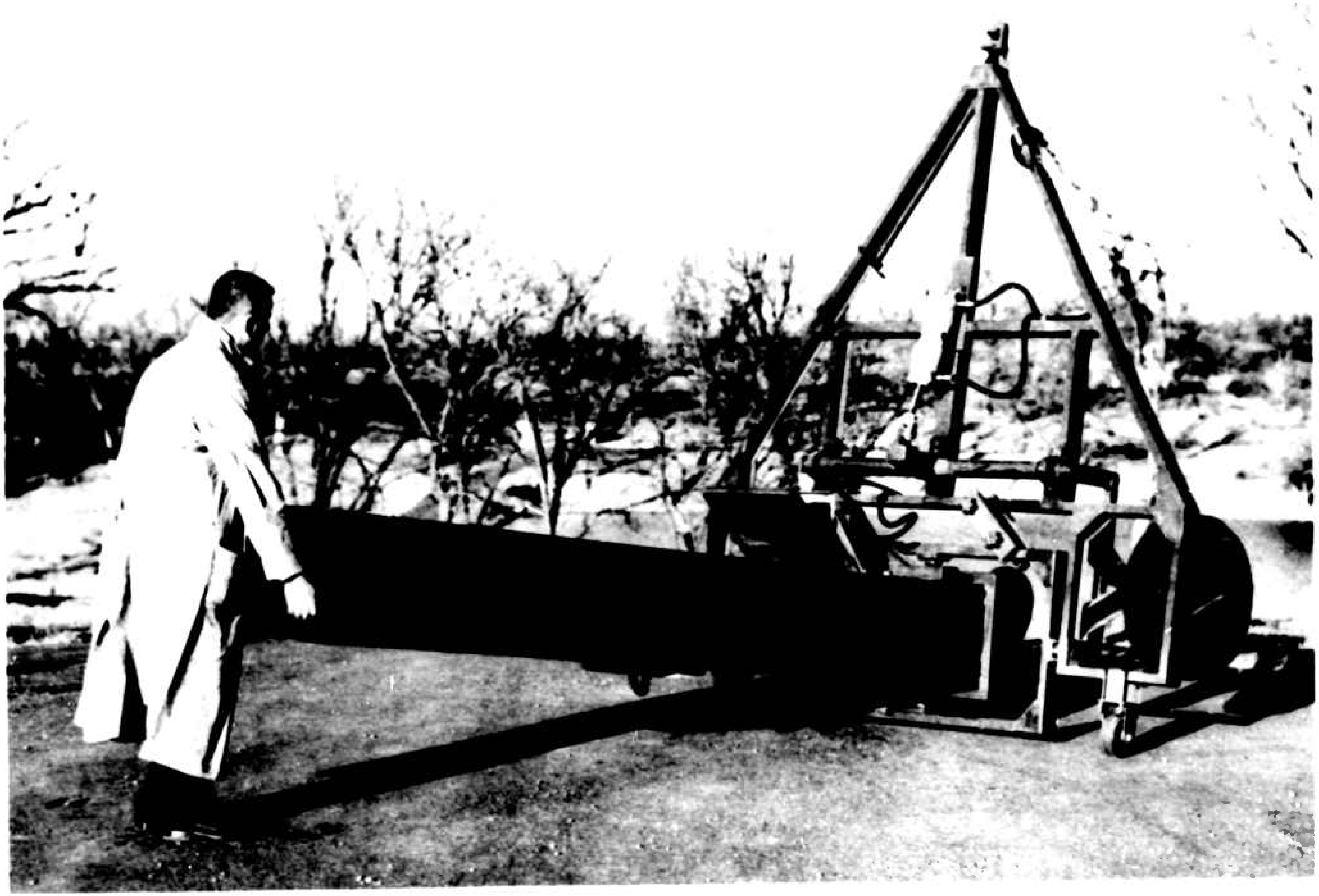

Figure 8. Horizontal Storage Position

COMPUTER PROGRAM - PHASE II

Data obtained by the profilometer are punched on eight-channel paper tape (see Figure 9). A reading of the height of the beam sensor head above the surface is taken every time the odometer wheel is rotated the equivalent of 6 inches of forward travel. The readings, which range within the arbitrarily chosen limits of 50 to 196 inches, are recorded as two digits on the tape. If the reading is greater than 99, a special punch is recorded on the most significant of the two digits. There are no spaces or other marks separating the recorded readings.

The purpose of the computer program is to convert the two-digit data obtained by the profilometer to four-digit data referenced to the first reading taken in the survey. This process is termed normalizing. The program must also analyze each reading to determine its validity and to make logical corrections where necessary. A complete listing of the validity checks and data correction instructions is given in the technical maintenance manual furnished with the equipment.

The first reading of each survey is arbitrarily set equal to 5,000 inches, and subsequent readings vary from this reference elevation through all of the data processed.

A survey of a terrain area is made up of many short runs of from 300 to 600 feet. Each run is terminated by an end line punch in the tape which produces a record mark in the computer storage. The computer interprets a record mark as a signal that the first reading to follow must be made equal to the reading preceding the record mark. In this way the steps in the data caused by relocation of the light source are removed and a continuous profile is obtained.

Each datum point is examined as it is read into the computer to ensure a logical relationship to preceding data. Tests are performed within the computer to differentiate between setups and several types of possible errors which can result from momentary interruption of the electrical power. A special connection panel has been provided for a tape-to-card converter which permits the computer to accept invalid or erroneous punches without interruption of the operation. The bad datum point is recognized and replaced with a zero reading which records for later analysis the extent of the difficulty. Any malfunction can be monitored in this way and remedial action taken if required.

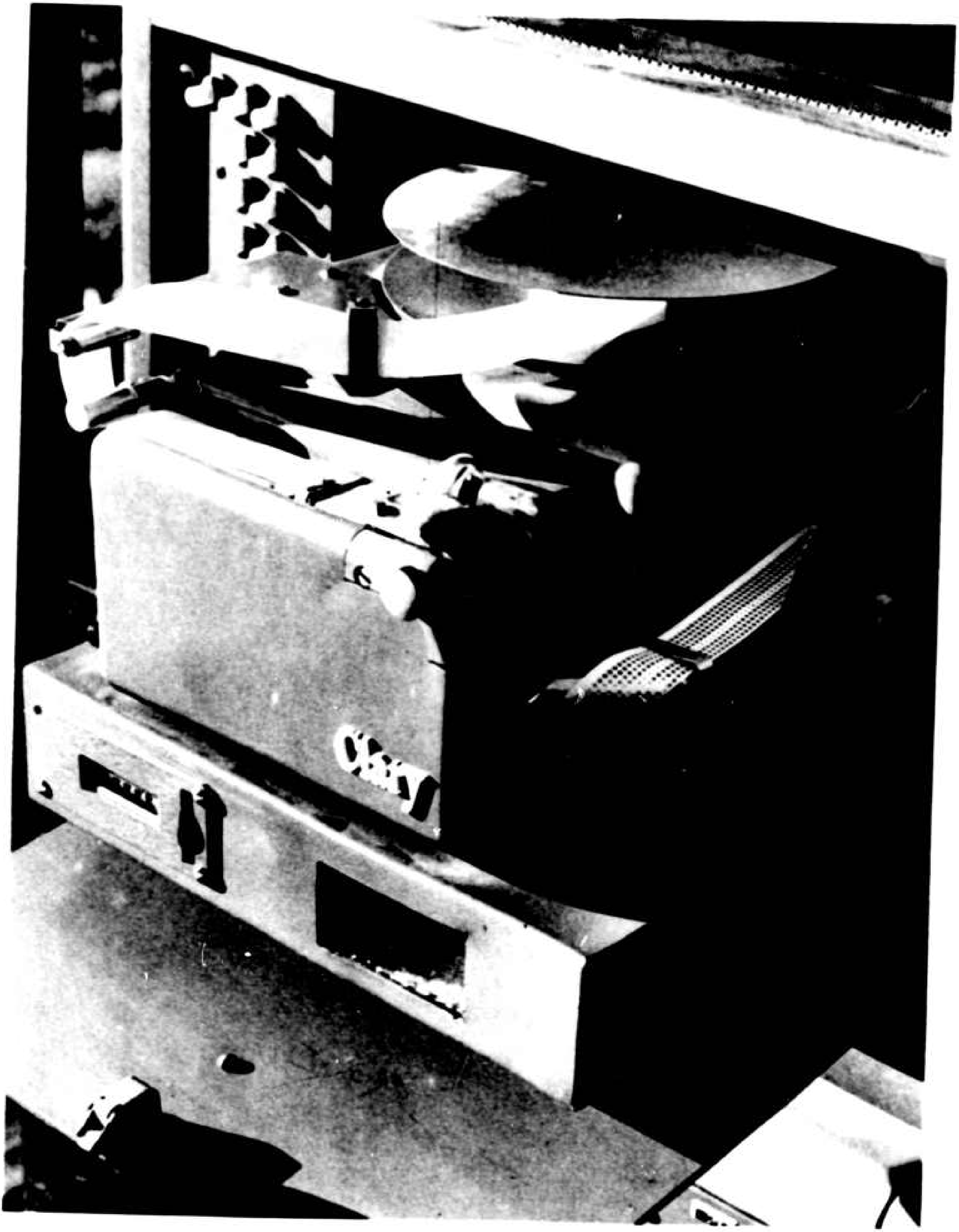

Figure 9. Profile Data Punched in Paper Tape

It is convenient to do some analysis of the data in the course of the normalizing process. A detailed example of these processes is given as Appendix II of this report.

YUMA SURVEY OPERATIONS - PHASE III

The terrain profilometer system was shipped to the Yuma Proving Ground to obtain typical profiles in the areas of test operation of the Overland Train. Specific test courses for the Overland Train Evaluation had been selected and marked by the U. S. Army Engineer Waterways Experiment Station. Aerial imagery, topographic maps, and terrain factor data of these areas are presented in Technical Report No. 3-588. A study of the various courses prior to initiation of survey operations led to the selection of course 2, because of its proximity to the station facilities and access roads and because of the wide range of terrain types included within its boundaries. The western end of course 1 offered the typical desert paving with steep-sided washes not found on course 2. Test courses 3, 4, 5, 6, and 12 were studied and found to exhibit no significant differences from courses 1 and 2. The one exception was the southern ends of courses 3, 4, and 5. The area south of the boundary-line road was deemed impassable to the Overland Train due to the crested or peaked hill tops and deep intervening gullies. The areas surveyed are shown in Figures 10, 11, 12, and 13.

The high reflectivity of some types of desert surfaces made it necessary to work out methods for nighttime operations. Techniques were also developed for selecting a suitable survey path through areas with relatively dense vegetation.

Examination of the data tapes produced during the initial surveys revealed numerous invalid characters. Further tests showed the cause of this difficulty to be a momentary interruption of electrical power caused by operation over rough ground. Since alteration of the survey equipment would require considerable loss in time, it was decided to alter the computer program and data handling methods to permit analysis of the existing data.

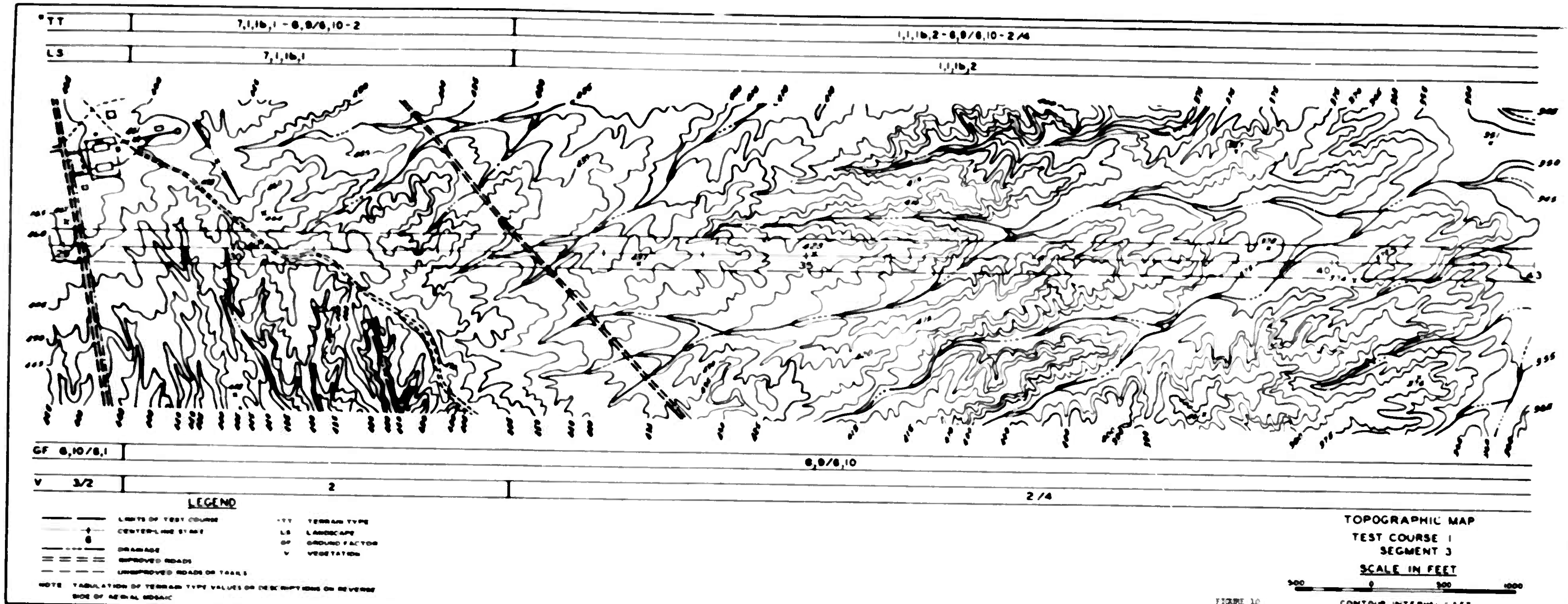

FIGURE 10

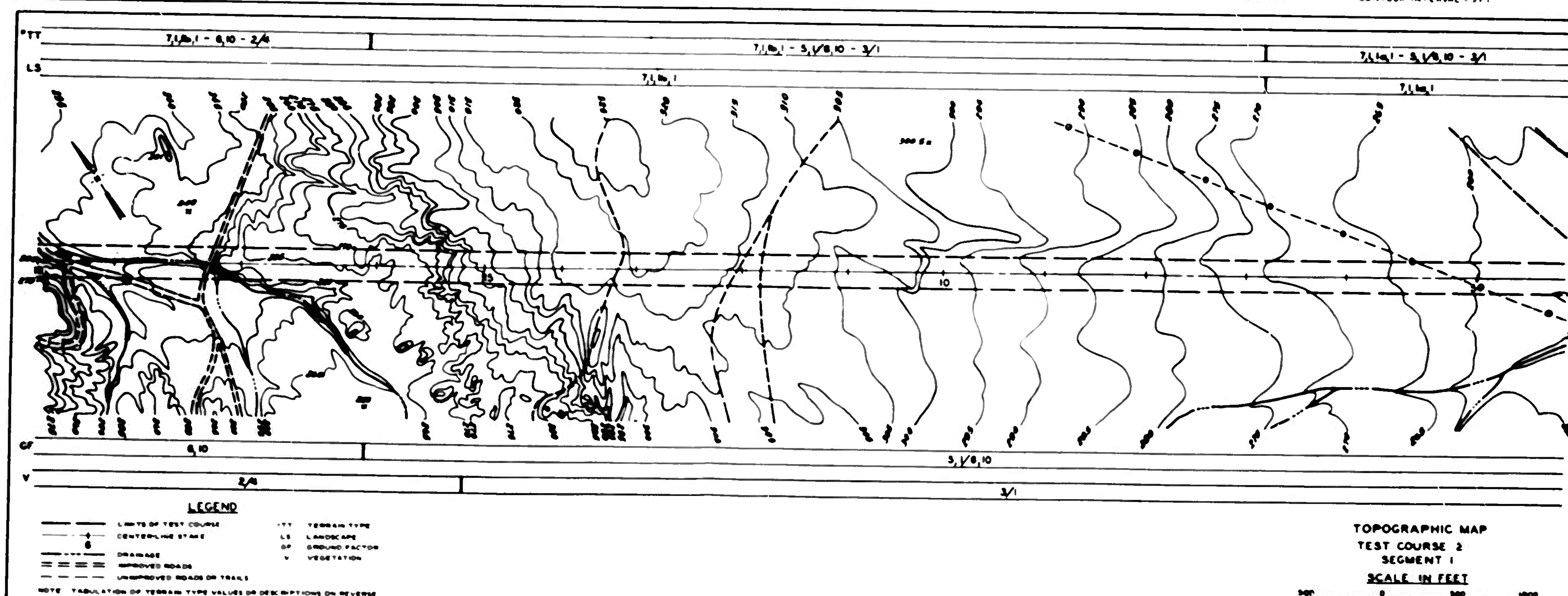

FIGURE 11

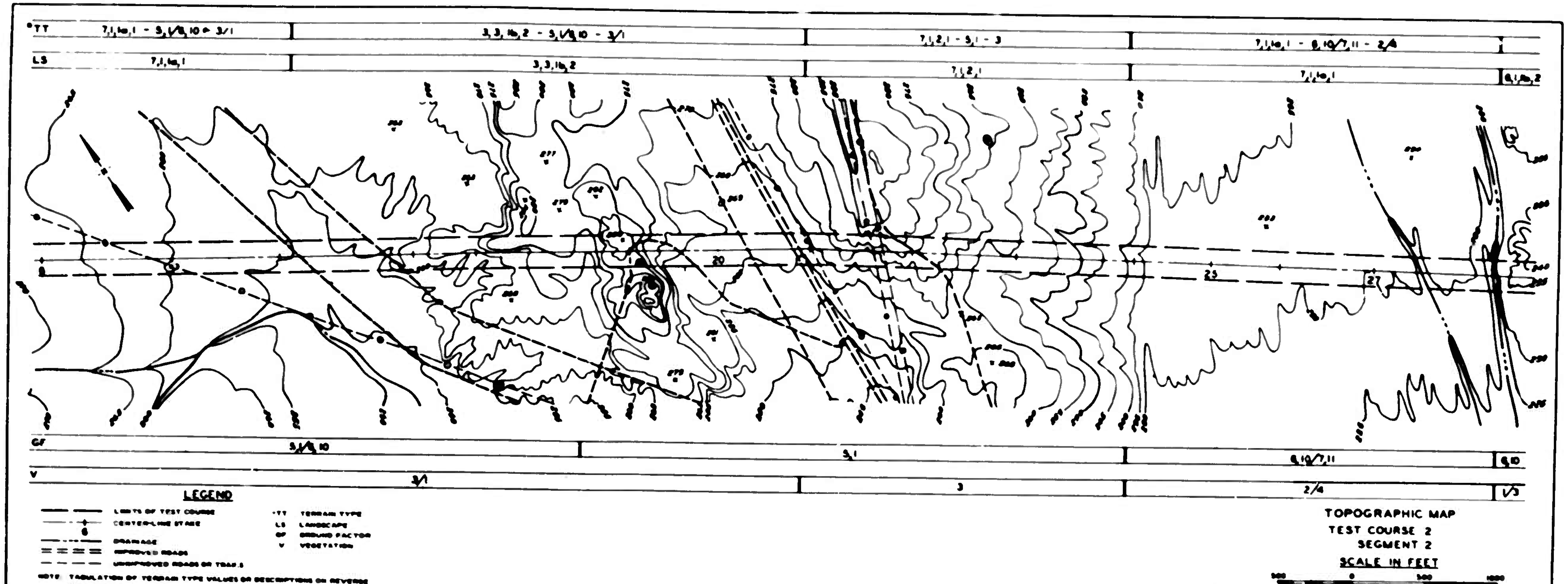

FIGURE 12

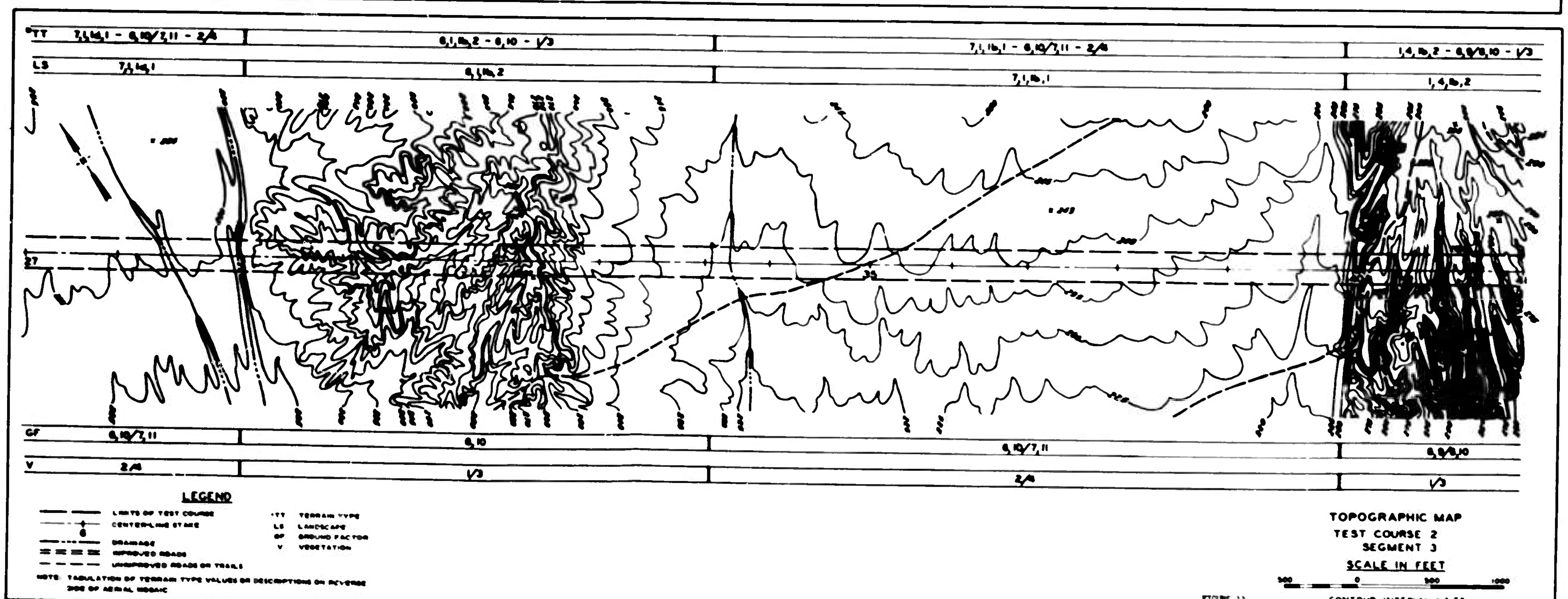

FIGURE 13

SURVEY RESULTS

The most valuable result of the survey is the basic elevation data measured at 6-inch intervals in a specific test course. Statistical analyses of terrain types have long been available, but a reconstruction of the minute obstacles from the analysis is a difficult task. Further, no normal proving ground is available which matches, in all respects, the reconstructed obstacles.

The method of data collection used for the survey stresses the point-to-point differences of distance and elevation. By this method, the cumulative error may become quite large although the point-to-point relationship is satisfactorily accurate. Correlation of the data with contour maps should be based on identifiable terrain features such as ridges and valleys rather than on absolute readings of distance or elevation.

Using just the basic elevation data in tabular form, it is impossible to interpret surface condition or to compare one section of terrain with another. An example of a relatively small portion of the data is used to illustrate methods of interpreting and analyzing surface features. The area indicated near the eastern end of course 2 has been chosen as a sample and plotted using two different horizontal scales (see Figure 14). Although the lower plot shows the geometrical shape of the profile, it represents only 25 feet of surface and does not contain much useful information. The upper plot with a condensed horizontal scale shows variation in roughness throughout the sample length. The profile data from which these plots are made are included as Appendix I. These plots serve to illustrate the basic disadvantages of an analog presentation. Although both plots show the surface condition, they fail to provide an index or value of roughness which would be of major interest in the evaluation of mobility.

A special analysis of the profile data has been added in an effort to quantitatively describe surface roughness. The results of this analysis, the sums of the first and second differences, are shown above two adjacent 50-foot sections of the sample profile. The sum of the first differences or total variation is found by adding the absolute value of the differences between successive elevation readings. The sum of the second differences, which could be called the total change in surface variation, is found by adding the absolute value of differences between successive first differences. This procedure is best explained in a sample calculation (see Appendix II).

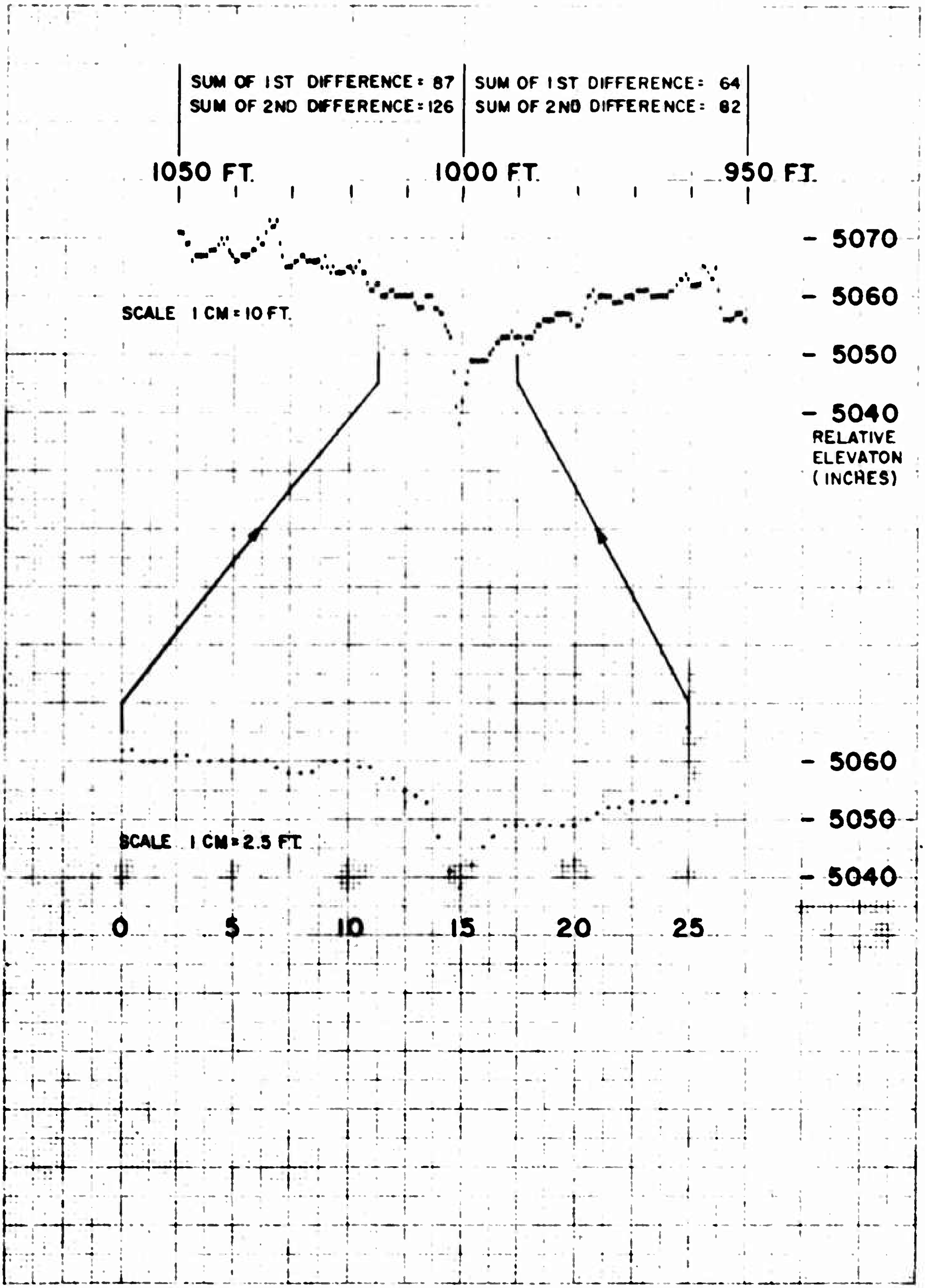

Figure 14. Sample Plot of Desert Terrain Located on Course 2, Segment 3 (See Figure. 13)

POST OPERATIONAL MODIFICATION - PHASE IV

The need for several minor changes in the terrain-measuring equipment was indicated during the field work at Yuma. These modifications were undertaken in an extension to the original contract.

The only equipment malfunction encountered during the field tests was the momentary interruption of the electrical power during operation over rough terrain. This power interruption to the digital circuitry caused invalid characters to be punched in the paper tape. A study of alternate power sources showed it to be impractical to operate the digital circuitry from the towing vehicle's electrical system. The alternate solution of replacing the existing motor generator with the spare Onan generator was then carried out. Subsequent operational tests under very rough field conditions proved the new generator set to be satisfactory.

The following equipment changes were made to increase the efficiency and ease of operation of the terrain-measuring system:

1. A battery-powered telephone set has been provided to permit the sensor operator to give verbal instructions to the operator of the towing vehicle.

2. A special cradle has been added to both the high and low light source mounting positions to prevent possible injury to the light source while moving to a new location (see Figure 7, p. 10).

3. A wider seat with a back support has been provided for the sensor operator. The seat folds forward to permit access to the hydraulic power supply engine (see Figure 15).

4. The possibility of damage and subsequent leaking of the existing hydraulic valves was eliminated by redesign of the pitch control travel limits.

5. A metering valve was inserted in the hydraulic circuit to permit adjustment of the rate of response of the attitude controls.

6. A wooden platform was added for the light-source operator to stand on.

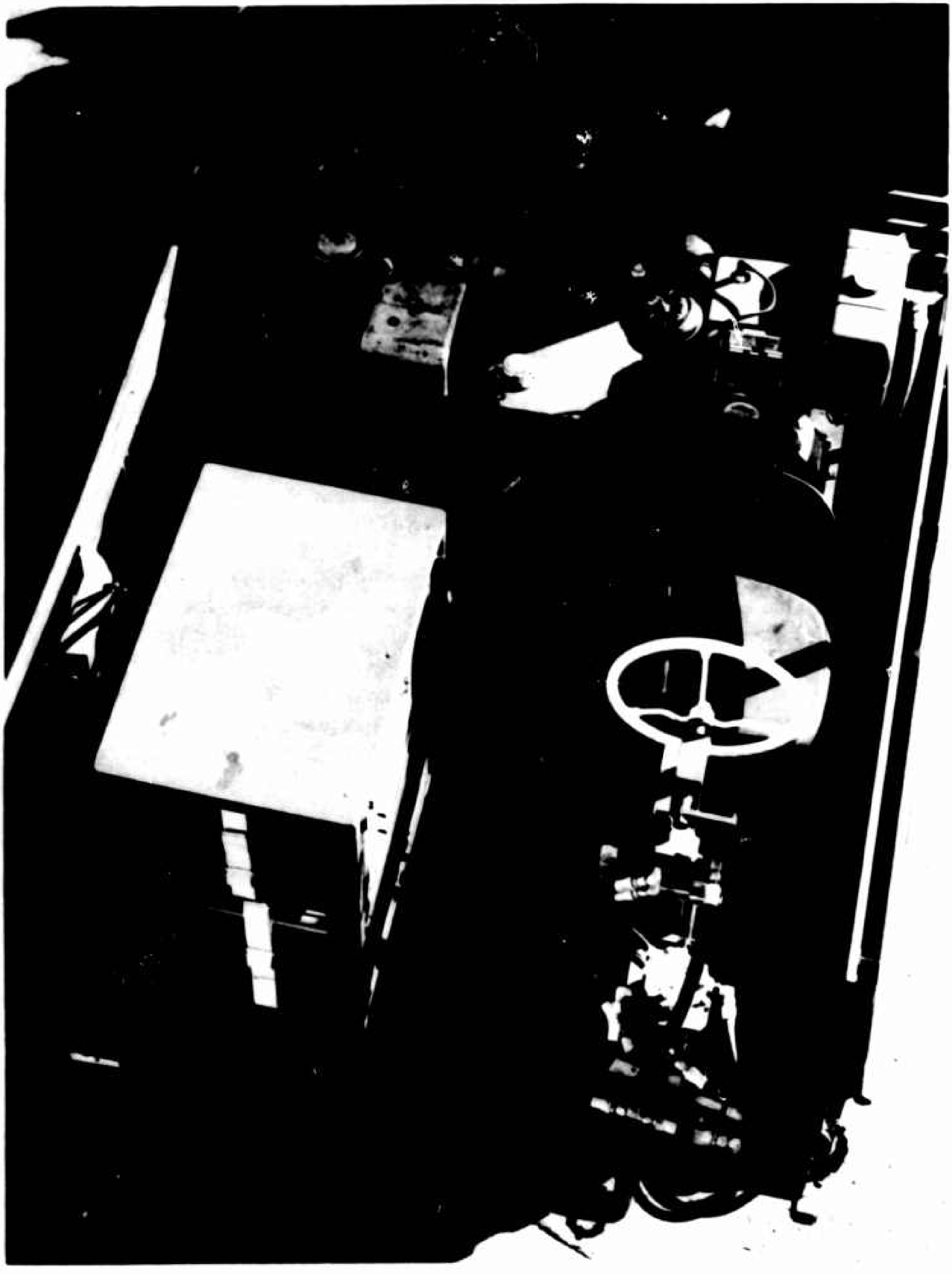

Figure 15. Modifications of Equipment Mounted on Towing Vehicle

7. Automotive-type jacks were added to both rear corners of the jeep to help stabilize the light source during the survey runs.

8. The bubble attitude indicator was redesigned to secure a more reliable seal.

A complete set of engineering drawings of the component parts was prepared. The operation and maintenance manual was enlarged to include a more detailed description of the terrain profilometer system as well as the changes made under Phase IV.

The acceptance tests were designed to assess the reliability of the equipment over extremely rough terrain. Of major importance in these tests were the reliability of the new electrical generator unit and the effectiveness of the new light-source mount over rough terrain. The desired terrain conditions were simulated by placing split logs along the track to be surveyed. The terrain profilometer system performed satisfactorily over these obstructions. It was necessary to exceed the allowable punching speed of 4 miles per hour to induce malfunctioning of the system.

PROFILE DATA SAMPLE

Profile Readings (inches)										Card Identity and Distance (ft.) From Start of Run
5056	5056	5057	5057	5057	5056	5056	5056	5056	5058	04900955
5061	5065	5063	5063	5064	5065	5065	5062	5062	5062	05000960
5062	5063	5064	5063	5063	5062	5061	5061	5060	5060	05000965
5060	5060	5060	5060	5060	5061	5061	5061	5061	5061	05000970
5060	5060	5060	5060	5059	5059	5059	5059	5060	5060	05000975
5060	5060	5060	5059	5061	5060	5060	5058	5056	5055	05100980
5055	5057	5056	5057	5057	5057	5057	5057	5056	5056	05100985
5056	5056	5055	5055	5054	5053	5053	5053	5052	5053	05100990
5053	5053	5054	5053	5053	5053	5053	5052	5052	5051	05100995
5050	5049	5049	5049	5049	5049	5049	5049	5047	5045	05201000
5042	5038	5041	5047	5053	5054	5055	5057	5057	5058	05201005
5058	5060	5060	5060	5058	5058	5058	5059	5060	5060	05201010
5060	5060	5060	5060	5060	5061	5061	5060	5060	5060	05201015
5062	5062	5061	5061	5062	5064	5064	5066	5065	5064	05301020
5065	5065	5064	5064	5064	5064	5065	5064	5065	5067	05301025
5065	5066	5066	5066	5066	5066	5067	5067	5066	5056	05301030
5065	5065	5065	5067	5069	5073	5072	5072	5073	5071	05301035
5069	5069	5070	5068	5068	5067	5067	5067	5067	5066	05401040
5066	5067	5068	5070	5069	5070	5069	5068	5068	5068	05401045
5067	5067	5067	5067	5067	5066	5069	5069	5071	5071	05401050
5071	5073	5073	5070	5069	5068	5068	5067	5067	5067	05401055

NOTE: The above data have been plotted in the upper portion of Figure 14. The large-scale plot in the lower portion of the figure corresponds to the data shown on the lines marked - 05100990 - 05201010.

APPENDIX II

SUPPLEMENTARY ANALYSIS

The following analysis, performed during the normalizing process, yields values which are indicative of both roughness and slope and therefore may be related to mobility.

EVERY 50 FEET

1. The sum of the absolute values of the first differences in the data (see example below).

2. The sum of the absolute values of the second differences in the data (see example below).

3. The number of feet from the start of the survey.

EVERY 500 FEET

1. A histogram of the differences between successive readings. (Successive numbers of the histogram indicate the total number of -8-inch, -7-inch, -6-inch, and so on to +8-inch changes of elevation within the 500-foot section.)

2. Number of feet from the start of the survey.

The above simple analysis is not mathematically related to any real property of the terrain surveyed; however, the second differences do serve as a valuable indicator of the relative roughness of each 50-foot section of the survey after the general slope of the terrain has been removed. This analysis portion of the program can be bypassed in the processing by proper use of computer switches.

EXAMPLE OF SUPPLEMENTARY ANALYSIS

	Profile Elevation	First Differences	Second Differences
	5057		
	5057	0	
950	5056	-1	1
	5056	0	1
	5057	+1	1
	5057	0	1
	5057	0	0
	5056	-1	1
	5056	0	1
	5056	0	0
	5056	0	0
	5058	+2	2
	5061	+3	1
	5065	+4	1
	5063	-2	2
	5063	0	2
	5065	+2	2
	5065	0	2
	5067	+2	2
	5067	0	2
	5067	0	0
960	5067	0	0
		Sum of First = 18	Sum of Second = 22