AHTD TRC TRANSPORTATION RESEARCH COMMITTEE

TRC8802

Pavement Management Surveillance Systems Evaluation

Mark Bradley

Final Report

1988

PAVEMENT MANAGEMENT SURVEILLANCE SYSTEMS EVALUATION

DEPARTMENT OF TRANSPORTATION
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FINAL REPORT

TRANSPORTATION RESEARCH PROJECT NO. TRC8802

NOVEMBER 1988

PREPARED BY
ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT
MATERIALS AND RESEARCH DIVISION
RESEARCH SECTION
IN COOPERATION WITH
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

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The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the Arkansas State Highway and Transportation Department or the Federal Highway Administration.

METRIC CONVERSION FACTORS

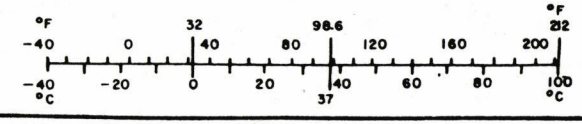
Approximate Conversions to Metric Measures

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

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

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



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16. Abstract The purpose of this study is to evaluate available pavement distress surveillance equipment and the result is the recommendation of a system of proven value to the Arkansas State Highway and Transportation Department.

The requirements of the system are that it be; (1) able to provide summary data for pavement management purposes; (2) able to provide data in such form that it is capable of multiple interpretations and uses; (3) economically adaptible to future innovations and state-of-the-art developments. Three equipment systems, ARAN, PASCO-RR, and Laser RST, were demonstrated and after evaluation were found to meet these requirements.

ARAN and Laser RST are the most automated providing all significant data except cracking and faulting objectively. PASCO-RR is the least automated providing only rut depth summaries and longitudinal profile with all other data involving considerable manual and subjective processes. Classification and quantification of cracking and detection of faulting is a visual subjective process in all systems. Cracking and faulting data is obtained by viewing images of the pavement surface, ARAN uses video and PASCO-RR uses 35mm pictures, while Laser RST uses a windshield survey. ARAN and Laser RST have maximum operating speeds in excess of 50 mph while PASCO-RR's maximum system speed is 12.5 mph.

ARAN is the most compatible with future developments. Laser RST would require the addition of some sort of image acquisition device. PASCO-RR is not compatible.

This study recommends that ARAN best meets the needs of the Arkansas State Highway and Transportation Department and would be economically compatible with image processing. It is recommended that the Arkansas State Highway and Transportation Department buy the ARAN system.

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EXECUTIVE SUMMARY

INTRODUCTION

The purpose of this study is to evaluate available pavement distress surveillance equipment and to recommend an equipment system of proven value to the Arkansas State Highway and Transportation Department.

The requirements of the equipment system are that it be:

1. able to provide summary data for pavement management purposes;

2. able to provide data in such form that it is capable of multiple interpretations and uses;

3. economically adaptable to future innovations and state of-the-art developments.

SYSTEMS EVALUATED

Three equipment systems were demonstrated and evaluated. These equipment systems are ARAN, PASCO-RR, and Laser RST.

ARAN

The ARAN equipment was provided by Highway Products International of Paris, Ontario, Canada. ARAN features automation of rut depth measurements, longitudinal grade, cross fall, transverse profile and radius of curvature. Video images are provided with very good resolution of the right-of-way and of the pavement's surface. The images of the pavement surface are of a quality that surface distress can be determined. The rating given to ARAN with respect to future development and purposes for which AHTD would need this equipment is very good.

PASCO-RR

PASCO-RR's equipment is made in Japan and provided by AVIAR Inc. of Austin, Texas. The PASCO equipment consists of four systems which are mounted in the same vehicle. However, with but one exception, they must be operated during separate passes. PASCO-RR70 uses 35mm continuous photography, at night, for interpreting surface distress. PASCO-RR75 uses 35mm slit photography, taken at night, in a unique photographic foreshortening method to measure rut depth and determine transverse profile at preselected intervals. PASCO-RR85B supplies summary rut depth information to supplement -RR75's data and may be used in conjunction with either -RR70 or -RR75. Longitudinal profile is provided by PASCO-RR77. PASCO-RR77's maximum speed is 25 mph while the others have a maximum speed of

50 mph. PASCO-RR has a system maximum speed of 12.5 mph while all other systems evaluated have operating speeds in excess of 50 mph. This system is not compatible with future developments and is rated very poor in this respect. Overall rating for purposes for which AHTD would need this equipment is poor.

Laser RST

Laser RST was developed and is owned by the Swedish Government and was provided by Infrastructure Management Service of Arlington Heights, Illinois. This device uses laser distance measuring technology for determining rut depths, surface macrotexture, and crack detection. No image of the pavement's surface is provided, consequently, surface distress is a through-the-windshield process. This device is available on a lane mile lease arrangement but is not for sale. Adaptability to future development rating is good. Overall rating for AHTD's need is fair.

RECOMMENDATIONS

The subcommittee makes the following recommendations:

1. That the ARAN equipment system provided by Highway Products International best meets the AHTD's needs and should be purchased.

2. That the Principal Investigator spend at least five (5) working days observing this equipment and associated processes. Missouri DOT has this equipment and has indicated a willingness to help.

3. That, after 2 above, specifications should be written.

4. That, as a condition of purchase, Highway Products International demonstrate, on a road of our choice, the operation and output capabilities as specified in 3 above.

IMPLEMENTATION

Implementation of the findings of this report would require the purchase of the ARAN equipment system as provided by Highway Products International. Full implementation for all who desire to independently use the visual data would require that a 3/4 inch VCR and a high resolution color monitor be acquired for each independent user.

The users include, but are not limited to the Project Planning Committee, Roadway Design Division, Bridge Division, Traffic Division, Planning Division, Materials and Research Division, the Districts, and Programming and Scheduling.

The Project Planning Committee should find the visual and numeric data of material value in setting project criteria. The field inspections conducted by Roadway Design Division would be aided by viewing the visual data and reviewing the numeric printed data on a project level basis. Items or features of particular interest could be identified and located prior to field inspection.

The Bridge Division will be able to use the right-of-way images to evaluate bridge approach geometrics. The numeric horizontal and vertical alignment data should also be of value in this respect. The images normal to the pavement's surface will allow a more precise evaluation of bridge deck condition both time specific and through time.

The Traffic Division would be able to conduct their sign inventory by reviewing the right-of-way images. In addition the same images when viewed in conjunction with printed data will be of value in accident analysis. Most on site inspections would be obviated and those that were necessary could be better prepared for. Of particular value in accident causation analysis is the vertical and horizontal alignment data. Such an analysis has not been possible in the past due to lack of information.

The District Engineer will have detailed printed and visual data which will be of value to them in determining priorities for overlay betterment and sealing projects.

The ARAN equipment would provide detailed data with respect to project sites. These data would greatly reduce the number of field trips required by the Research Section of Materials and Research Division in its project monitoring program. Changes through time could be readily determined and quantified.

All Pavement Management, Needs Survey, and HPMS data is collected by two field crews composed of two people each from the Technical Services Section, Planning Division. These two Field

crews collect all of the structural pavement data for Pavement Management and make PSR ratings of the pavement for the Needs Survey. Because of the complexity of the data to be collected and the Traffic Congestion present, the field crews may have to make two or three passes over a section of highway to collect all of the necessary data for the Needs Survey. While the Needs Survey data on the State Highway System is used for the HPMS data, an extra trip is required to collect HPMS data on off system roads. Separate trips are required to collect Pavement Management data. The data is collected on a sample basis and includes subjective measurement. The recommended system will provide this data on a 100 percent coverage basis, at traffic flow speeds, in one pass, with complete objective data except for cracking. Cracking data, at present, would be obtained in the office from the images normal to the pavement. However, studies are now underway, at the Federal level, to develop image processing. When these are completed and implemented they will provide objective evaluation of cracking and other associated pavement distresses using images created by the ARAN system.

The Programming and Scheduling Section of Programs and Contracts Division has among its various functions the maintenance of a Pavement Management System and the scheduling of needed projects. The data provided by the recommended system would greatly improve the quality of these functions. Improvements to pavement management data collection will include better quality rut data, measurements of degree of curvature and percent grade, measurement of profile and improve, more effective methods of roughness data collection. Improvement in the quality of data collected would result in more effective programming of needed projects.

The recommended data collection would not only improve the quality of data now collected but also provide considerable quality data not now collected. While the office work would increase the field work and trips, as well as associated costs, would be greatly reduced.

CHAPTER 1

INTRODUCTION

The purpose of this study is to evaluate all available pavement distress surveillance equipment that would be of value to the Arkansas State Highway and Transportation Department (AHTD). The results of this evaluation will be the recommendation of an equipment system with proven value and with the capability of being economically upgraded with future enhancements.

Emphasis has been placed on the ability to collect detailed data and information that can serve as a permanent record of a pavement's condition. The primary requirement of the system is that it be able to provide summary data for pavement management purposes. A secondary requirement is that the system be able to provide data in such a form that it is capable of multiple interpretations and uses.

Those systems which were found to be acceptable based on primary and secondary criteria were further evaluated with respect to a tertiary criteria that they be economically adaptable to future innovations and state-of-the-art developments.

CHAPTER 2

DISTRESS SURVEY EQUIPMENT AND PROCEDURE OVERVIEW

Pavement distress surveys are traditionally performed by raters in one of two ways or a combination of these two. The oldest of these is performed by a panel of raters, who travel the length of the road and classify and quantify distress based upon their visual observations. The other method is to select a comparatively short length of the road and make fairly detailed measurements at preselected intervals. The rating thus obtained is applied to the total universe of length. At present the AHTD uses a combination of these two. That is, detailed measurements are made of a small length, approximately 100 to 300 feet, of the sample with the rest of the sample interval being rated subjectively.

The second generation devices were developed to objectively measure selected elements. Examples of such devices are the Mays Ride Meter for roughness measurement and various types of profile measuring instruments. These have been contact devices and as such are subject to mechanical interference which is not stable through time. This instability creates problems when one attempts to make comparisons of values across sites and/or through time.

Devices which produce a permanent visual image of the surface of a pavement may be considered third generation devices. These devices used photo sensitive film, 35mm or 16mm, or electronic sensing devices, video, to obtain these images. Generally, these devices produced two images, one of the right-

of-way and one of the pavement's surface. The images of the right-of-way were of a quality sufficient for the purposes intended. However, the images of the pavement's surface were not of a quality which would permit them to be used for surface distress identification. Various types of devices were developed or adapted for on board use to aid in recording distress as observed and evaluated by raters while the images were being obtained. These devices reduced field data collection time while providing a record for later office use. However, distress identification remained a through-the-windshield process and heavily dependent upon first and second generation devices and processes.

Changes in electronic technology have made the development and employment of a fourth generation class of devices feasible. These devices are capable of measuring all significant elements of surface distress, except cracking, objectively. This is accomplished by using some combination of photo, photo-optical foreshortening, laser, ultrasonic, or electron wave propagation devices along with or in conjunction with ultrastable gyroscopic and accelerometric instruments suitably integrated and appropriately processed by an on-board computer. Cracking and faulting are still measured subjectively by viewing images of the roadway's surface. This is done in the office and can be repeated at will.

A fifth generation device, currently under development, will use electronic imaging processing in conjunction with appropriate pattern recognition algorithms to classify and quantify pavement

distress directly without subjective evaluation by human raters. When used with fourth generation devices, the desired information will be objectively determined and will be provided not only for pavement management purposes but also for research and project level purposes.

This project will examine and evaluate all known fourth generation systems not only with their ability to meet primary and secondary criteria but also the tertiary criteria of economic compatibility with fifth generation devices.

CHAPTER 3

DESCRIPTION OF EQUIPMENT SYSTEMS REVIEWED

A brief description of the various devices and systems are given here. A detailed description of each demonstrated equipment system is presented in the Appendices. As stated in Chapter 2, the study has limited itself to fourth generation devices and those fourth generation devices which would be compatible with fifth generation devices. These are PASCO-ROADRECON, ARAN, Laser RST, Earth Technology, Video Comp, and Pavedex.

The Laser Road Surface Tester, Laser RST, was developed in Sweden by the Swedish Road and Traffic Institute and provided by Infrastructure Management Service of Arlington Heights, Illinois. This instrument uses eleven bumper mounted laser devices and a body mounted accelerometer to measure crack depths and widths, rut depths, longitudinal profile, roughness, macrotexture, and cross profile. An onboard computer uses these instruments, integrated with distance and time, to process data in real time. This device does not produce a visual image, consequently classification of some elements of surface distress is a through the windshield process. This system provides 100 percent coverage in one pass at speeds of 5 to 55 mph. Laser RST is designed to operate during daylight and under dry conditions. Appendix A contains a description of Laser RST's equipment and operating process.

The PASCO ROADRECON, or PASCO-RR, system of surface distress identification devices was developed in Japan by the

PASCO Corporation of Japan and provided by PASCO USA INC., Lincoln Park, New Jersey through their marketing agents, AVIAR Inc., Austin, Texas. The equipment for the various series is mounted in the same van. PASCO-RR70 makes use of 35mm continuous strip film photography to detect cracking, patching and other surface distress. PASCO-RR75 uses a hair line projector and 35mm photography to detect and quantify ruts. PASCO-RR77 measures longitudinal roughness using a fifth tracking wheel. PASCO-RR85B employs lasers for measuring rut depth and provides summary rut information. PASCO-RR70, -RR75, -RR85B have a 50 mph upper speed limit for operation while PASCO-RR77's upper speed limit is 25 mph. PASCO-RR70 & -RR85B can be operated simultaneously, but requires a pass independent from all others. PASCO-RR75 and PASCO-RR77 each require separate independent passes. To be able to use all of the PASCO-RR devices requires three different passes over the same road. The two pass requirement at 50 mph along with a third pass requirement at 25 mph equates to a maximum average system speed of 12.5 mph. A detailed description of PASCO's ROADRECON series of data acquisition devices is presented in Appendix B.

The ARAN, Automatic Road Analyzer, system is produced by Highway Products International, Inc. of Canada. ARAN is a van mounted video based system which provides a through the windshield image and an image normal to the surface. The camera mounted normal to the surface is monochromatic and is used for surface distress determination. The through the windshield mounted camera is color and has uses similar to Planning Division's video logging equipment. A front bumper-mounted

ultrasonic bar is used to measure rut depth and transverse profile. Longitudinal roughness is measured using a differential mounted accelerometer in conjunction with a body mounted accelerometer. A pitch and roll gyroscope measures longitudinal grade and crossfall. A precision directional gyroscope measures curve radii from 50 feet to 31,680 feet. All of this equipment is operated simultaneously in one pass and at speeds which are traffic flow dependent. The system is restricted to operating under dry conditions during daylight hours. A description of ARAN's system is given in Appendix C.

Other systems were considered worthy of examination but due to monetary and other considerations beyond the control of the subcommittee were not demonstrated. These are; PCES by Earth Technology Corporation, Long Beach, California; Video Comp by Audio and Video Systems, Boise State University, Boise, Idaho; and Pavedex Corporation of Spokane, Washington. None of these devices have been proven to be of value nor have they wide acceptance by the various states. These systems are in the developmental stage and do not meet the basic condition of being a proven system. They are described here for information purposes only and are not evaluated further. These systems are all based upon video technology and appear to have various levels of sophistication. Presented below is a brief summary of the equipment. The information was obtained by reviewing literature provided by them and from telephone conversations with the companies.

Video Comp uses three CCD video cameras to produce images of

the roadway surface. These cameras are mounted in a dedicated trailer. Apparently the towing vehicle is dedicated also. However the subcommittee was unable to verify this. The system is to be used at night. Consequently, it is provided with an internal light source. Each frame is digitized and cracking data is extracted using their own analysis software. Very little else is known.

PCES is a van mounted video system using CCD cameras with an onboard light source. Very little is known about this system. They appear to approach the problem by a line by line analysis of the video. The equipment is claimed to operate in real time. The subcommittee was not able to verify any of this.

Pavedex is a Spokane, Washington based company which uses CCD video cameras to produce images of the roadway surface. They appear to determine surface distress by using stereoscopic principles. The subcommittee was not able to obtain anymore information. We requested them to send us a description of their equipment, but we never received it.

All of the equipment systems described above have appropriate and adequate means of measuring distance and identifying frames with respect to position along the roadway.

With the exception of Laser RST, which does not produce a visual image, the roadway images have to be viewed and subjectively evaluated for pavement distress on a frame by frame basis.

CHAPTER 4

CAPABILITIES AND LIMITATIONS

The equipment systems demonstrated are here evaluated with respect to the various broad categories of data which the AHTD wishes to collect. All of the equipment suppliers indicated that they intended to add various enhancements to their existing equipment. If this enhancement was not demonstrated, the proposed enhancement was not considered.

VISUAL IMAGE RECORD

An image of pavement surface serves as a useful permanent record of pavement surface features. Side-by-side comparisons of the images of a pavement surface allow determination of the development of distress through time. These images should be of such quality that various distress categories can be identified. A means of retrieving these images with respect to location should be available. These images should be compatible with anticipated development in the state-of-the-art with respect to image processing for determining surface distress.

ARAN and PASCO-RR were the only devices that demonstrated a capability of providing a visual image. ARAN used video technology to produce these images while PASCO-RR uses a photographic technique. Both of these have been determined to be of such quality that surface distress can be determined.

Retrieval of an image for a specific location is accomplished by various means. ARAN's retrieval system is a computer based system. The images are stored on tape or

diskette. A PC is used to retrieve an image at a specific location by entering route, section, and log mile. PASCO-RR's pictures are in a bound volume and indexed by route, section, and log mile.

SURFACE DISTRESS

All surface distress determination, except cracking, is a manual subjective process in whole or part. Laser RST has an automated process to detect, measure, and classify some but not all types of cracking. All of these systems use a manual process to detect and classify cracking. Laser RST's classification of cracking is accomplished by a through-the-windshield survey during data collection and any errors are locked in. The images produced by ARAN are viewed frame by frame and any distress noted is classified and quantified and entered to a computer record associated with the frame viewed. The images generated by PASCO-RR are viewed frame by frame and any distress noted is classified and quantified and the areal extent of distress is entered into a computer. The chief difference being that with ARAN's method, a frame with a desired distress can be retrieved and viewed while this can not be done with PASCO-RR's method. While a specific location can be computer retrieved from Laser RST data, the information presented is a series of numbers which are the results of run specific summations over length with the original discrete measurements lost. Because these discrete measurements are lost, the data does not lend itself to re-interpretation. If

the original discrete data elements were retained, technology exists to convert these data into a visual image and would make this system compatible with anticipated fifth generation devices. This conversion was neither demonstrated nor contemplated by Laser RST.

ROUGHNESS

Roughness data provided by ARAN and Laser RST is obtained by the use of a body isolating accelerometer. ARAN uses two accelerometers, one to sense variations in rear axle movement and another to sense variations in body movement, suitably integrated with distance to produce roughness measurements. Laser RST employs a body mounted accelerometer in conjunction with laser measurements, suitably integrated with distance, to obtain their roughness data. PASCO-RR employs two devices to obtain roughness data. PASCO-RR77 employs a body isolating accelerometer in conjunction with a tracking wheel, suitably integrated with distance, to obtain roughness. This device produces data which is equal in quality to ARAN and Laser RST. However, this device gives information about the right wheel path only. The other device which PASCO-RR claims can produce roughness data is PASCO-RR85B. This device uses the measurements of distance obtained by a body mounted laser in the right wheel path to compute roughness. There are no means employed to compensate for the body's suspension and for this reason this device does not provide true roughness measurements.

The roughness data produced by these systems is considered

to be superior to that obtained using the Mays Ride Meter. Calibration of these devices is simple and less time consuming when contrasted with calibration of the Mays Ride Meter. The Mays Ride Meter is calibrated semiannually by being run over a calibration track. The AHTD has one such track. This track is assumed to have a known roughness which is assumed to be constant through time. This process is very time consuming. Similar but less time consuming procedures are anticipated with the other devices. However, the chief problem, and one of considerable magnitude, is that there is no way to tell when or how much it is out of calibration when in use. The other devices employ relatively simple dynamic and static instrumentation and ranging checks in their calibration process. The static process takes about three to five minutes and is made at the beginning of each production day. The dynamic calibration consists of automated checks of instrument performance and is continuous during a run. Thus, calibration is insured both daily and continuously.

RUT MEASUREMENTS

Rutting and rut measurement is the area where the most divergent approaches are employed. The PASCO-RR75 device projects a black line, at an angle of 26 degrees and 33 minutes, on to the roadway surface and this line is photographed normal to the surface. The foreshortening deviation is placed into a computer by tracing the line with a computer mouse. These measurements can be made at intervals of 0.9 meters to 99.9 meters. This is basically a sampling device and does not provide summary rut depth information. PASCO-RR85B employing three laser

devices, one located in each wheel path and one centered between the wheel paths, sums rut depths at the interval selected and records the maximum accumulated rut depth. All of PASCO-RR's summary rut depth data is obtained by the use of the PASCO-RR85B device. ARAN uses ultrasonic sensors spaced 4" apart across a 12' wide path to measure rutting. Laser RST uses 11 sensors mounted on a beam to measure rutting. These measurements are automated for ARAN and Laser RST. The measurement intervals by ARAN and Laser RST are speed dependent. This is due to the recovery time of the instruments used and at 55 mph may be made at minimum intervals of 5 inches. There is no upper interval length. Cross profile can be provided by all systems at intervals selected. These profiles can be produced by ARAN at any interval while Laser RST can do this only at summation points and PASCO-RR is limited to producing them at points where PASCO-RR75 has taken a picture. ARAN can produce these crossprofile plots at points selected at will in the office while Laser RST and PASCO-RR can produce them only at points selected during the data collection run.

ROADWAY ALIGNMENT

Measurements of grade, radius of curvature, and cross slope are provided by ARAN. This feature is not available from any of the other systems.

SYSTEM OPERATION

System operation is a broad category which describes the capabilities and limitations of the various equipment devices when operated as a complete system. The elements within this

category include, traffic interference and safety, atmospheric restrictions, degree of objective coverage, and effectiveness.

The traffic interference and safety element can best be described within the context of traffic environment of two types of highways. These types are urban interstate & rural highways. The urban interstate's traffic environment is best described with rural highways because the speeds encountered are on the order of those on rural two lane roads. The following is extracted from AHTD Planning Division's speed studies and logs:

1. The State Highway System 2-lane paved rural roads have:

   a) 26,682 lane miles
   b) an average speed of 55 mph
   c) 65 to 91 percent of traffic exceeding 50 mph
   d) 100 percent of traffic exceeding 25 mph

2. The State Highway System multilane interstate type roads have:

   a) 3,232 lane miles
   b) an average speed of 63 mph
   c) 87 to 99 percent of traffic exceeding 50 mph
   d) 100 percent of traffic exceeding 25 mph

A vehicle traveling at a speed of 50 mph on 2-lane rural roads would find that 65 to 91 percent of the vehicles encountered would be going faster than 50 mph. The same vehicle traveling at 50 mph on the rural interstate type roads would find that 87 to 99 percent of the vehicles encountered would be going in excess of 50 mph. A vehicle traveling at a speed of 25 mph on any rural highway would find that all vehicles encountered would be traveling at speeds in excess of 25 mph. The ARAN equipment system would not pose a traffic interference or safety problem on any of these highways. The Laser RST would not pose a traffic interference or safety problem on rural two lane roads. Laser

RST operating at its maximum speed of 55 mph would pose some traffic interference and safety problem on rural interstate type highways. The three PASCO-RR 50 mph devices would pose a traffic interference and safety problem on two-lane rural roads and on interstate type rural roads. The PASCO-RR 25 mph device would pose a traffic interference and safety problem on all highway systems.

All systems must be operated when the pavement is dry and the atmosphere is free of ground fog. ARAN and Laser RST are designed to operate only during daylight hours while PASCO-RR is designed to operate at night. None of these systems can operate when ambient temperature is at or below 32 degrees F. ARAN's upper ambient temperature limit is 140 degrees F, while PASCO-RR and Laser RST have an upper limit of 104 degrees F.

ARAN and Laser RST require one pass to obtain 100 percent data coverage. PASCO-RR's system requires three passes to obtain all data. All PASCO-RR systems except PASCO-RR75 provide 100 percent coverage. This is basically a sampling device and does not provide 100 percent coverage. No system has demonstrated the capability to objectively detect faulting and pumping associated with PCC pavements. No system has demonstrated the capability to objectively determine either type or extent of cracking. All of these systems require a significant amount of manual subjective evaluations.

An important consideration in the evaluation of any equipment with respect to system operation is its efficiency or, as in this case, field productivity. Field productivity is a

function of pass speed, passes required, site mobilization and site demobilization time. If one assumes that the mobilization and demobilization time is a constant across systems, then the only variables to consider are pass speed and passes required. For purposes of this illustrative comparison, no system will exceed an average speed of 50 mph. Since we do not intend to have raters on-board the ARAN and Laser RST vehicles, speed is not a variable with respect to these vehicles. Both ARAN and Laser RST have the capability of obtaining all data in one pass. Hence, the number of passes required for these systems is a constant. However, speed and number of passes are variables when one compares PASCO-RR with the other systems. If one assumes that the two PASCO-RR 50 mph devices can average 50 mph during their respective passes and that the PASCO-RR 25 mph device can average 25 mph during its pass, the average system speed for PASCO-RR's system is 12.5 mph. This means that under the most favorable speed conditions PASCO-RR's system would be only 25 percent as efficient as either ARAN or Laser RST. If all of PASCO-RR's devices could average 50 mph, PASCO-RR's system average speed would be 16.7 mph or only 33.3 percent as efficient as ARAN or Laser RST. This assumes that ARAN and Laser RST can maintain an average speed of 50 mph. They can in fact exceed this average speed. When this occurs, PASCO-RR's efficiency drops even more in comparison. The reason for this is PASCO-RR's maximum speed limitation and the three pass requirement.

CHAPTER 5

EVALUATION AND RANKING OF DEMONSTRATED EQUIPMENT

Chapter 4 outlined the capabilities and limitations of the various equipment systems with respect to several broad categories of data which the AHTD wishes to collect. Various comparisons were made among the systems with respect to their relative capabilities within various data categories and implications were made that one system performs a particular task or function better than others. No attempt was made to qualify these systems performance with respect to desired performance. Quantification of the merits of each system's performance with respect to desired performance was not addressed. This chapter will evaluate and rank each demonstrated equipment system's performance with respect to desired performance criteria.

There are five general areas of desired performance criteria. These criteria are: permanent record of pavement surface; field data collection, processing, interpretation, and summary; operating restrictions; equipment durability; and adaptability to future developments.

The following table is an evaluation of each demonstrated system's performance with respect to each desired performance criteria ranked from 1 (very good) to 5 (very poor).

Criteria	PASCO-RR	ARAN	Laser RST
1. Permanent Record of Pavement Surface			
a) Reliability	3	1	5
b) Usefulness	1	1	5

	PASCO-RR	ARAN	Laser RST
2. Field Data Collection Processing, Interpretation and Summary			
a) Level of Automation	3	2	1
b) Accuracy	2	2	5
c) Quality of Rut Data	3	1	1
d) Repeatability	1	1	3
e) Ease of processing	4	3	2
f) Ease of interpretation of Outputs	2	2	2
3. Operating Restrictions			
a) Environmental	2	2	3
b) Traffic Interference	4	1	3
c) Operating Speed	4	1	2
d) Operational Productivity	5	1	1
4. Equipment Durability	2	2	2
5. Adaptability to future developments	5	1	3
OVERALL RANKING	2.9	1.5	2.7

Ranking: 1=Very Good; 2=Good; 3=Fair; 4=Poor; 5=Very Poor

PERMANENT RECORD OF PAVEMENT SURFACE CRITERIA

The permanent record of pavement surface criteria includes the elements of reliability and usefulness. A permanent record of a pavement surface serves as a point in time record of surface features. Since it has been determined that all surface distress determinations are to be accomplished by viewing images of the surface, it is imperative that a visual record be produced. Laser RST does not produce a visual image of the pavements surface, hence Laser RST has been assigned a rating of very poor for both elements within this criteria.

RELIABILITY OF RECORD

ARAN's reliability has been rated very good because the

video image is viewed as it is being made and any problems can be detected and corrected immediately. PASCO-RR has been rated fair because film in the undeveloped state is subject to loss or damage due to improper handling or processing. The time delay associated with processing can cause a problem to go undetected for from 30 to 90 days. Film processing takes 30 to 90 days and during this time a problem which is undetected in the field could cause considerable loss of time and money. Because Laser RST produces no image, it has been given a rating of very poor.

USEFULNESS OF RECORD

The usefulness of the images were rated very good for those systems producing images. This rating was given because they are of such quality that they can be used to determine surface distress. Those systems which produced no image were rated very poor.

FIELD DATA COLLECTION, PROCESSING, INTERPRETATION, AND SUMMARY CRITERIA

Elements in the field data collection, processing, interpretation, and summary criteria category include automation, accuracy of surface distress data, quality of rut depth data, repeatability, ease of processing, and ease of interpretation of outputs.

LEVEL OF AUTOMATION

The level of automation was rated very good for Laser RST because no further processing is required. ARAN was rated good instead of very good because some but not all surface distress

must be determined in the office. PASCO-RR was rated fair because all determination of distress requires office processing.

ACCURACY

The accuracy of surface distress data was given a rating of good for ARAN and PASCO-RR. The through the windshield survey by Laser RST has been rated very poor because of the inability to accurately determine distress at highway speeds.

QUALITY OF RUT DATA

Quality of rut measurements for ARAN and Laser RST were given a rating of very good because of the objective nature of these measurements. PASCO-RR was given a rating of fair because there is considerable manual subjective involvement in their measuring process.

REPEATABILITY

Repeatability of all distress features was rated very good for PASCO-RR and ARAN while Laser RST was rated fair. Laser RST has been rated fair because of the nature of through the windshield rating.

EASE OF PROCESSING

Ease of processing raw data was rated poor for PASCO-RR because of the technique employed. The film must be viewed and interpreted not only for surface distress determinations but also for rut depth profiling and quantifying. This involves a substantial degree of manual and subjective processes. The person must be trained to use a digitizing board and a digitizing

computer for rut depth, be trained to interpret surface distress, and be trained in keyboard skills for entry of information into a computer. ARAN was rated fair because operators only had to be trained in interpretation of surface distress and be able to operate a PC. Laser RST was rated as good because only keyboard skills are required.

EASE OF INTERPRETATION OF OUTPUTS

The ease of interpretation of outputs was rated good for all systems. This is because the subcommittee is to specify how the data is presented.

OPERATING RESTRICTIONS CRITERIA

There are four elements in the operating restrictions criteria. These elements are environmental, traffic interference, operating speed, and operational productivity.

ENVIRONMENTAL

All systems are restricted by environmental conditions to some extent. None can operate unless the pavement is dry and the atmosphere is free of ground fog. ARAN and Laser RST must operate during daylight hours, while PASCO-RR is operated at night. No system can operate when ambient temperature at a point 12 to 18 inches above the pavement is below 32 degrees F. ARAN cannot operate when ambient temperature, at a point 12 to 18 inches above the pavement, is greater than 140 degrees F. Laser RST and PASCO-RR can not operate when ambient temperature, at a point of 12 to 18 inches above the pavement, is greater than 104 degrees f. During daylight hours in the summer ambient

temperature, at the above point, is very likely to exceed 104 degrees F. It is not as likely to exceed 140 degrees F during the same time period or at night. ARAN is not likely to encounter temperatures above its maximum operating range and for this reason is given a rating of good. PASCO-RR, because operations are conducted at night when temperatures are not likely to exceed 104 degrees F, is rated good. Laser RST is likely to encounter temperatures greater than 104 degrees F and is rated fair.

TRAFFIC INTERFERENCE

The basic physical body configuration of all systems is such that the vehicle size would not cause traffic interference. However, the traffic environment within which these vehicles must operate, when related to the maximum speed at which these systems must operate, is another matter. PASCO-RR's two 50 mph passes would pose a traffic interference problem to a minimum of 65 percent and a maximum of 91 percent of those vehicles encountered when operating on rural two lane roads. When these same devices are operating on interstate rural type facilities they pose a traffic interference problem to a minimum of 87 percent and a maximum of 99 percent of those vehicles encountered. The PASCO-RR 25 mph device would pose a traffic interference problem to 100 percent of those vehicles encountered on any rural road. Because of this PASCO-RR has been assigned a rating of poor. Laser RST has a maximum operating speed of 55 mph and would not pose a traffic interference problem to a majority of the traffic on rural two lane highways but would pose a problem to a majority of the traffic on rural interstate type facilities. For this reason

Laser RST is given a rating of fair. ARAN has a maximum operating speed which is vehicle and not system dependent and can travel at any speed likely to be encountered and for this reason is given a rating of very good.

OPERATING SPEED

The operating speed of ARAN is traffic flow dependent and for this reason is given a rating of very good. Laser RST's maximum 55 mph operating speed makes it traffic flow dependent on two lane rural highways but not traffic flow dependent on interstate type rural highways and because of this is given a rating of good. PASCO-RR when considered as a system has a maximum system speed of 12.5 mph and for this reason is given a rating of poor.

OPERATIONAL PRODUCTIVITY

The operational productivity element as used here refers to the performance of the complete system if all capabilities of the system are employed. The performance of a system is dependent upon the rate of data collection or more simply stated the maximum system speed at which these systems will operate. The system speed is a function of the systems' pass requirements and pass maximum speed. PASCO-RR's maximum system speed is 12.5 mph. The other systems have maximum system speeds in excess of 50 mph. PASCO-RR, when operating at maximum speed, can gather data from 12.5 lane miles in one hour. During the same time period and under the same conditions, ARAN and Laser RST can each gather data from 50+ lane miles. This means that PASCO-RR's operational

productivity is 25 percent or less of either of the other two systems. For these reasons PASCO-RR has been given a rating of very poor. For the same reasons ARAN and Laser RST have been rated very good.

EQUIPMENT DURABILITY CRITERIA

All systems were assigned a durability rating of good. PASCO-RR and Laser RST might have more problems with the lasers that they use than ARAN will have with ultrasound devices. The decision here was not between good and very good but was between good and fair.

ADAPTABILITY to FUTURE DEVELOPMENTS CRITERIA

The adaptability of a system to anticipated developments in the state-of-the-art is of great importance. Developments in image processing and electronic technology has the ability to make some systems obsolete. Laser RST has been assigned a rating of fair. This has been done because the addition of video equipment can make this system much more attractive while enhancing its present capability. This would make conversion to any development much less expensive. ARAN has been assigned a rating of very good because, while it is not the ultimate system, it lends itself well to the incorporation of other devices and to anticipated developments in image processing. Because PASCO-RR's system does not lend itself to anticipated developments in electronic image processing, PASCO-RR's system has been given a rating of very poor. When image processing is developed PASCO-RR's system will be obsolete.

CHAPTER 6

COST ANALYSIS FOR TWO AUTOMATED DEVICES

Laser RST is not included in this cost analysis because they will provide equipment and personnel on a lease arrangement. The lease terms are dependent upon the anticipated mileage to be covered. Furthermore, most of the items for which cost are examined are not applicable to Laser RST because of the cost per mile lease arrangement. The only systems analyzed here are PASCO-RR and ARAN.

BASIC ASSUMPTION ITEMS

1. Total analysis period will be 66 days per year.

2. Sixteen days per year will be set aside for Mobilization/Demobilization. This cost is $300/day/operator and includes subsistence.

3. The total field production per year is 50 days.

4. Assumed that this survey will be accomplished during the summer months when field crews are on a 10 hour day.

5. Of the ten hour day eight hours will be production time.

6. The basic production per year is a function of each systems maximum speed and length of production season. From Item 3 above length of production season is 50 days which is equal to (from Item 5 above) 400 data gathering on site hours. PASCO-RR has a maximum system operating speed of 12.5 mph. ARAN will be restricted to a system speed of 50 mph. This restriction for ARAN has been imposed for analysis purposes only since ARAN's system can exceed a speed of 50 mph. Thus the system's basic annual production is:

PASCO-RR = 12.5 X 400 = 5,000 lane miles
ARAN = 50 X 400 = 20,000 lane miles

7. Travel exclusive of production lane miles is assumed to be 1,800 miles.

8. That during production time ARAN equipment will average 50 mph.

9. That during production time PASCO-RR equipment will be able to operate at maximum speed.

10. Unit cost of equipment includes software conversion to AHTD specifications as well as equipment required to interpret distress data. The source of this data is suppliers. These costs break down as follows:

	PASCO-RR	ARAN
Software	$77,000.00	$50,000.00
Equipment	40,000.00	none
Total	$117,000.00	$50,000.00

11. Depreciation = $D = C\ L^{-1}\ (1-S)$,
where D = depreciation in dollars per year.
C = cost per unit in dollars.
S = percent salvage value divided by 100.
L = expected life of equipment in years.

12. Investment, insurance, and storage = 0.5D

13. Maintenance and repair of equipment other than computers = 0.3D

14. Maintenance of computers and associated equipment = $400.00. Source Computer Services AHTD.

15. Cost of film processing and printing is $18.00 per film can. PASCO-RR requires two film cans per lane mile. Extracted from FHWA-TS-87-213, page 261.

16. Office data processing cost extracted from FHWA-TS-87-

213, page 261. It is assumed that we will not have problems understanding data we specify.

17. When anticipated developments in computer image processing becomes available the cost of office data processing should drop to about $10 lane mile for those systems which are compatible. PASCO-RR is not compatible. PASCO-RR will either have to digitize all their pictures or convert to a video system. It is assumed that they will retain their present system. The $10 per lane mile processing cost assigned to ARAN is an estimate. At this time, no specific cost can be assigned to image processing. However, it would be a function of computer processing time and could be a mainframe or real time process. The real time process would be at no cost. However, computer equipment cost would be increased to $50,000.00 (estimate). ARAN's cost per unit would then be $530,000.00 which would cause the Cost/Lane mile to be $2.52.

18. The costs associated with personnel is assumed to be $300/day/man for field crews. One driver and one technician is required for field data collection. The driver does not have to be technically qualified; however, this is desirable in order to provide relief and maintain production. The technician should be an electronics qualified person. The technician will have to be qualified to make minor adjustments to equipment and be knowledgeable but not expert in its repair. He or she will be able to make minor repairs and be able to recognize when elements are not functioning properly. The person should be well qualified to perform those repairs and adjustments which are required for field level maintenance technicians. Our shop repair

people should have knowledge and expertise in the fields of electronic technology, gyroscopes, accelerometers, ultrasonic and laser ranging devices, TV cameras, TV monitors, frame grabbers, TV signal processors, TV recorders both tape and disk, and computers. The shop should be able to accomplish all repairs up to but not including depot and rework facility level. It is doubtful that all of these qualities will be found in one person.

In office personnel should be able to use a PC keyboard and be able to recognize the various types of distress which we wish to identify. To provide relief due to fatigue more than one in office person should be available in order that production will not suffer. For purposes of this study they have been assigned a salary of $12 per hour.

TOTAL SYSTEM COSTS

	PASCO-RR	ARAN
Equipment Cost		
Cost/Unit	$617,000	$480,000
Expected Life (years)	15	15
Salvage Value, percent	20	20
Depreciation	$32,907/yr	$25,600/yr
Investment Insurance		
Storage cost = .5 Depreciation	$16,453/yr	$12,800/yr
Maintenance/Repair		
Other Than Computers	$9,872/yr	$7,680/yr
Computer Maintenance	$400/yr	$400/yr
Total Cost/Unit	$59,632/yr	$46,480/yr
Annual Production	5,000 ln/mi	20,000 ln/mi
Cost/lane mile	$11.93	$2.33
Operating Costs		
Number of Units	1	1
Crew Size	2	2
Mobilization/Demobilization	$1.92 ln/mi	$0.48 ln/mi
Fuel	$0.36 ln/mi	$0.12 ln/mi
On Site Costs	$6.00 ln/mi	$1.50 ln/mi
Total Operating Cost	$8.28 ln/mi	$2.10 ln/mi
Data Processing Costs		
Film Processing	$36 ln/mi	none
Office Processing	$60 ln/mi	$42 ln/mi
Total Data Processing	$96 ln/mi	$42 ln/mi
	---	---
Total Cost	$116.21 ln/mi	$46.43 ln/mi

Summary of Cost Analysis Per Lane Mile in Dollars

	Equipment	Operating	Data Proc.	Total
PASCO-RR as is	11.93	8.28	96.00	116.21
Future all Enhancements (See Note 17)	11.93	8.28	96.00	116.21
ARAN as is	2.33	2.10	42.00	46.43
Future mainframe Enhancements (See Note 17)	2.33	2.10	10.00	14.43
Future real time Enhancements (See Note 17)	2.52	2.10	0.00	4.62

The AHTD currently expends $202,730 annually to evaluate pavement distress on 20,000 lane miles. This is equal to $10.14 per lane mile. However, since AHTD employs a sampling procedure with 100 to 300 feet sections being objectively measured at 2.50 mile intervals, only 0.8 to 2.3 percent of these 20,000 lane miles are measured objectively. The same amount of money would provide 100% objective coverage of 4,366 lane miles by ARAN, without enhancements, and 1,745 lane miles by PASCO-RR. ARAN, with mainframe enhancement, could provide objective coverage for 14,049 lane miles for the above money. However, 20,000 lane miles could be 100% objectively covered by ARAN, with real time enhancement, for $92,400.00. At current funding levels, ARAN, with real time enhancement, would pay for itself in less than five years.

CHAPTER 7

SUMMARY AND RECOMMENDATIONS

A summary of the findings from the evaluation of a selected number of distress survey systems is presented in this chapter. Recommendations of devices which meet AHTD's minimum requirements are also presented.

SUMMARY

ARAN

The ARAN features automation of rut depth measurements, longitudinal grade, cross fall, transverse profile, and radius of curvature. Video images are provided with very good resolution of the right-of-way and of the pavement's surface. The right-of-way images are in color while the surface images are monochromatic. The resolution quality of the monochromatic images of the surface are of a quality that lend them to use in interpretation of surface distress. Distress is evaluated by displaying images on the PC's CRT and entering observed distress into a computer. The ARAN system is the most economical to use now and probably will be more economical in the future. The rating given to ARAN with respect to future developments is very good. Overall rating for purposes for which AHTD would need this system is very good. The system is compatible with probable state-of-the-art developments and would not soon become outdated.

PASCO-ROADRECON

The PASCO-RR70 system takes 35mm continuous strip photographs of the pavement at night at varying speeds. These

photographs are considered adequate for interpreting surface distress. The distresses are interpreted from the black and white film using a 35mm strip film projector and a rectangular overlay grid. Distress is input into a computer. The PASCO-RR75 system uses a unique photographic method to measure the transverse profile of a pavement to determine rut depths at selected intervals. The profile is inputted into a computer using a computer mouse.

PASCO-RR85B supplies rut depth summaries to supplement above rut data. Longitudinal profile is provided by PASCO-RR77. Due to the operational productivity limitation of 5,000 lane miles per year, it would take PASCO-RR 6.2 years to cover the paved rural highway system. The life of the equipment would expire before three complete highway system passes could be completed. The PASCO-RR system is not compatible with future developments. However, this system does meet the minimum requirements the subcommittee has established. Overall rating for purposes for which AHTD would need this system is poor. The decision here was not between poor and fair but was between poor and very poor. Before this system can complete one complete pass of the rural highway system, developments in the art of image processing will make this equipment obsolete and unacceptable for AHTD uses.

Laser RST

The Laser RST features the use of laser distance measuring technology for determining rut depths and surface macrotexture and for detecting transverse cracks. An onboard computer is used to record through-the-windshield distress determinations. This

device produces no visual image. This device does provide considerable and detailed information about macrotexture. This macrotexture could be of value in skid determinations; however, this would require extensive research. Cost on a lane mile basis would probably fall between the cost for ARAN and PASCO-RR. More precise information can not be determined at this time. Laser RST did not provide a lease cost on a lane mile basis. The rating for adaptability to future enhancements is rated good instead of very good because it would require the addition of a video image system and associated equipment. Overall rating for AHTD's needs is fair because no image of the surface for distress determinations through time is provided.

Recommendations

The committee makes the following recommendations:

1. The ARAN system as provided by Highway Products International best meets AHTD's needs and should be purchased.

2. That, prior to writing specifications for equipment, equipment performance, and data output quality and format, the Principal Investigator spend at least five working days observing this equipment and associated processes. Missouri has this equipment and has indicated a willingness to help in this respect.

3. After 2 above has been done, specifications should be written.

4. A condition of purchase be that Highway Products International demonstrate, on a road of our choice, the operation and output capabilities as we have specified in 3 above.

TRC 8802 A

PAVEMENT MANAGEMENT SURVEILLANCE SYSTEMS EVALUATION

APPENDIX A
TO
FINAL REPORT

TRANSPORTATION RESEARCH PROJECT NO. TRC8802

NOVEMBER 1988

PREPARED BY
ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT
MATERIALS AND RESEARCH DIVISION
RESEARCH SECTION
IN COOPERATION WITH
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

APPENDIX A

THE LASER ROAD SURFACE TESTER

The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the Arkansas State Highway and Transportation Department or the Federal Highway Administration.

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EMPLOYMENT OF LASERS

Eleven lasers are mounted on the front of the van. (see figure 1)

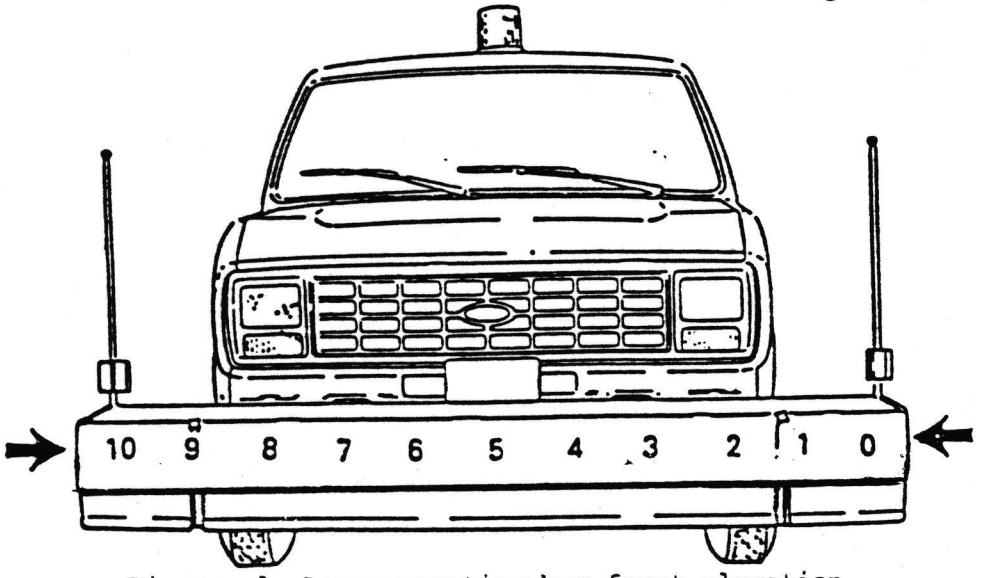


Figure 1. Laser mounting bar front elevation.

Rut Depth - Utilizes all eleven lasers

Longitudinal Profile - Uses lasers 2 or 8

Macrotexture - Uses lasers 2 and 8

Cracking - Uses lasers 2, 4, 6, and 8

Lasers 1, 3, 5, 7, 9 are "regular" lasers: Regular lasers operate at 16khz and send signals to the rut depth calculation computer only.

Lasers 0, 10 are "angled" lasers: Angled lasers operate at 16khz and are positioned at a 45 degree angle outward, making it possible to measure a width of 3.1 meters with the laser bar only 2.6 meters wide.

Lasers 2, 4, 6, 8 are "combination" lasers: Combination lasers operate at 32khz and are capable of sending signals to the special rut depth, macrotexture, cracking and profile measuring computers

MEASUREMENT OF RUT DEPTH

All eleven lasers supply signals to a special rut depth measuring card. The rut depth measuring card plots a transverse profile of the pavement and records the deepest rut every 10cm.

At the end of the test section, an average rut depth is reported and a percentage of distance where the rutting was greater than two operator selected limits (normally 1/2" and 1") is reported. The data is reported in real time. Rut depth is measured objectively by the wire method (see figure 2).

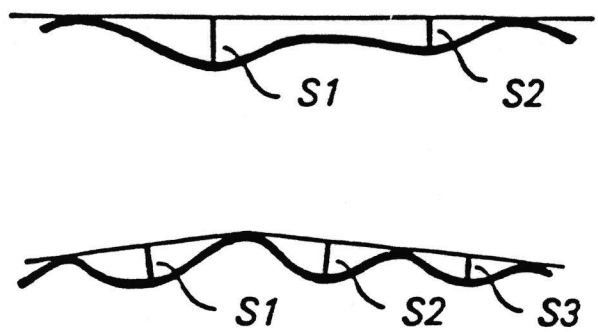


Figure 2. Rut depth is measured by the wire method.

MEASUREMENT OF LONGITUDINAL PROFILE

AND DETERMINATION OF ROUGHNESS

To measure longitudinal profile, three measurements must be recorded simultaneously at various points over the length of the test section.

1. Vertical movement of the laser, measured with the accelerometer

2. Vertical movement of the pavement and laser, recorded with the laser

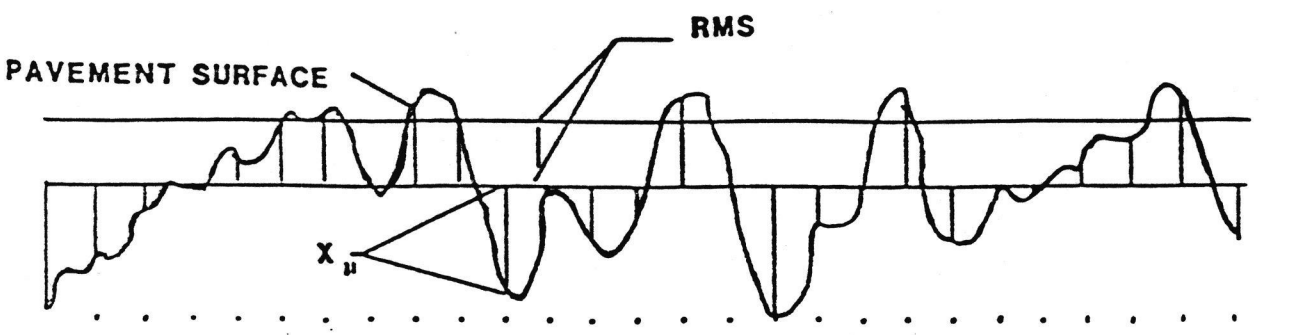
3. Horizontal velocity of the laser, measured with the pulse transducer (speed measuring device mounted on the right front wheel)

With these measurements, a true profile slope is calculated in the time domain which is evaluated every 20 meters. We sample the pavement at a rate of 250hz.

IRI (Quarter car) and RMSVA (MO) are calculated from the true profile slope for each 20 meter section within the test limits in real time.

MEASUREMENT OF MACROTEXTURE

Lasers 2 and 8 (page A- 5) supply signals to special macrotexture measuring cards. The high speed 32khz lasers (one in each wheel path) take many distance readings from the laser to the pavement. At 55 mph, one laser measurement is recorded every 0.75mm longitudinally (measurement distance is proportional to velocity, i.e. at 30 mph one laser measurement is recorded every 0.42mm). Velocity is accounted for in the calculations for repeatability at any speed between 5 mph and 55 mph. The laser readings record the texture of the pavement. The computer sorts the texture into various wave forms. Wavelengths between 2mm and 10mm are in one group called fine macrotexture and wavelengths between 10mm - 80mm are in another group called rough macrotexture. For both fine and rough macrotexture, a root-mean-square (RMS) is calculated (see figure 3) and reported. This RMS is a measure of amplitude. The RMS values for a given length of pavement are distributed into ten ranges. The value in each range is a percentage of the length of the section where the RMS value was in that range (see figure 4).



$$RMS = \sqrt{\frac{\sum X_1^2 + X_2^2 \ldots X_n^2}{n}}$$

n = NUMBER OF SAMPLES

X = DISTANCE FROM REFERENCE

Figure 3. Root-mean-square calculations for both fine and rough macrotexture.

MACROTEXTURE OUTPUT

RMS values meas. in mm	rms	0.2	0.2 / 0.3	0.3 / 0.4	0.4 / 0.6	0.6 / 0.9	0.9 / 1.3	1.3 / 2.0	2.0 / 3.0	3.0 / 5.0	
			Category limits in mm								
macro 1											
rough	0.83	0	8	28	25	19	7	8	3	0.0	0.0
fine	0.63	0	2	17	43	28	6	1	0	0.0	0.0
macro 4											
rough	0.54	2	48	14	14	10	6	1	0.0	0.0	0.0
fine	0.57	0	6	2	66	21	1	1	0.0	0.0	0.0

Explanation of terms:

RMS: Root Mean Square of the surface texture in mm

macro 1: Texture of left wheel path

4: Texture of right wheel path

rough: Surface texture with wavelength between 10mm and 80mm

fine: Surface texture with wavelength between 0mm and 10mm

Figure 4. Example of macrotexture output.

MEASUREMENT OF CRACKING

Lasers 2, 4, 6, 8, (page A- 5) supply signals to special crack measuring cards which register cracking and categorize it according to its width and depth. The special cracking measuring cards essentially determine that amplitudes greater than the texture are cracks (see figure 5). Depth and width of cracks are stored in the proper categories in real time (see figure 6).

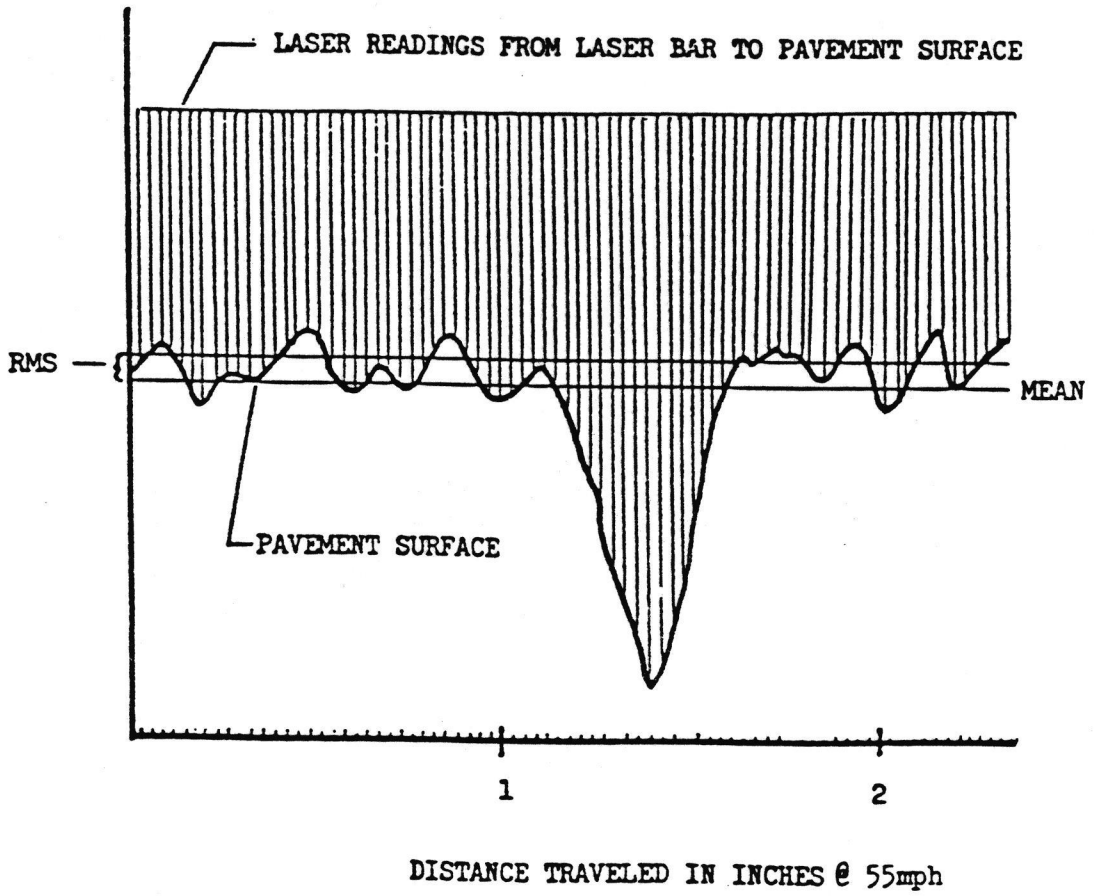


Figure 5. Amplitude of surface varations as a function of distance, in inches, while traveling at a speed of 55 mph.

CRACK OUTPUT

	Depth #1 (3mm→6mm)				Depth #2 (6mm +)		MC * 6.0
Laser #	Width #1 3→6 mm	W #2 6→12mm	W #3 12 →25mm	W #4 25→50 mm	W #2 6→12mm	W #3 12 →50mm	*Both
crack 1	60	26	14	0	5	4	
2	38	27	9	0	4	5	22
4	14	9	4	0	0	1	
3	23	15	2	0	4	3	14

* Values in the "Both" category indicate numbers of cracks which both laser #1 and #2, or laser #3 and #4 measured at the same time

* MC is Macrotexture Compensation Factor

Note! All values indicate number of cracks per 100 meters

Figure 6. Example of crack output.

MEASUREMENT OF DISTANCE AND VELOCITY

An optical strobe actuated pulse transducer sends 5 volt pulses to a special speed measuring card to determine distance and velocity. The transducer sends 360 five volt pulses per revolution of the tire. This information is utilized continuously in the crack, macrotexture, rut depth and profile calculations. Calibration of the transducer stores the number of pulses which equal 1 meter. The accuracy of the transducer is reported to be 0.2% over any distance, however, results of our calibration show an accuracy of 0.1%.

PATTERN RECOGNITION

An objective density and severity of cracking is recorded with lasers 2, 4, 6, 8 (page A- 5). Types of cracking are identified by utilizing 8, three position toggle switches (see figure 7). The laser must cross a crack to record it, therefore, longitudinal cracks and edge cracks are rated subjectively with the switches.

SUBJECTIVE SWITCHES

SWITCH #1 DRAINAGE
1- Curb and gutter or 5' to 8' ditch with storm sewers.
2- Greater than 2' ditch.
3- Less than 2' ditch.

SWITCH #2 SHOULDER TYPE
1- Curb and gutter or 8' paved.
2- 8' paved down to 2' paved.
3- Less than 2' paved.

SWITCH #3 SHOULDER CONDITION
1- Good
2- Fair
3- Poor

SWITCH #4 ALLIGATOR CRACKING
1- None
2- Showing small patches of alligator cracking (up to 33%).
3- More than 33% alligator cracking.

SWITCH #5 EDGE CRACKING
1- None or a single crack less than 1/4".
2- Multiple cracks extending over 2' from pavement edge but no more than 3'.
3- Multiple cracks extending over 3' from pavement edge with outermost area begining to alligator.

SWITCH #6 LONGITUDNAL CRACKS
1- None
2- Less than 1/2"
3- Greater than 1/2"

SWITCH #7 RANDOM CRACKING
1- None
2- Less than 1/2"
3- Greater than 1/2"

SWITCH #8 EDGE PROFILE
1- Shoulder even with pavement.
2- Shoulder lower 1" or more.
3- Shoulder higher 1" or more.

Figure 7. Explination of subjective rating switches.

SELCOM LASER SPECIFICATIONS

	Lasers 1, 3, 5, 9 Regular	Lasers 0, 10 Angled	Lasers 2, 4, 6, 8 Combination
Stand Off Distance	323mm	457mm	323mm
Measuring Range	256mm	362mm	256mm
Laser Foot Print	1mm	1mm	1mm
Frequency	16khz	16khz	32khz

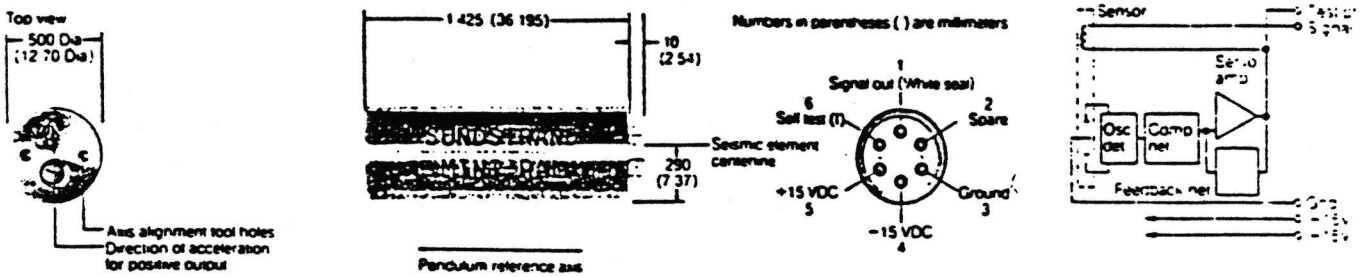
Expected life of the lasers is unknown. However, downtime has been inconsequential because each unit carries 3 spare lasers, one combination, one angled, and one regular.

The following specifications apply to all lasers:

Resolution, Digital	0.025% of measuring range (MR)
Accuracy, at 25 C	± 0.1% of MR
Linearity	± 0.1% of MR
Power Requirements	110/220 VAC, 50/60 Hz
Operating Temperature	0 - 40 C (32 - 104 F)
Storage Temperature	-30 - 70 C (-22 - 158 F)

Note: The laser is insensitive to ambient light and surface reflectivity. Surface color, temperature and density are also irrelevant.

ACCELEROMETER SPECIFICATIONS



Range Full Scale	± 1 g to ± 50 g max
Sensitivity, Voltage (Vg)	5 V/g to 0.03 V/g
Output Voltage Linear Range	± 5V max
Sensitivity Current (Ig)	0.3 ± 1% mA/g
Source Impedance	RL = Vg/Ig
Supply Voltage	± 15 VDC, ± 10%, 350 mW max
Natural Frequency	150 Hz, min
Damping	0.3 to 1.0
Linearity	<0.05% of full range or 0.005 g whichever is greater (BFSL)
Hysteresis & Repeatability	<0.02% of full range or 0.005 g whichever is greater
Threshold	.005% of full range maximum
Output at Zero g	0 ± 0.010 g maximum
Scale Factor Temperature Coefficient	± 0.02%/°C maximum
Temperature Zero Shift	± 0.00005 g/°C maximum
Axis Alignment Error	0.005 g/g maximum
Case Alignment Error	.75° maximum
Vibration Rectification Coefficient (Sine)	0.00015 g/g^2 20Hz To 100Hz, 0.00010 g/g^2 Above 100Hz
Vibration Limit 20 to 2000 Hz	16 g RMS
Acceleration Limit	250 g
Shock Limit (5 ms pulse)	200 g peak
Temperature, operating	− 55°C to + 71°C
Temperature, storage	− 60°C to + 100°C
Humidity	Sealed Case
Current Self Test (pins 1 and 6)	3.33 ± 0.3 g/mA
Weight	20 grams

COMPUTER SYSTEM

Computer - Primal Data 2000, 6809 chip, an advanced multi-user, multi-tasking 64k.

Storage - Two 8" floppy disks with 1 meg capacity each.

Printer - CITOH

Terminal - ADDS.

INVENTORY COMPUTER

To organize the raw surface data produced by the Laser RST, an IBM PC is mounted onboard. Inventory data required for test section identification is entered on the IBM PC. The following information is entered:

1. Section number
2. Object number
3. Beginning and ending locations
4. Traffic classification
5. Pavement type
6. Direction of travel
7. Lane tested

The above data is entered in real time and makes organization of the raw surface data quick and easy.

CALIBRATION OF EQUIPMENT

CALIBRATION OF LASERS:

A straight edge (calibration bar) is placed under the 11 lasers, then a computer program is used which stores the distance from the 11 lasers to the calibration bar (in units of 1/16mm). This program establishes a straight reference line for rut depth calculations. To test whether or not a laser is working properly, approximately 300 readings to the calibration bar are recorded and the standard deviation is calculated and checked (this is done automatically for each laser). This procedure takes about 10 minutes and is performed daily. If dirt or mud covers the laser while testing, an invalid light will illuminate (one light for each laser). However, in the past three years, this has never occurred.

CALIBRATION OF ACCELEROMETER:

A program is run which prints a reading from the accelerometer in the horizontal position (approximately -1700) then the accelerometer is turned 90 degrees upwards and another reading is obtained (approximately -21320). The important thing is that the difference is -19620 ($\pm$ 50). If the difference is greater than $\pm$ 50, a potentiometer must be adjusted. This procedure takes about 10 minutes if adjustment of the potentiometer is required, and about 2 minutes if no adjustment is needed. Calibration of the accelerometer is performed daily.

CALIBRATION OF DMI:

A section of pavement must be measured accurately to 400m or less. A program is run which counts the number of pulses from the transducer as the RST travels the distance. At the end of the section the number of pulses is shown; the distance travelled is input and the computer calculates the number of pulses per meter and stores it. If a 400m or less length is pre-measured, the procedure will take about 10 minutes. This is performed weekly.

PERSONNEL REQUIRED TO OPERATE THE LASER RST

Three persons are normally required to operate the Laser RST. Their duties involve:

1. Driving
2. Operation of subjective switches
3. Operation of the inventory computer
4. Starting and ending test sections

The driver of the Laser RST has no other duties other than driving. This allows full attention to safe driving.

The operator of the subjective switches also presses the button to start the objective measurements. The Laser RST can be preprogrammed by the operator to end the objective data collection at any desired length. So, full attention to subjectively rated surface distresses is possible.

The operator of the inventory computer enters necessary test section identification information on an onboard IBM PC in real time.

NCJ.kjr

Ref: 01-9000A02-2

ADVANTAGES

The advantages of using the Laser RST for a surface condition survey are as follows:

1. Data collection is continuous
2. Data is collected and reported in real time
3. Data is stored on floppy disk and on hard copy printout in real time
4. Floppy disk allows automated error free transfer of information to other computers for immediate processing and analysis
5. Lasers are highly accurate distance measuring devices
6. Lasers take as many as 32,000 readings per second
7. Lasers are insensitive to surface color, or reflectivity
8. Lasers can operate in daylight or at night
9. Lasers can operate over a high range of temperatures
10. The Laser RST is used daily in production, therefore, is continually available in the latest "state of the art"
11. The Laser RST data is reported in an easily understandable format
12. The Laser RST collects data independent of speed
13. The onboard computer program is user friendly
14. The onboard computer is flexible and is operator programmable

Ref: 01-9000A02-3

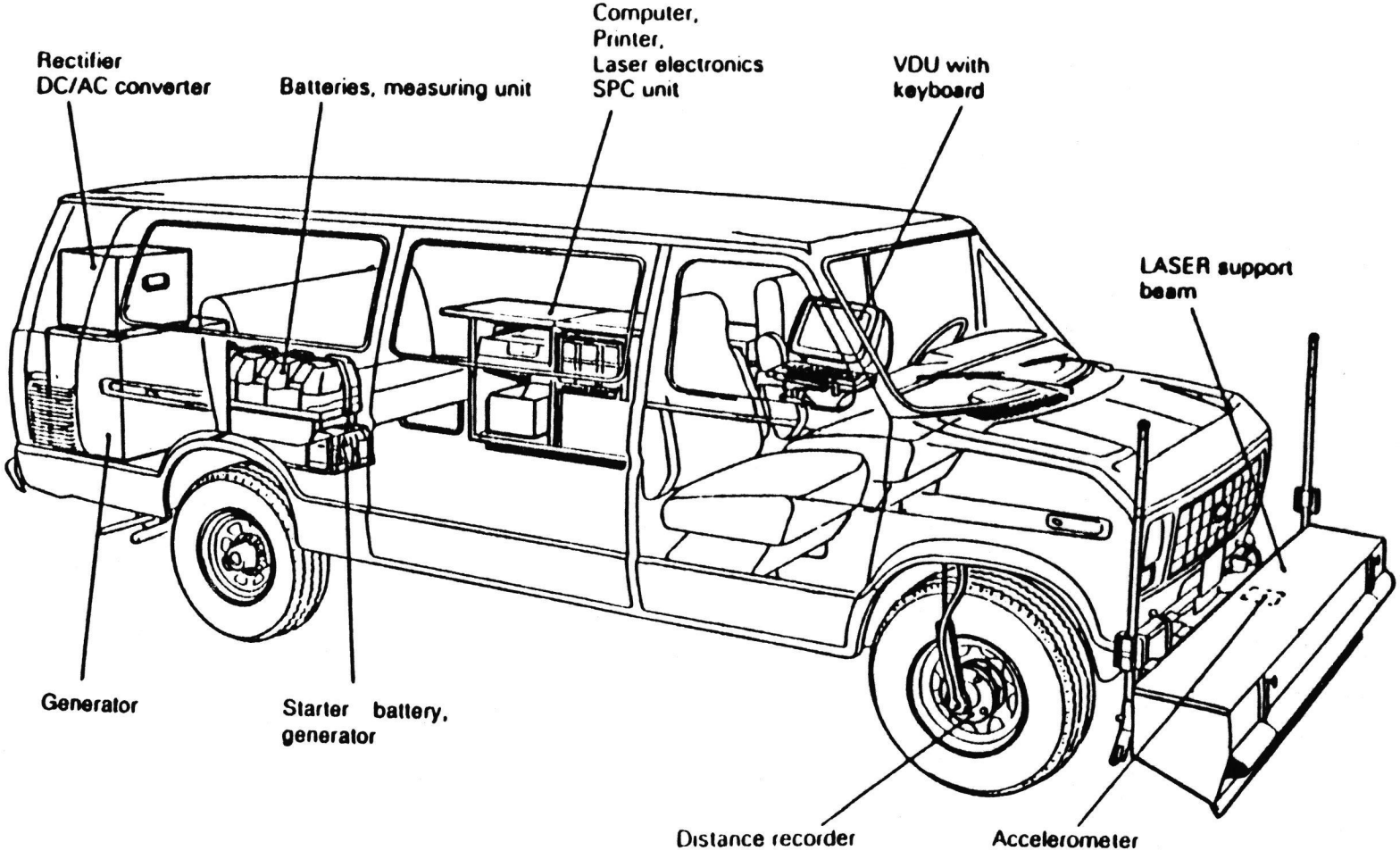


Figure 8. Schematic illustrating various components of the IMS Laser Road Surface Tester.

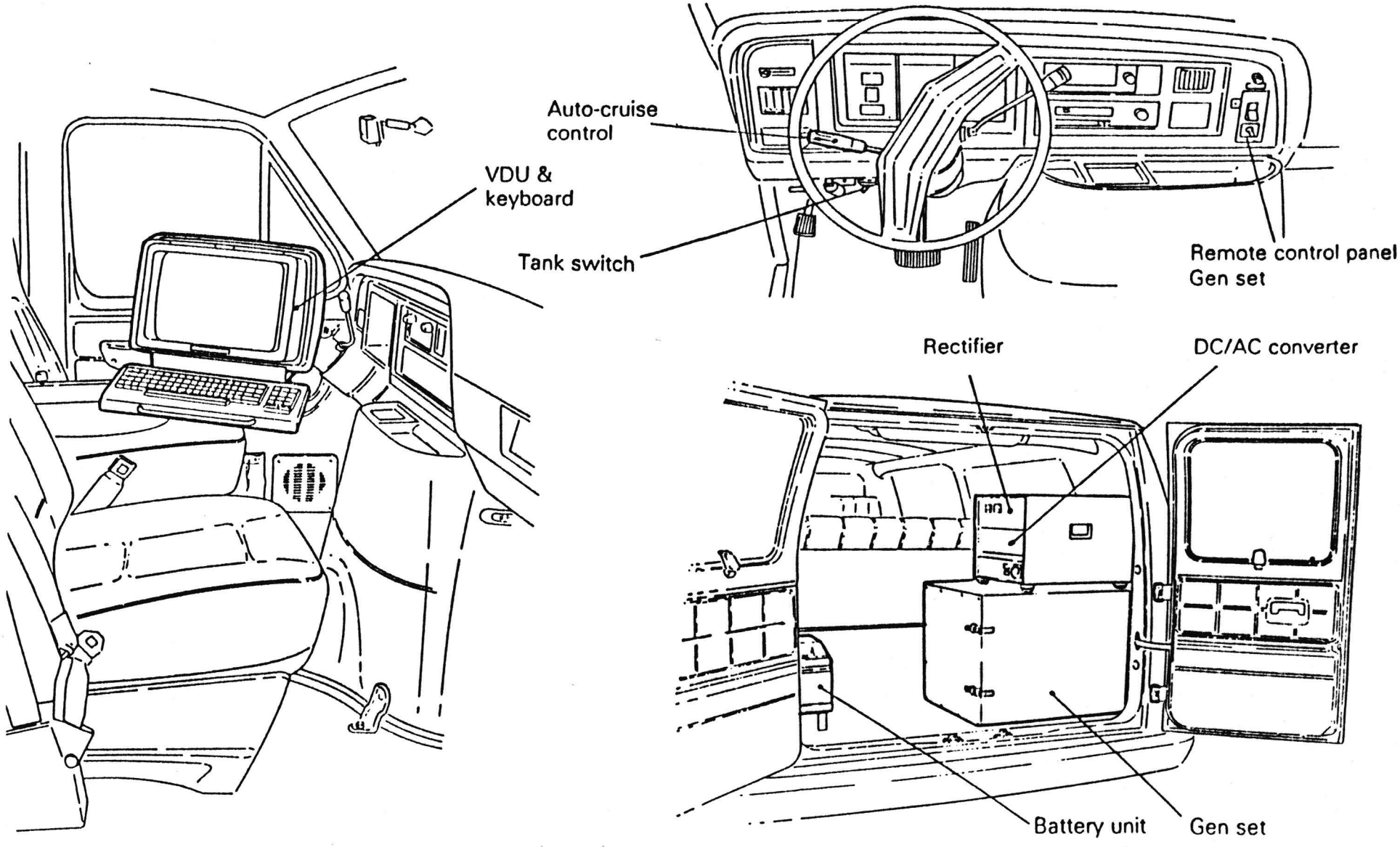


Figure 9. Schematic illustrating equipment components and layout of the drivers console, power sources, and raters console.

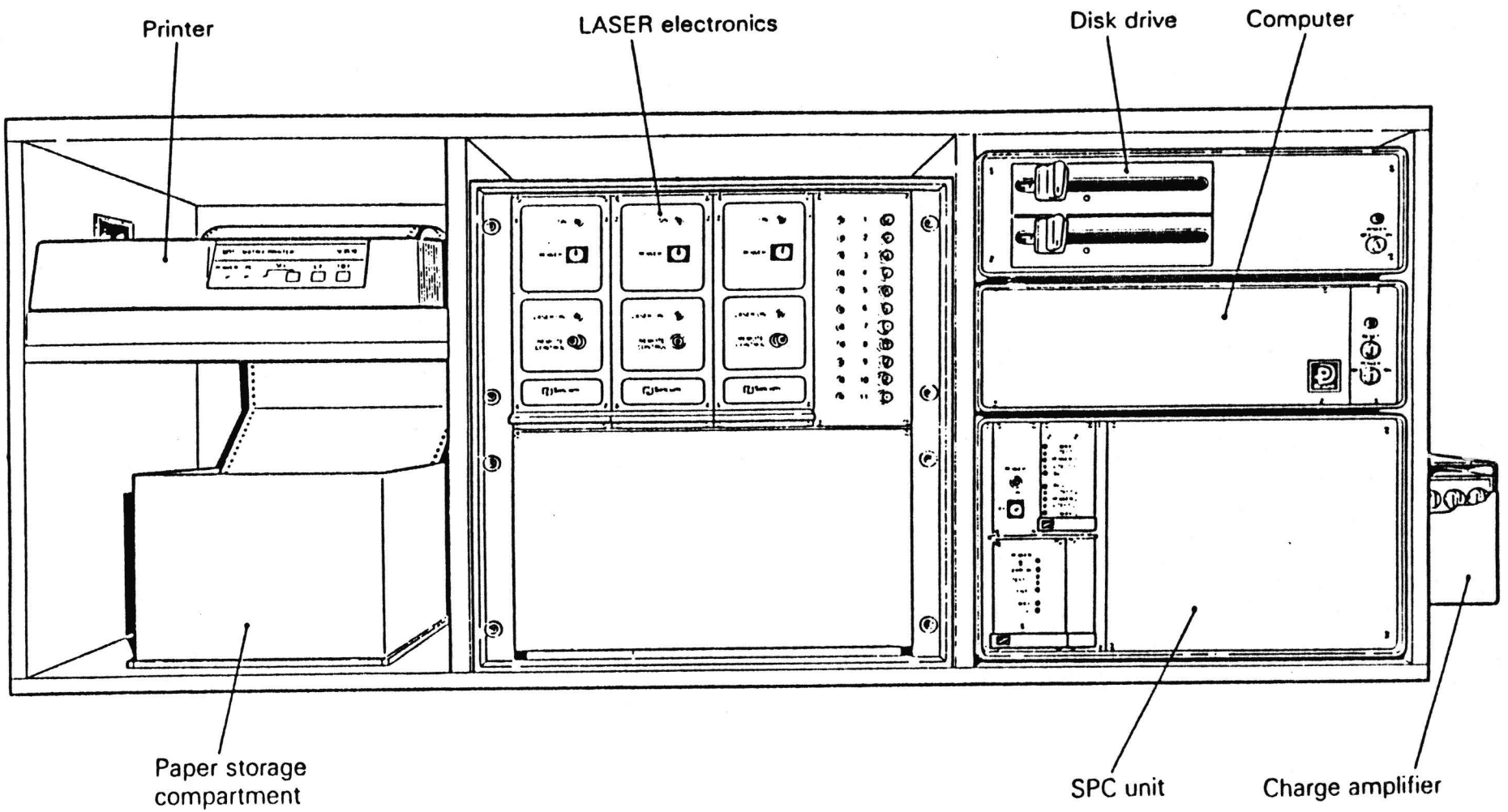


Figure 10. Schematic illustrating equipment components and layout of the inventory computer.

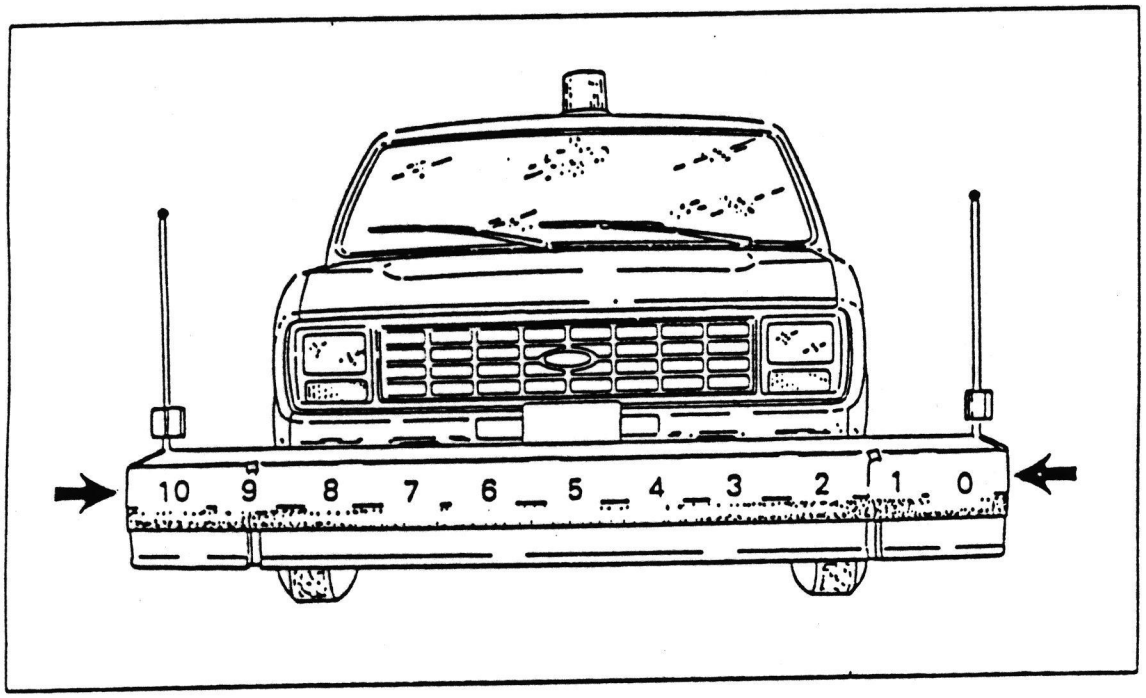


Figure 11. LASER RST mounting support beam and laser configuration.

The lasers are mounted on a support beam at the front of the vehicle. They are numbered from 0 to 10 looking from the driver's position. Laser No. 10 is easy to disconnect from the operator's panel while the vehicle is moving by pressing in the Camera 10 button. For example, if the vehicle is close to a sidewalk or similar object which could influence the measurement values, Camera 10 could be disconnected.

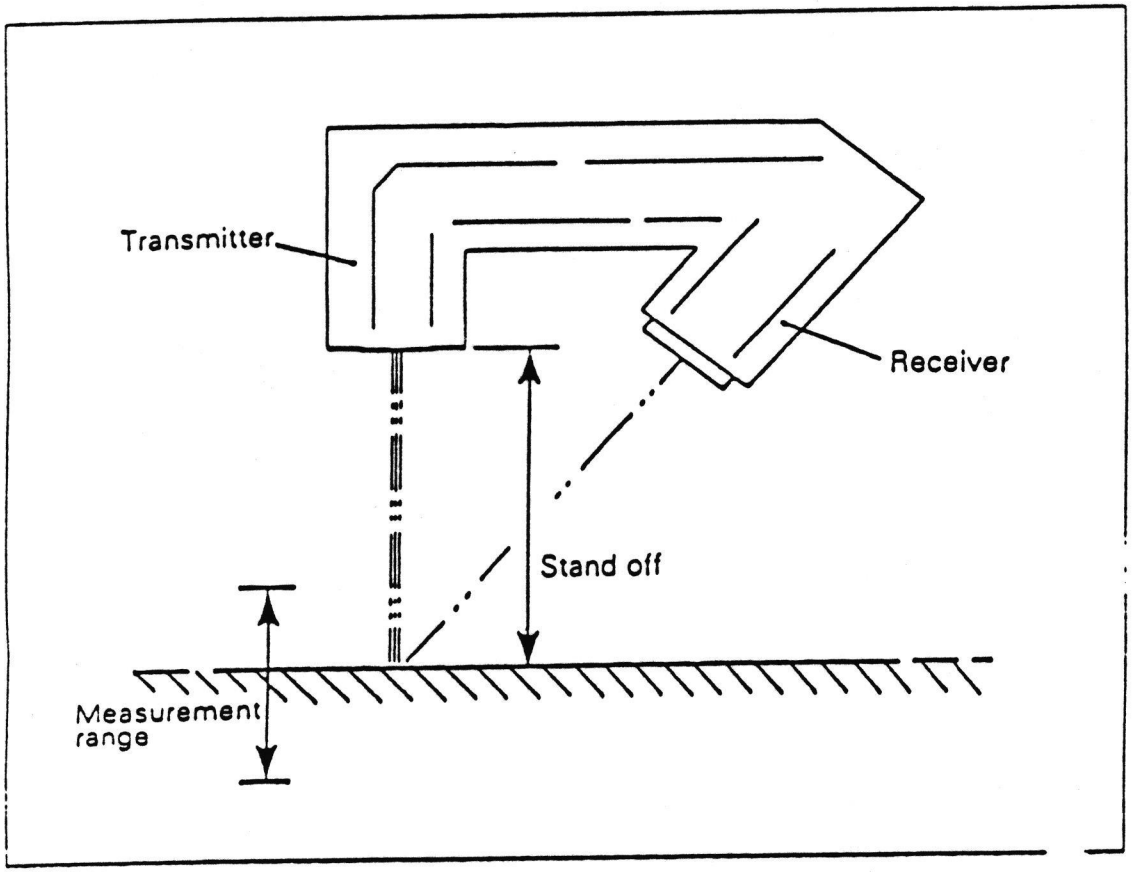


Figure 12. Laser equipment operating requirements.

Make: SELCOM AB

Quantity: 11

Measurement width: Approx. 310—320 cm

Ambient temperature limits for measurement: 0° — +40° C

Performance data:

A. 5 lasers numbered 1,3,5,7, 9
   Sampling frequency 16 kHz
   Stand-off 355 mm
   Measurement range ± 128 mm

B. 2 outer lasers numbered 0,10
   Sampling frequency 11 kHz
   Stand-off 500 mm
   Measurement range ± 362 mm

C. 4 lasers for compensation factor and crack measurement, numbered 2,4,6, 8
   Sampling frequency 32 kHz
   Stand-off 355 mm
   Measurement range ± 64 mm

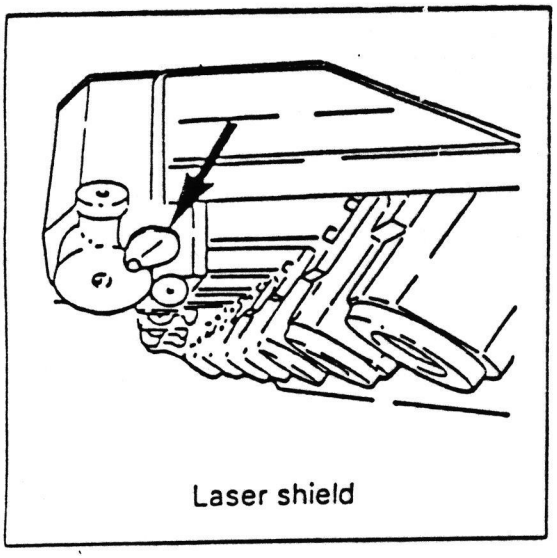


Figure 13. Laser shield operation.

The shield covering each laser must be pushed aside befor starting measurements. For longer transport distances between measurement points, they can be folded down.

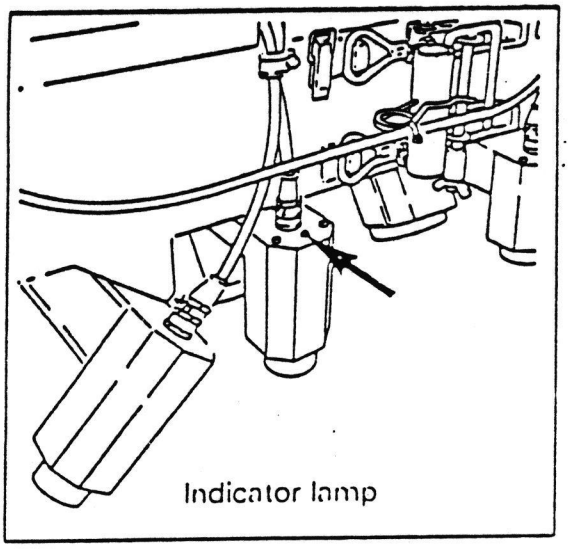


Figure 14. Laser indicator lamp operation.

Each laser has a red indicator lamp that glows when voltage is supplied to the laser.

IMS Infrastructure Management Services

June 17, 1987

Mr. Mark Bradley
Pavement Management Engineer
Arkansas State Highway and Transportation Department
Roadway Design
P.O. Box 2261
Little Rock, Arkansas 72203

Dear Mr. Bradley:

We are looking forward to our demonstration of the Laser Road Surface Tester on June 26, 1987, at 1:30 p.m. at the Arkansas State Highway and Transportation Department Offices.

For your information I am enclosing in this letter additional information on the Laser Road Surface Tester and am also including some literature that describes some of the functions of the RST and a sample output. It should be noted that this output and the parameters of the information can be varied depending on the needs of the client.

The RST gathers objective and accurate data on a continuous basis, i.e., continuous sampling of any test parameter measured. The equipment measures roughness, rut depth, relative transverse section, macrotexture, and unfilled cracks. All data collected is stored on disk on an on-board computer which can also provide hard copy output as testing proceeds.

The RST operates at speeds from 5 m.p.h. to 55 m.p.h. Data collection is speed independent and the accuracy of the data is, therefore, unaffected by variable speeds. Collection of data is unaffected by light, noise, or normal rainfall.

ROUGHNESS MEASUREMENT

The RST is able to output roughness values in IRI (quarter-car) or Mo (root-mean-square vertical acceleration). These values are obtained using a servo-mechanical vertical accelerometer, a 32 khz laser in either wheel path and a distance or speed measuring device. The values are read by an on-board computer in the time domain. Calculations are done internally on a signal processing card (SPC) and results are reported in real time.

3350 SALT CREEK LANE SUITE 117 ARLINGTON HEIGHTS, ILLINOIS 60005 (312) 506-1500

RUT DEPTH MEASUREMENT

The RST has a front laser bar which is made up of seven 16 khz and four 32 khz lasers. Each of these 11 lasers sample the road cross profile. This normally measures a width 3.1 meters or 10.17 feet. The rut depth is calculated for each profile. A straight line drawn between the readings of the outer most lasers serves as a reference. Rut depth can also be calculated using a wire method. The computer also calculates the mean profile standard deviation and the mean greatest rut depth for a given distance. The percentage of road length within any test section having a rut depth exceeding 10mm and 20mm is also printed out. These particular depth parameters (10mm and 20mm) are easily changed to suit a particular client's needs.

CRACK MEASUREMENTS

Cracks are measured by four 32 khz lasers. They are classified into categories of depth and width which can be varied. The output indicates the number of cracks per 100 meters of length. Six different categories of cracks are possible, four at a shallow depth and two at a greater depth. The operator can change the limits for each category. In addition, any cracks or joints seen by two adjacent cameras within a preset distance are recorded in a "both" category.

MACROTEXTURE MEASUREMENTS

Two high-speed 32 khz lasers (one on each wheel path) take many readings of the pavements. These readings record the texture of the pavement. The computer breaks down the texture into various wave forms. Wavelengths between 2mm and 10mm are in the group called fine macrotexture, and wavelengths between 10mm and 80mm are in the group called rough macrotexture. Within each group, a root-mean-square (RMS) is calculated and reported. This RMS is a measure of amplitude. The RMS values for a given length of pavement are distributed into 10 ranges. The macrotexture in each range is reported as a percentage of the total section with RMS in the range. These values are all reported for both the cameras, i.e., in each wheel path.

DISTANCE MEASURING

Longitudinal distances are measured by means of a pulse transducer which has an accuracy of +0.2 percent. The length of an object or section being tested can be done automatically at any interval a client may require, i.e., 10 sections per mile, one-half mile, one mile. The automatic measuring can be overridden manually in the vehicle to record intersections or other locations required by the client.

The operator may also turn off the lasers when travelling on an unrepresentative section, i.e., crossing railway tracks or bridge decks of a different material. This will result in a difference between the length on which data is measured and the section length (both values of which are indicated in the printout), but will ensure that the data collected on the roadway surface is not contaminated by unrepresentative situations.

If you have any questions regarding any of the aforementioned, please feel free to contact me.

Yours very truly,

IMS INFRASTRUCTURE MANAGEMENT SERVICES

Robert L. Novak
Director of Engineering

Encls.

RLN.kjr

Ref: 01-9029A00

Object
---

(1)	Object	6
(2)	Length	200 m
(3)	Measured	200 m
(4)	Speed	78 km/h
(5)	Ocar IRI	1.8 mm/m
	MO	1.0 miles/1000
(6)	Rut Dpth	5.4 mm
	>10.0mm	4 %
	>20.0mm	0 %
(8)	Button 1	0 %
	Button 2	0 %
	Button 3	0 %

(12)Laser Road Surface Tester
hiway Program
June 26. 1987 12:38:47
Ver 03.86c

(11) . . . . . .

(7)	Switches	1 1 1 1 1 1 1 1									
	Mean Prf	0.0	-2.1	-2.3	-4.4	-1.2	-3.3	-1.7	-4.7	-3.7	-3.2	0.0
(11)	Dev Prf	0.0	3.7	3.5	3.3	3.2	3.0	2.9	2.7	2.6	3.0	0.0

		3.0					6.0			
		3.0	6.0	12.0	25.0	6.0	12.0			
		6.0	12.0	25.0	50.0	12.0	25.0	100		
	Crack 1	4	2	4	0	0	0			
(9)	2	1	0	2	0	0	0	4		
	Crack 3	2	0	0	0	0	0			
	4	1	1	1	0	0	0	2		

				0.2	0.3	0.4	0.6	0.9	1.3	2.0	3.0	5.0
		RMS	0.2	0.3	0.4	0.6	0.9	1.3	2.0	3.0	5.0	
	Macro 1											
(10)	Rough	0.26	47	43	5	3	1	1	0	0	0	0
	Fine	0.16	84	15	0	0	0	0	0	0	0	0
	Macro 2											
	Rough	0.20	72	21	4	1	0	0	0	0	0	0
	Fine	0.14	92	8	0	0	0	0	0	0	0	0

Figure 15. Example to be used with EXPLINATION OF RAW DATA page A-31.

EXPLANATION OF RAW DATA COLLECTED WITH THE

* LASER ROAD SURFACE TESTER *

(1) Object: IMS Location Number

(2) Length: Actual length of section in meters

(3) Measured: Length of test section sampled, normally (2) & (3) are equal

(4) Speed: Average speed of RST over test section

(5) Quartr car: A ride quality index standard measured in mm per km.

RMSVA (MO): A secondary ride standard of root mean squared verticle acceleration.

(6) Rutdepth: Average rutdepth over the test section of the deepest rut (sampling dist = 5 meters)

> 10 mm: Percentage of the test section with rutdepth greater than 10 mm

> 20 mm: Percentage of the test section with rutdepth greater than 20 mm

(7) Switches: Eight toggle switches for subjective input of environmental and inventory data

(8) No 1: Buttons for measuring lengths within a test section - - Value
No 2: is a percentage of the test section length during which the
No 3: button was depressed

(9) Cracking:

		Depth #1 (3mm-->6mm)				Depth #2 (6mm +)		MC * 6.0
Laser	#	Width #1 3->6 mm	W #2 6->12mm	W #3 12 ->25mm	W #4 25->50 mm	W #2 6->12mm	W #3 12 ->50mm	*Both
crack	1	60	26	14	0	5	4	
	2	38	27	9	0	4	5	22
	4	14	9	4	0	0	1	
	3	23	15	2	0	4	3	14

* Values in the "Both" category indicate numbers of cracks which both laser #1 and #2, or laser #3 and #4 measured at the same time

* MC is Macrotexture Compensation Factor

Note! All values indicate number of cracks per 100 meters

EXPLANATION OF RAW DATA COLLECTED WITH THE

* LASER ROAD SURFACE TESTER *

(10) Macrotexture:

RMS values meas. in mm	rms	0.2	0.2 / 0.3	0.3 / 0.4	0.4 / 0.6	0.6 / 0.9	0.9 / 1.3	1.3 / 2.0	2.0 / 3.0	3.0 / 5.0		
			Category limits in mm									
macro 1												
rough	0.83	0	8	28	25	19	7	8	3	0.0	0.0
fine	0.63	0	2	17	43	28	6	1	0	0.0	0.0
macro 4												
rough	0.54	2	48	14	14	10	6	1	0.0	0.0	0.0
fine	0.57	0	6	2	66	21	1	1	0.0	0.0	0.0

Explanation of terms:

RMS: Root Mean Square of the surface texture in mm

macro 1: Texture of left wheel path

4: Texture of right wheel path

rough: Surface texture with wavelength between 10mm and 80mm

fine: Surface texture with wavelength between 0mm and 10mm

(11) Profile: Average transverse profile of lane tested

_ · · · · · · · · · · · · _

Mean Profile: Average elevation of each laser above or below the line projected between lasers 1 and 11

Deviation: The standard deviation of each laser within the test section from the mean profile

(12) Date tests were made.

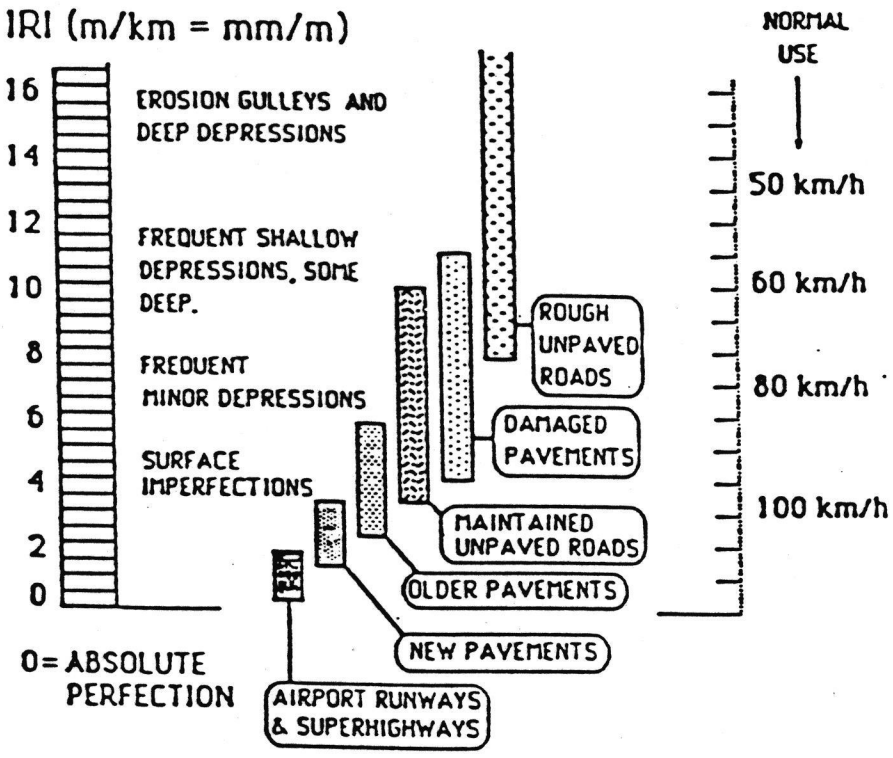


Figure 16. The IRI roughness scale.

Object

Laser Road Surface Tester
hiway Program
June 26. 1987 12:38:47
Ver 03.86c

Object	1
Length	200 m
Measured	200 m
Speed	27 km/h
Ocar IRI	2.9 mm/m
MQ	3.2 miles/1000
Rut Depth	5.2 mm
>10.0mm	1 %
>20.0mm	0 %
Button 1	0 %
Button 2	0 %
Button 3	0 %
Switches	1 1 1 1 1 1 1 1

Mean Prf	0.0	0.9	0.7	-2.0	1.6	-1.0	1.0	-2.1	-0.7	-0.2	0.0
Dev Prf	0.0	3.4	4.2	4.6	4.7	5.2	5.2	5.4	5.3	4.9	0.0

	3.0				6.0		
	3.0	6.0	12.0	25.0	6.0	12.0	
	6.0	12.0	25.0	50.0	12.0	25.0	100
Crack 1	5	1	1	0	0	2	
2	3	2	0	0	0	2	4
Crack 3	3	0	0	0	0	1	
4	5	1	0	0	2	0	2

			0.2	0.3	0.4	0.6	0.9	1.3	2.0	3.0	5.0
	RMS	0.2	0.3	0.4	0.6	0.9	1.3	2.0	3.0	5.0	
Macro 1											
Rough	0.49	25	46	9	2	2	0	1	0	1	0
Fine	0.21	[illegible]	45	1	1	1	0	0	0	0	0
Macro 2											
Rough	0.40	43	31	16	7	0	0	1	0	0	0
Fine	0.20	55	42	0	0	1	0	0	0	0	0

Figure 17. Laser RST data printout 000 to 200 meters.

Object

Laser Road Surface Tester
hiway Program
June 26. 1987 12:38:47
Ver 03.86c

Object	2
Length	200 m
Measured	200 m
Speed	76 km/h
Mean IRI	1.5 mm/m
MB	1.3 miles/1000
Rut Path	7.4 mm
>10.0mm	7 %
>20.0mm	0 %
Button 1	0 %
Button 2	0 %
Button 3	0 %
Switches	1 1 1 1 1 1 1 1

Mean Prf	0.0	-2.3	-3.6	-3.6	1.7	1.8	2.8	-2.3	-3.5	-3.5	0.0
Dev Prf	0.0	3.4	3.3	3.0	2.5	2.8	3.2	2.8	1.9	2.8	0.0

	3.0				6.0		
	3.0	6.0	12.0	25.0	6.0	12.0	
	6.0	12.0	25.0	50.0	12.0	25.0	100
Crack 1	2	0	0	0	0	0	
2	0	0	0	0	0	0	0
Crack 3	0	0	0	0	0	0	
4	0	0	0	0	0	0	0

			0.2	0.3	0.4	0.6	0.9	1.3	2.0	3.0	5.0
	RMS	0.2	0.3	0.4	0.6	0.9	1.3	2.0	3.0	5.0	
Macro 1											
Rough	0.24	35	31	9	3	0	0	0	0	0	0
Fine	0.30	12	47	29	11	0	0	0	0	0	0
Macro 2											
Rough	0.11	93	5	0	0	0	0	0	0	0	0
Fine	0.21	58	33	5	2	0	0	0	0	0	0

Figure 18. Laser RST data printout 200 to 400 meters.

Object

Object	3
Length	200 m
Measured	200 m
Speed	76 km/h
Ocar IRI	0.7 mm/m

Laser Road Surface Tester
hiway Program
June 26. 1987 12:38:47
Ver 03.86c

REMAINDER OF REPORT MISSING.

Figure 19. Laser RST data printout 400 to 600 meters.

Object

Laser Road Surface Tester
hiway Program
June 26. 1987 12:38:47
Ver 03.86c

Object	4
Length	200 m
Measured	200 m
Speed	79 km/h
Ocar IRI	2.2 mm/m
MO	2.1 miles/1000
Rut Dpth	6.1 mm
>10.0mm	8 %
>20.0mm	3 %
Button 1	0 %
Button 2	0 %
Button 3	0 %
Switches	1 1 1 1 1 1 1 1

Mean Prf	0.0	-1.2	-1.8	-3.9	-0.9	-3.4	-1.8	-4.4	-2.9	-2.2	0.0
Dev Prf	0.0	4.5	4.1	4.0	4.2	3.9	3.8	3.2	3.3	5.0	0.0

	3.0				6.0		
	3.0	6.0	12.0	25.0	6.0	12.0	
	6.0	12.0	25.0	50.0	12.0	25.0	100
Crack 1	2	2	4	1	0	1	
2	5	2	2	0	0	0	5
Crack 3	2	2	1	0	0	0	
4	2	0	1	0	0	0	1

			0.2	0.3	0.4	0.6	0.9	1.3	2.0	3.0	5.0
	RMS	0.2	0.3	0.4	0.6	0.9	1.3	2.0	3.0	5.0	
Macro 1											
Rough	0.26	53	40	2	2	0	0	1	0	0	0
Fine	0.13	83	15	0	0	0	0	0	0	0	0
Macro 2											
Rough	0.19	65	30	3	1	0	0	0	0	0	0
Fine	0.14	89	11	0	0	0	0	0	0	0	0

Figure 20. Laser RST data printout 600 to 800 meters.

Object

Laser Road Surface Tester
hiway Program
June 26. 1987 12:38:47
Ver 03.86c

Object	5
Length	200 m
Measured	200 m
Speed	81 km/h
Rear [5]	2.0 mm/m
MM	1.1 miles/1000
Rut Depth	5.6 mm
[illegible]mm	6 %
120.[illegible]mm	2 %
Button 1	0 %
Button 2	0 %
Button 3	0 %
Switches	1 1 1 1 1 1 1 1

Mean Prf	0.0	2.2	-2.0	-2.6	-0.3	-2.3	-1.0	-4.0	-2.8	-2.2	0.0
Dev Prf	0.0	5.5	5.0	4.6	4.3	3.9	3.6	3.4	3.2	5.9	0.0

	3.0				6.0		
	3.0	6.0	12.0	25.0	6.0	12.0	
	6.0	12.0	25.0	50.0	12.0	25.0	100
Crack 1	1	1	1	0	0	0	
2	0	0	0	0	0	0	1
Crack 3	1	0	0	0	0	0	
4	4	1	2	0	0	0	1

			0.2	0.3	0.4	0.6	0.9	1.2	2.0	3.0	5.0
	RMS	0.2	0.3	0.4	0.6	0.9	1.2	2.0	2.0	5.0	
Macro 1											
Rough	0.21	74	21	2	1	0	0	0	0	0	0
Fine	0.15	83	12	0	0	0	0	0	0	0	0
Macro 2											
Rough	0.19	80	14	2	2	0	0	0	0	0	0
Fine	0.12	94	3	0	0	0	0	0	0	0	0

Figure 21. Laser RST data printout 800 to 1000 meters.

Laser Road Surface Tester
hiway Program
June 26. 1987 12:38:47
Ver 03.86c

Object

Object	6
Length	200 m
Measured	200 m
Speed	78 km/h
Ocar IRI	1.8 mm/m
MO	1.0 miles/1000
Rut Dpth	5.4 mm
>10.0mm	4 %
>20.0mm	0 %
Button 1	0 %
Button 2	0 %
Button 3	0 %
Switches	1 1 1 1 1 1 1 1

Mean Prf	0.0	-2.1	-2.3	-4.4	-1.2	-3.3	-1.7	-4.7	-3.7	-3.2	0.0
Dev Prf	0.0	2.7	3.5	3.2	3.2	3.0	2.9	2.7	2.6	3.0	0.0

	3.0					6.0					
	3.0	6.0	12.0	25.0	6.0	12.0					
	6.0	12.0	25.0	50.0	12.0	25.0	100				
Crack 1	4	2	4	0	0	0	4				
2	1	0	2	0	0	0					
Crack 3	2	0	0	0	0	0	2				
4	1	1	1	0	0						

			0.2	0.2	0.4	0.6	0.9	1.3	2.0	3.0	5.0
			0.3	0.4	0.6	0.9	1.3	2.0	3.0	5.0	
	RMS	0.2									
Macro 1											
Rough	0.26	47	43	5	3	1	1	0	0	0	0
Fine	0.16	84	15	0	0	0	0	0	0	0	0
Macro 2											
Rough	0.20	72	21	4	1	0	0	0	0	0	0
Fine	0.14	92	8	0	0	0	0	0	0	0	0

Figure 22. Laser RST data printout 1000 to 1200 meters.

TRC 8802 B

PAVEMENT MANAGEMENT SURVEILLANCE SYSTEMS EVALUATION

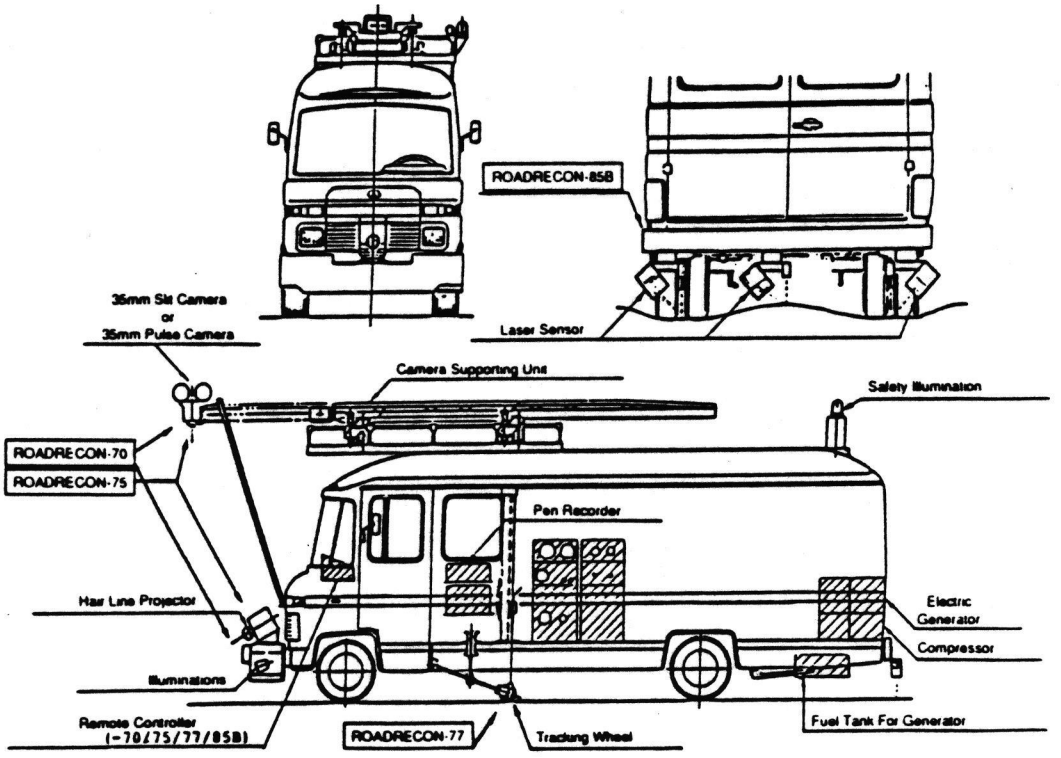
APPENDIX B
TO
FINAL REPORT

TRANSPORTATION RESEARCH PROJECT NO. TRC8802

NOVEMBER 1988

PREPARED BY
ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT
MATERIALS AND RESEARCH DIVISION
RESEARCH SECTION
IN COOPERATION WITH
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

APPENDIX B



PASCO'S ROADRECON SERIES

The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the Arkansas State Highway and Transportation Department or the Federal Highway Administration.

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INTRODUCTION TO PASCO

The PASCO ROADRECON series of devices is the Japanese answer to the collection and analysis of data on pavement condition for use in making pavement rehabilitation and design decisions.

The ROADRECON- model number reflects PASCO's historical development of these devices. A summary of PASCO's ROADRECON series of devices is contained in Table 1. The PASCO Corporation of Japan developed the continuous surface photographing device, ROADRECON-70, and in 1970 produced the first unit. ROADRECON-70 is shown in schematic form in Figure 1. In 1975, development and production of a photographic rutting measurement survey device, ROADRECON-75, was completed. This device, based upon a process developed by a Japanese national and published in 1937 and pictured in Figure 2, is capable of providing very accurate site specific rut depth measurements at preset sample intervals. Development of the automated system of analyzing the rutting measurements using a digitizing table was completed in 1983. The PASCO ROADRECON series of devices is capable of making measurements with two types of longitudinal profilers. One longitudinal profiler uses a tracking wheel, an accelerometer, and a differential transformer to measure surface elevations in the outer wheel path, ROADRECON-77. A schematic illustration is shown in Figure 3. The other longitudinal profiler measures the distance between the vehicle body and the road surface using three infrared lasers, one in each wheel path and the other in the center of the vehicle, ROADRECON-85B. This device which is schematically illustrated in Figure 4 is also used as an approximation of rut depth since each wheel path is measured. A schematic picture of the various ROADRECON series is shown in Figure 1. When looking at Figure 5 you should understand that all of the ROADRECON series are mounted in the same vehicle at the same time.

1965	Design of Automatic Continuous Road Surface Photographic Recorder on Vehicle (ROADRECON-70) was begun.
1970	First ROADRECON-70 was implemented.
1975	First Automatic Rut Depth Photographic Recorder (ROADRECON-75) was implemented.
1977	First longitudinal roughness survey equipment (ROADRECON-77) was implemented.
1980	Design of Laser Sensor Longitudinal Roughness Survey Equipment (ROADRECON-85) was begun.
1982	Design of Automated Film Analyzing System for Rutting Measurement was begun.
1983	Automated Film/Data Analyzing System with Digitizing Tablet was developed.
1984	Laser Sensor Longitudinal Roughness Survey Equipment (ROADRECON-85) was developed.
1986	Patent of New Laser Camera Logging System was filed. Development of Laser Disk Based Pavement Condition Data/Image Retrieval System was begun.

Table 1. A summary of PASCO's ROADRECON development history.

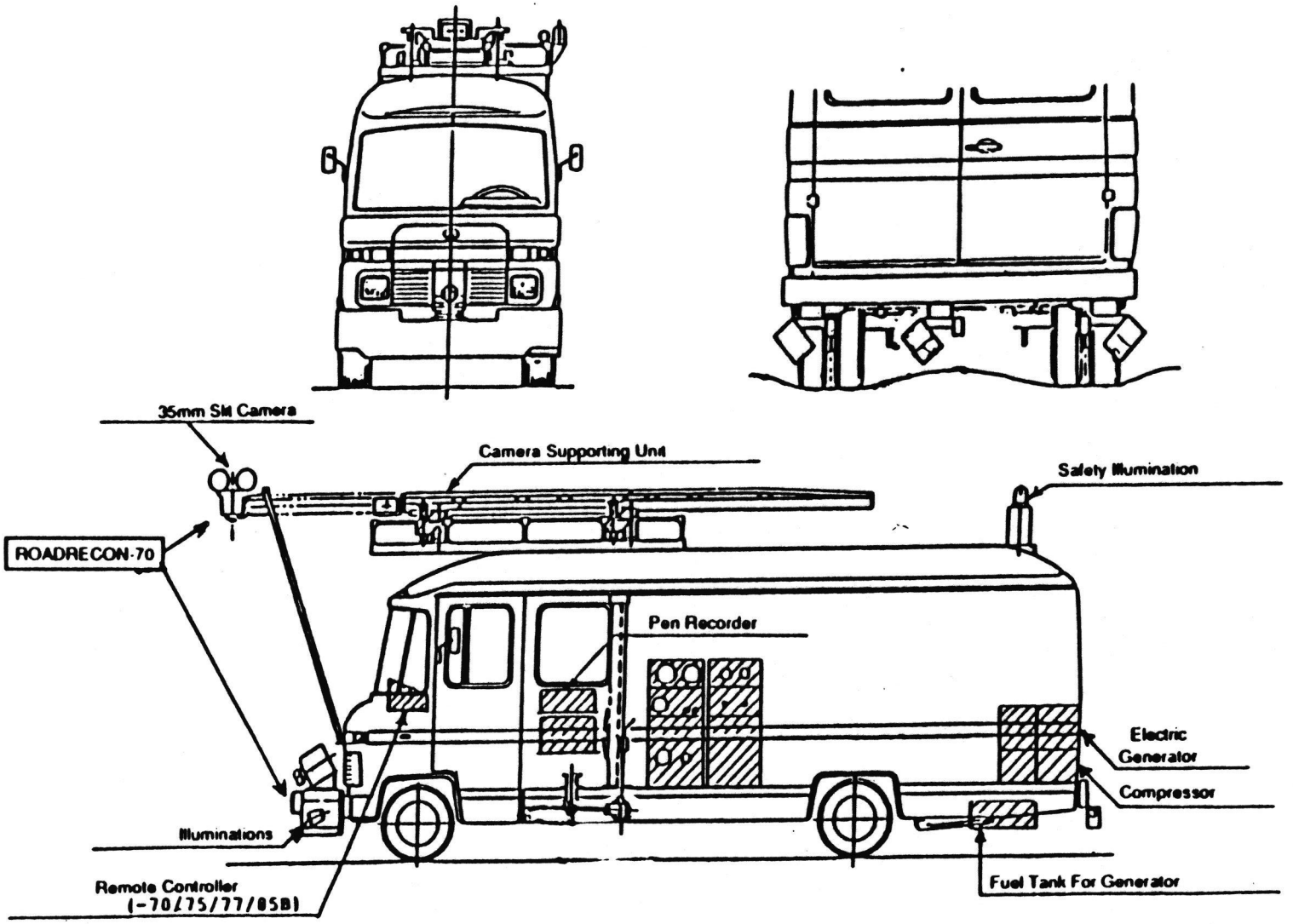


Figure 1. A schematic illustration of ROADRECON-70.

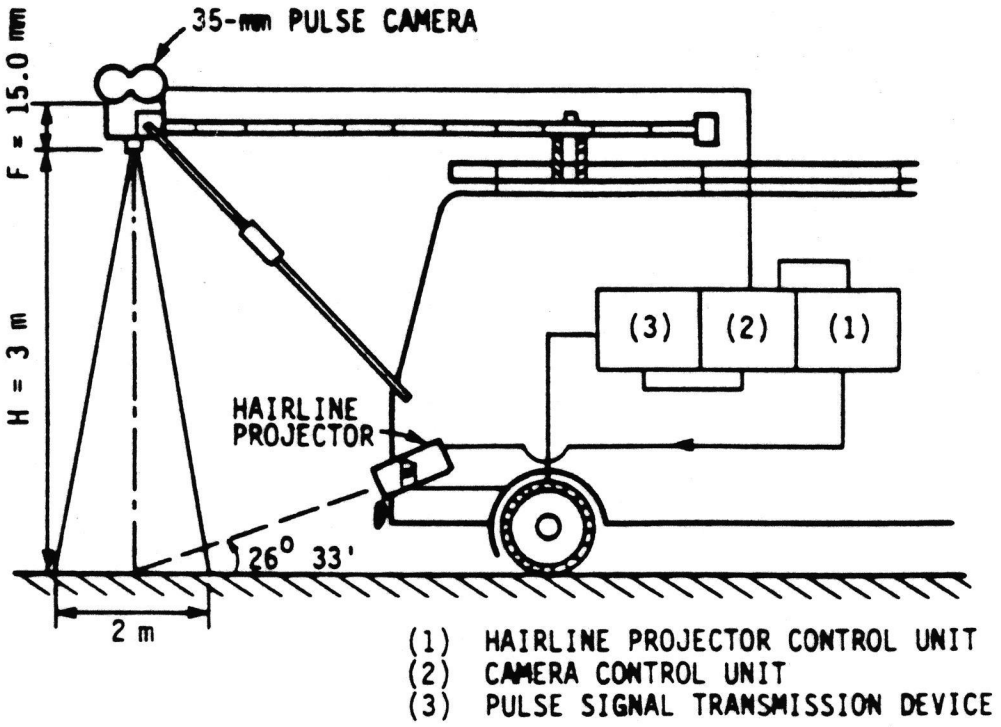


Figure 2. ROADRECON-75.

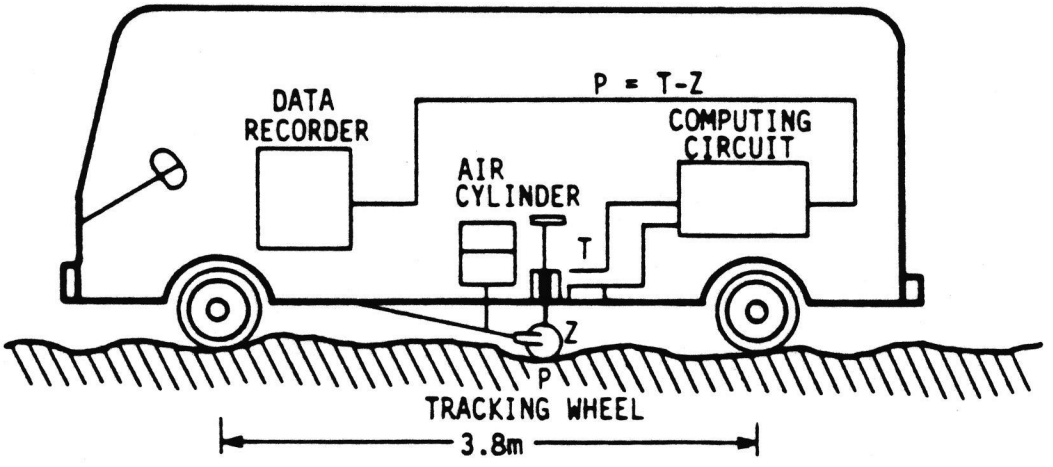
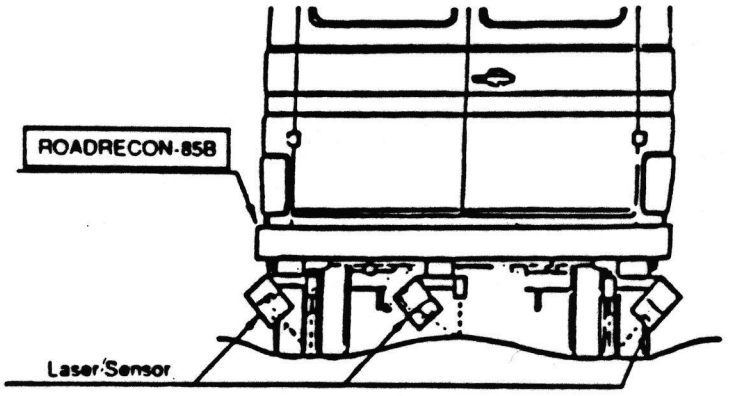


Figure 3. ROADRECON-77.



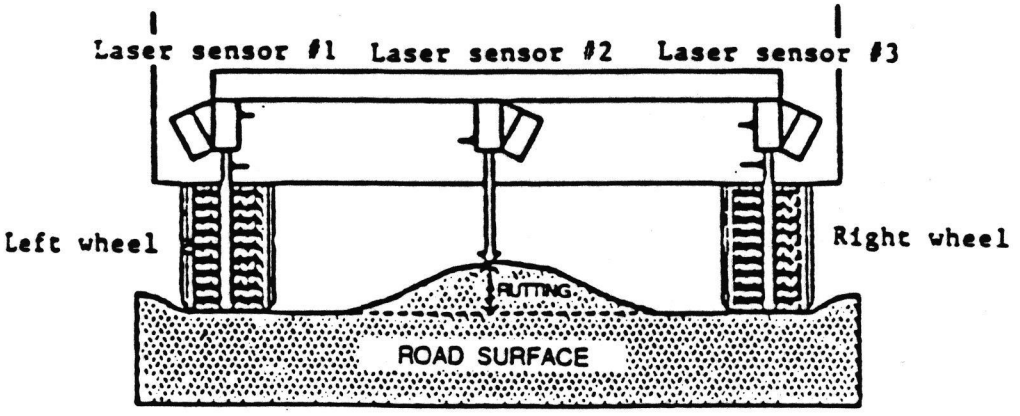


Figure 4. ROADRECON-85B.

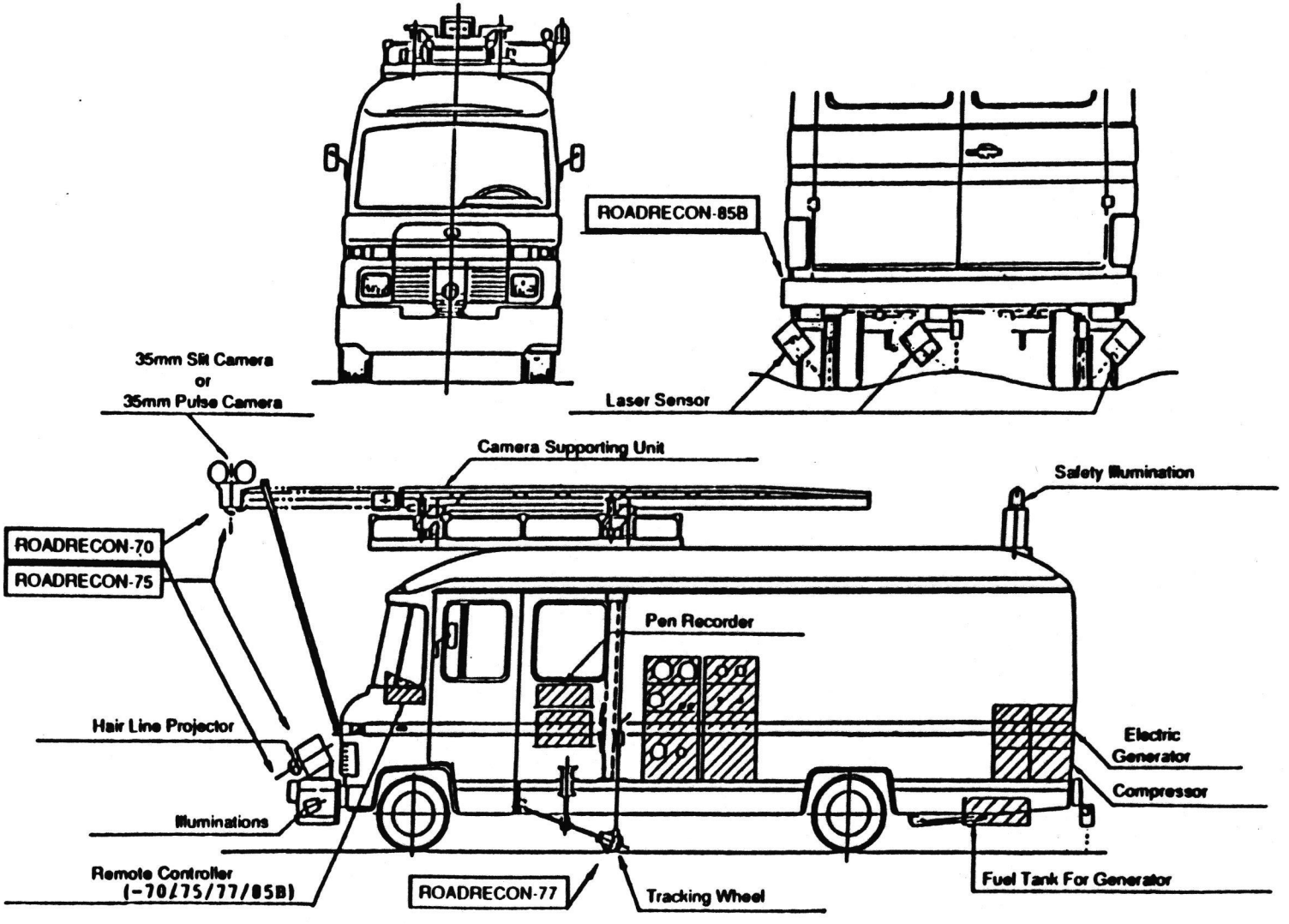


Figure 5. The ROADRECON series of survey instruments.

MAINTENANCE CONTROL INDEX MCI

When pavement condition is evaluated all available distress information should be considered. This is done so that a proper maintenance schedule can be developed. The PASCO system is configured to give surface condition information with respect to surface distress. The distress values, as used in PASCO's Maintenance Control Index (MCI), are roughness, cracking, patching, and rut depth. PASCO's MCI varies from 0(bad) to 10(good) as an overall estimate of the condition of the road.

The extent of cracking and patching of the road surface is determined with the ROADRECON-70 by obtaining continuous strips of photographs taken in the night time with a slit camera. Rut depth is determined when a hairline is projected at an angle and the projected image is photographed by a pulse camera, ROADRECON-75. Roughness is measured either as the movement of a wheel as measured in the vertical direction with an accelerometer as in ROADRECON-77 or as in ROADRECON-85B where the distance is measured with a laser beam.

The present condition of the road is evaluated and the future condition of the road is predicted from the values for cracking, patching, rut depth, and roughness as obtained above. The PASCO method computes an MCI from the equations:

1. When all data is available:
   $MCI = 10-1.48CR^{0.3} - 0.29RD^{0.7} - 0.47SD^{2}$. (1)
   Where CR = cracking ratio as a percent with all types of cracking and patching being lumped together.
   RD = rut depth in mm
   SD = longitudinal roughness in mm.

2. Where all data but roughness is available:
   $MCI = 10 - 1.51CR^{0.3} - 0.30RD^{0.7}$.
   Where CR = cracking ratio as a percent with all types of cracking and patching being lumped together.
   RD = rut depth in mm

3. Where only cracking ratio is available
   $MCI = 10 - 2.23CR^{0.3}$
   Where CR = cracking ratio as a percent with all types of cracking and patching being lumped together.

4. Where only rut depth is available
   $MCI = 10 - 0.54RD^{0.7}$
   Where RD = rut depth in mm.

PASCO uses the continuous photographs from ROADRECON-70's 35mm slit camera to interpret and measure the area of all cracking to obtain CR. The RD is measured from photographs of a hairline, projected at an angle, taken by a pulse camera, ROADRECON-75. The longitudinal roughness (SD) is measured either by ROADRECON-77 or by ROADRECON-85B. The ROADRECON-77 system uses a tracking wheel fitted with a differential transformer and a Servo accelerometer to measure longitudinal roughness, whereas the ROADRECON-85B uses three noncontact laser sensors to measure longitudinal profile and roughness.

ROADRECON-70

The ROADRECON-70 system uses a 35mm slit camera to obtain continuous strip photographs of the driven lane. The camera's slit aperture is 1.06 in. (27mm) long and can vary in width from 0.004 in. to 0.04 in. (0.1mm to 1.0mm). The lens has a focal length of 0.57 in. (14.5mm) with F/3.5. These features are illustrated in Figures 6 & 7.

The camera is mounted on a boom on top of the survey vehicle as shown in Figure 1, about 2.9 meters above the ground. This results in a photographic scale of 1.200. Because the slit size is 1.06 in. (27mm). the photographs cover over 5 meters of road width. The film speed and camera aperture size are synchronized with the vehicle speed to produce a continuous strip of photographs. With a standard 1,000 foot roll of film, 37.3 mi.(60km) of roadway can be photographed. This system can be operated between speeds of 1.24 mph(2kmph) and 49.7mph(80kmph). The system which can be operated during the day or night, uses a bank of 10 halogen lamps mounted under the front bumper to provide constant intensity of illumination. Data flow is illustrated in Figure 8.

The film is processed by an automatic film processor. The processed positive film is enlarged 10 times and projected onto a digitizing board (see Figure 9). A grid system, using a grid cell of 0.02X0.02 inches (0.5mmX0.5mm), is overlaid onto the projected area (see Figure 9). A key is used to interpret cracks and patches from the projected image as shown in Figure 10 & 11. The area of the interpreted patches and cracks is measured by counting the number of squares containing the determined distress. The CR in equation (1) is then given by:

$$CR = \text{The crack ratio}$$

$$= \frac{\text{Length of crack in meters X 0.3m X 100}}{\text{Total area in meters squared}}$$

$$= \frac{\text{Crack area } (m^2) \text{ X 100}}{\text{Total area } (m^2)}$$

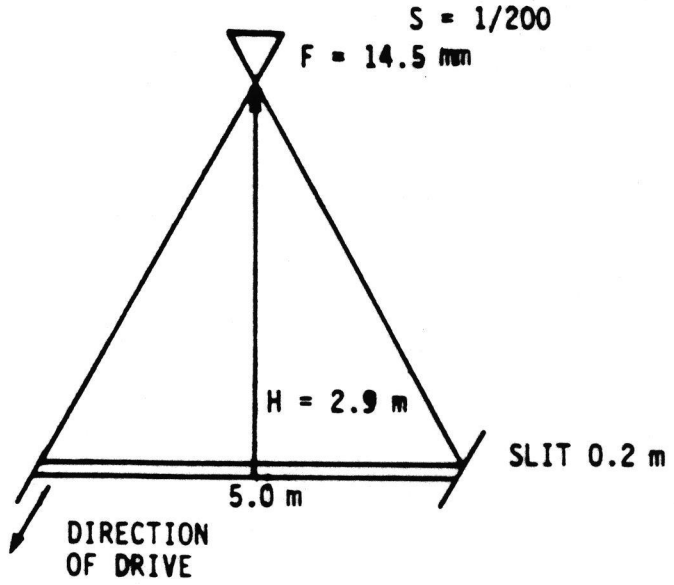


Figure 6. The ROADRECON-70 area of coverage.

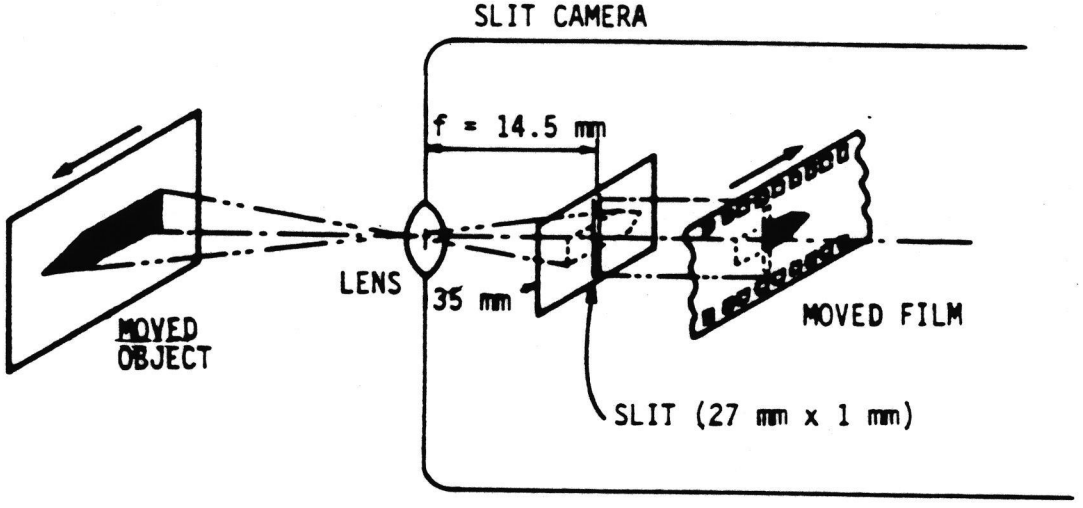


Figure 7. Slit camera theory of operation.

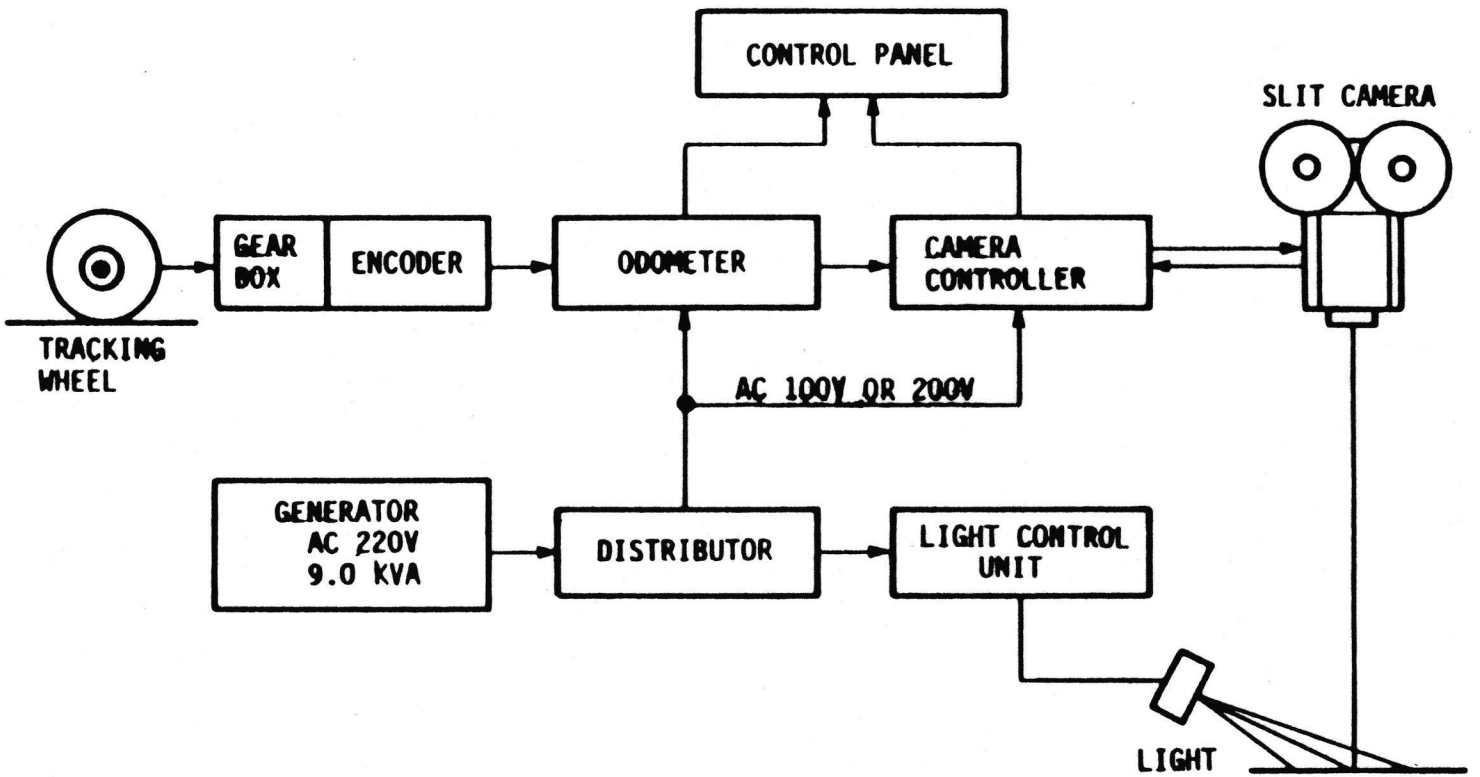
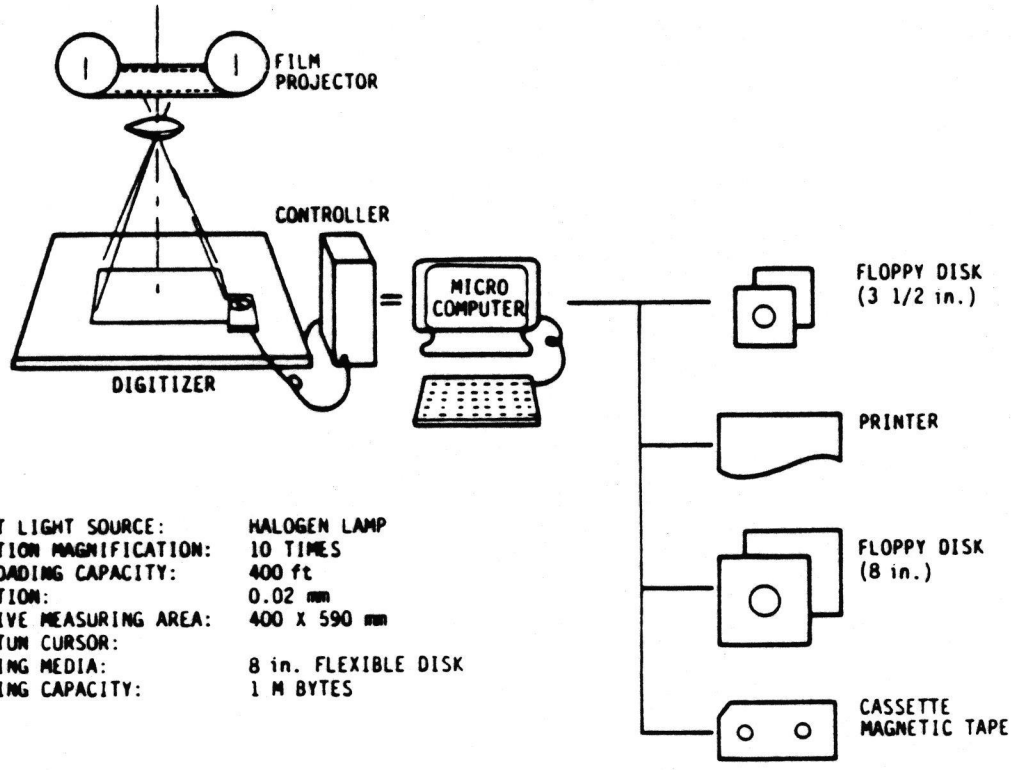
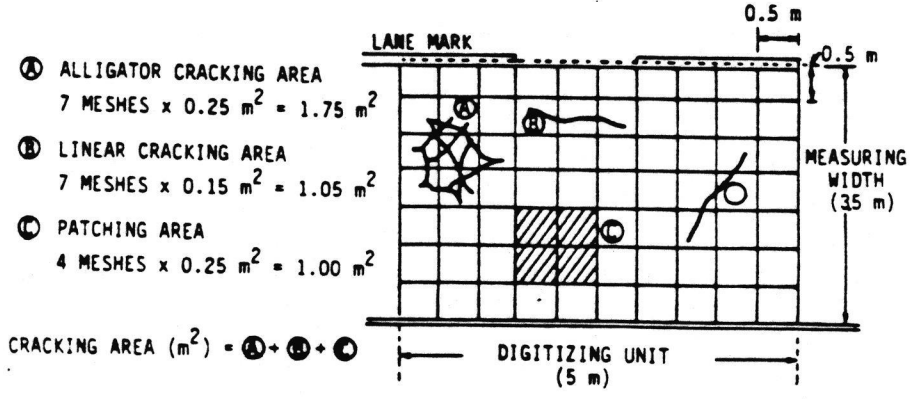


Figure 8. Schematic configuration of ROADRECON-70.



ROADRECON film digitizer.



Grid overlay used in crack digitizing.

Figure 9. ROADRECON digitizer and grid overlay.

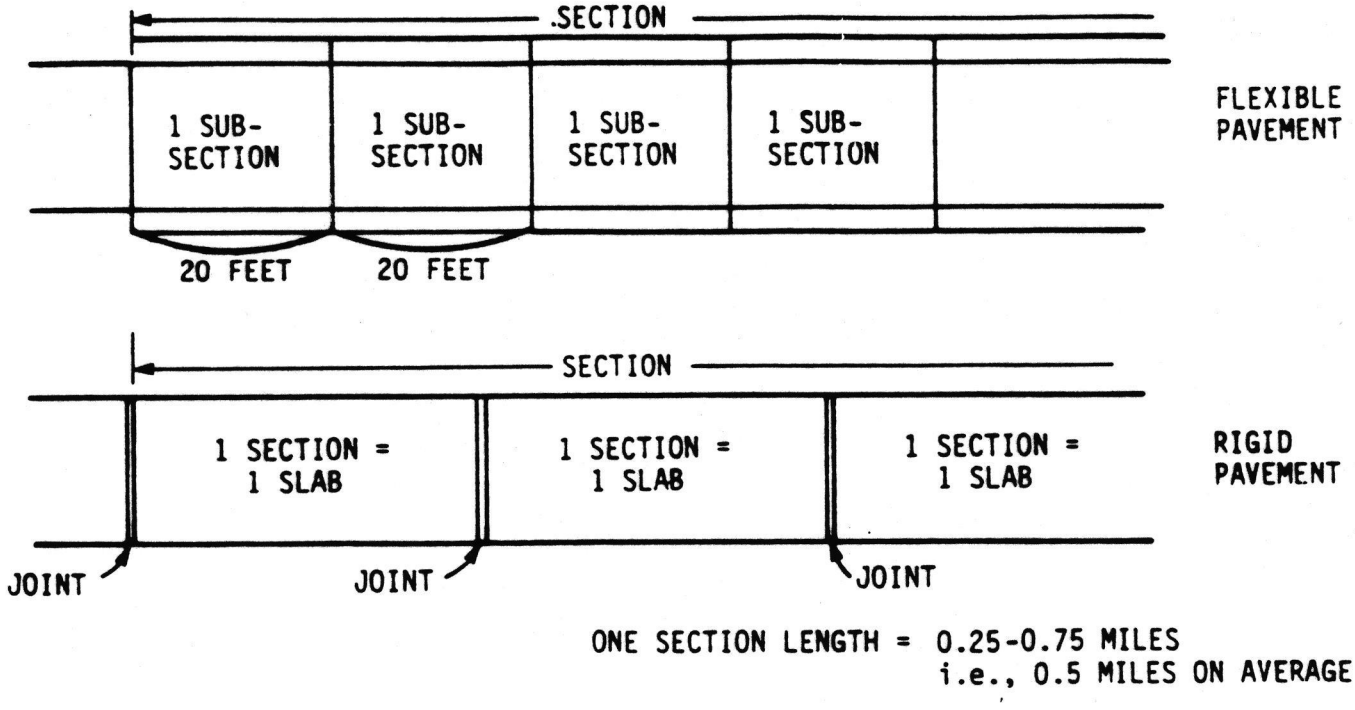


Figure 10. Defination of subsection.

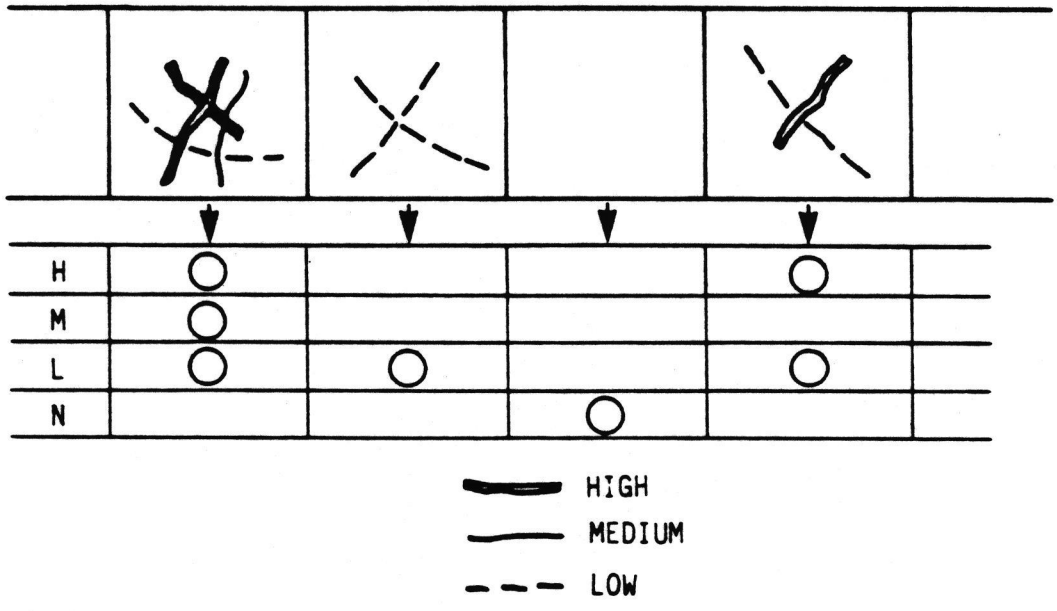


Figure 11. Interpretation of cracking on ROADRECON film.

The ROADRECON-75 system uses a 35 mm pulse camera and a hairline projector strobe light to photograph rutting wave patterns. A schematic illustration of this device is shown in Figure 2.

Figure 12 shows the projection of a hairline on the cross section of a road. If there is no rutting present, the hairline will be projected as a straight line SS'. However, if rutting is present a rutting wave pattern, LHM, will be observed. The hairline at the high point H will be projected as H_1 and at the low point L will be projected as L_1. The distance D_1 of H_1 from SS' is proportional to the height of rutting HH_1 and distance D_2 of L_1 from SS' is proportional to the depth of the rutting. If the projected line is photographed by a vertical camera directly above line SS', as shown in Figure 13, then, the distance:

$$D_1 = H/f(d_1)$$

and $$D_2 = H/f(d_2)$$

where

f = focal length of the camera
H = height above mean ground

The rut height = $HH_1 = D_1 \tan \theta$.
The rut depth = $LL_1 = D_2 \tan \theta$.
RD (total rut depth) = $D_1+D_2) \tan \theta$.
$= H/f(d_1+d_2) \tan \theta$.
$= S \tan \theta \ (d_1+d_2)$

Where S is equal to the scale of the photograph.

In the ROADRECON-75 system the strobe light is mounted on the front bumper of the survey vehicle and projects a hairline at an angle $\theta = 26^{o}33'$, such that $\tan \theta = .5$ (rounded). The camera, mounted on a boom on top of the vehicle and positioned forward of the vehicle, photographs the lane in which the vehicle is traveling (see Figure 14). The camera is aimed straight down so any rutting is represented by a wave pattern in the hairline. The focal length of the camera, f = 0.6 in.(15mm), and the height of the camera above the ground, H = 120 in. (3000mm), results in a scale for the photograph of S=200. Thus the total rut depth is given by the equation:

$$RD = 200(d_1+d_2).5$$

The accuracy of these measurements may be found and is dependent upon the method used to determine the measurement of d_1 and d_2. There are two means of measuring these values. One is by using a comparator, the other is by using a digitizing tablet, see Figure 9. The comparator is a photogrametric instrument used to measure x-y coordinates on a photograph. If a comparator is used to obtain measurement of d_1 and d_2 then the accuracy of d_1 and d_2 are each ±0.0002 in. (±0.005mm). However, if a digitizing tablet is used the measurements of d_1 and d_2 have an accuracy of ±0.0008 in. (±0.02mm).

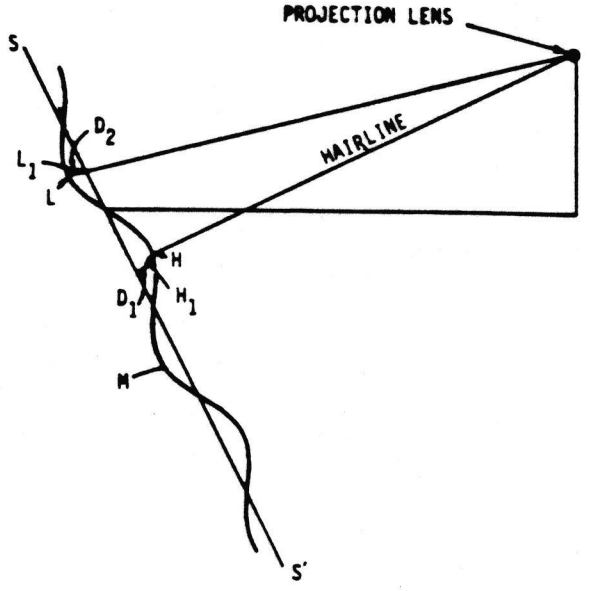


Figure 12. Hairline projection.

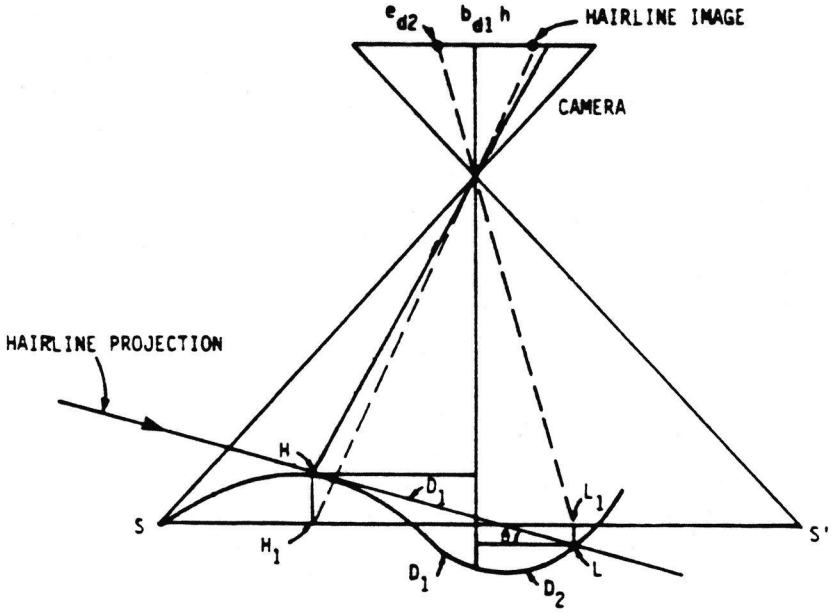


Figure 13. Theory of measurement determination using an enlarged projection.

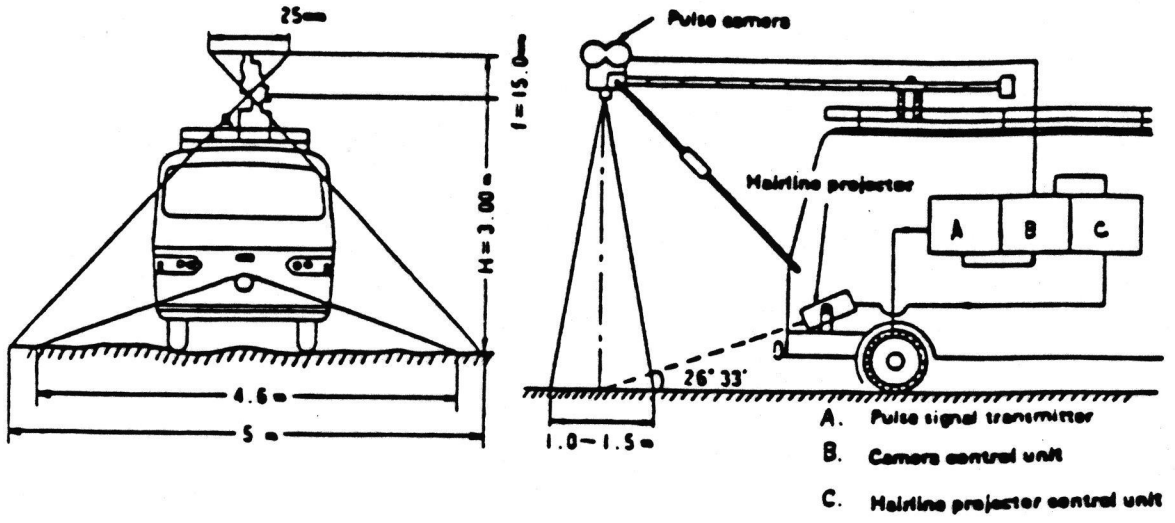
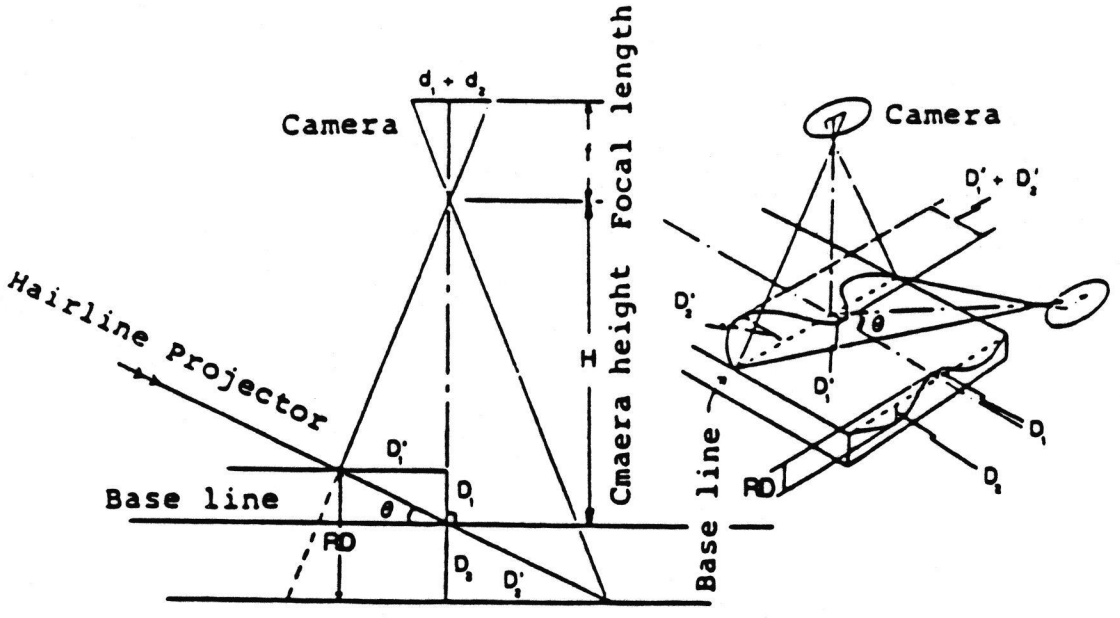


Figure 14a. Schematic representation of ROADRECON-75 mounted in a vehicle.



RD : Rut depth

$d_1 + d_2$: Rut depth as observed in photo (rd)

θ : Projection angle of hairline projector

Figure 14b. Geometric relations between the Optical Bar and the Pulse Camera.

Thus accuracy of RD using a comparator is

$$
\begin{aligned}
RD &= \pm 200\ ((.0002)+(.0002)).5 \\
&= \pm 100\ (.0004) \\
&= \pm 0.04 \text{ in.} \\
\text{or} \quad &= +200((.005)+(.005)).5 \\
&= \pm 100(.01) \\
&= \pm 1.0 \text{ mm}
\end{aligned}
$$

while accuracy of RD using a digitizing tablet is

$$
\begin{aligned}
RD &= \pm 200((0.0008)+(0.0008)).5 \\
&= \pm 100(0.0016) \\
&= \pm 0.16 \text{ in.} \\
\text{or} \quad &= +200((0.02)+(0.02)).5 \\
&= +100(0.04) \\
&= \pm 4 \text{ mm}
\end{aligned}
$$

The accuracy of rut measurements using a comparator is ±0.04 inches (1.0mm) while the accuracy using a digitizing tablet is ±0.16 inches (4.0mm).

This system can operate only at night because daylight may interfere with resolution of the hairline projection. The system can operate at speeds between 0 and 50 mph(80kmh). Both the strobe light and the camera shutter are triggered at given intervals of pavement travel. Intervals between 4 inches (0.1m) and 328 feet (99.9m) of pavement travel can be selected.

The camera has a maximum frame rate of ten frames per second in the pulse mode. The exposure time is about 1/64 sec. The film magazine has a loading capacity of 400 feet of film so that in the case of photographing at a regular interval of 66 feet (20m), for example, approximately 62.1 miles (100km) can be covered by one magazine load of film.

ROADRECON-77

The ROADRECON-77 uses a tracking wheel to measure longitudinal roughness of a road surface. The roughness is measured by a differential transformer and a Servo accelerometer attached to the tracking wheel. A schematic illustration of the arrangement is shown in Figure 3. The tracking wheel is arranged such that it measures the roughness in the right wheel path of the lane in which the survey vehicle is traveling. An accelerometer, attached to the tracking wheel or profile detector, measures the vertical acceleration and feeds the information to an on-board computer. The computer performs the necessary integration to determine the vertical displacement z. Thus

$$z = \int(\int a_z dt)\ dt = \Sigma a_{zi} dt^2$$

where a_z is acceleration and dt is the time interval. In road roughness, R=T-Z, T is the total displacement between the vehicle and the road, which the differential transformer computes. The roughness is then plotted on a chart and also saved on computer cassette tape. By using the proper encoder, the speed and the distance traveled by the survey vehicle are also fed into the on-board computer, which saves this information on the cassette tape and also plots it on the paper chart. A schematic illustration of the various components of this system is presented in Figure 15. An example of the paper chart printout is shown in Figure 16. The computer also computes the total cumulative roughness value, TCR, where

$$TCR = \Sigma \left| R_i - R_{i+1} \right|.$$

Tick marks are made on the paper chart to indicate every 10mm accumulation of TCR. Thus, total roughness between distances can be directly read on the paper chart. The longitudinal roughness, SD, as used in Equation 1 is then obtained by:

$$SD = \sqrt{\frac{\Sigma\ (R_i - \bar{R})^2}{n - 1}},$$

where

$$\bar{R} = \frac{\Sigma R_i}{n},$$

The R values saved on the cassette tape can be used to compute SD. Alternately, the device can be calibrated against a standard profilometer so that the correlation equation between the two systems can be determined. The TCR value and the correlation equation can then be used to determine the SD values.

The ROADRECON-77 can operate day or night at speeds between 0 and 25 mph. One cassette tape can hold data on 80 miles of roadway. The scale of the pen chart can be set at 1:100; 1:200, 1:400, or 1:500. The accuracy of the system is ±0.04 in. (±1mm).

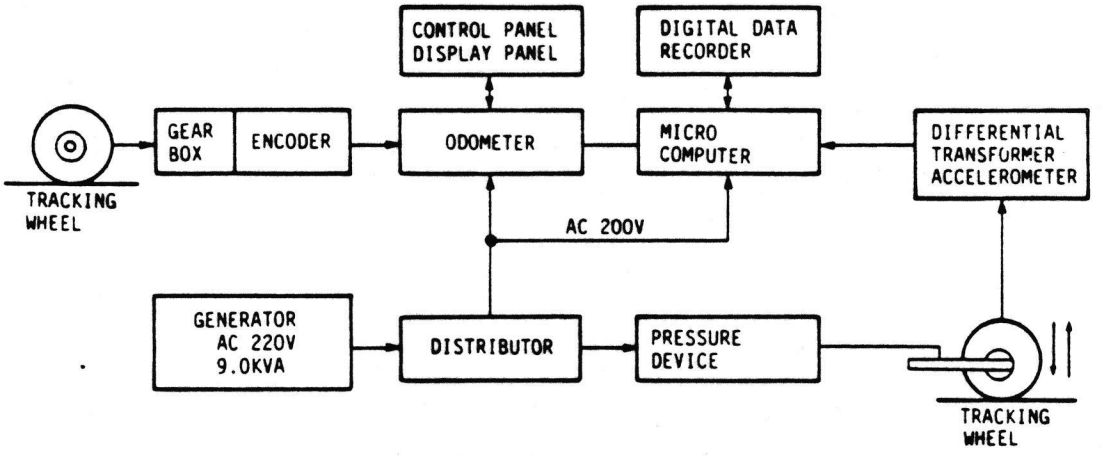


Figure 15. A schematic representation of ROADRECON-77.

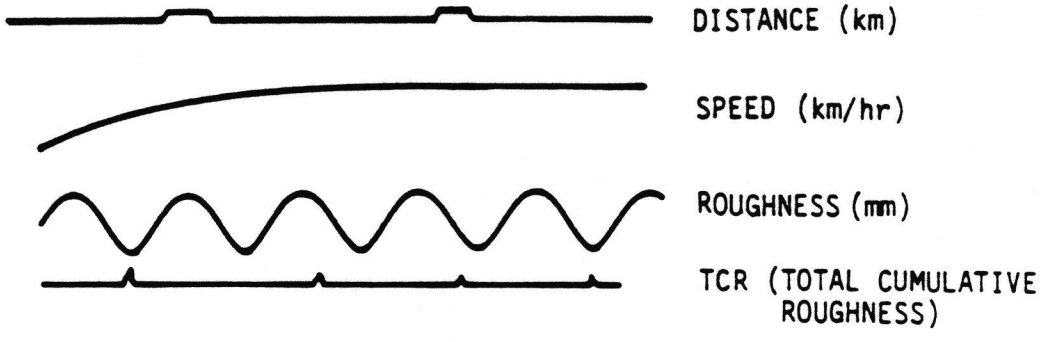


Figure 16. An example of the paper chart printout from ROADRECON-77.

The ROADRECON-85B uses three noncontact laser sensors to measure roughness. The lasers are on the rear bumper of the survey vehicle as illustrated in Figures 4 and 5. The lasers are mounted one over each rear wheel and one centered between the rear wheels.

As the vehicle progresses along the road, the lasers are fired at a given interval of pavement travel. The laser diode, in the Optocator, emits a coherent beam of infrared light via a lens system. The laser beam, when fired at a particular instant, hits the surface of the road and the diffused or scattered beam enters the detector via a lens system as shown in Figure 17. The lens of the detector focuses a spot image on an analog linear position detector semi-conductor. Here, the controllers for the laser measures the distance, r, of the spot image from the center of the detector and computes distance, x, between the vehicle and the road surface.

$$x = x_0 \pm r$$

where x_0 is the distance corresponding to the center of the detector.

The controller of the laser provides the distance, x, to the input/output controller of the computer. The encoder attached to the wheel of the survey vehicle communicates the distance, D, traveled by the survey vehicle to the input/output controller. The system control then plots these data on a chart in real time and also saves them on a tape cassette for future use. The function of these components is illustrated in Figure 18. The variation in x gives the roughness of the ride. The SD in Equation (2) is then computed using the expression

$$SD = \sqrt{\frac{\Sigma (X_i - \bar{X})^2}{n - 1}}.$$

Rutting measurements may also be computed from these laser measurements as illustrated in Figure 19. This is accomplished by using the following expression:

$$\text{Rutting: } RD = ((.5)(Da + Dc)) - Db .$$

Where Da is the distance measured by the laser in the inside wheel path.

Db is the distance measured by the laser centered between the wheels.

Dc is the distance measured by the laser in the outside wheel path.

The system can operate day or night at speeds between 0 and 50 mph (0 and 80kmh). The lasers can be fired at intervals between 4 inches (0.1m) and 33 feet(9.9m). One cassette tape can contain data for 40 miles (80km) of roadway. The resolution of the laser sensor is about 0.02 inches (0.4mm).

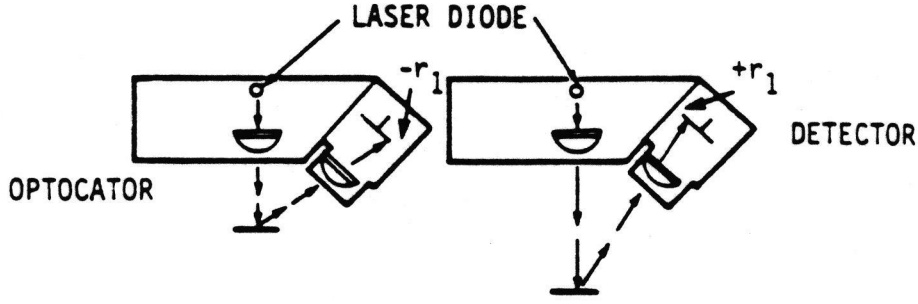


Figure 17. Theory of operation of the laser measuring device used in ROADRECON-85B.

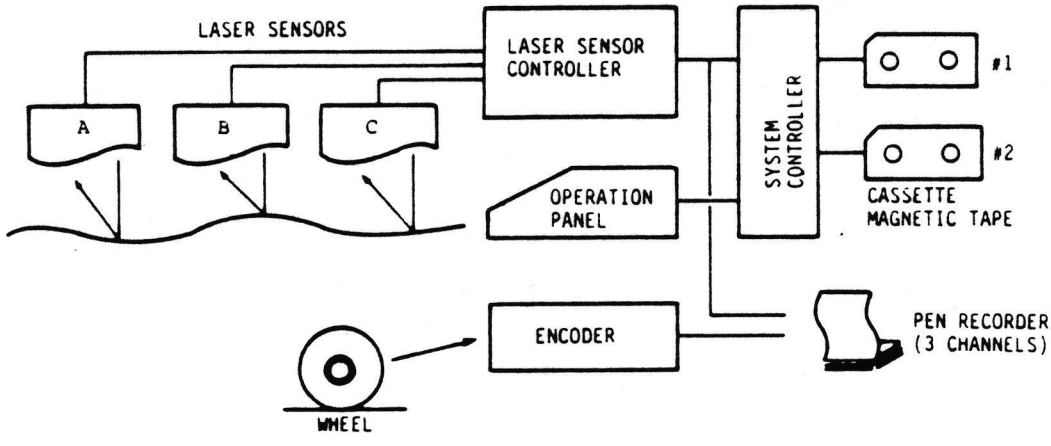
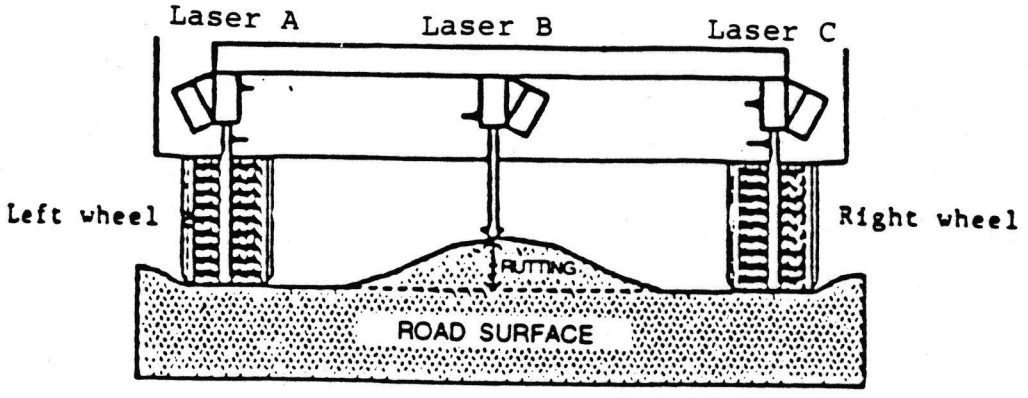
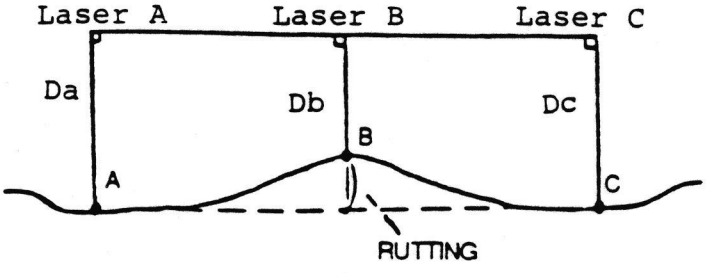


Figure 18. A schematic illustration of ROADRECON-85B.



Rear Profile of ROADRECON-85B.



Rutting: RD = ((.5)(Da+Dc)) - Db,

where:

RD = rut depth.

Da = rut depth measured by Laser A in the inside wheel path.

Db = depth measured by Laser B centered between the wheel paths.

Dc = rut depth measured by Laser C in the outside wheel path.

Figure 19. Rut calculations using measurements from ROADRECON-85B.

PASCO Data Collection Procedures and Data Output

Setting up ROADRECON-70 takes about 20 minutes by two persons. After the necessary cables are connected, the slit camera is mounted and the camera boom is extended, adjusted, and secured. Since speeds below 1.25 mph (2 kmph) causes overexposure of the film, a running start is necessary at the beginning of the section as well as each stop. A strip on the ground of about 3.0 to 3.5 in. (8 to 9 cm) in length is blanked out during stops. These films are then sent for developing, printing, and interpretation. Figure 20 shows a typical strip photograph made from film from the slit camera.

It takes two persons about 30 minutes to set up the pulse camera, ROADRECON-75. The slit camera is replaced with the pulse camera, the hairline projector is mounted, and the camera boom is extended, adjusted, and secured. The first pulse shot is taken manually to include pavement markings at the beginning of the section. Two or three photographs are taken at the end of each section. The film is then sent for developing, printing, and plotting of the cross profile. Figure 21 shows a typical pulse camera photograph and Figure 22 shows a typical cross profile of the pavement from which rut measurements are made.

Assembly time for the ROADRECON-77 is minimal since the system is mounted on the survey vehicle. A check of the connections and the paper feeds, which takes about five minutes, is done before the operation begins. The system is started well before the operation begins, and a mark on the paper chart is made manually at the beginning and end of the section. The cassette and paper chart are sent for computations of roughness. Figure 23 shows the paper chart of a typical run. The strip chart is broken into four separate tracing areas longitudinally. The upper trace is used to identify the distance traveled with 0.8 in. (2 cm) along the paper being equal to 6.6 ft. (2m) of travel. The second line of data is the longitudinal profile of the section surveyed. The vertical scale on the graph is 2.0 in. of roughness per 0.4 in. (10mm). The third trace is a plot of the speed of the survey vehicle. Its scale is 6.21 mph (10 kmph) for each 0.4 in. (10 mm) on the vertical scale. The fourth trace consists of vertical tick marks that represent the TCR count with each one equal to 0.4 in. (1 cm) of additional roughness. The additional information associated with this trace pertains to PASCO's needs and was not explained. The bottom area of the chart contains notes about problems noted in the survey such as intersections or other special features.

For ROADRECON-85B the mounting of the lasers takes about 10 to 15 minutes. Checking of proper connections and paper feeds takes another five minutes. The system is started well before the operation, and marks are made on the paper chart manually at the beginning and end of each section. The charts and cassette tapes are sent for computation of the roughness. Figure 24 shows the paper chart of a portion of a section. This chart is laid out in a manner similar to the one used in the ROADRECON-77 example. Distance is measured in the same manner along the top of the chart. The second line of data is the rut depth and utilizes a scale of 2.0 in. for each 0.4 in. (10mm) of graph vertically. The third trace uses the same vertical scale to describe the profile at the inside wheelpath, and a similar condition exists in the fourth trace to identify the outside wheel path profile. The remainder of the chart is used for notes.

All of the above is combined and presented in PASCO's evaluation sheet which is illustrated in Table 2. Table 2 does not contain data gathered during PASCO's demonstration in Arkansas.

Figure 20. An enlarged print from ROADRECON-70's slit camera. This is a photograph of the outside lane north bound I-30 .

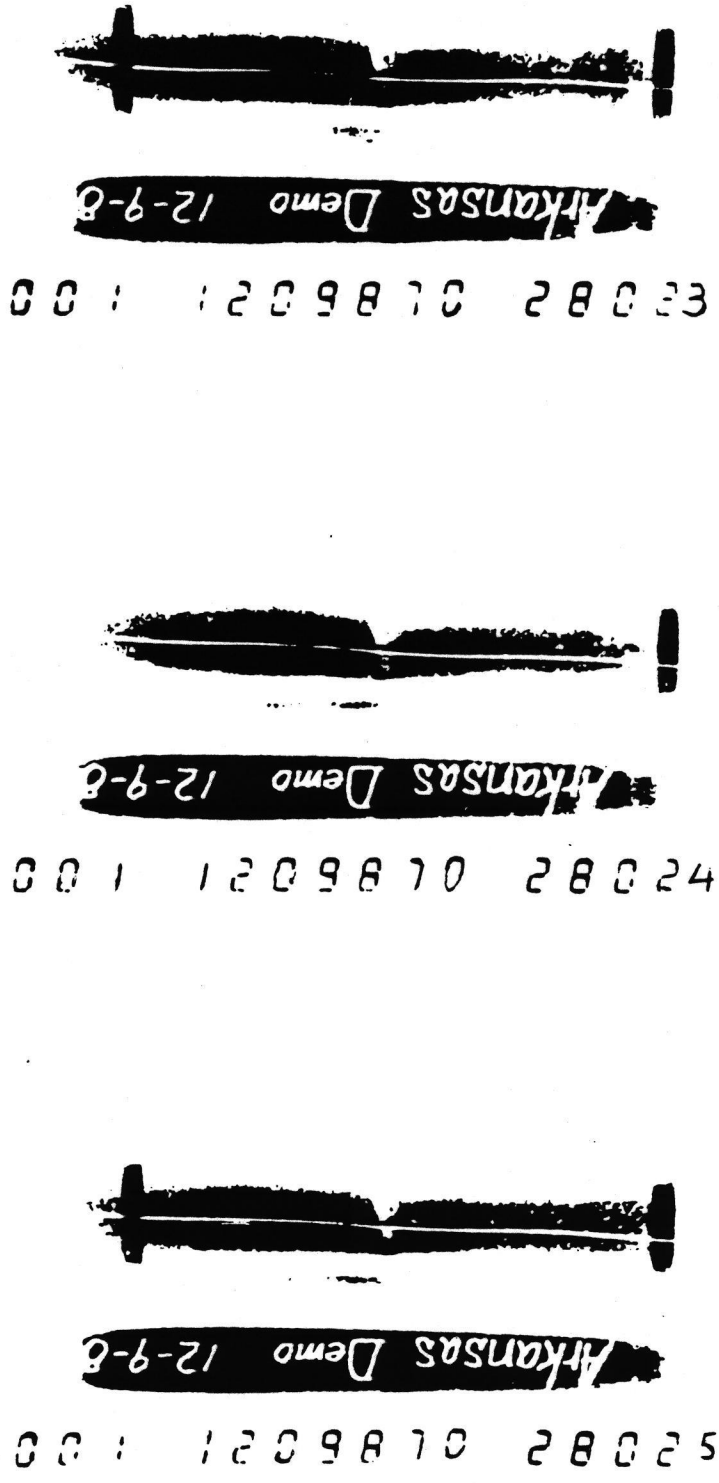


Figure 21. A typical photograph, enlarged, of the ROADRECON-75's pulse camera. Picture 001 1209870 28024 is of I-30, North Bound, outside lane, at PASCO's mile point 28024, Profile No. 2200.

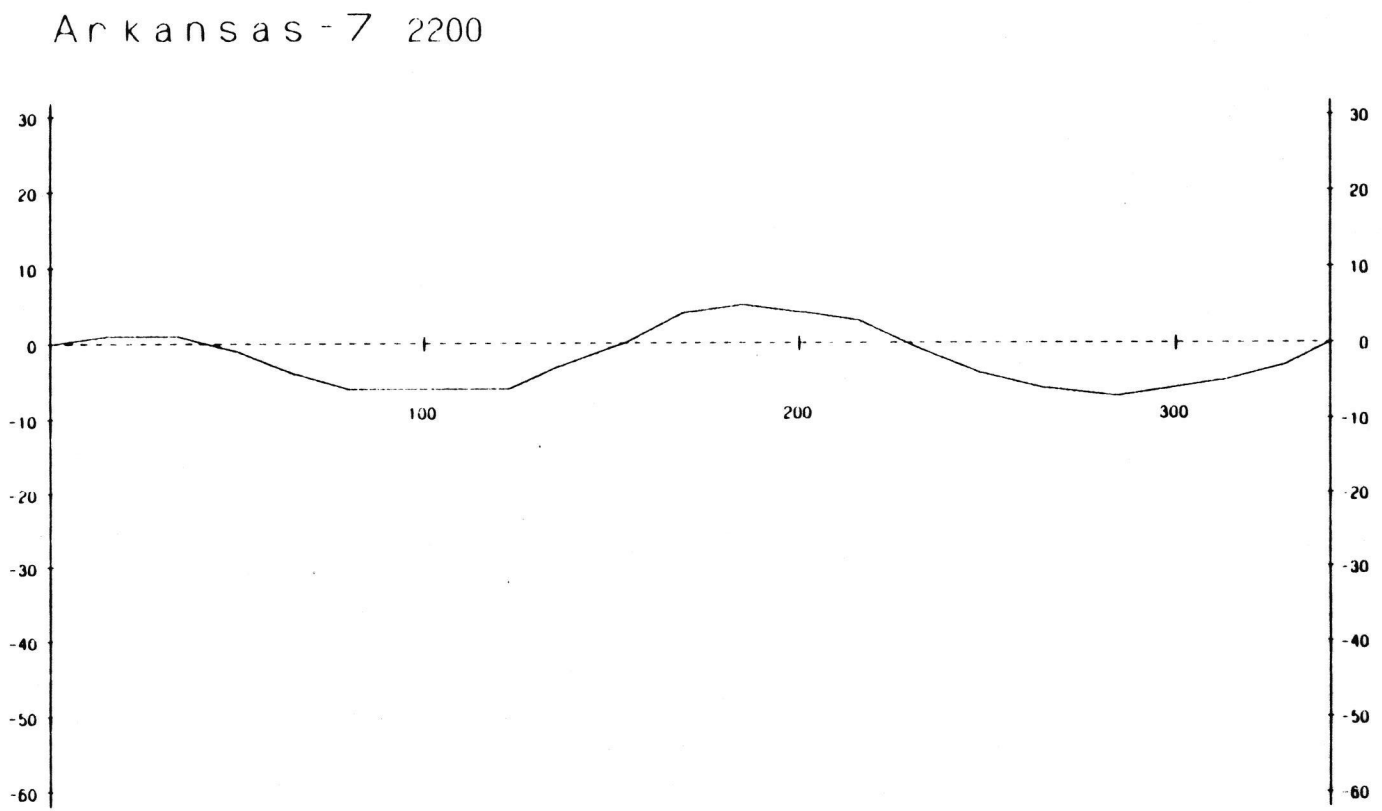


Figure 22.A typical cross profile of the pavement from which rut measurements are made. This cross profile is made from picture 001 1209870 28024, Figure 21. This cross profile shows a rut depth of 10 mm.

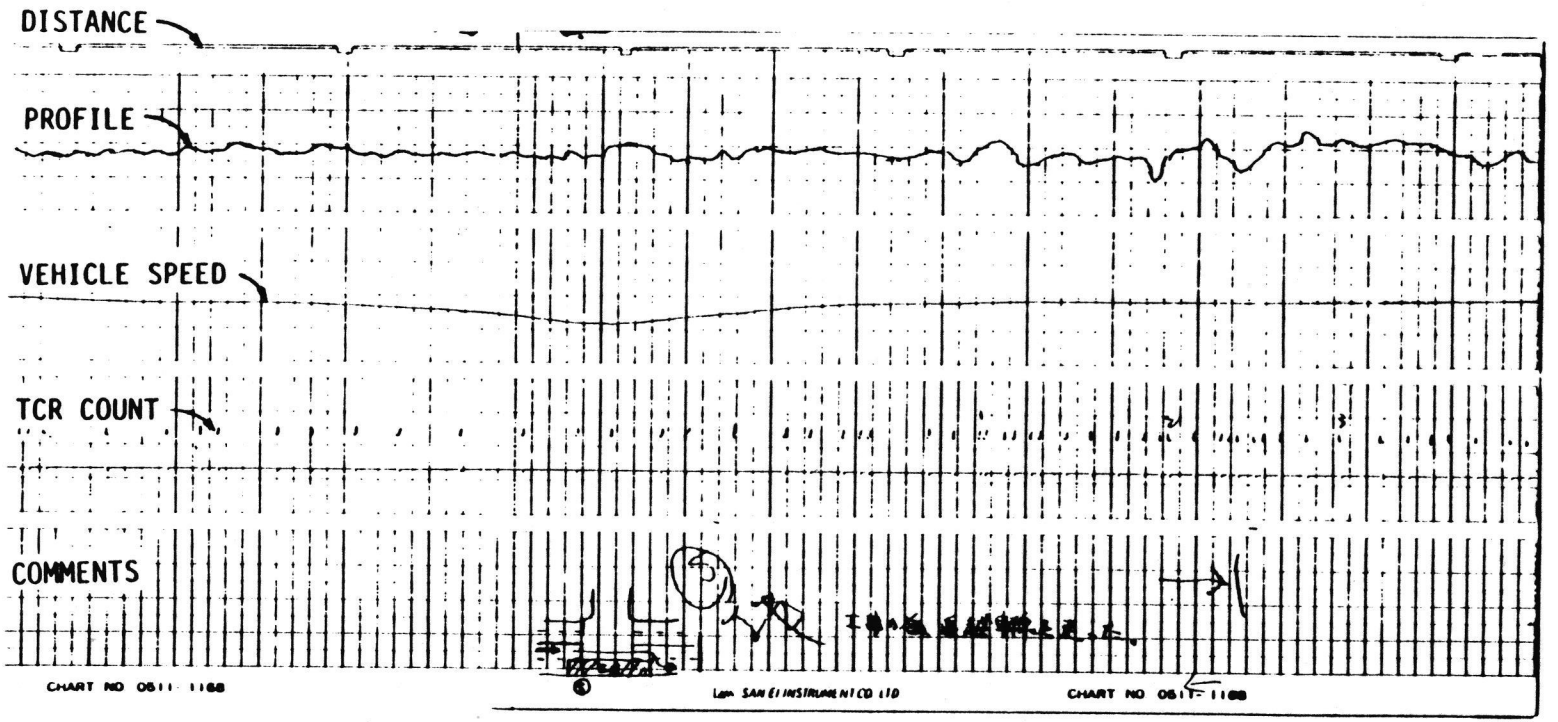


Figure 23. Typical paper strip chart output from ROADRECON-77.

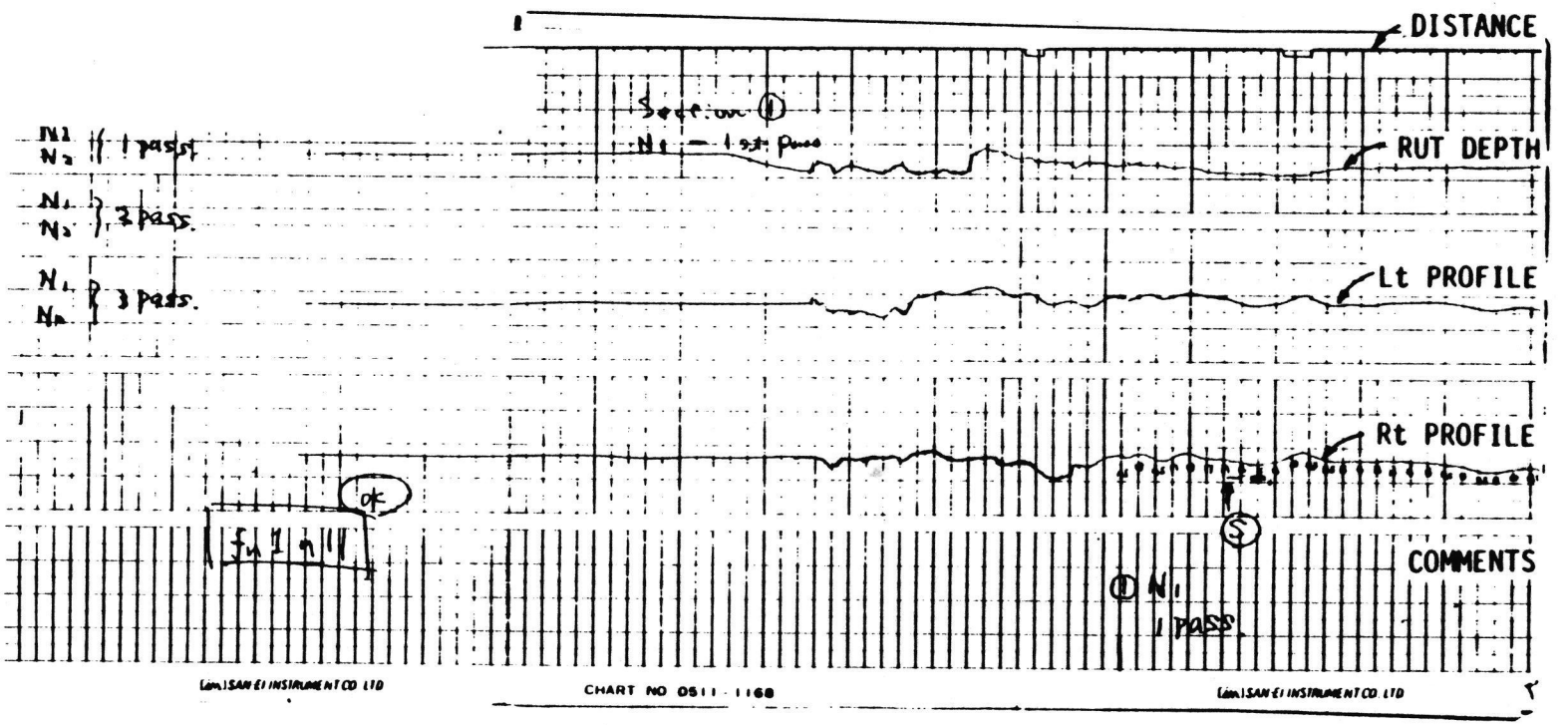


Figure 24. Typical paper strip chart output from ROADRECON-85B.

路面性状データ一覧表

53頁

PASS # — U.S.A. 1073 — LANE #

SECTION #

SUB-SECTION

CRACK, PATCH TOTAL, max RD, MEAN RD, SD

距離程(km) 自	距離程(km) 至	プレート	構造物 1	構造物 2	区間延長(m)	調査年度	路面種別	ひびわれ率(度)(%, m/d) クラック	ひびわれ率(度)(%, m/d) パッチング	ひびわれ率(度)(%, m/d) 計	わだち掘れ量(mm) 最大値	わだち掘れ量(mm) 平均値	縦断凹凸量σ(mm)	MC最小	MCI値	予測値(昭和 年 月) 路面種別	予測値(昭和 年 月) ひびわれ率(度)(%, m/d)	予測値(昭和 年 月) わだち掘れ量(mm) 最大値	予測値(昭和 年 月) わだち掘れ量(mm) 平均値	予測値(昭和 年 月) 縦断凹凸量σ(mm)	予測値(昭和 年 月) MC最小	予測値(昭和 年 月) MCI値	舗装年度	最新補修 年度	最新補修 工法	延長	路線区分1	路線区分2	車線区分	CBR(%)	TA(cm)	備考
0.0	0.065				65	S61	AS	27.2	1.2	28.4	37	31	9.36	2.0	1																	
0.065	0.085				20	S61	CO	10.7	6.4	32.1	9	9	9.36	2.3	3																	
0.085	0.100				15	S61	AS	10.7	0.0	10.7	9	9	9.36	4.9	1																	
0.100	0.110				10	S61	AS	44.9	10.7	55.6	3	3	5.25	2.6	3																	
0.110	0.200				90	S61	CO	10.5	1.1	14.2	3	3	5.25	4.6	3																	
0.200	0.300				100	S61	CO	10.3	0.6	12.2	3	3	5.06	5.0	3																	
0.300	0.400				100	S61	CO	9.6	1.4	14.4	12	8	4.39	4.6	1																	
0.400	0.500				100	S61	CO	15.6	1.0	18.9	3	3	4.30	4.0	3																	
0.500	0.600				100	S61	CO	16.1	3.1	26.6	3	3	6.11	3.0	3																	
0.600	0.700				100	S61	CO	10.4	1.6	15.9	7	5	3.63	4.4	3																	
0.700	0.800				100	S61	CO	7.3	2.4	15.2	4	4	6.02	4.5	3																	
0.800	0.860				60	S61	CO	22.4	5.1	39.5	7	7	6.88	1.6	3																	

Table 2. Typical output from combining data by using PASCO's evaluation procedures. This is the form which PASCO uses to report to the user. This data was not derived from the demonstration in Arkansas.

AVIAR Inc

P.O. Box 162184 Austin, Texas 78716

March 23, 1988

Mr. Mark Bradley
Arkansas State Highway
and Transportation Department
Pavement Management Engineer
Roadway Design Division
P.O. Box 2261
Little Rock, AR 72203

Dear Mark,

Thank you for taking the time to speak with me last week when I dropped by your office. Our discussion was very informative. I have enclosed the information you requested regarding the cost of PASCO's film reading equipment.

I think a head-to-head comparison is an excellent way to completely evaluate both the ROADRECON and the ARAN data collection systems. PASCO would appreciate the opportunity to participate in this study. The value of this investment in addition to the importance of the equipment certainly justifies the cost of conducting this comparison.

Let me know if I can be of any assistance.

Best regards,

Ron

Ron White

RW/es

Enclosure

"Supplying Measuring Equipment to the Transportation Industry"

AVIAR Inc.

P.O. Box 162184 Austin, Texas 78716

TECHNICAL MEMORANDUM

TO: Mark Bradley DATE: March 23, 1988

FROM: Ron White FILE: 303

SUBJECT: Data Reduction Hardware and Software

HARDWARE

There are two pieces of equipment PASCO uses to reduce pavement distress information from ROADRECON-70 (RR-70, surface photographs) film and ROADRECON-75 (RR-75, Cross profile photographs) film.

The first piece of equipment is the manual-feed film enlarger. This piece of equipment enlarges RR-70 35mm film ten times (one-twentieth of the actual pavement size) onto a tablet. Information is visually interpreted by an operator and entered onto a paper form or directly into a computer. A grid of known dimensions is superimposed over the film or placed on the tablet to facilitate the objective interpretation of pavement distresses. The film is manually advanced by the operator as information is connected. The cost of this equipment is $2,000 per unit. PASCO has four manual feed film enlargers in New Jersey on the shelf ready for immediate delivery. This enlarger is not used by PASCO to interpret RR-75 film.

A second piece of equipment is available that is more automated than the one discussed above. This enlarger comes with digitizing cursor that an operator uses to identify distresses on the RR-70 film. This enlarger has a frame advance feature which automatically feeds the film one frame at a time at the operator's command. The rewind and fast-forward functions are motorized on this equipment.

"Supplying Measuring Equipment to the Transportation Industry"

In addition to RR-70 film, this automatic enlarger is used by PASCO to digitize RR-75 cross profile film. Several points on each optical line are digitized by the operator using the cursor. This information is fed directly into a computer where rut depth is calculated. The cost of this automatic enlarger is $33,500. In addition, an IBM-PC/AT compatible computer is required which costs $6,500 and consists of the following specifications:

640 KB. 1.2 ,FD. 360 MB HD w/controller, monographic monitor w/adapter, graphic printer, IEEE-48 I/F adapter.

The delivery time for one piece of this equipment is three months.

SOFTWARE

The RR-70 distress interpretation software used by PASCO sums patching ad all types of cracking into a single index. This index is called "crack ratio" and is combined with rut depth and roughness to calculate a pavement condition index called MCI (maintenance condition index).

Arkansas will probably break distresses into the various types of cracks (alligator, transverse, etc.) according to severity and extent. This detail can be interpreted from the photographs. If Arkansas desires, PASCO can develop surface distress film analyzing software to meet Arkansas' data requirements. PASCO can perform this work on request and can deliver the product in three months for $77,000.

RR-75 cross profile film can be interpreted and stored with software available from PASCO. The software acts on digitized information from RR-75 film. PASCO reports rut depth by taking the maximum wheelpath rut (inside or outside) from each photograph, and summing these up over an entire section. This summation is divided by the total number of measurements to give the maximum average rut depth for a section. The maximum single rut depth in each section is also reported. In addition, PASCO has a plotting program which uses the digitized information to plot

the cross profile of the pavement at user selectable locations. The cost of this software is included in the cost of the ROADRECON system. This software will be available in English form by May of 1988. the ROADRECON film analyzer must be supported by a plotter if the plotting function is to be used.

PASCO can perform the rut digitizing and plotting service for Arkansas for $10 per measurement.

RW/es

APR 4 1988
Programming & Scheduling
Ark. St. Hwy. & Trans. Dept.

B

AVIAR inc

P.O. Box 162184 Austin, Texas 78716

RECEIVED
FEB 26 1988
ROADWAY DESIGN

February 24, 1988

Mr. Mark Bradley
Arkansas Department of Transportation
Roadway Design Division
P. O. Box 2261
Little Rock, Arkansas 72203

Dear Mark,

Enclosed you will find tabulated rut depth data we collected on IH 30 (Table 3). The values correspond to the cross profile plots we sent you earlier (letter dated February 1, 1988). Figures 25 and 26 are examples of how PASCO Inc quantifies rut depth. Call us if you have any questions.

Sincerely,

Ron

Ron White

RW/es

Enclosures: Tabulated Rut Depth Data

"Supplying Measuring Equipment to the Transportation Industry"

Arkansas - 7

Profile No.	Mileage	Rut Depth (mm)
0	28002	12
200	28004	12
400	28006	10
600	28008	7
800	28010	12
1000	28012	12
1200	28014	11
1400	28016	9
1600	28018	14
1800	28020	12
2000	28022	12
2200	28024	10
2400	28026	12
2600	28028	7
2800	28030	9
3000	28032	8
3200	28034	8
3400	28036	7
3600	28038	7
3800	28040	8
		AV=10

Arkansas - 8

Profile No.	Mileage	Rut Depth (mm)
0	27002	5
200	27004	5
400	27006	4
600	27008	6
800	27010	6
1000	27012	6
1200	27014	6
1400	27016	7
1600	27018	5
1800	27020	6
2000	27022	5
2200	20024	6
2400	27026	5
2600	27028	4
2800	27030	3
3000	27032	4
3200	27034	3
3400	27036	4
3600	27038	4
3800	27040	5
		AV=5

es/02/23/88 Table 3. Arkansas rut depth table.

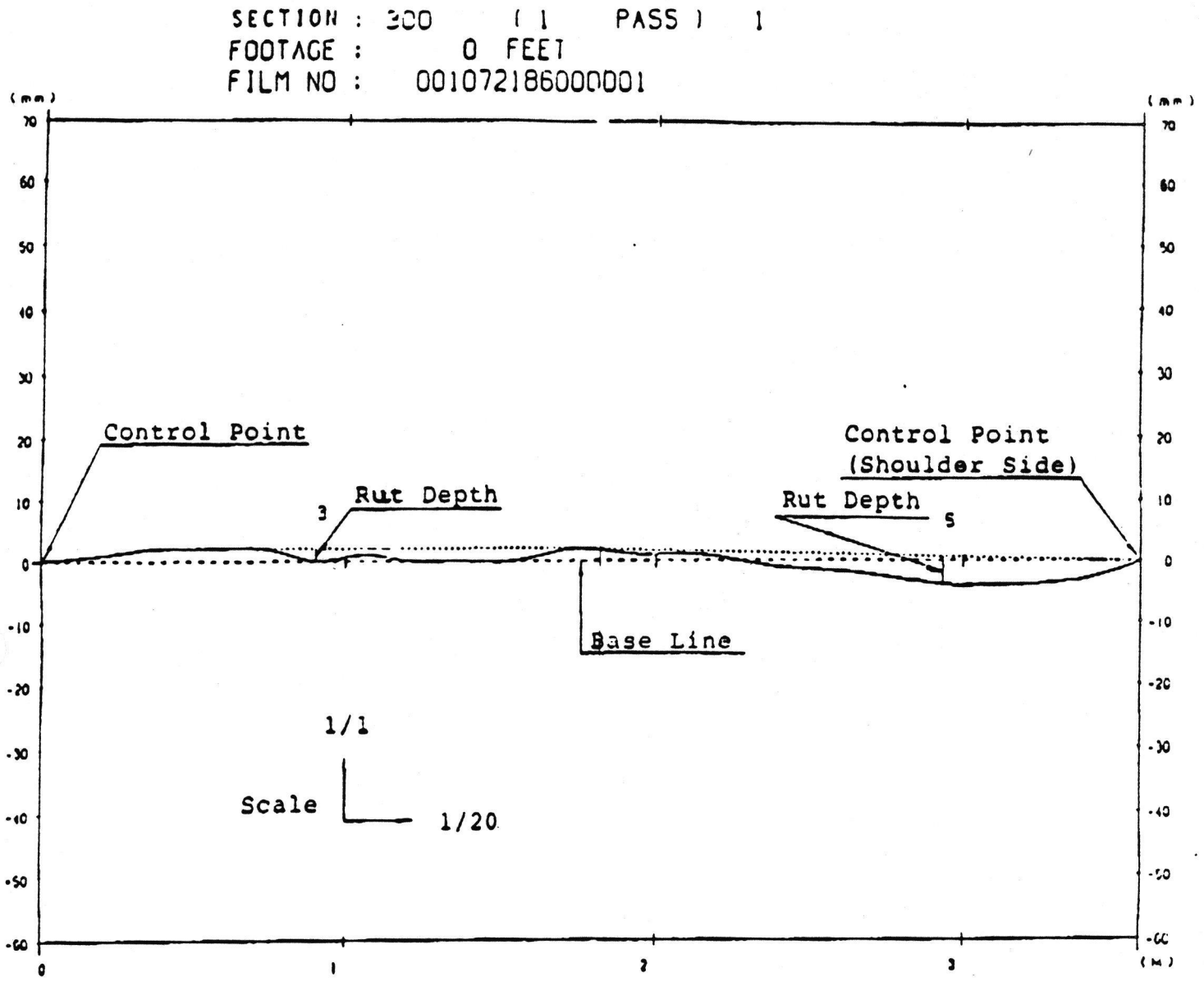


Figure 25. Example of rut depth quantification, condition one.

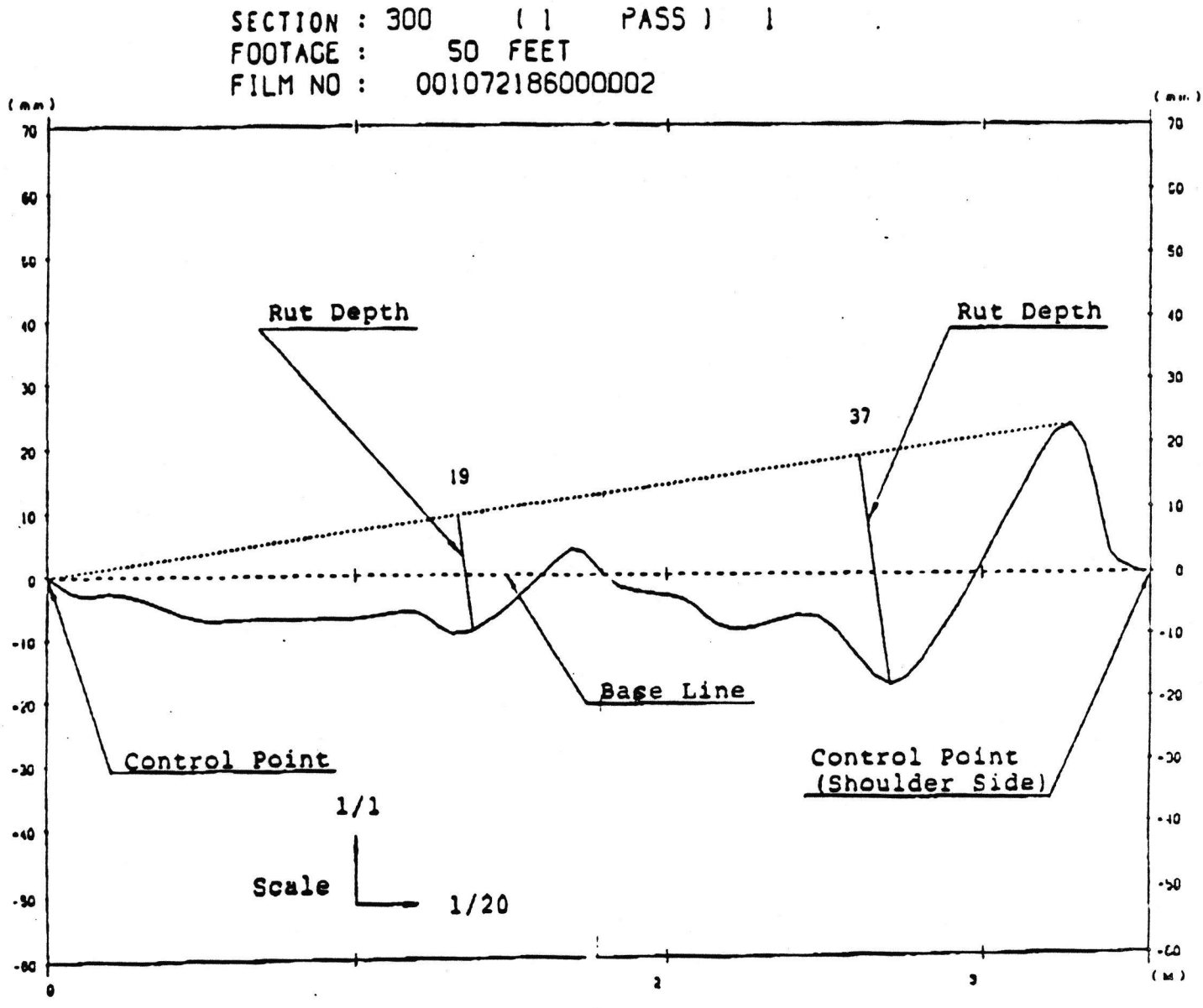


Figure 26. Example of rut depth quantification, condition two.

AVIAR inc

P.O. Box 162184 Austin, Texas 78716

February 1, 1988

Mr. Mark Bradley
Arkansas Department of Transportation
Roadway Design Division
P. O. Box 2261
Little Rock, Arkansas 72203

Dear Mark,

We have enclosed the information we collected with the PASCO ROADRECON (RR) automatic survey equipment. This information includes two rolls of film and rut depth plots.

The two rolls of film are output from the RR-70 and RR-75 operation. You can use a film strip projector or similar device to review the RR-70 film. The RR-75 film has been reduced and plotted.

RR-75 photographs were taken every 100 feet. Therefore, there were 52 photographs (±) taken in each direction. Forty of the photographs were digitized and plotted as shown (20 in each direction). Starting from the threshold of each section, every other photograph was digitized (200 foot spacing) until 20 photographs were entered. No photographs were digitized in the last 1,280 feet of each section.

The two sets of plots give rut depth in centimeters. One set is of the actual digitized values. The other is an exact duplicate except the plots are "smoothed". Though not now available, you will receive a print-out of rut depth values at a later time.

Please let us know if we can be of any assistance.

Sincerely,

Ron

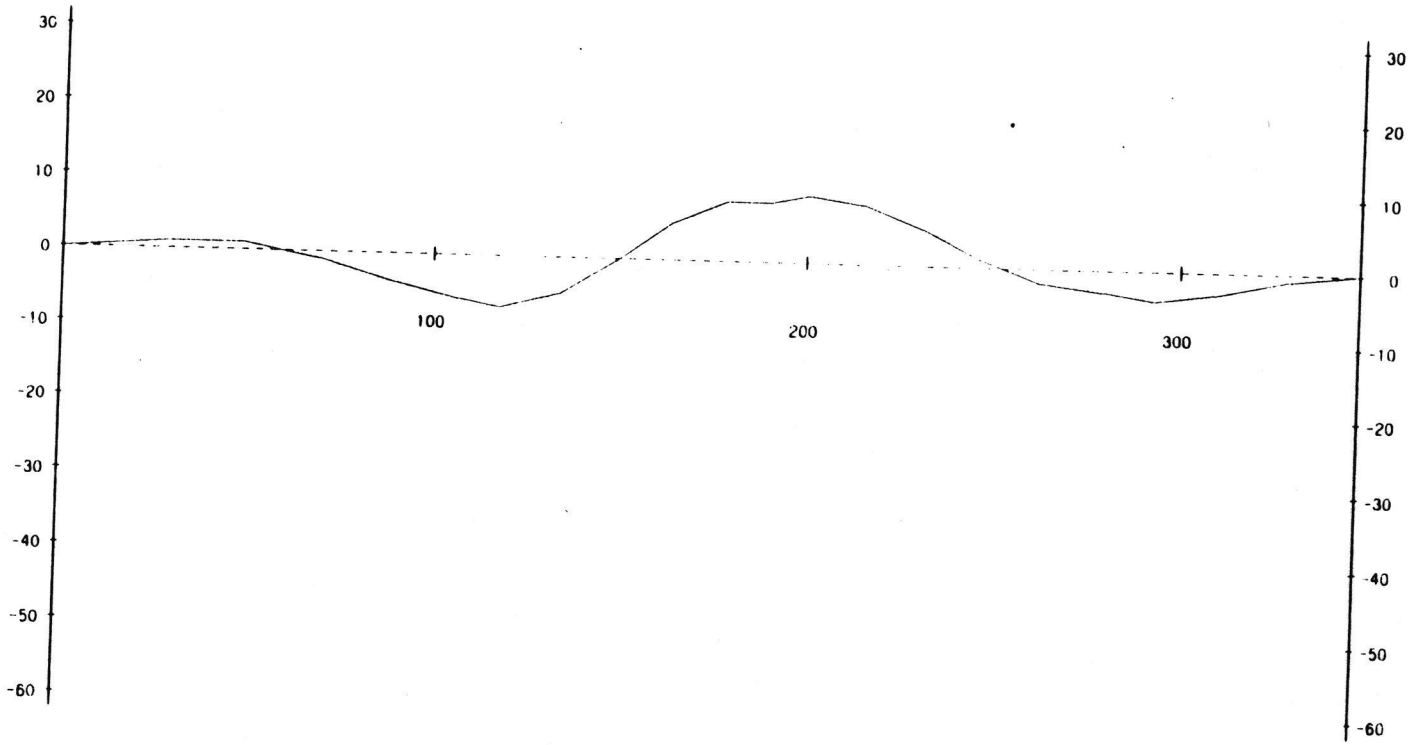
Ron White

RW/es

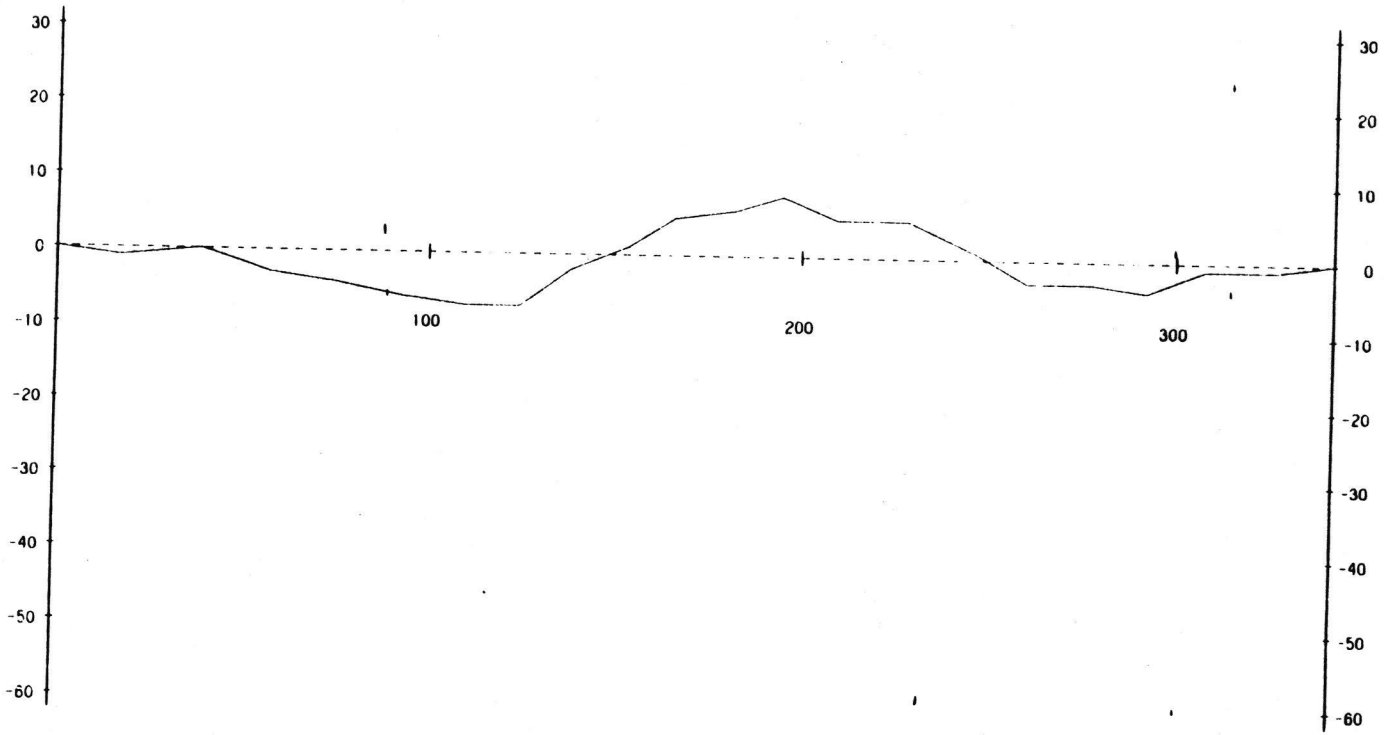
Enclosures: Film and plots

"Supplying Measuring Equipment to the Transportation Industry"

Arkansas-7 0



Arkansas 7 200



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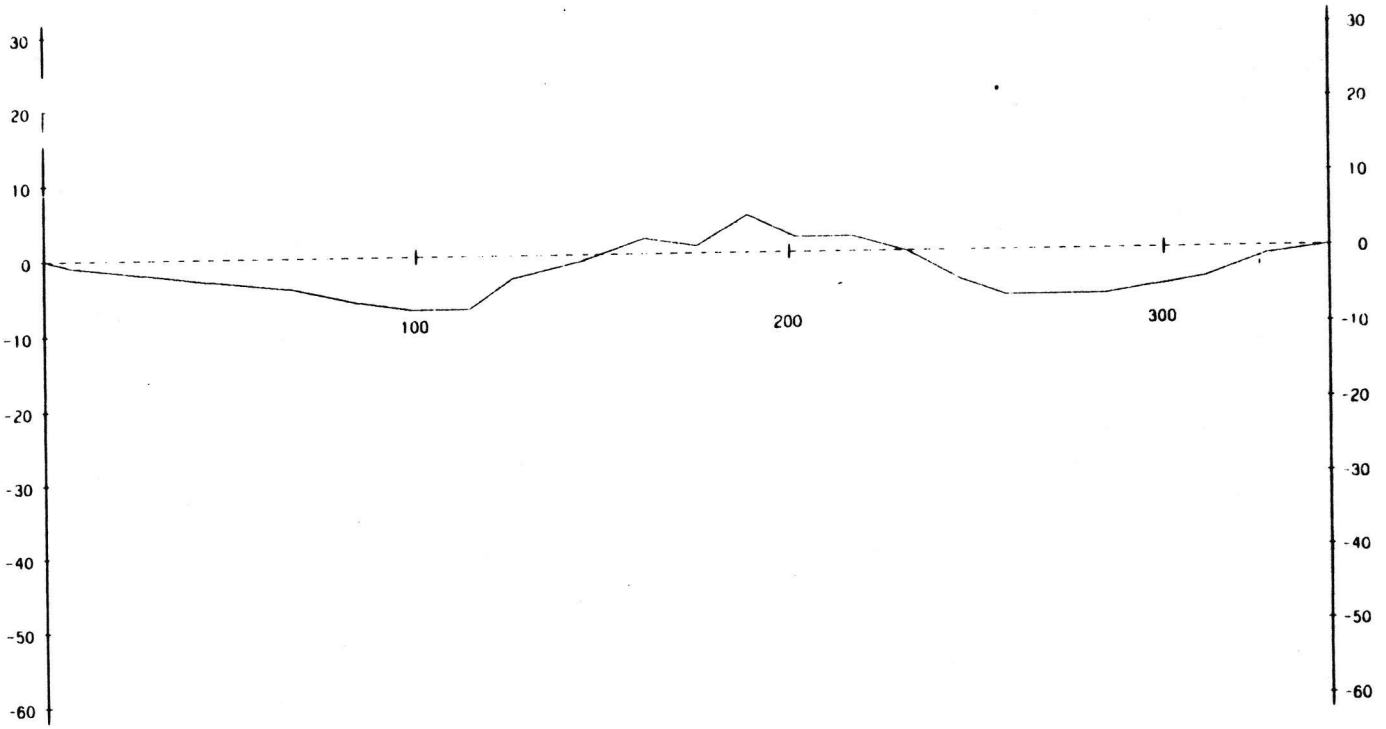

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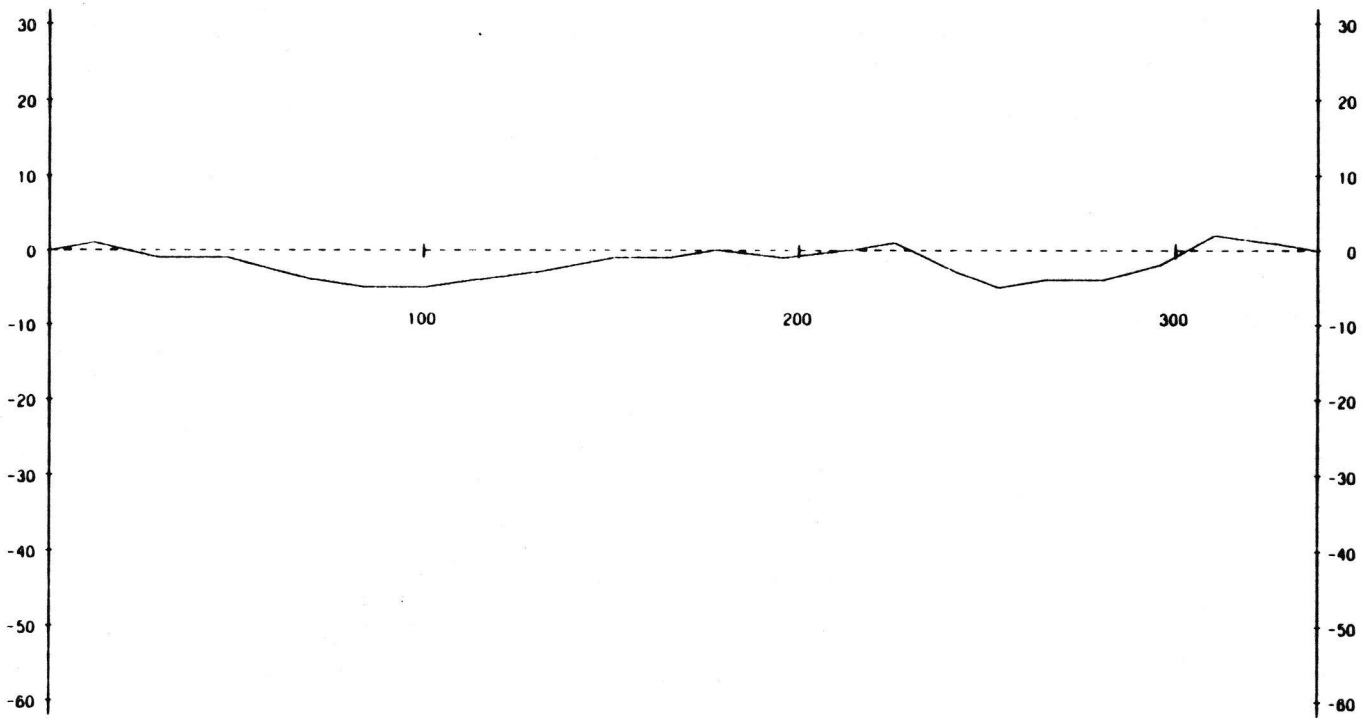

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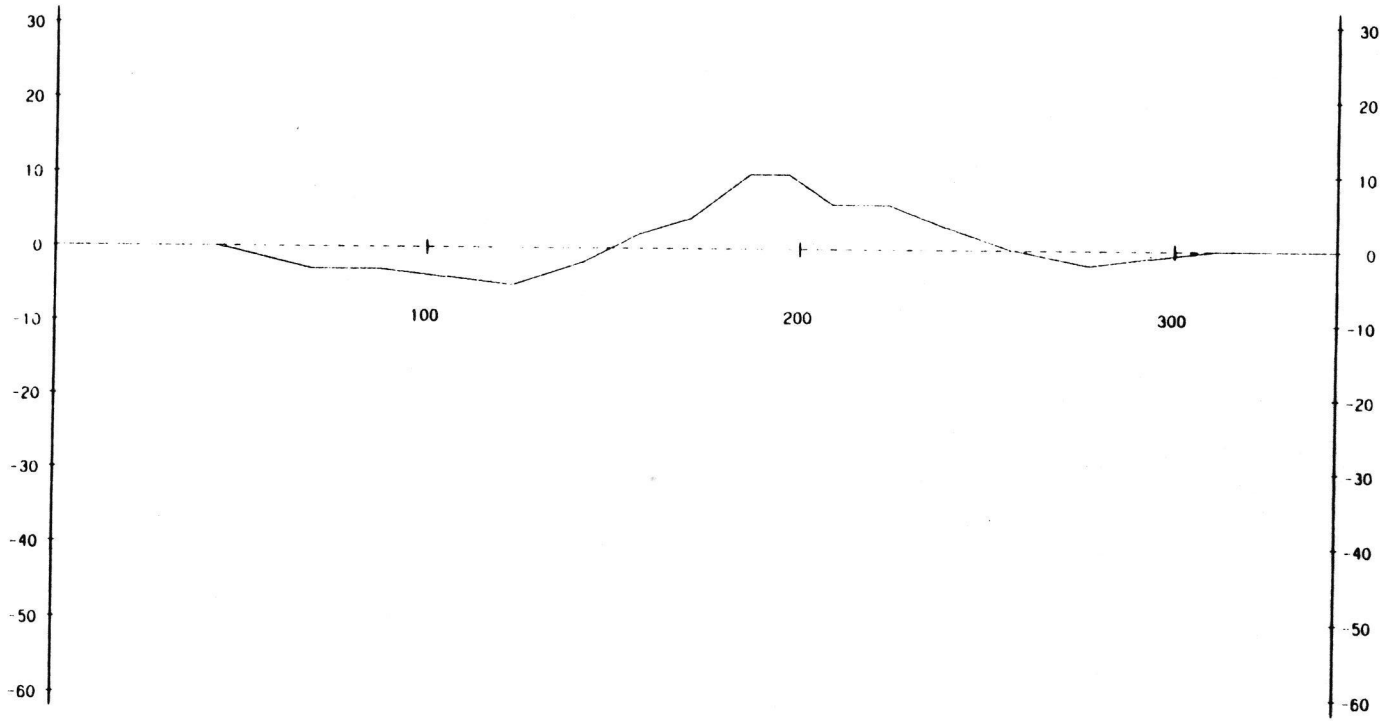

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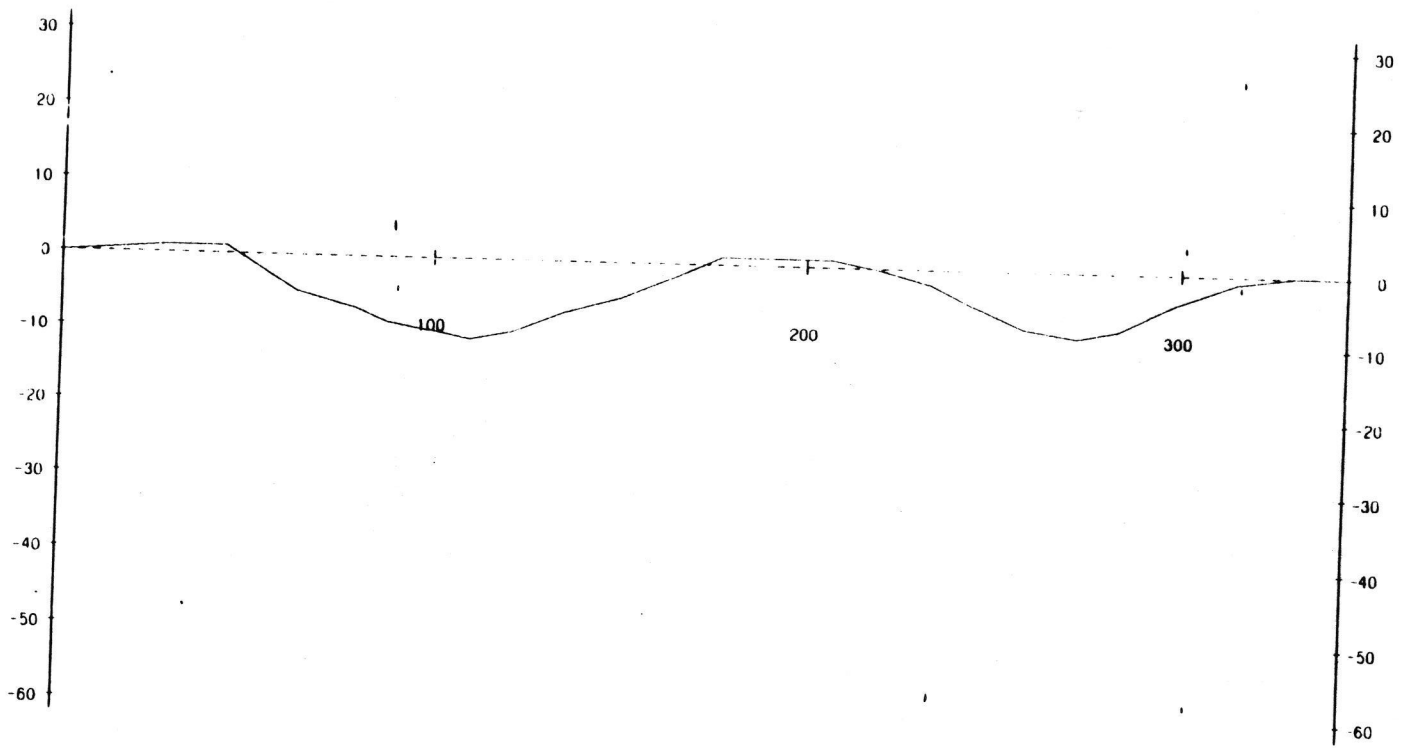

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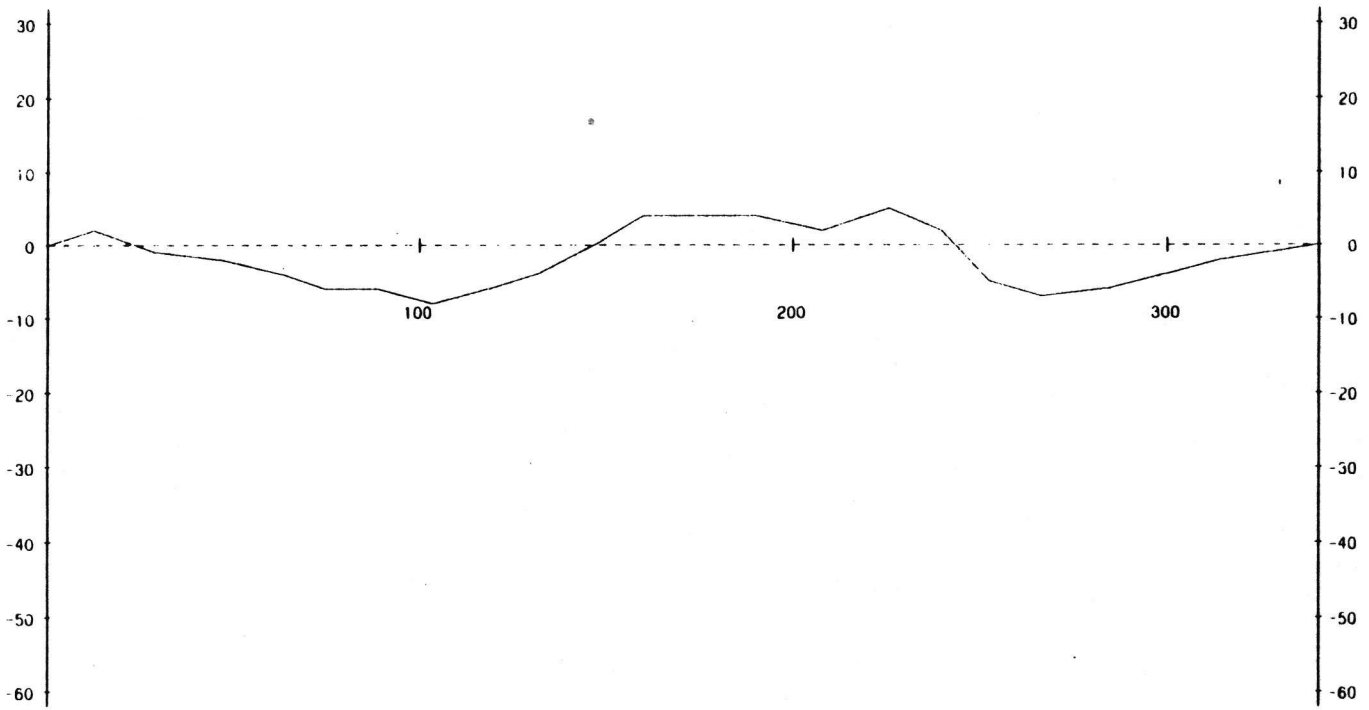

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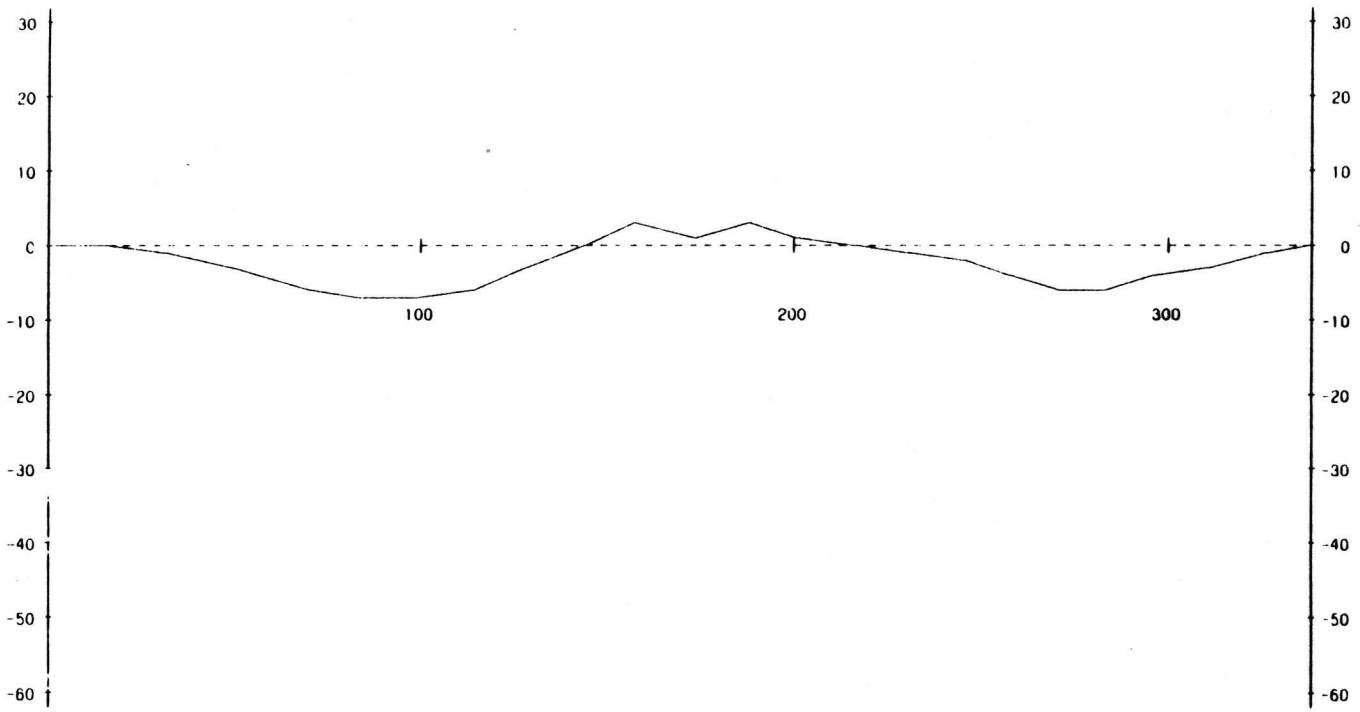

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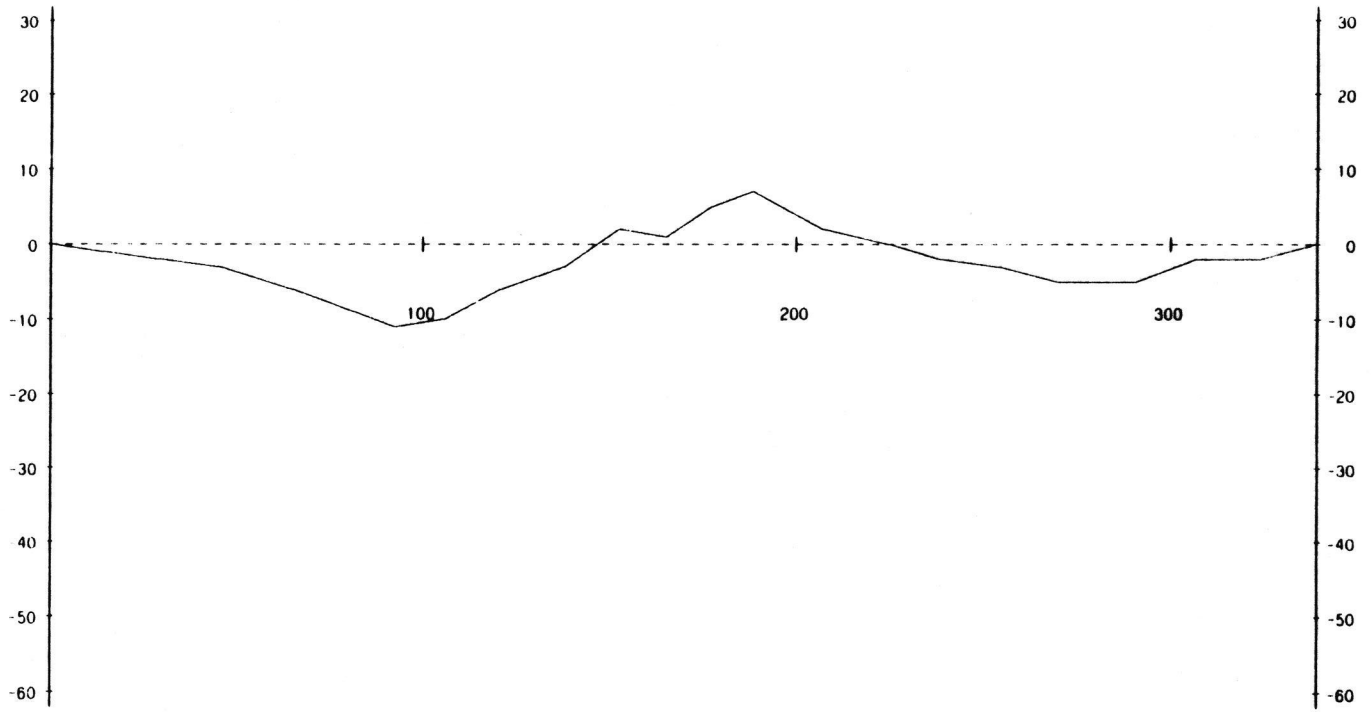

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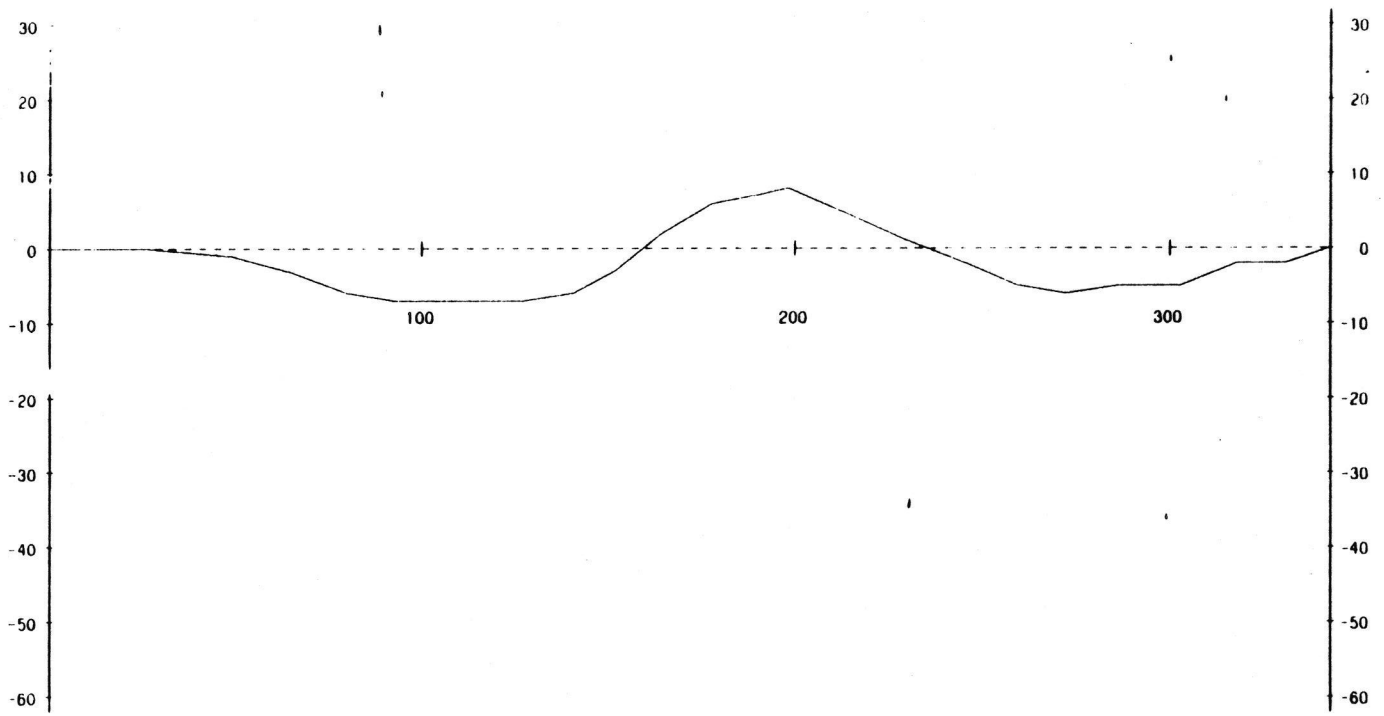

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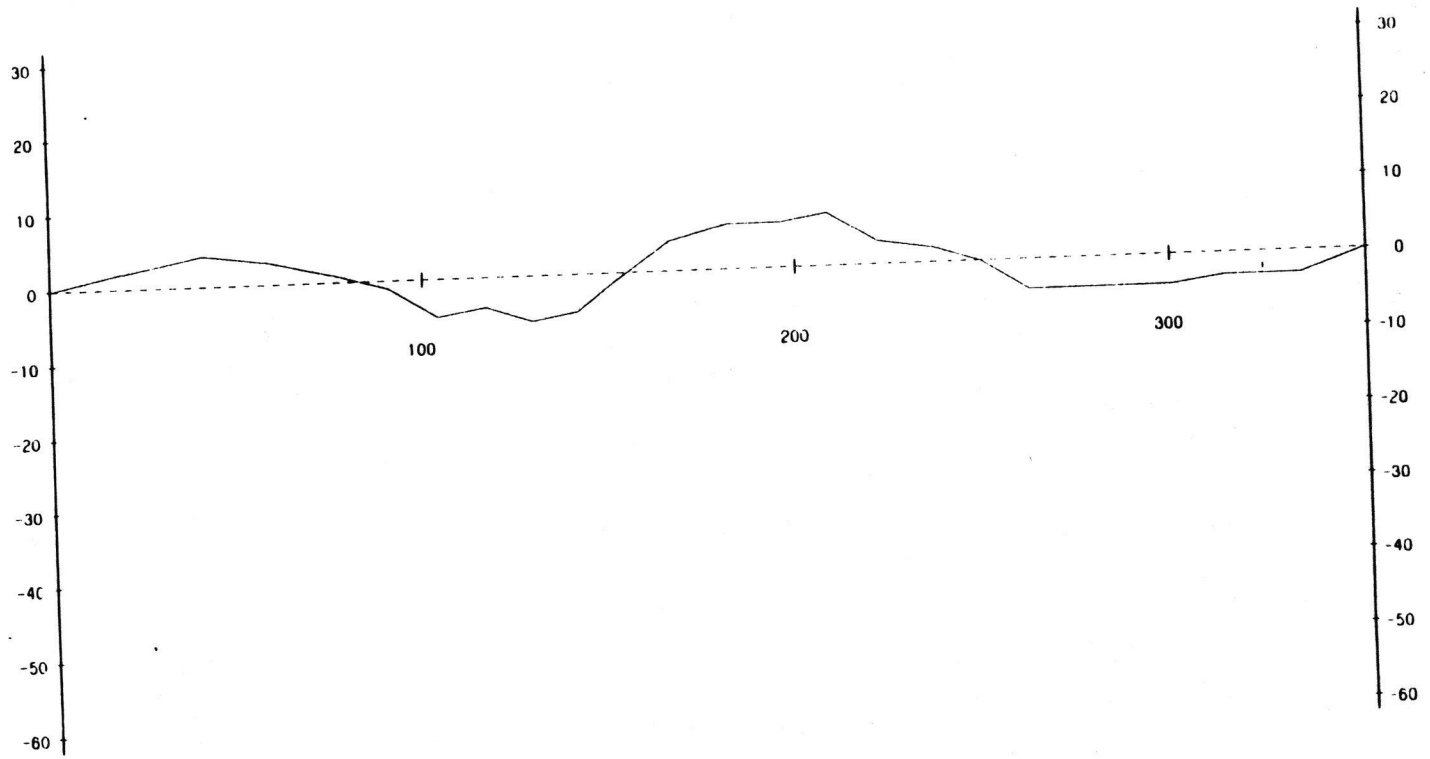

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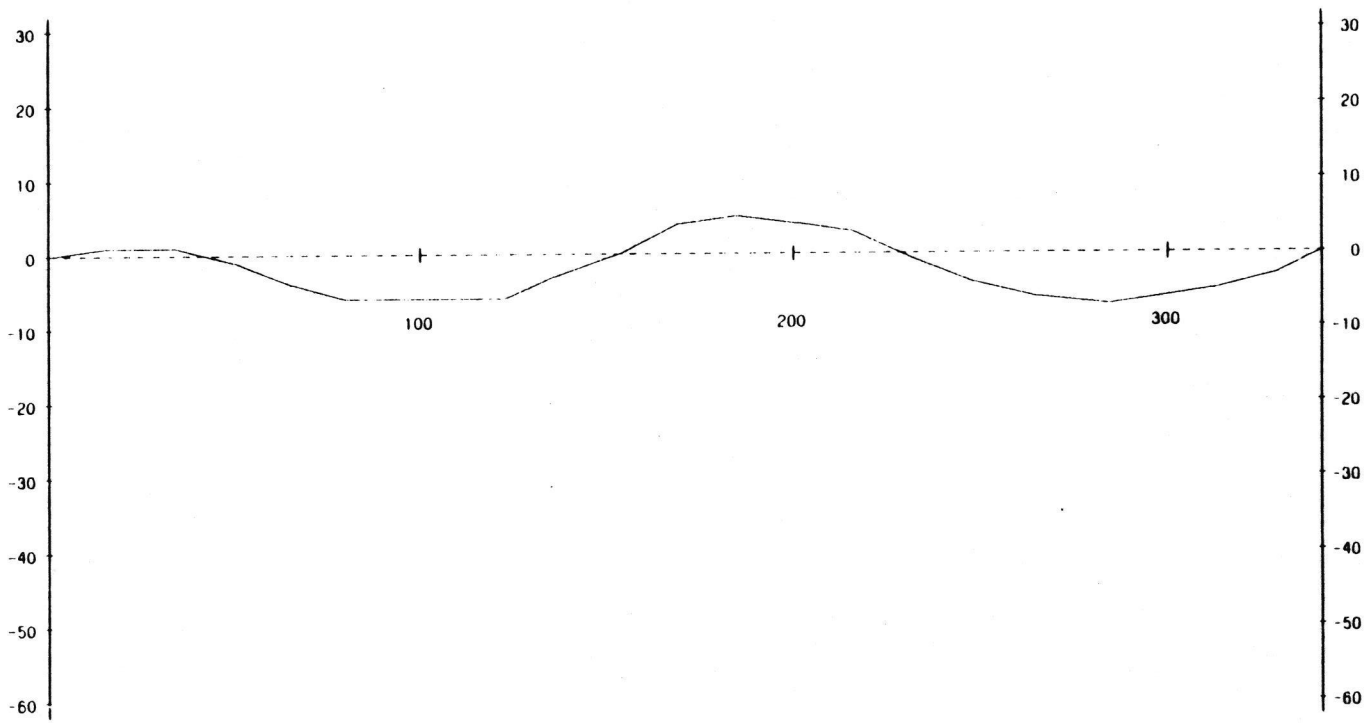

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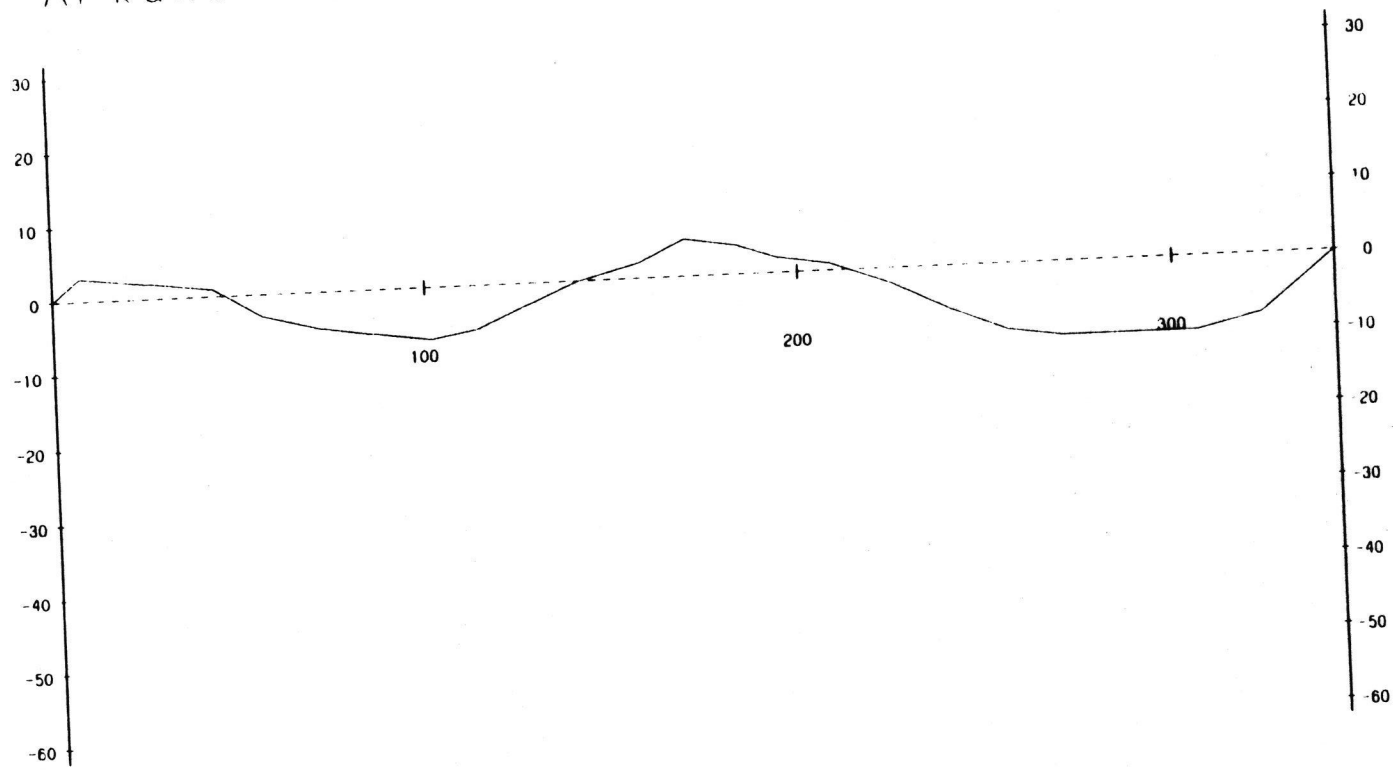

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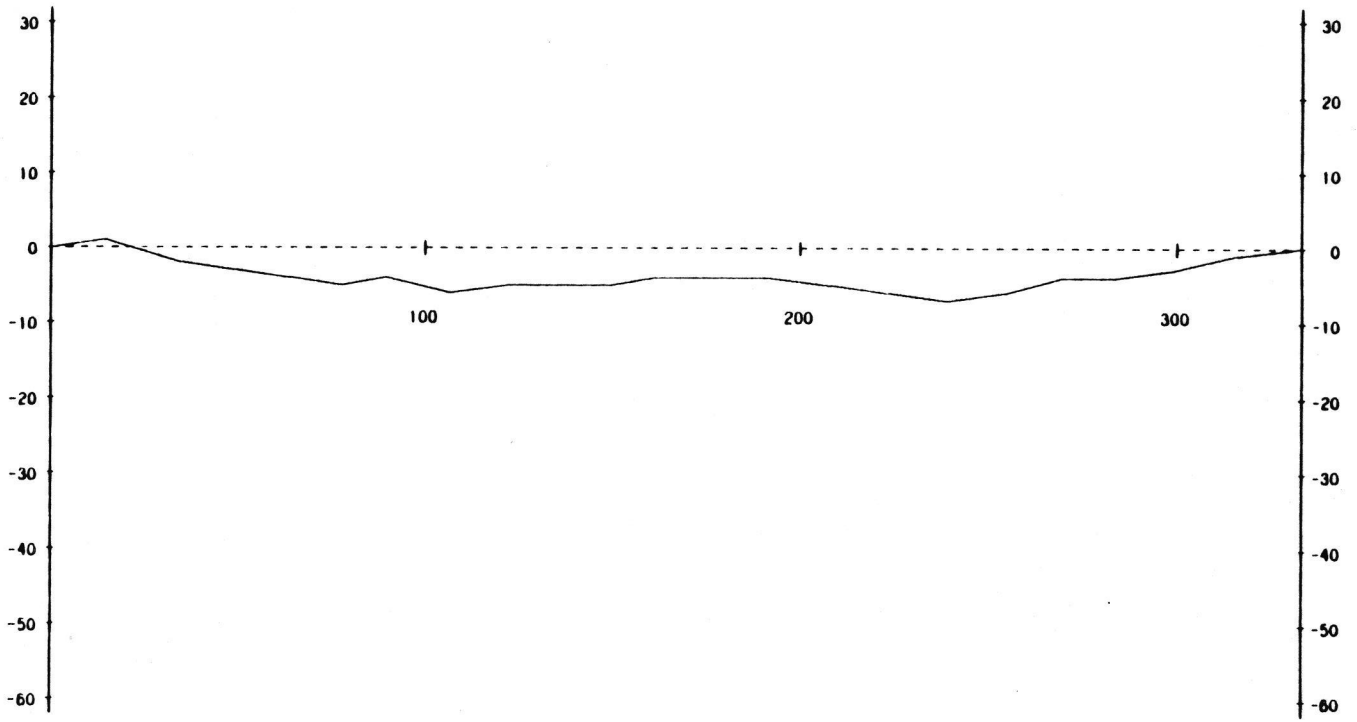

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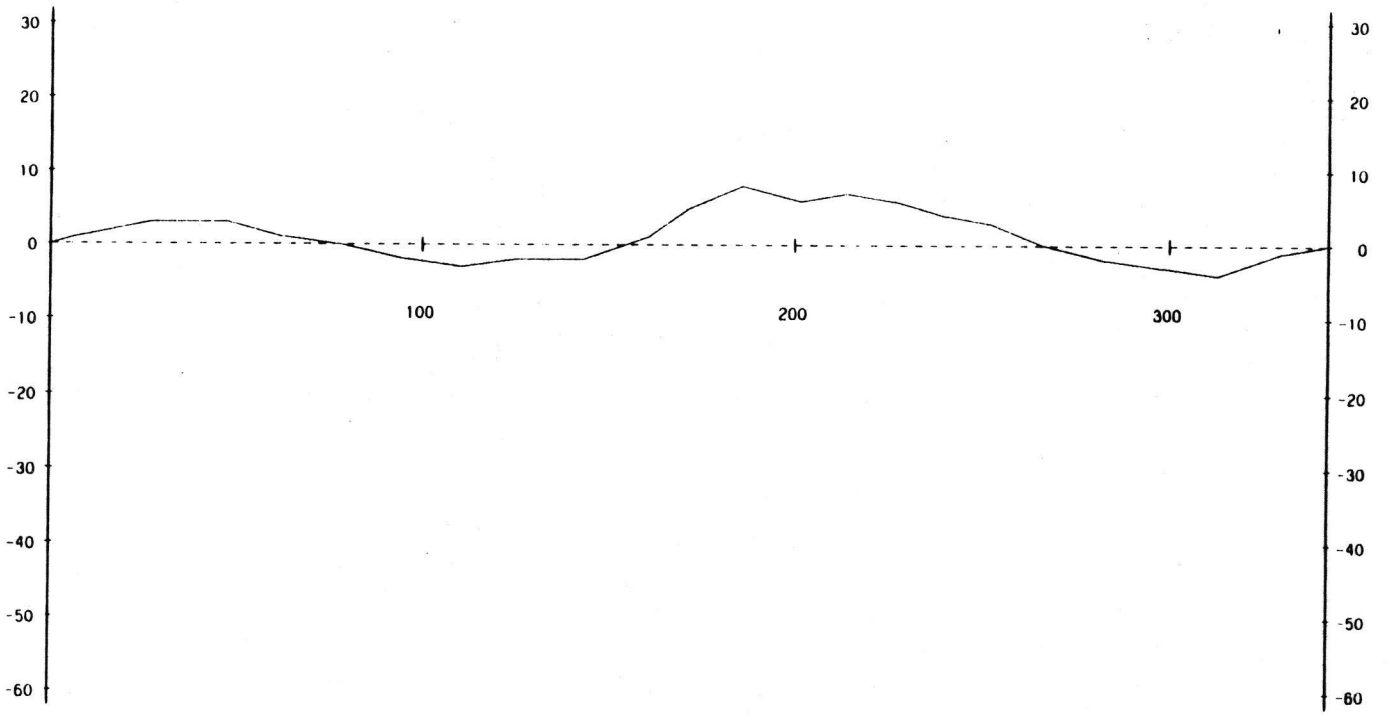

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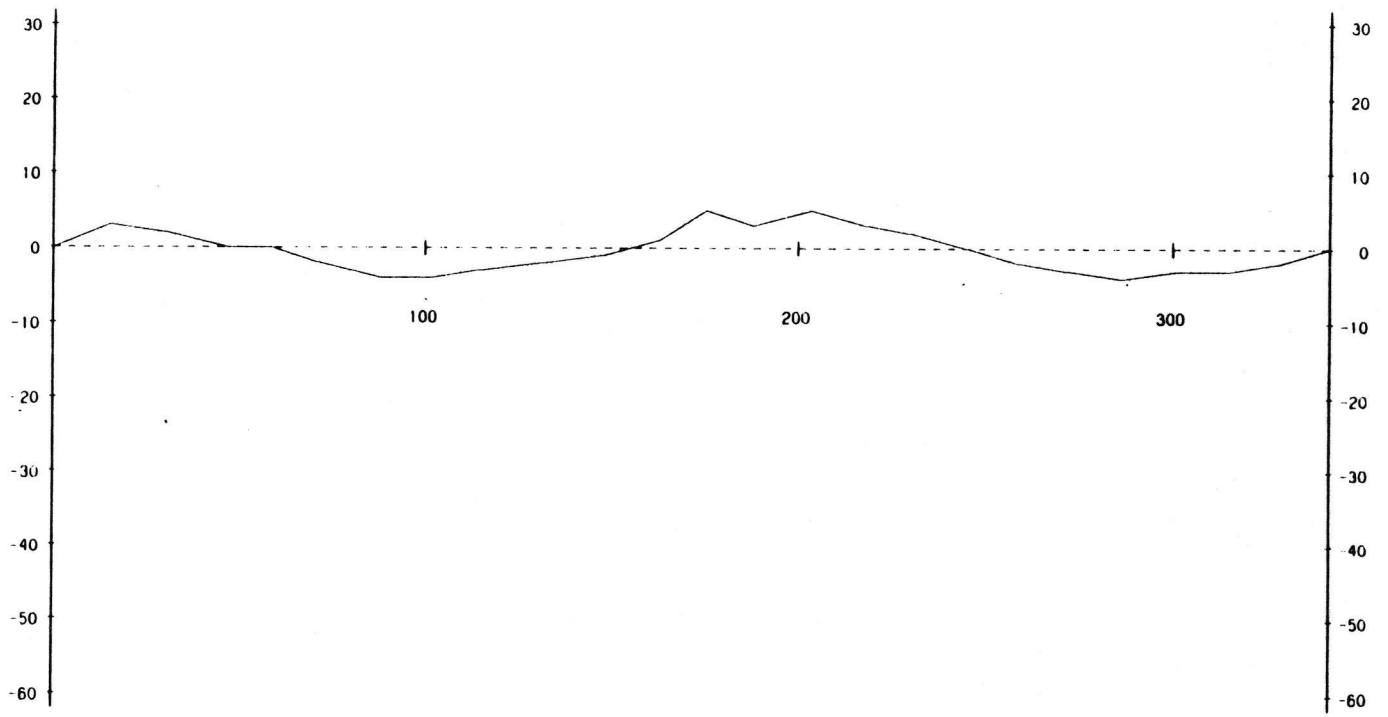

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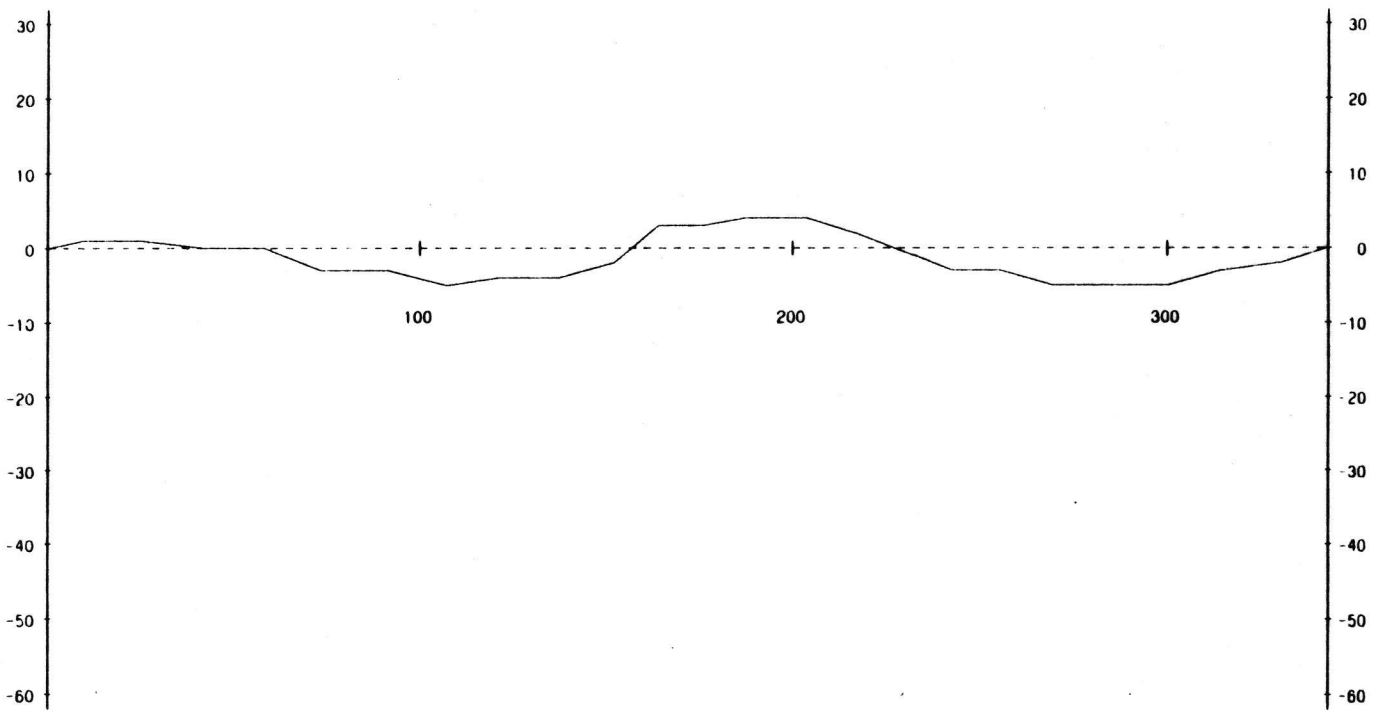

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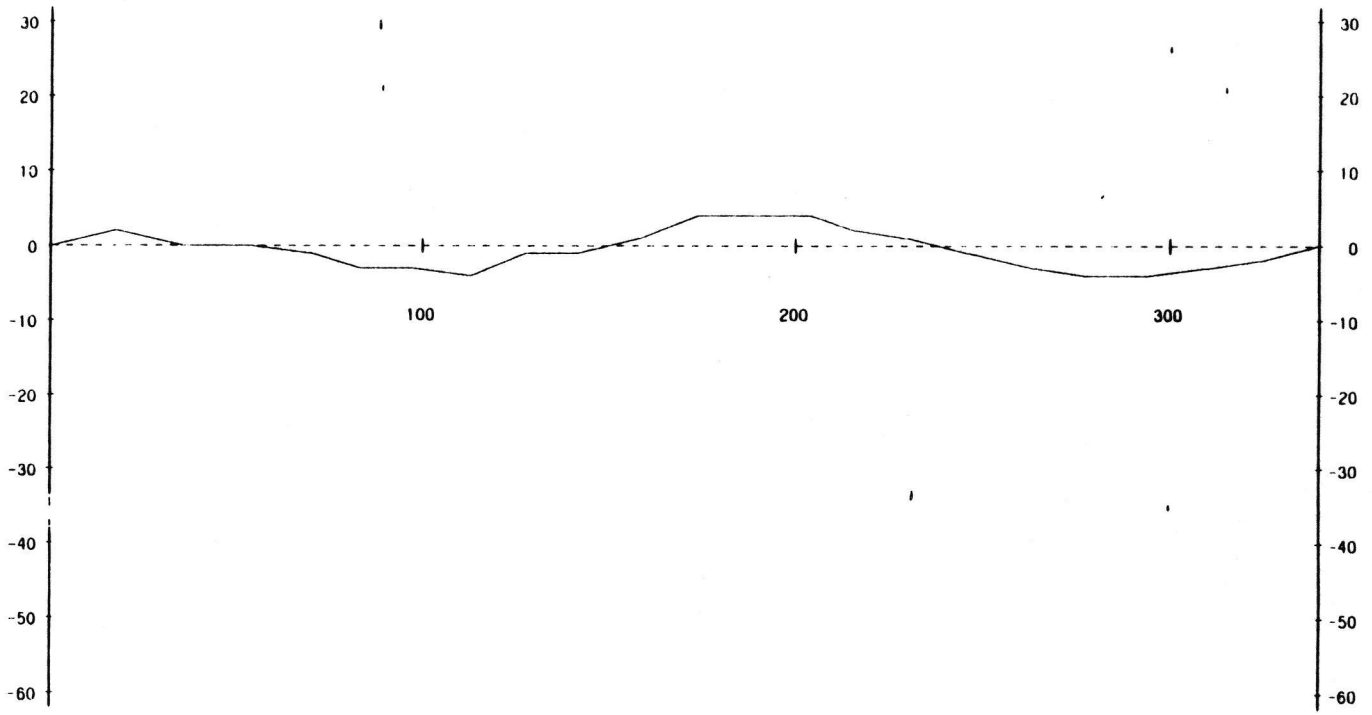

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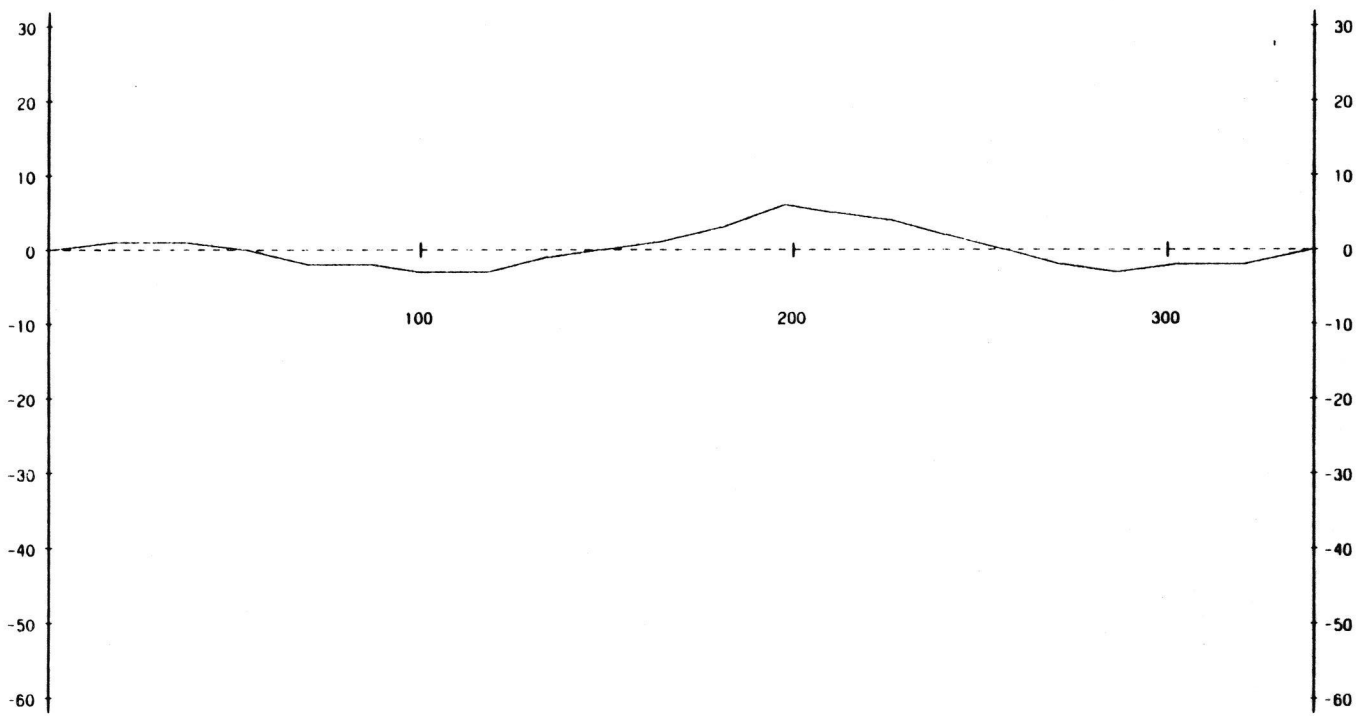

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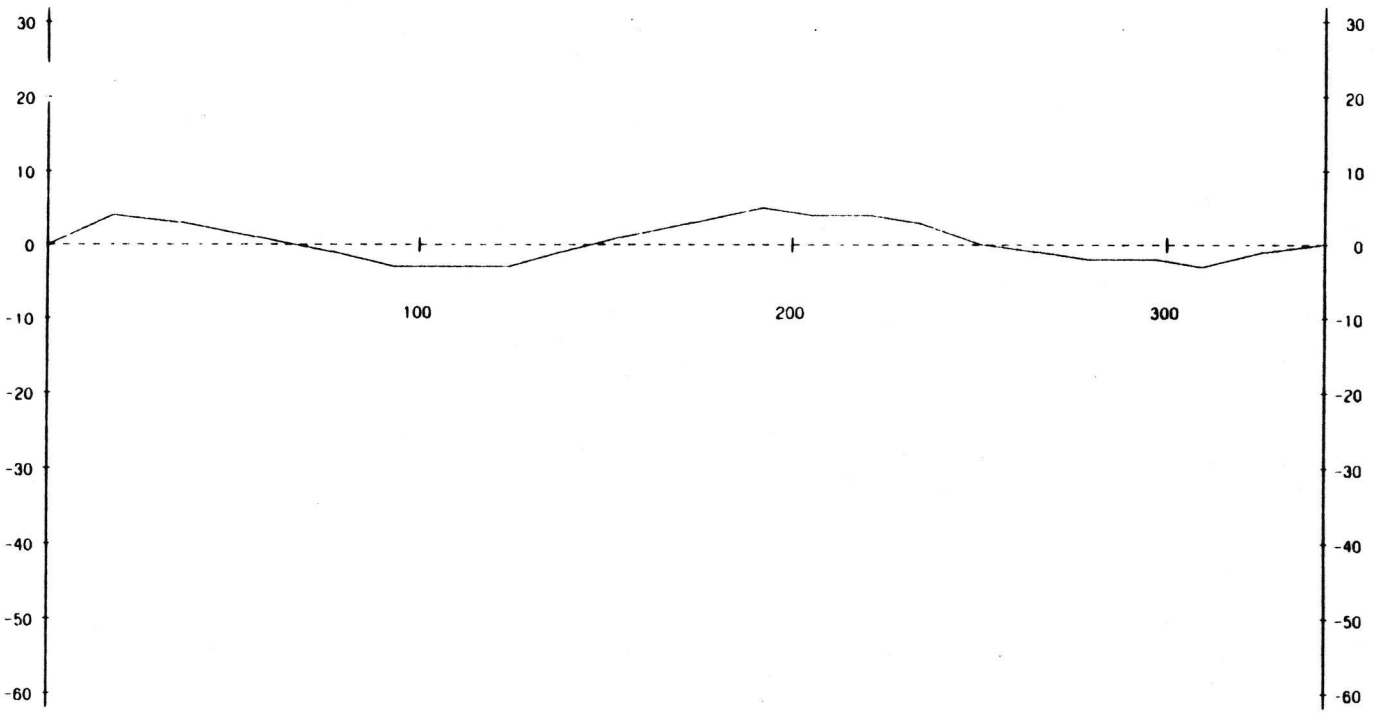

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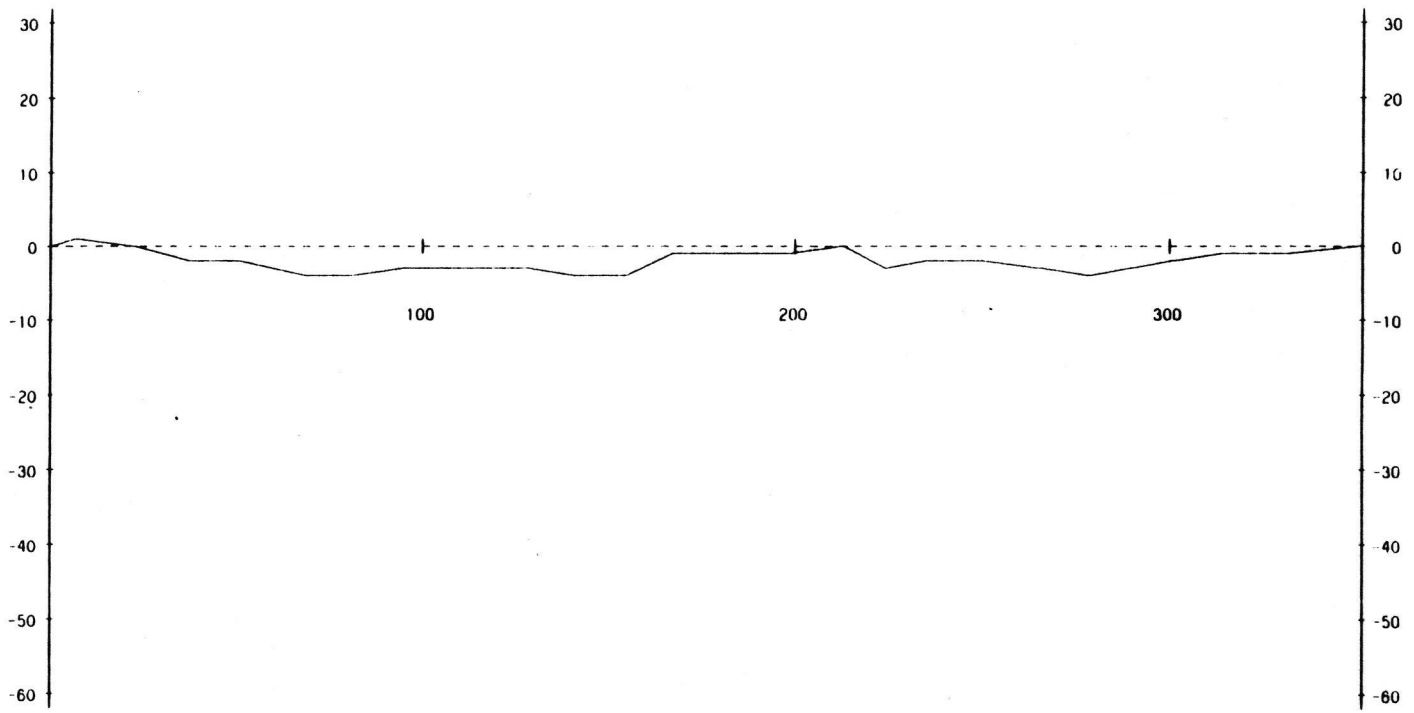

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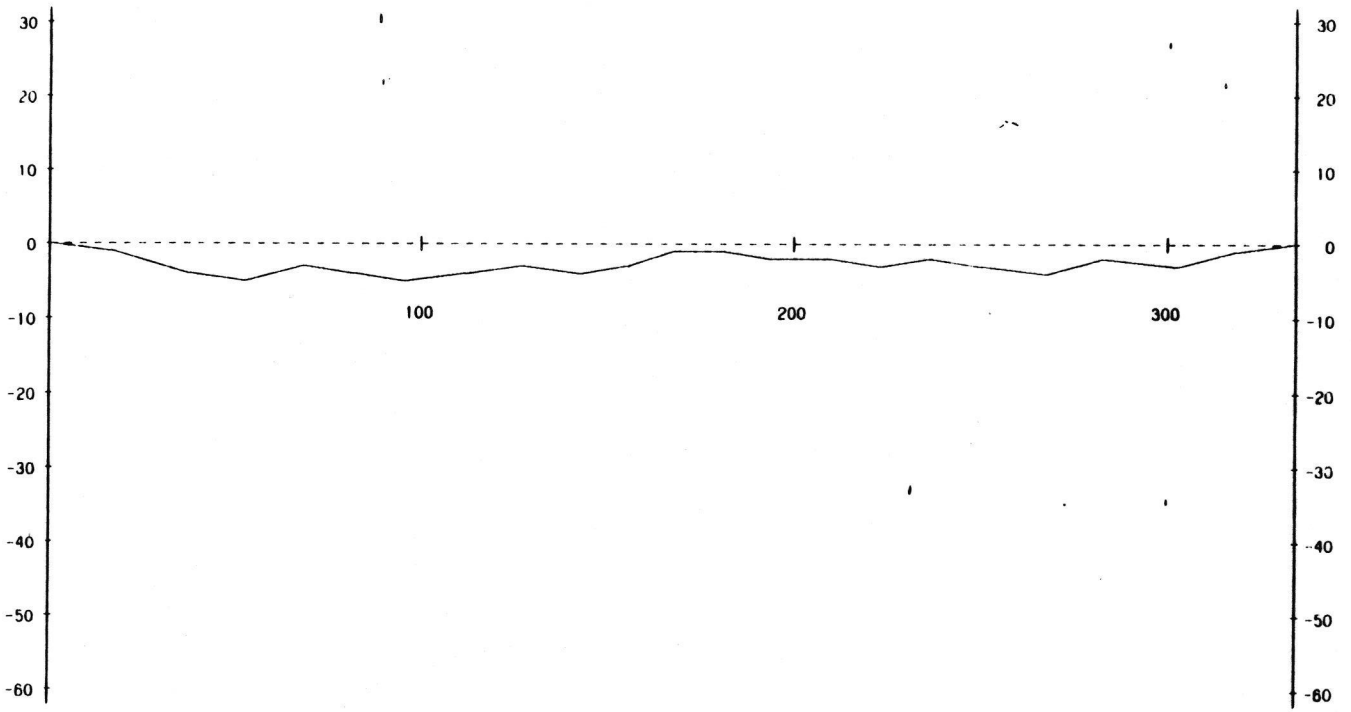

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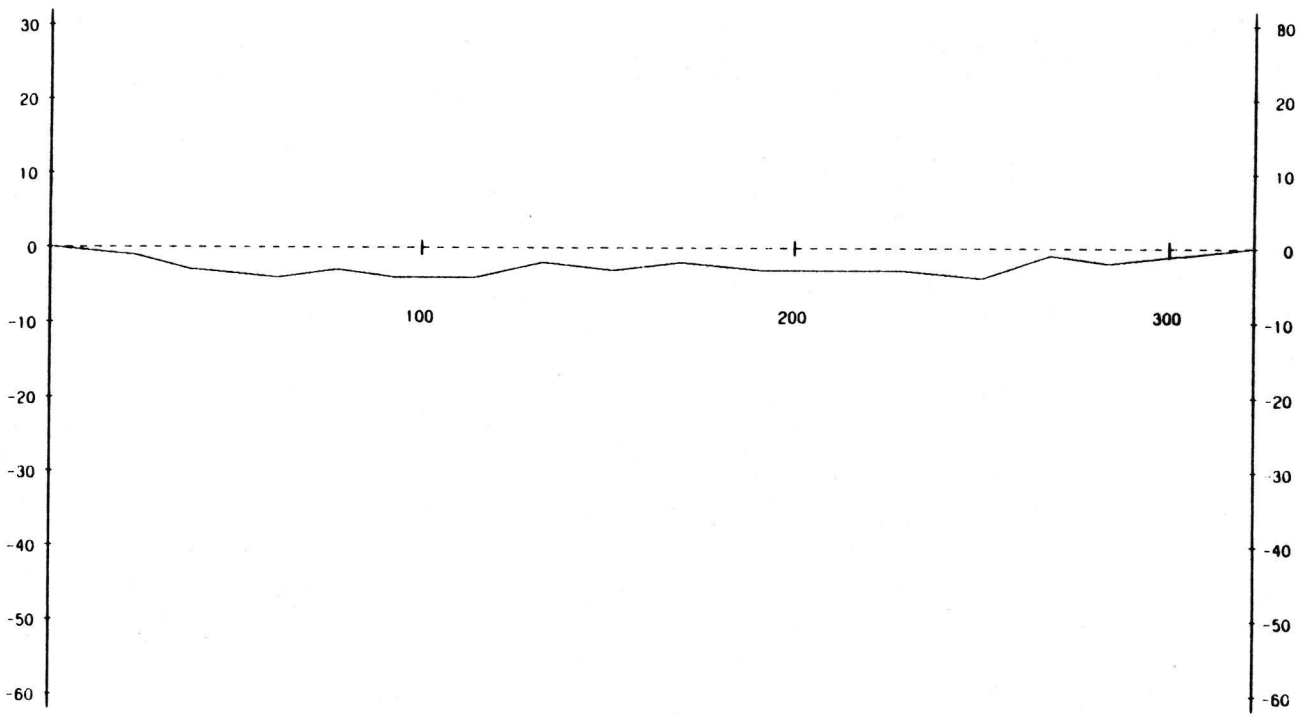

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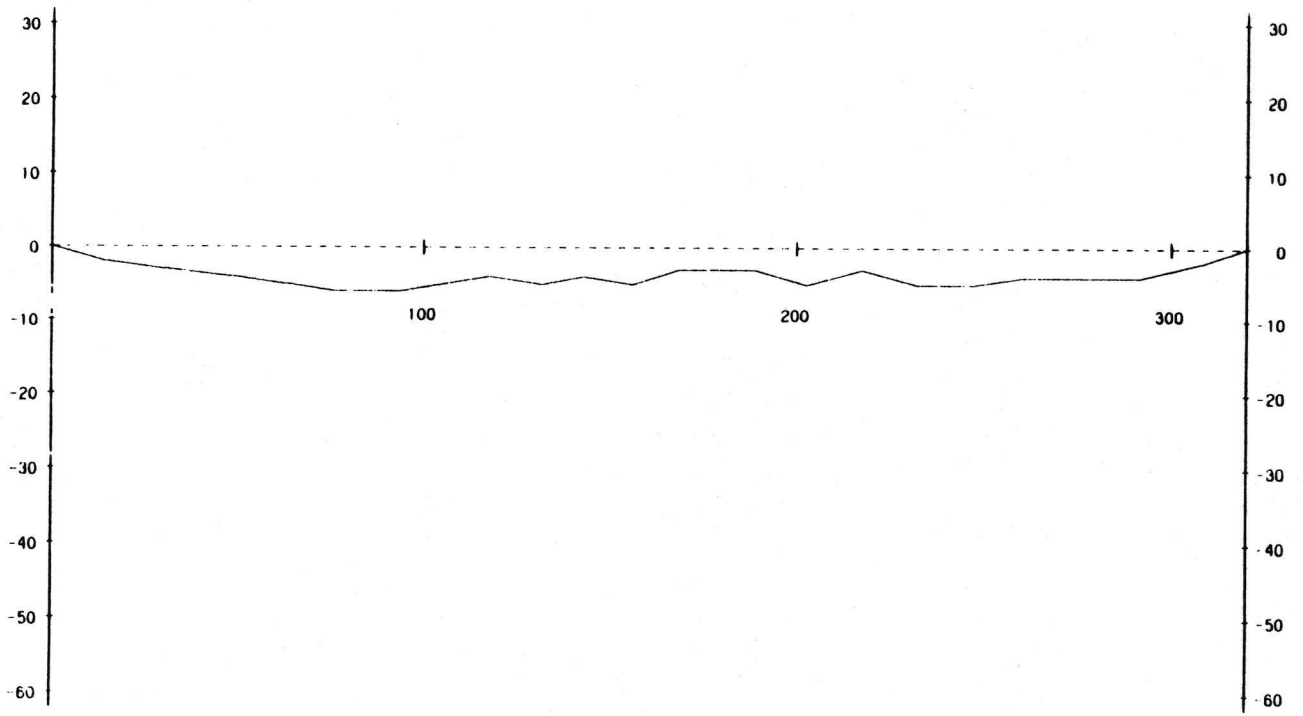

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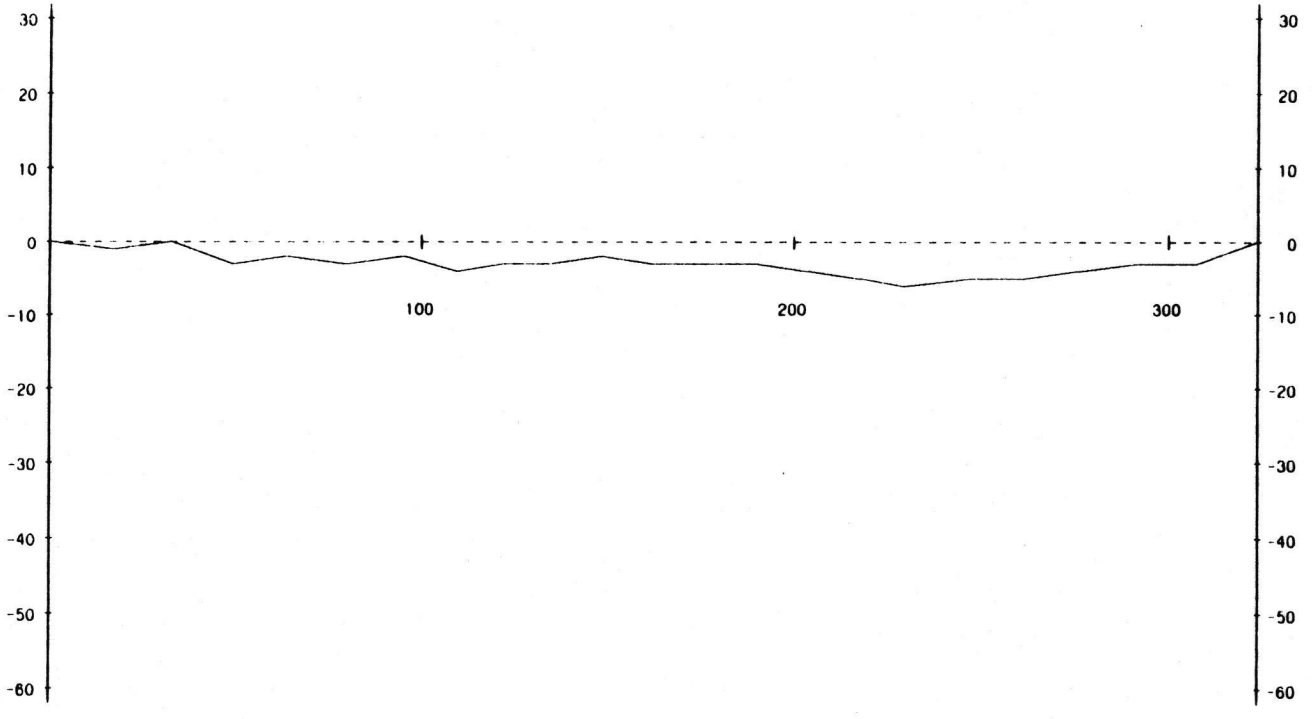

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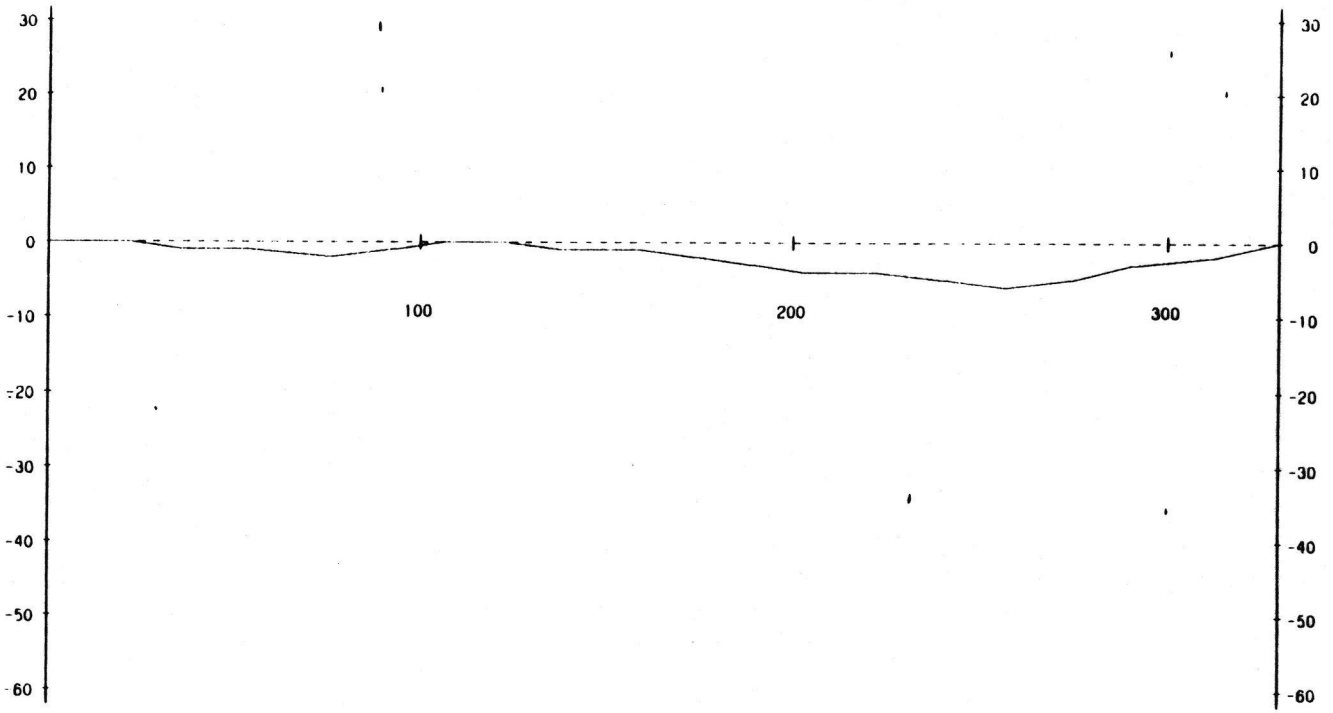

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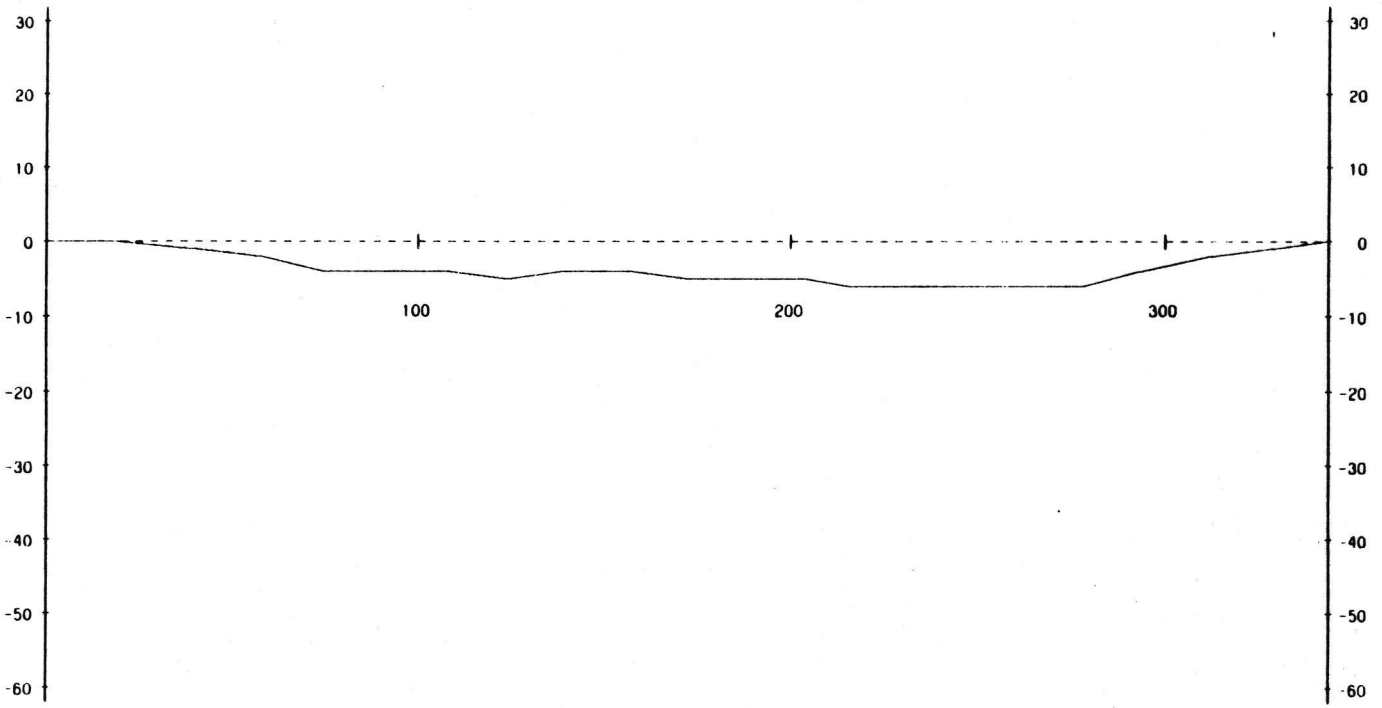

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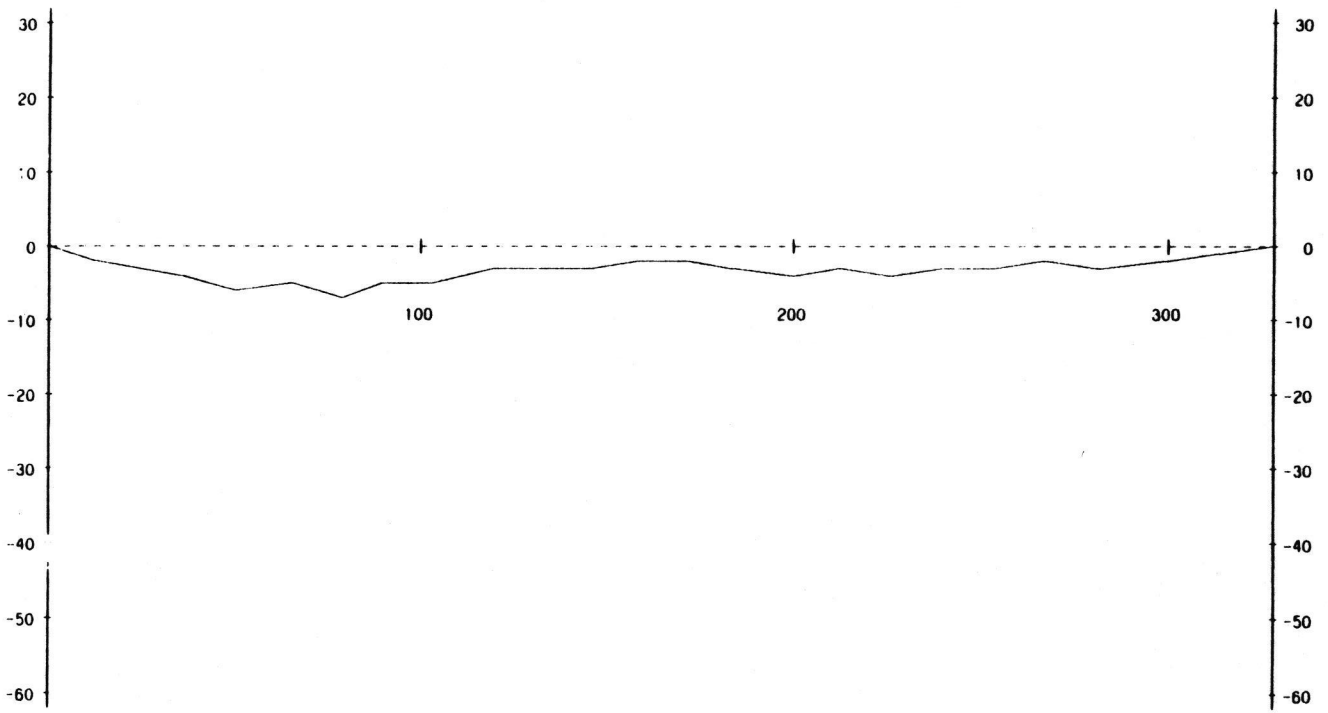

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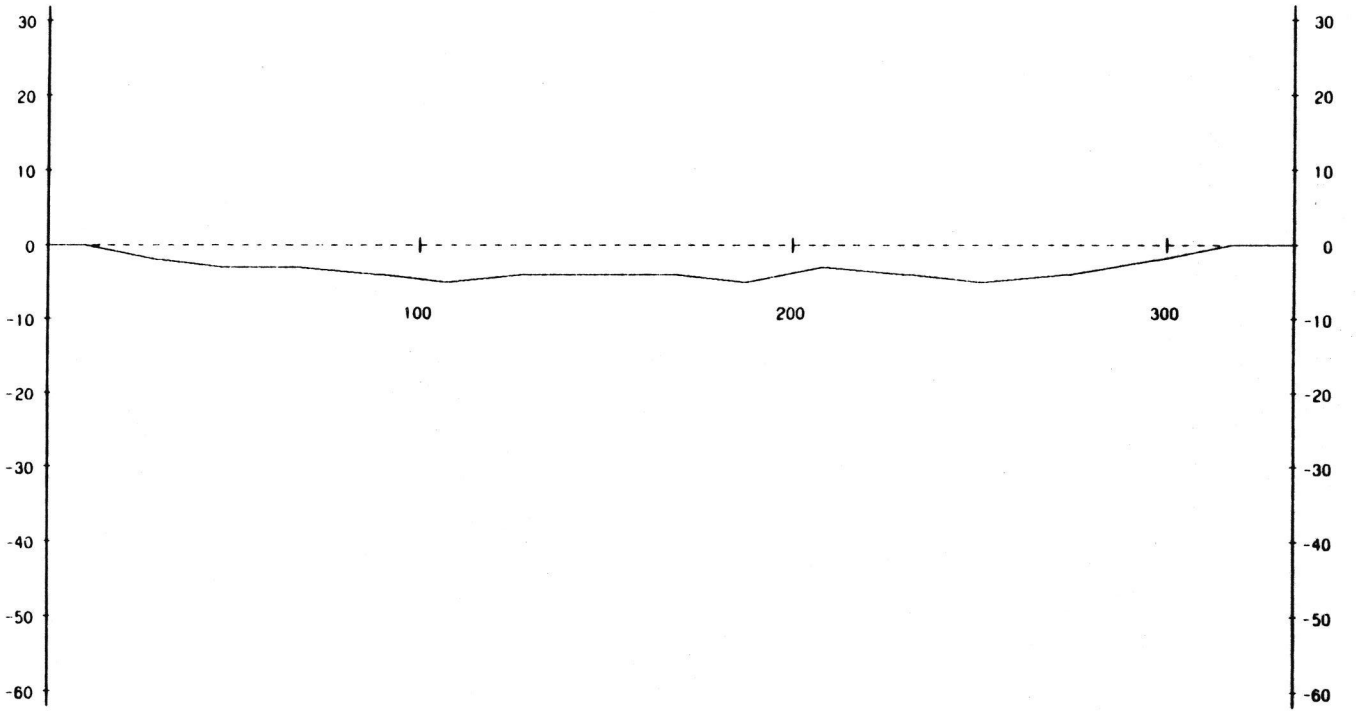

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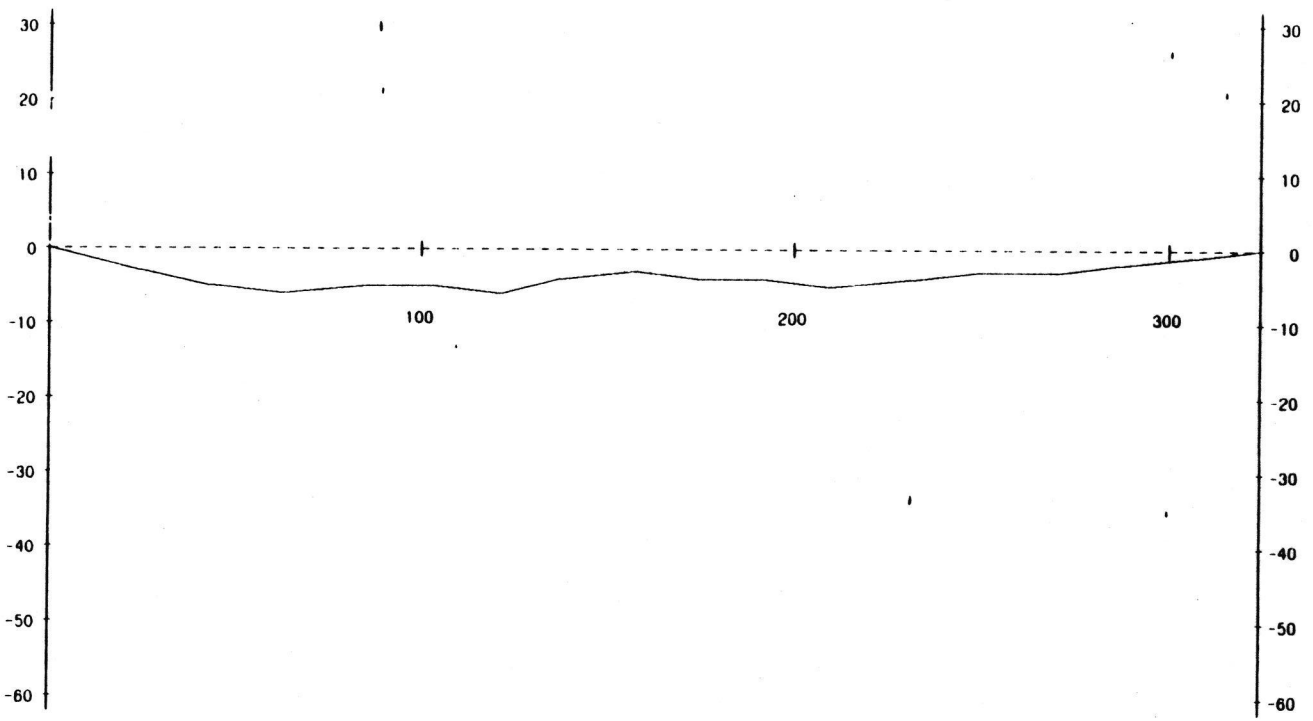

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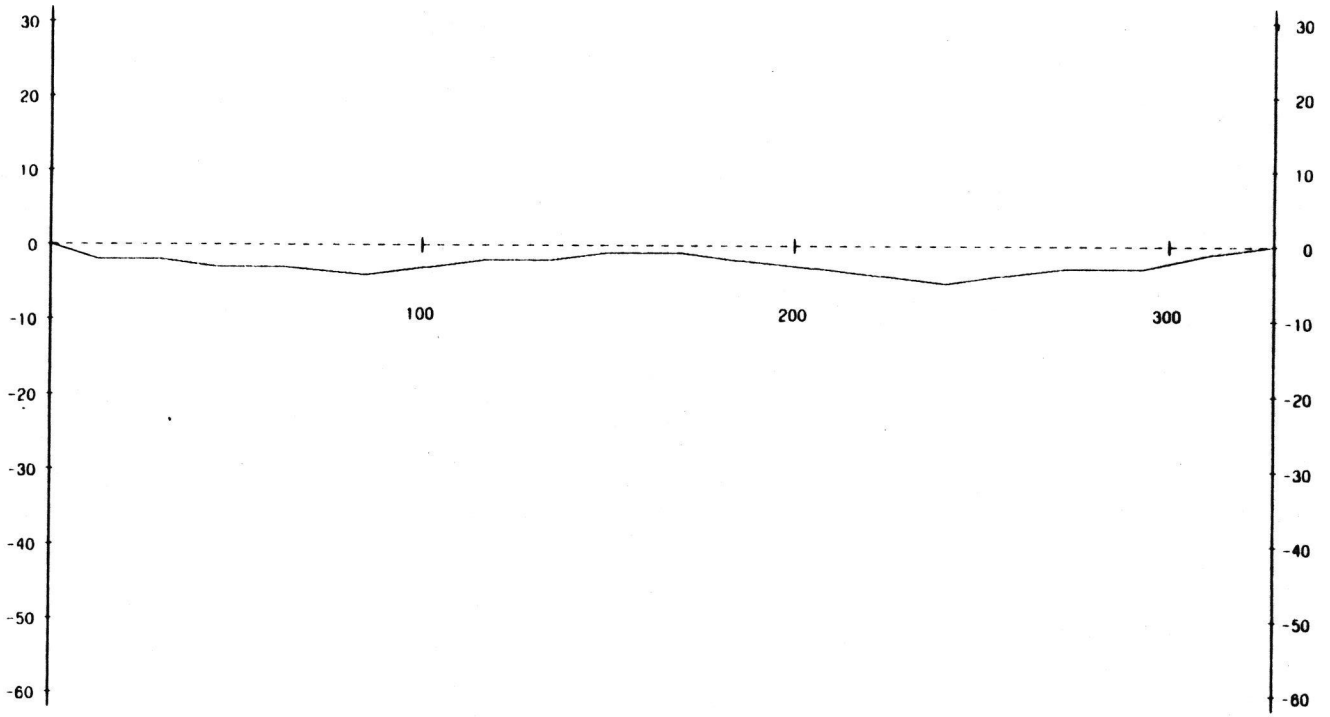

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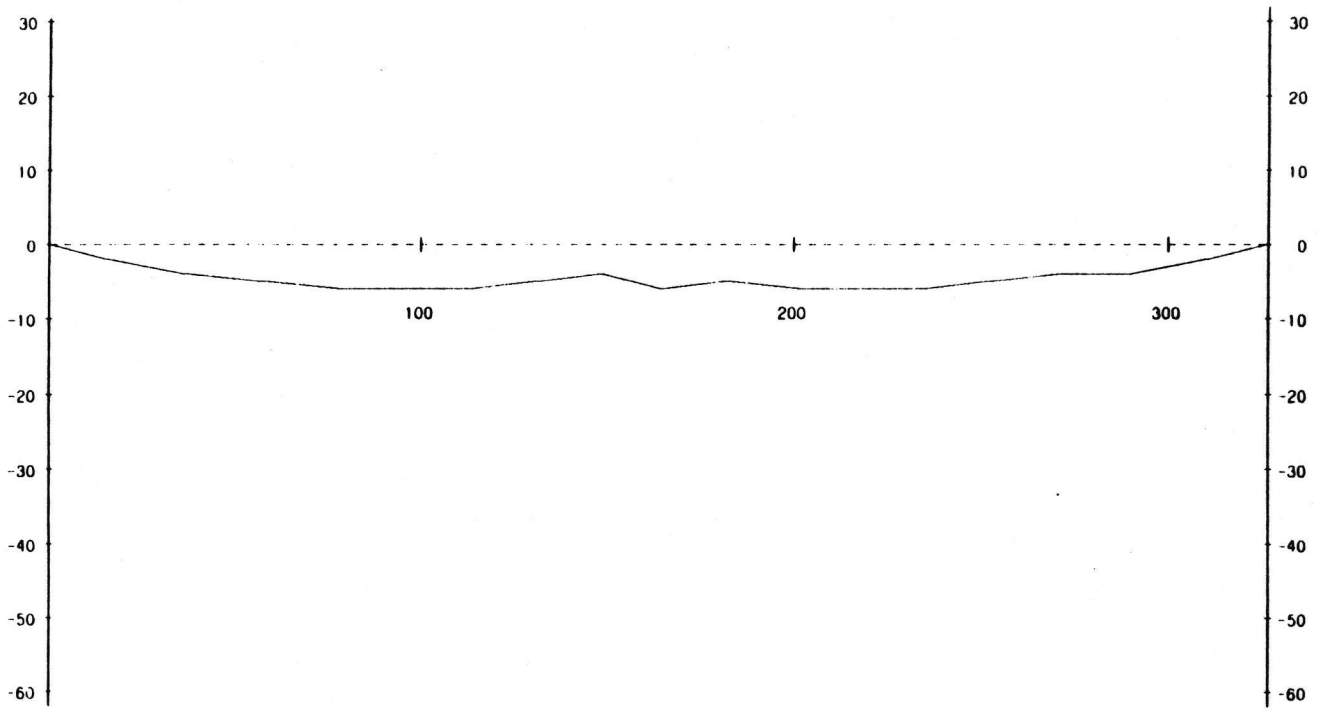

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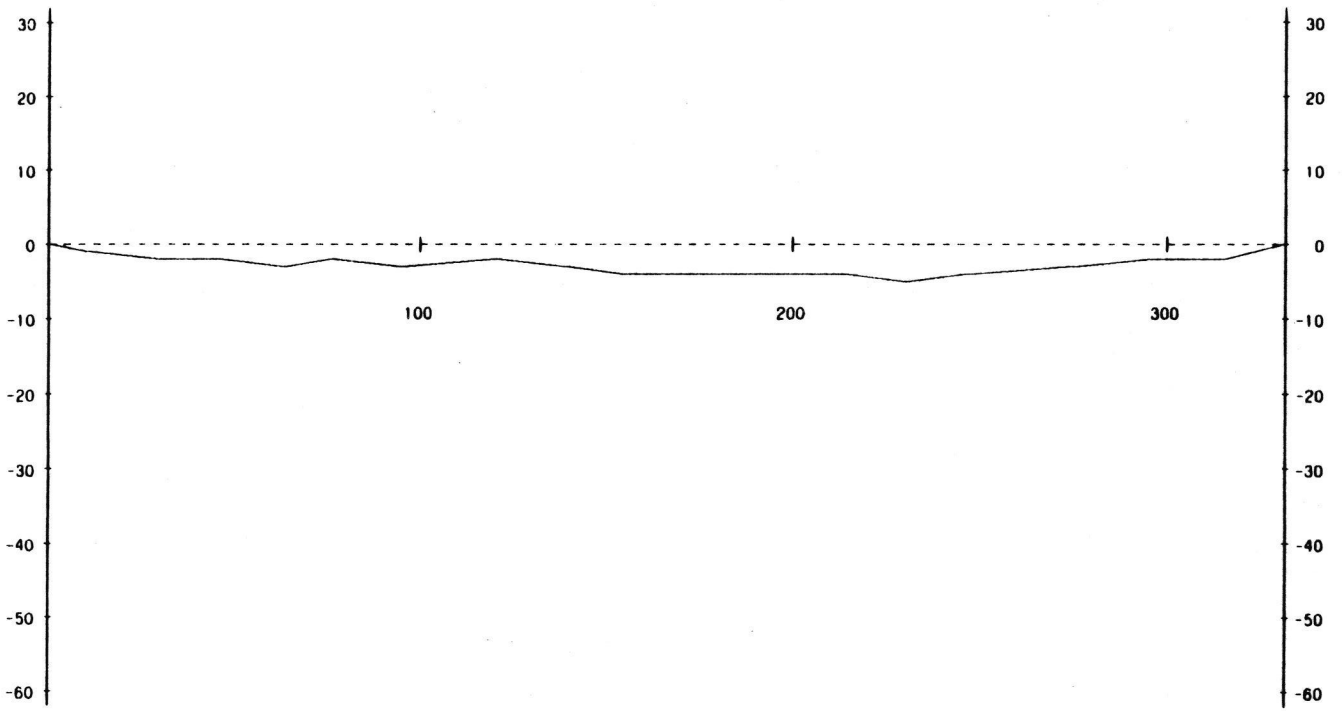

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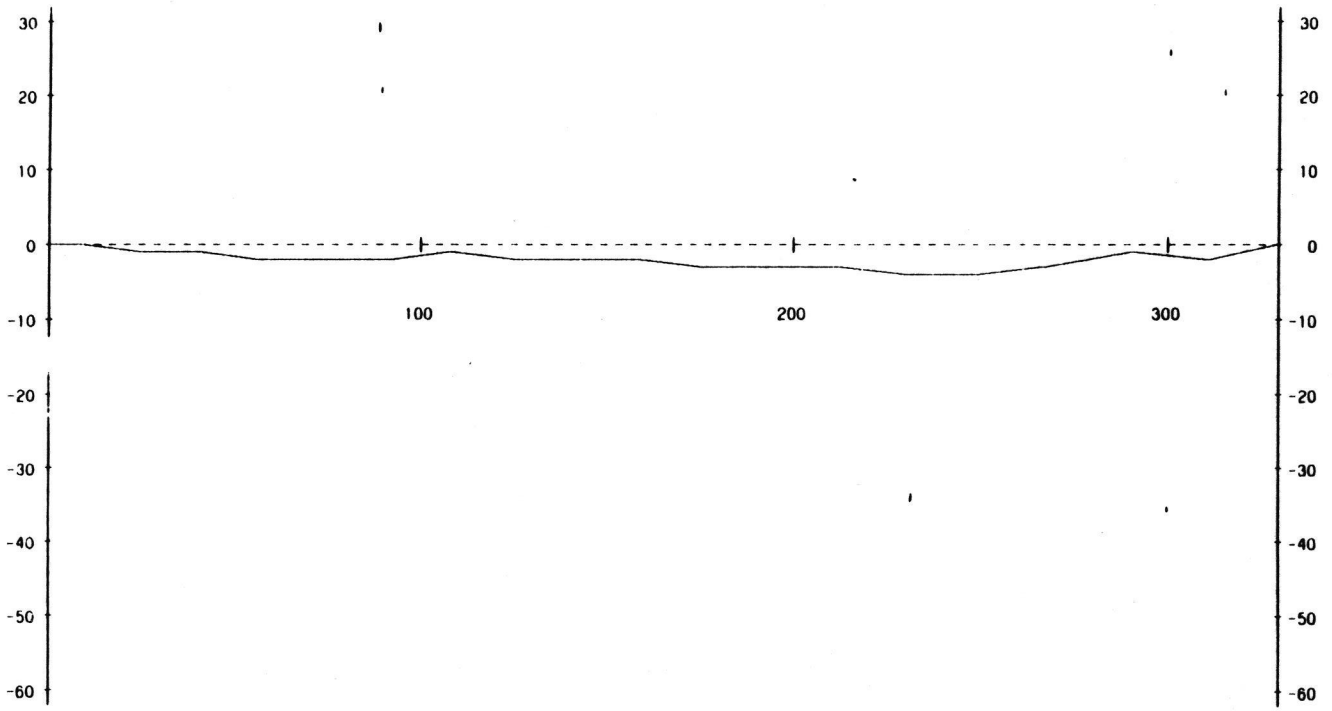

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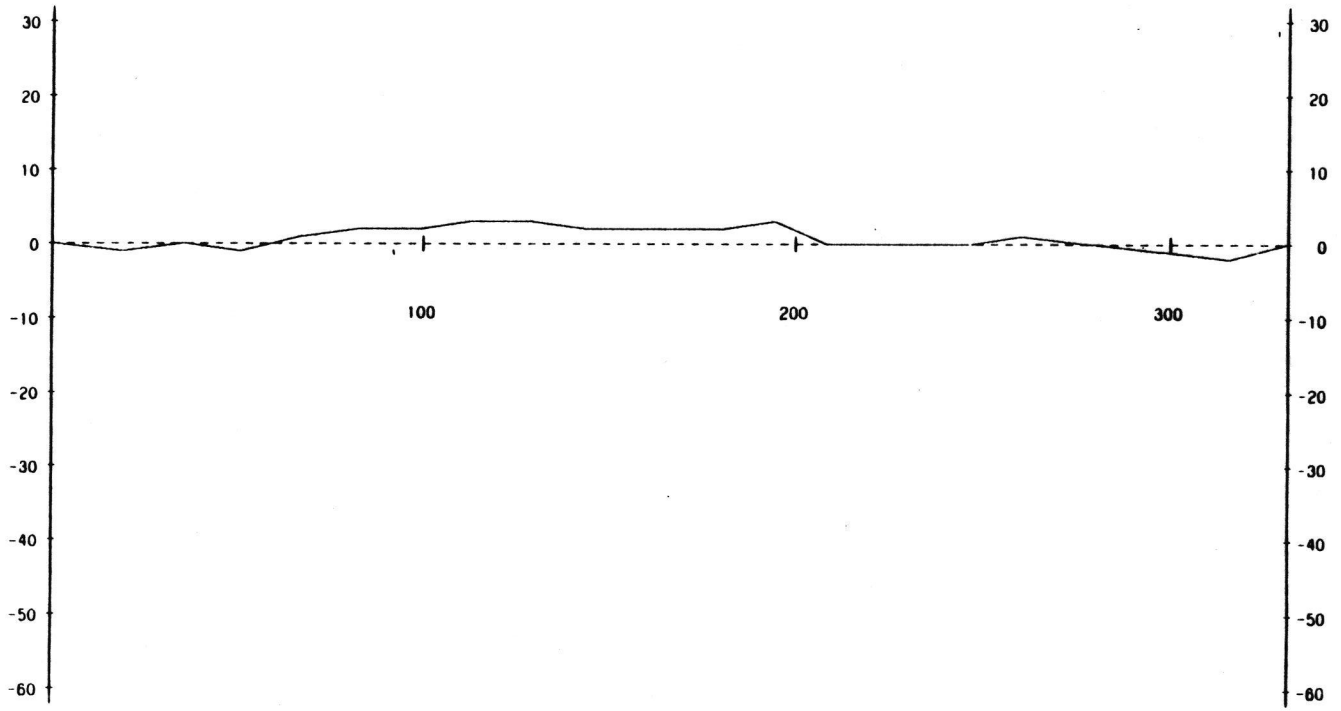

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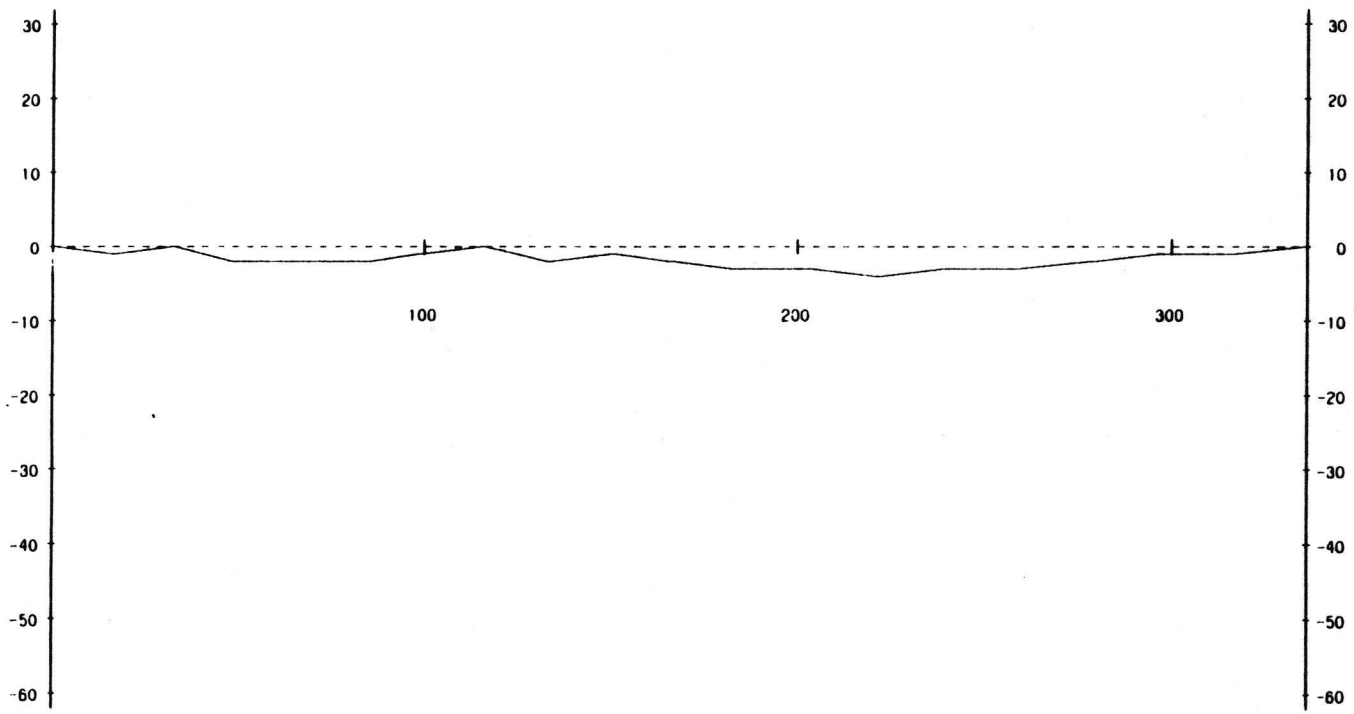

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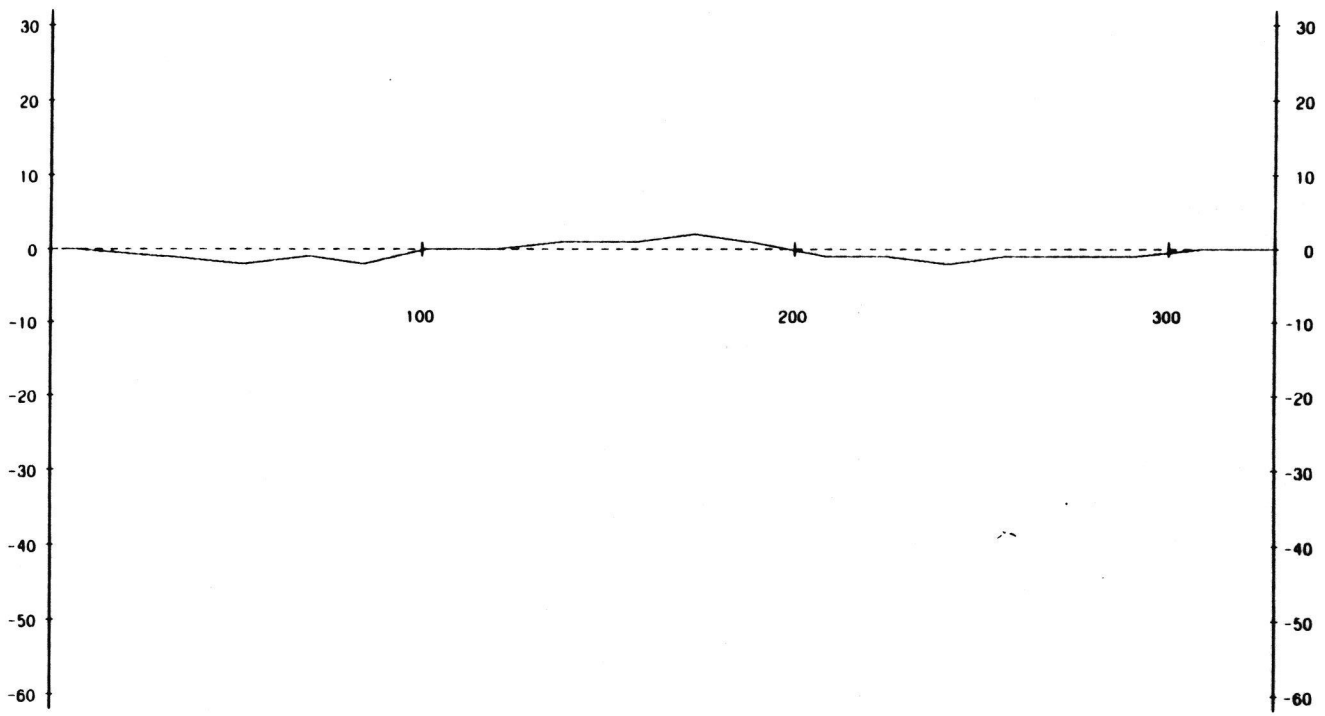

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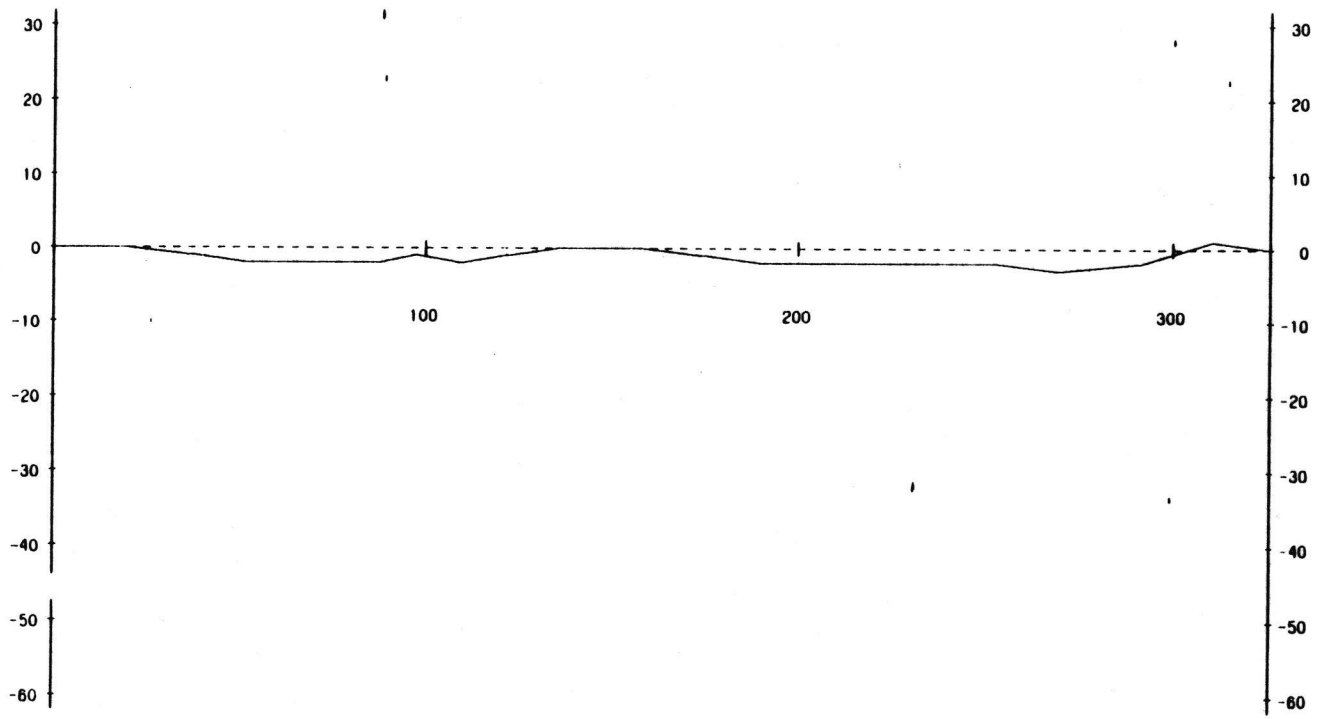

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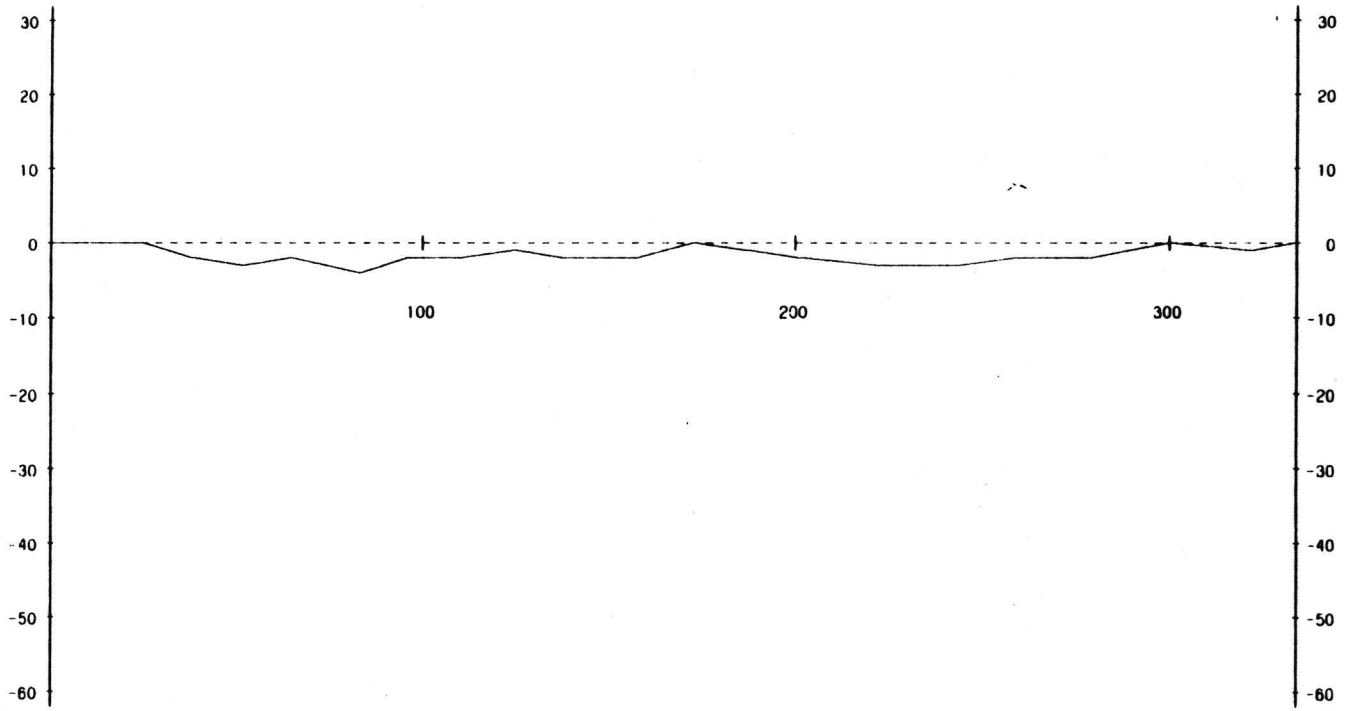

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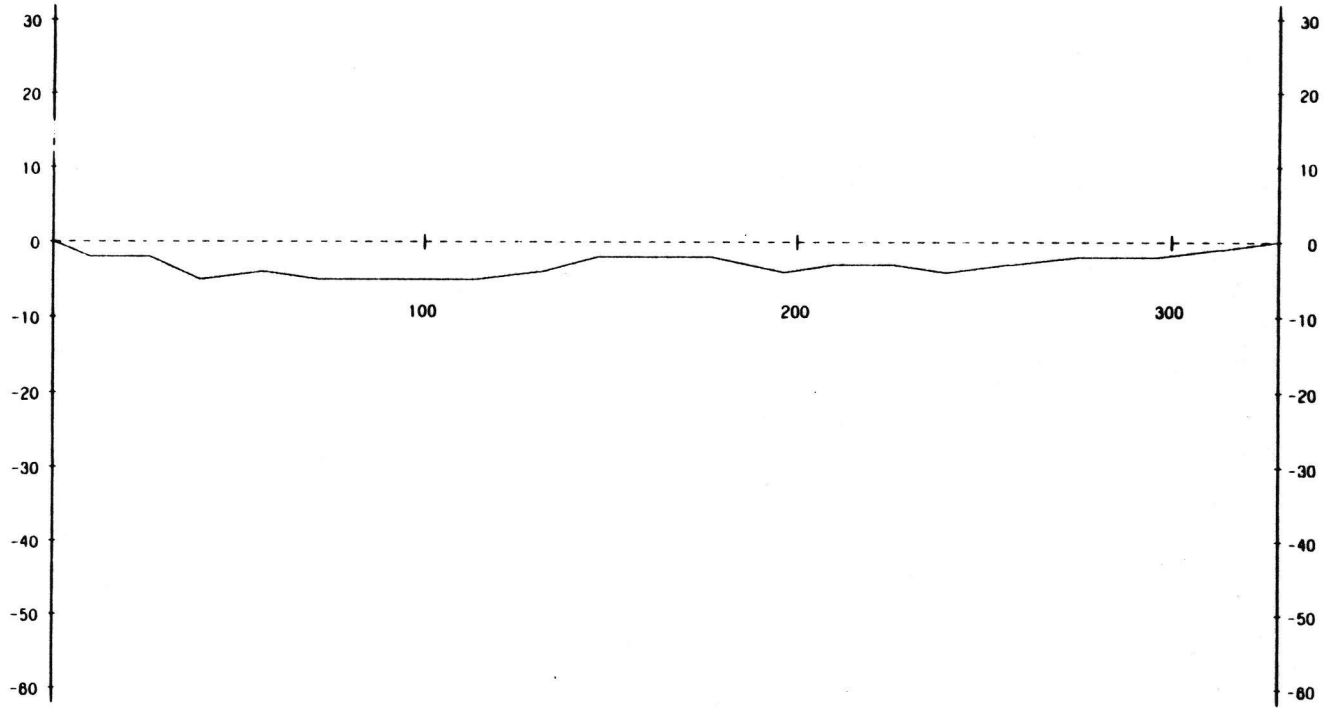

This is processed by " SMOOTHING ".

Digitizing Output

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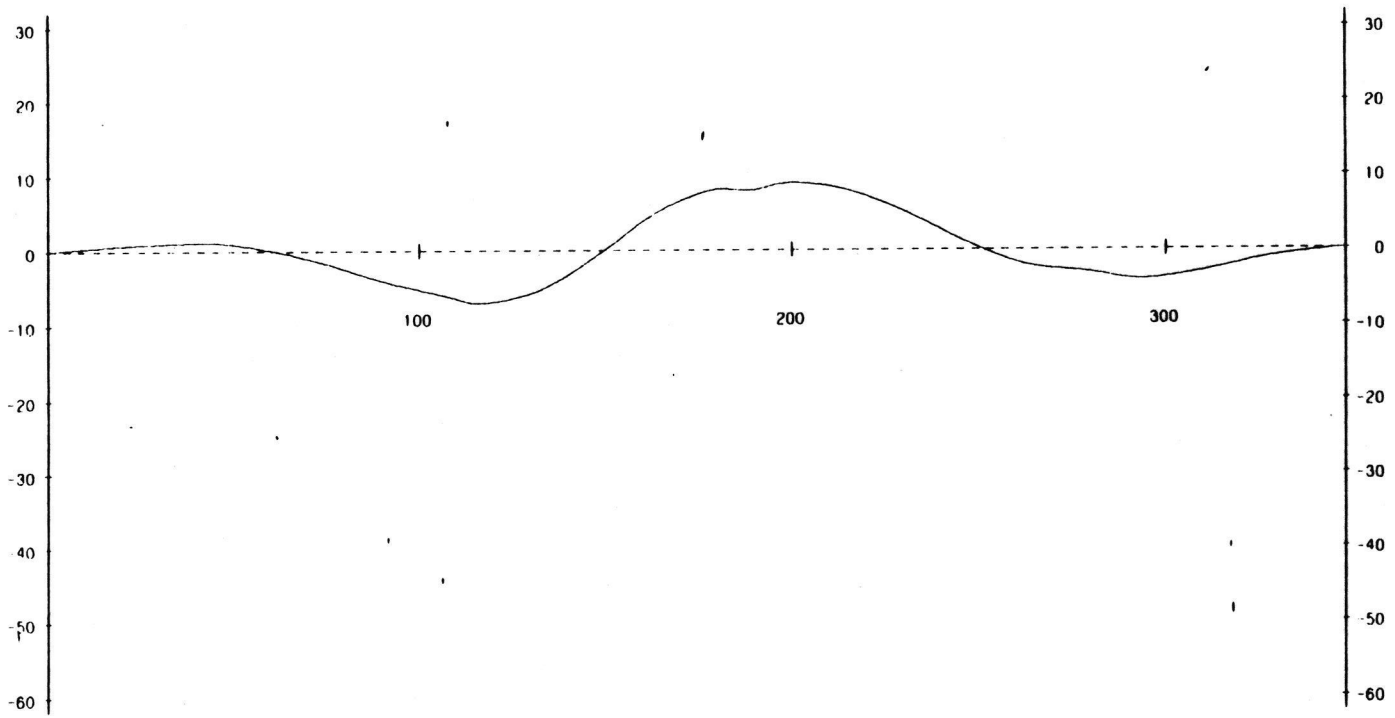

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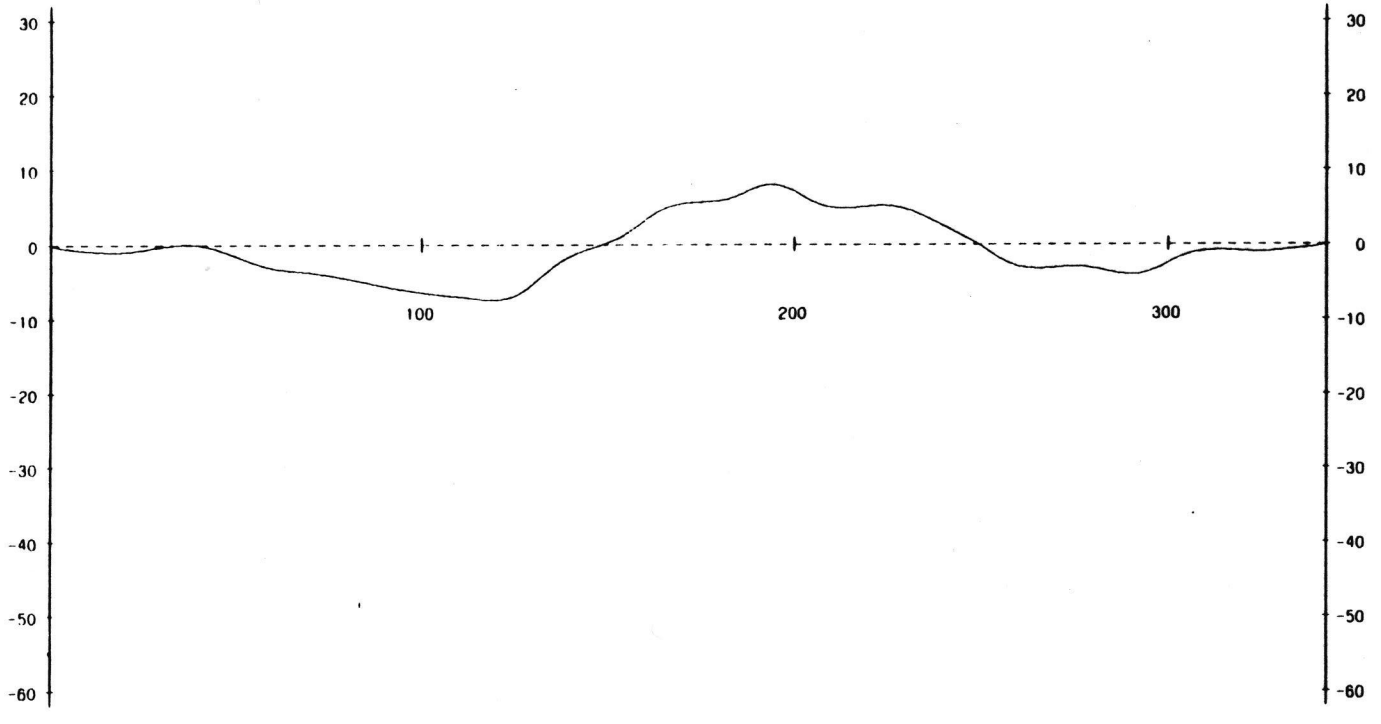

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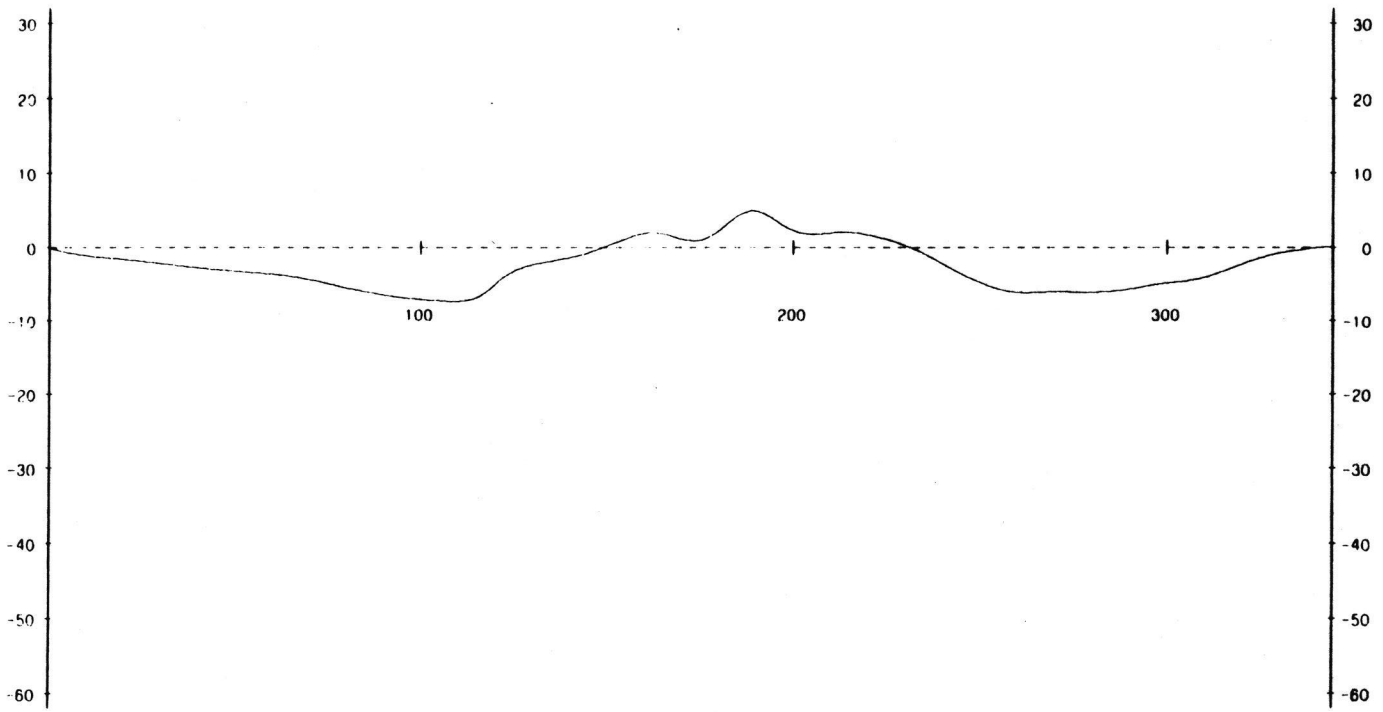

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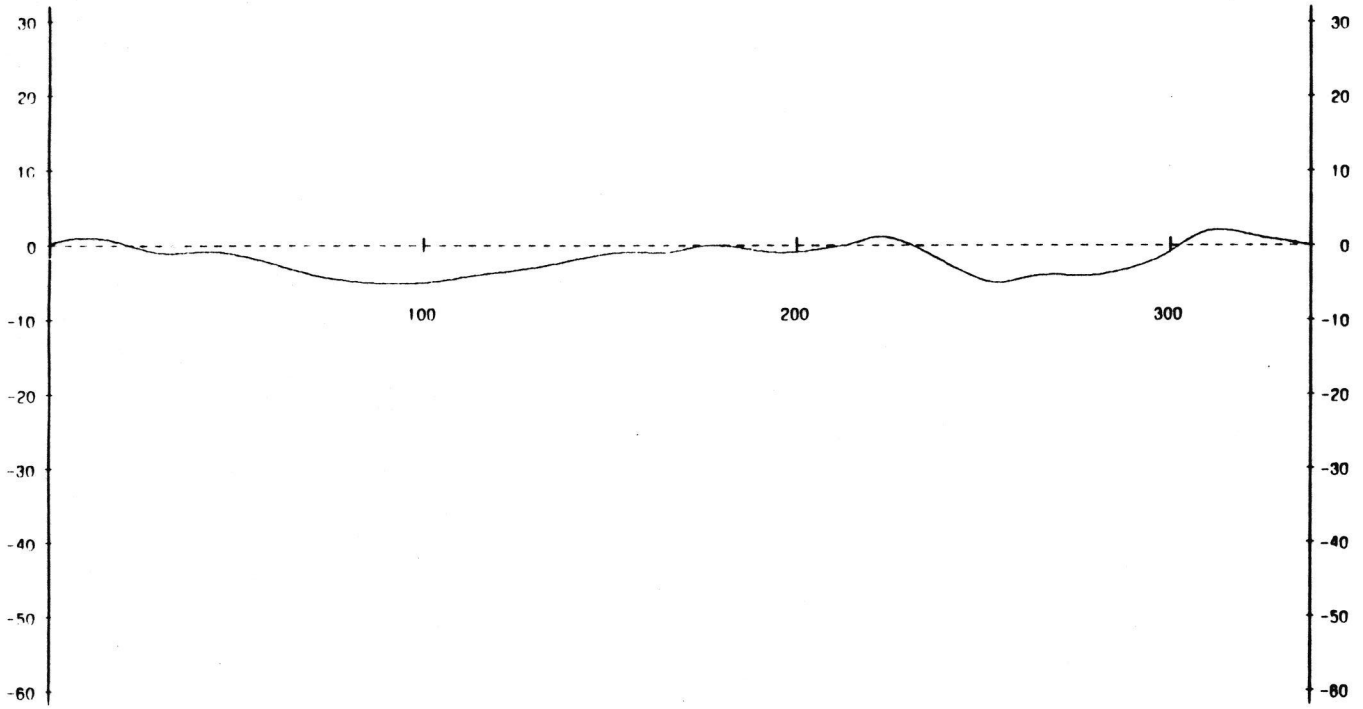

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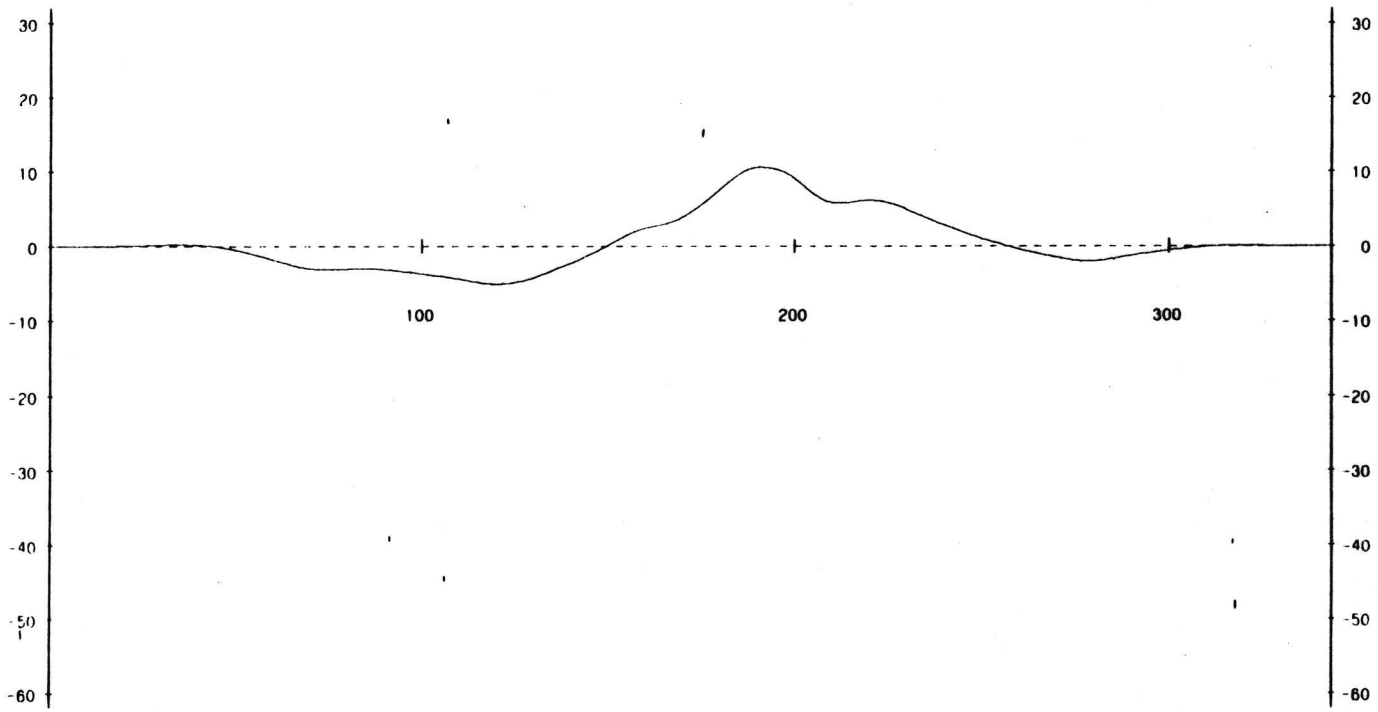

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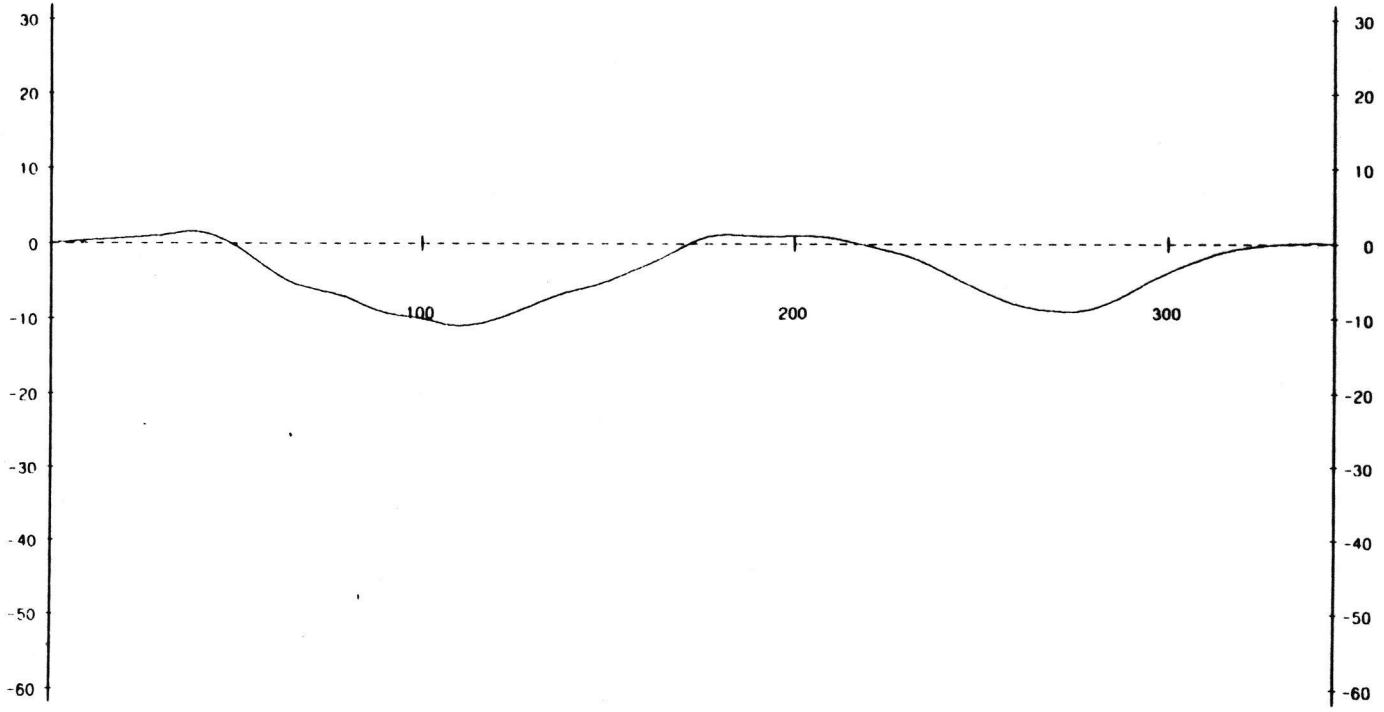

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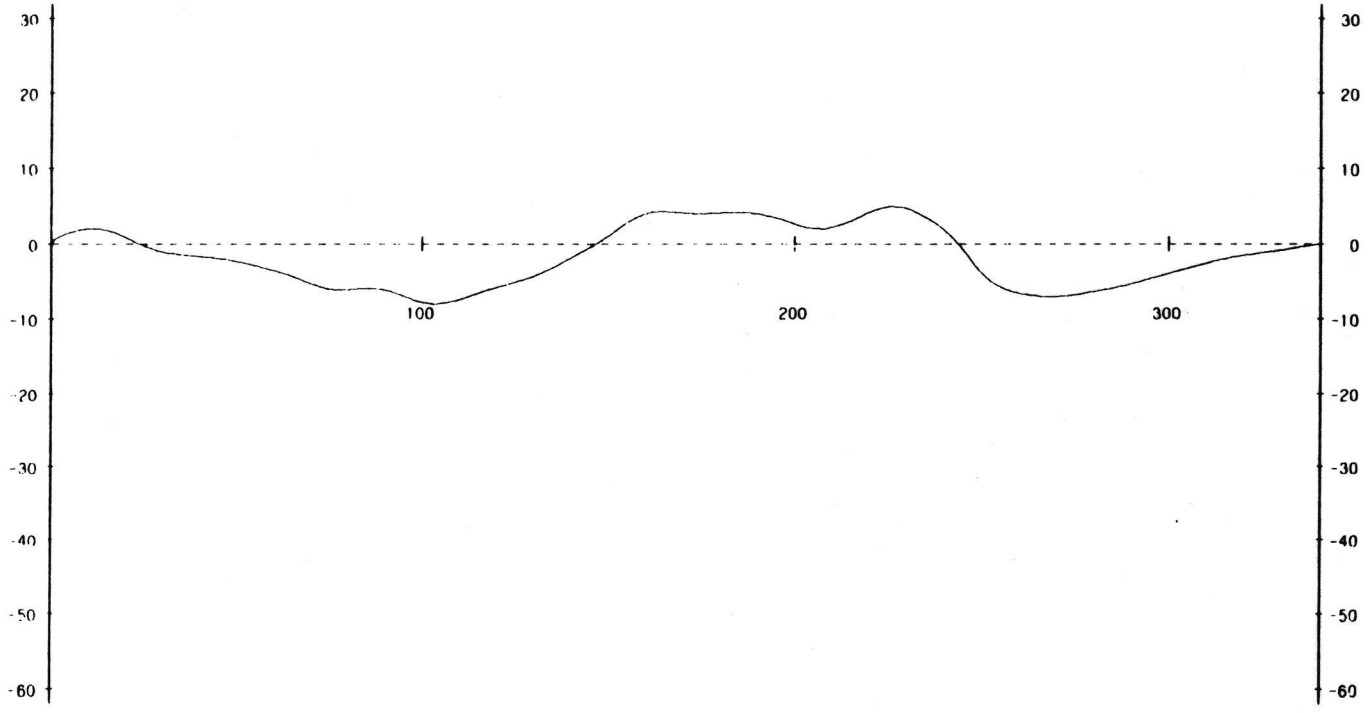

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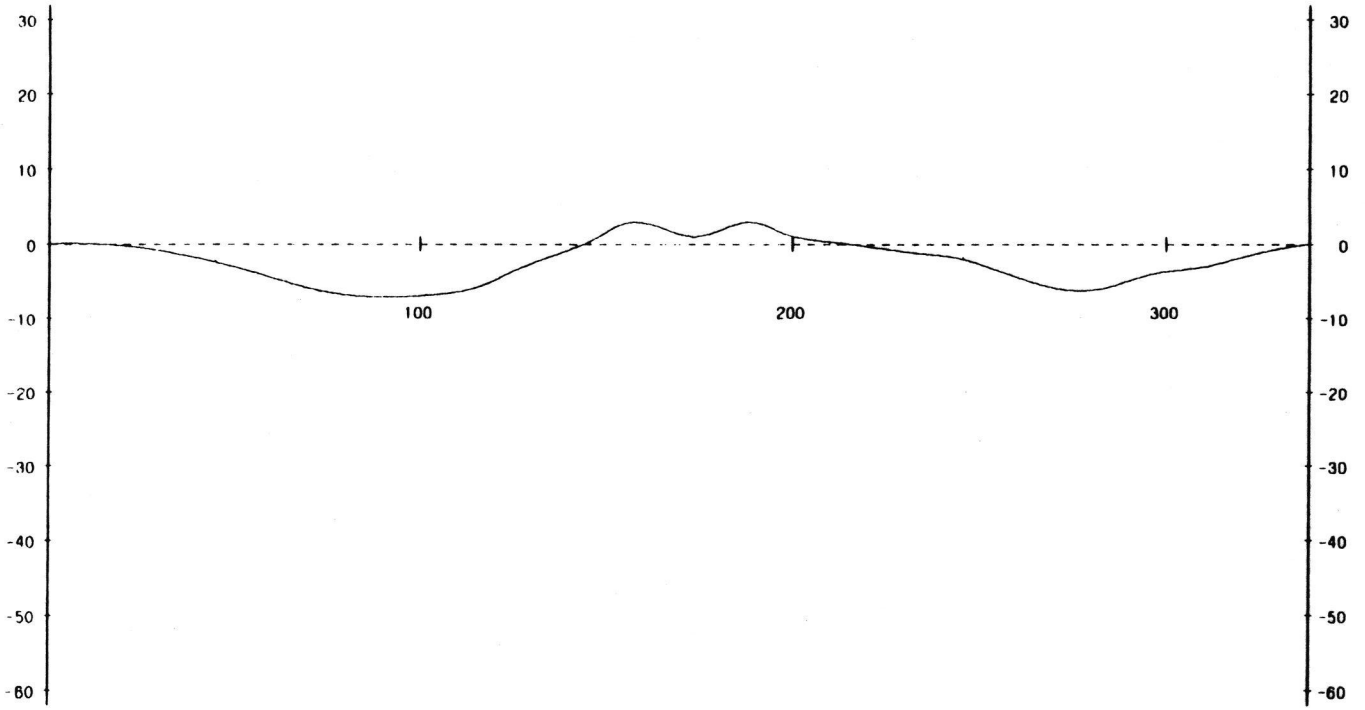

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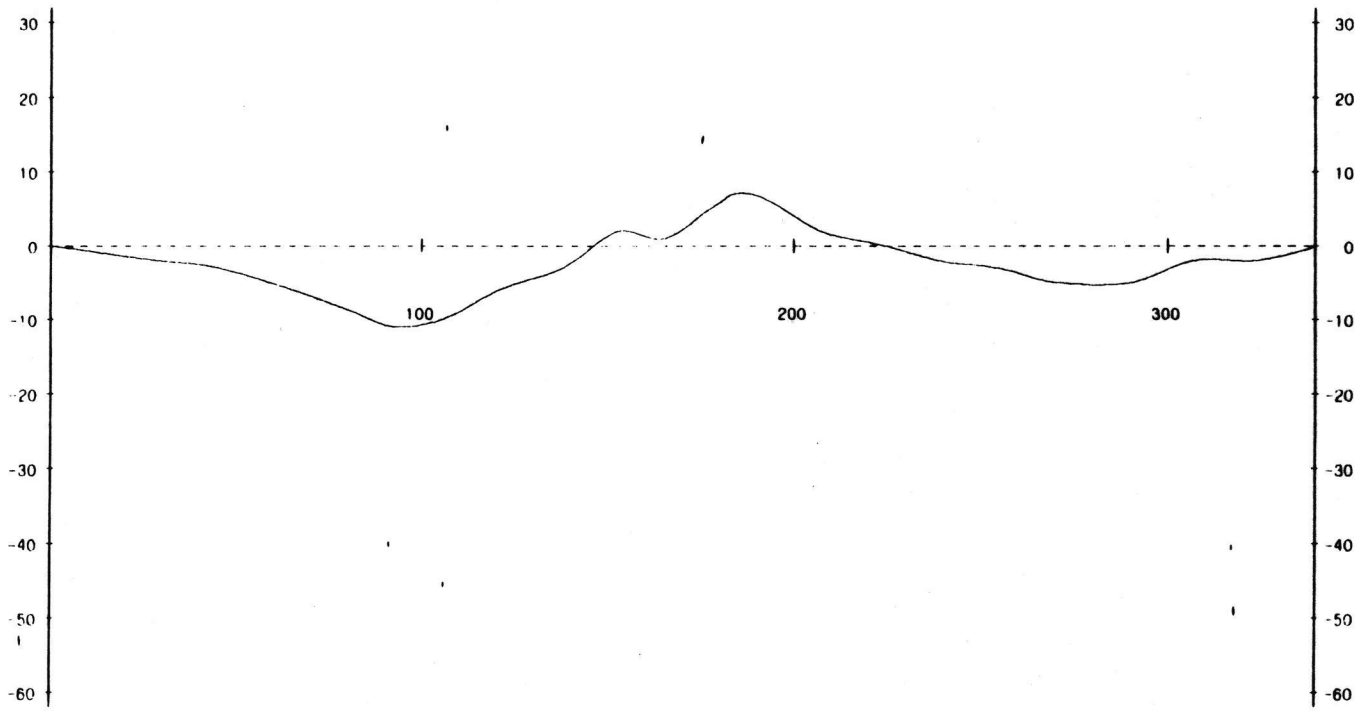

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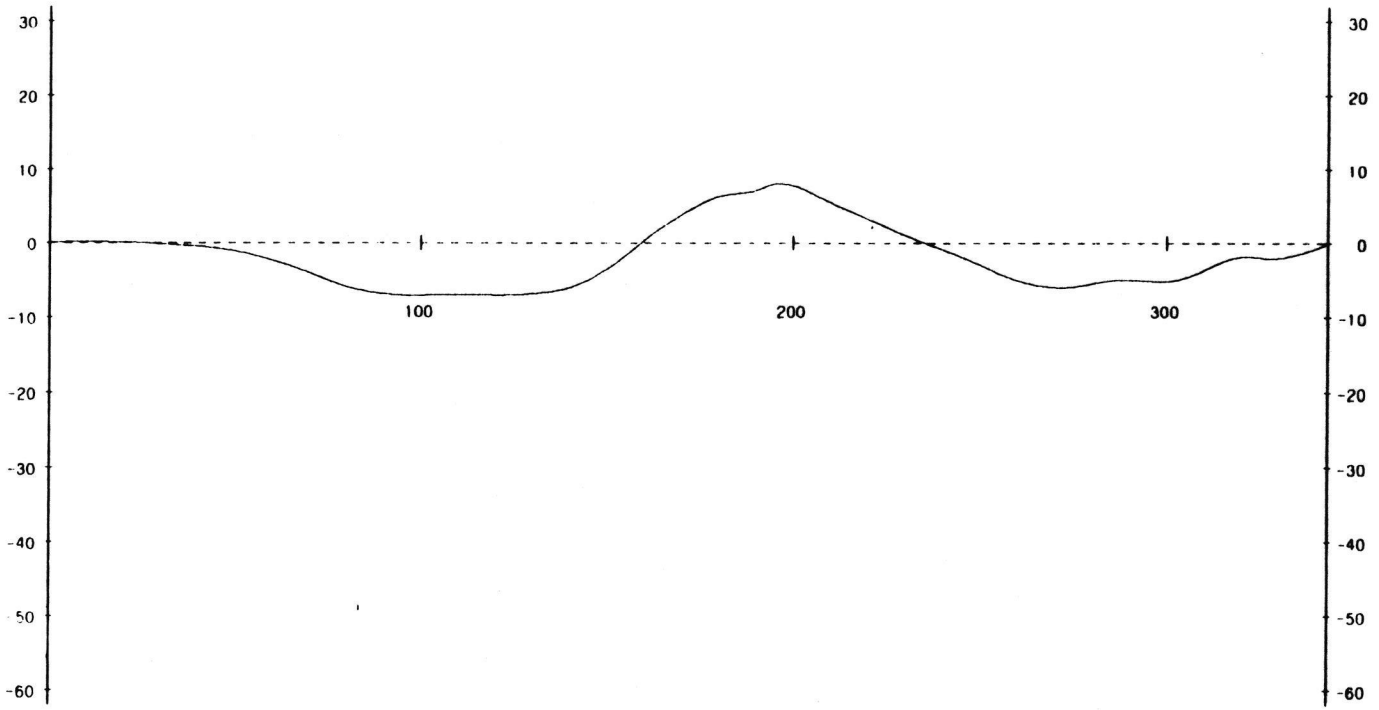

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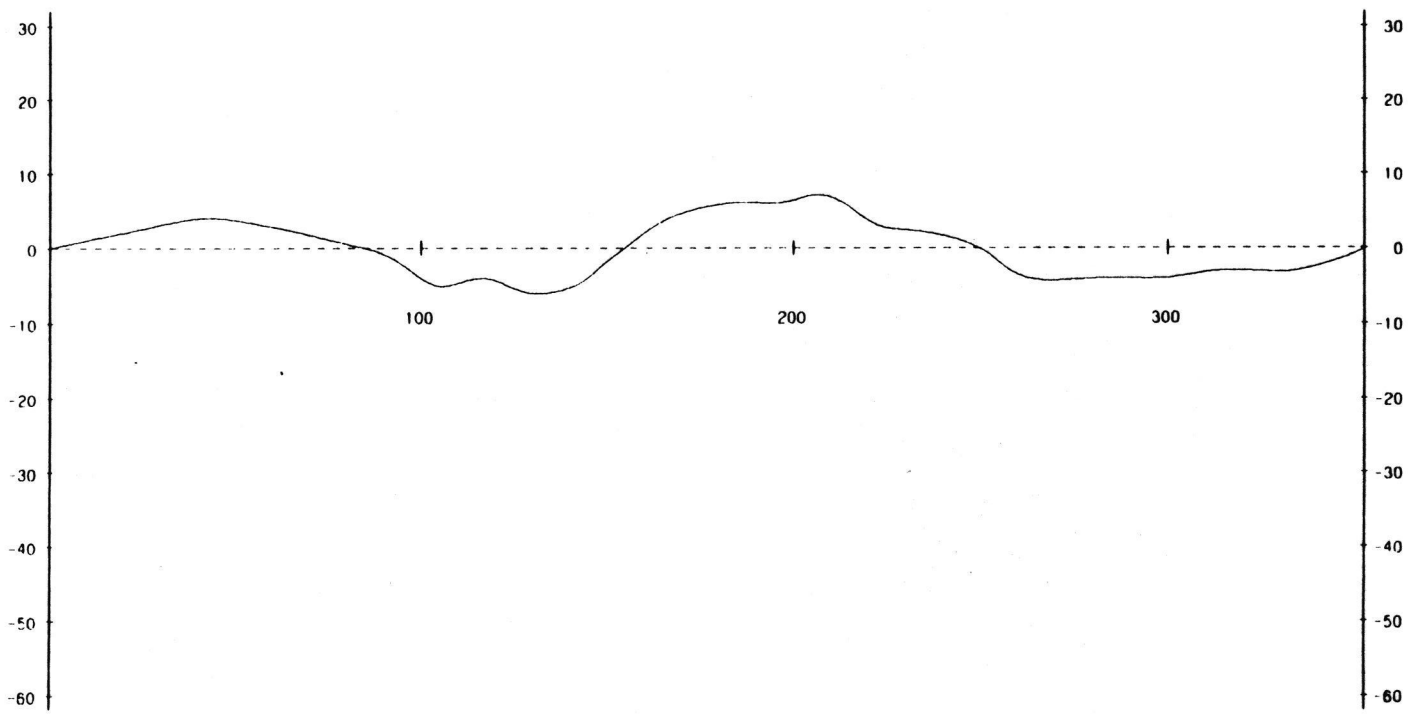

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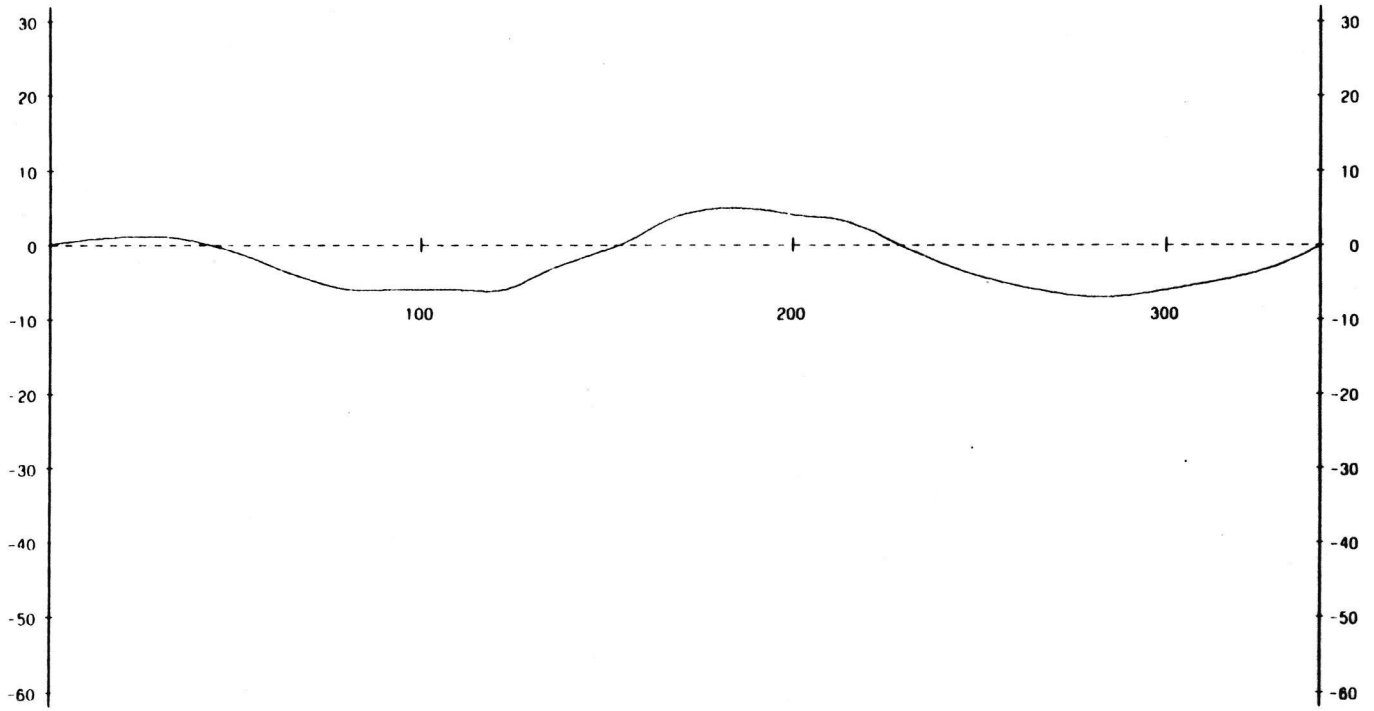

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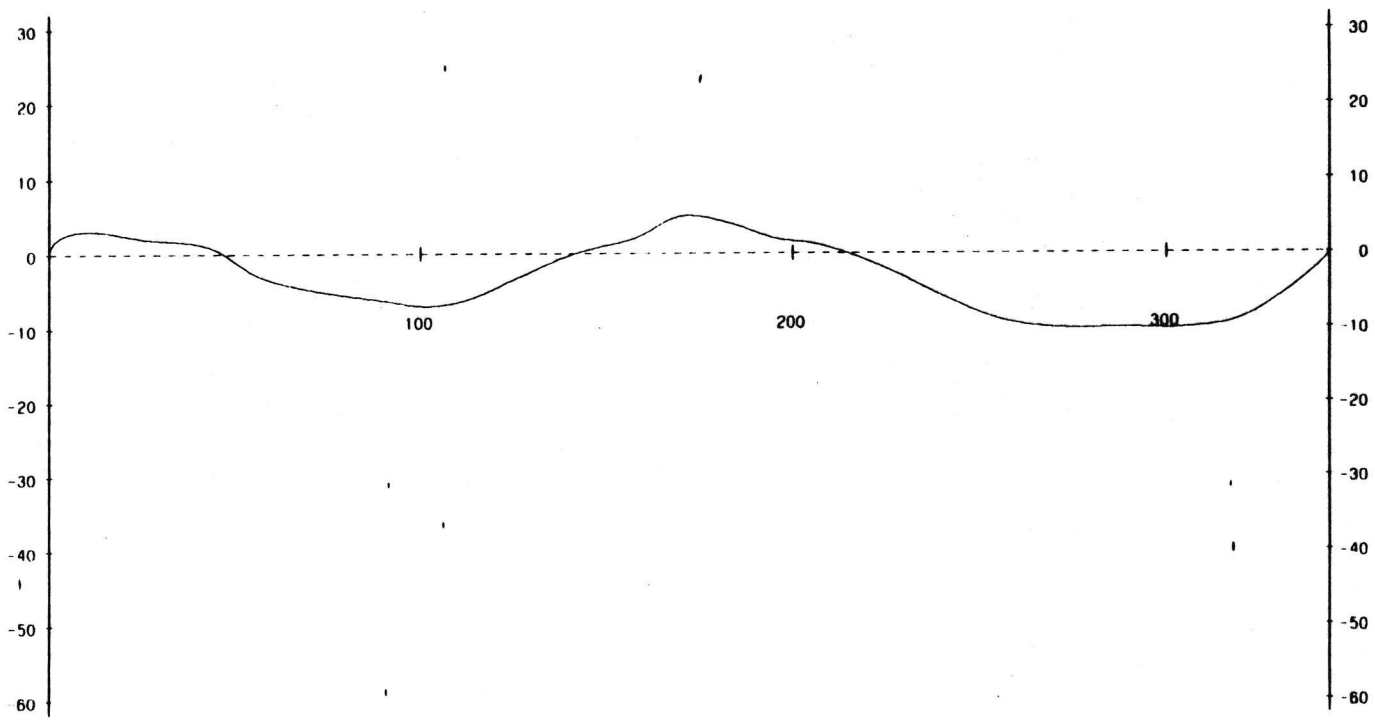

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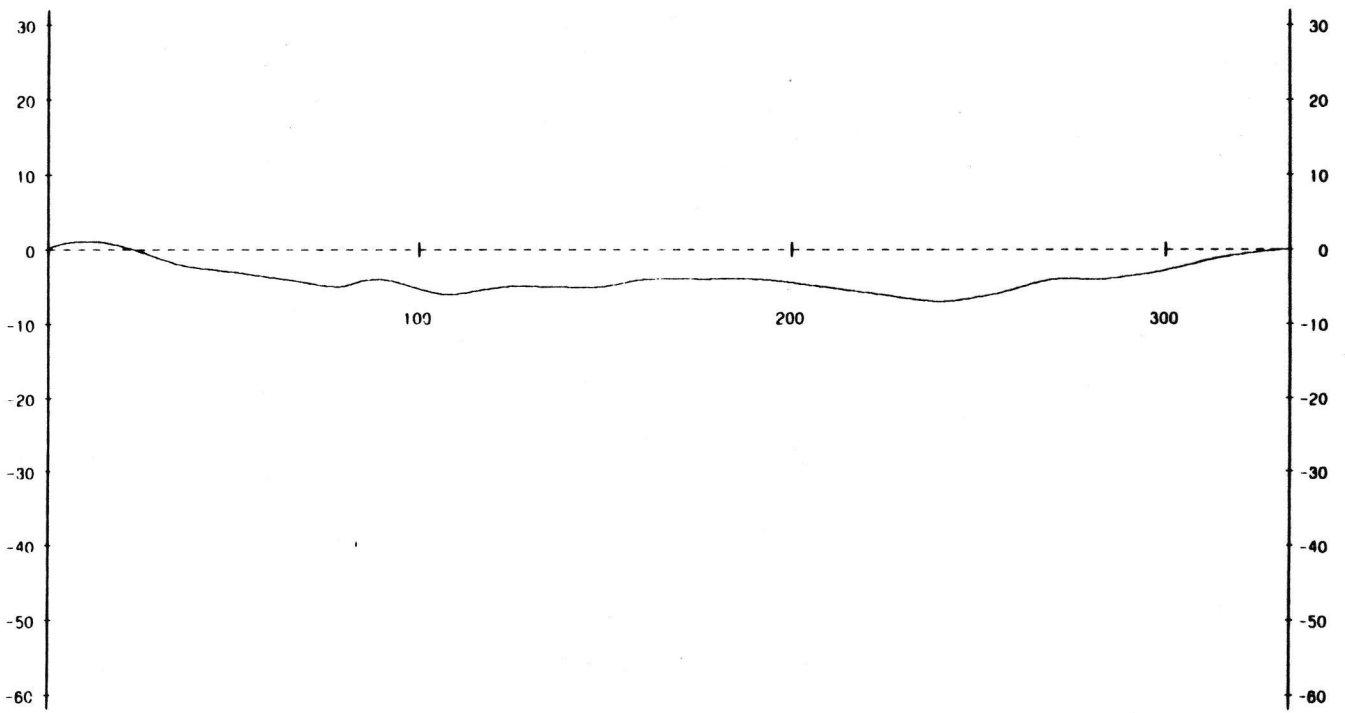

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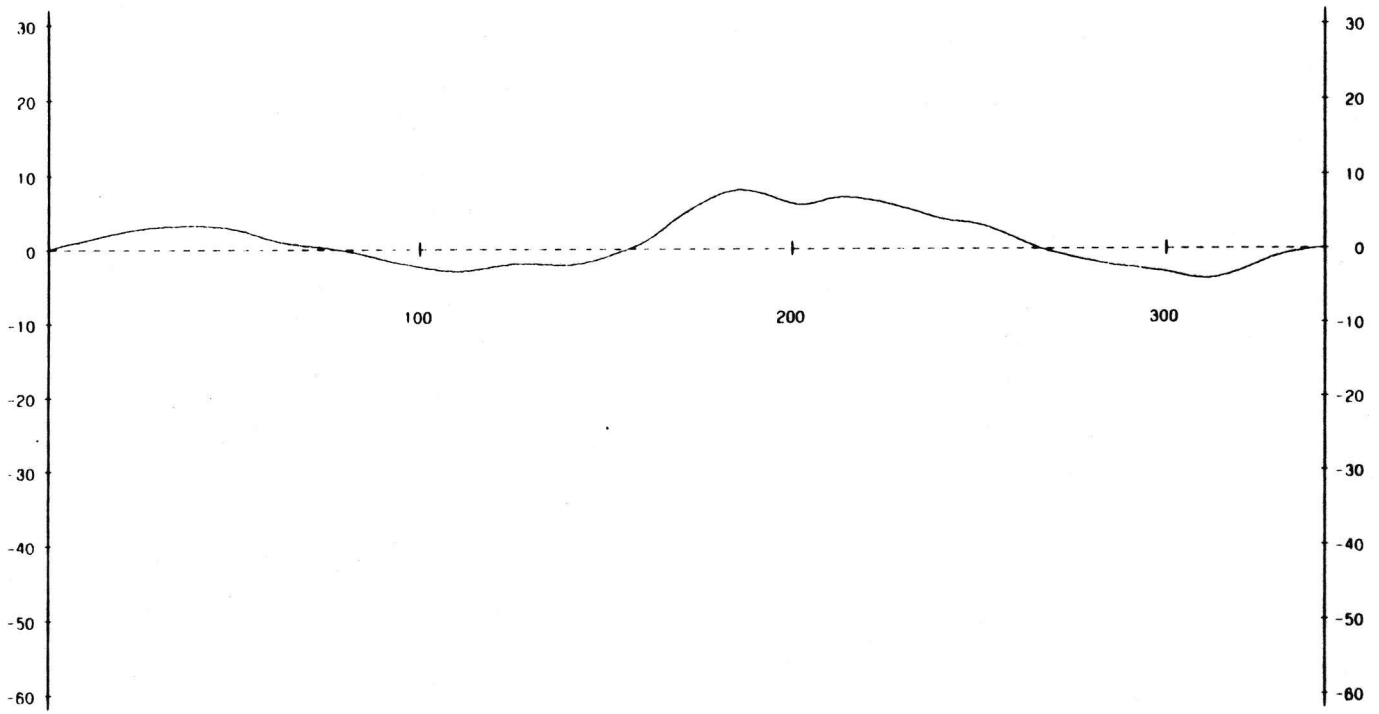

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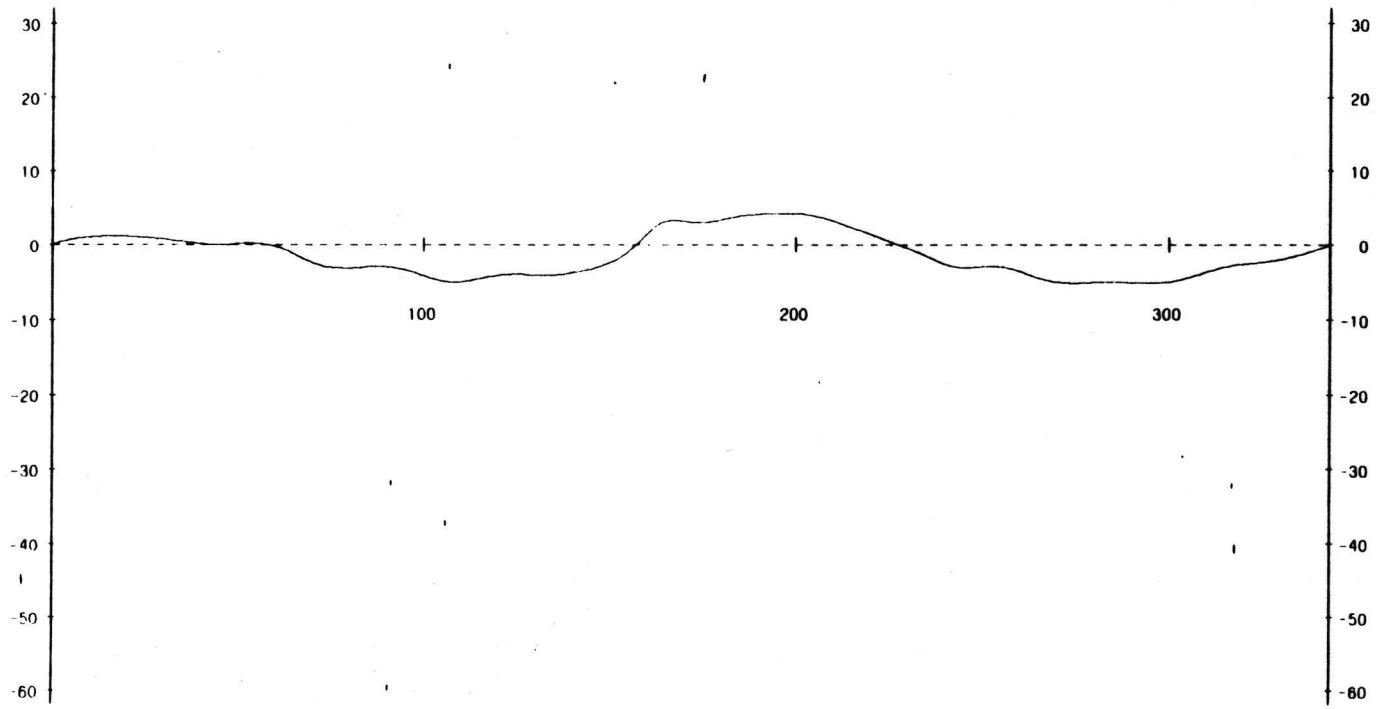

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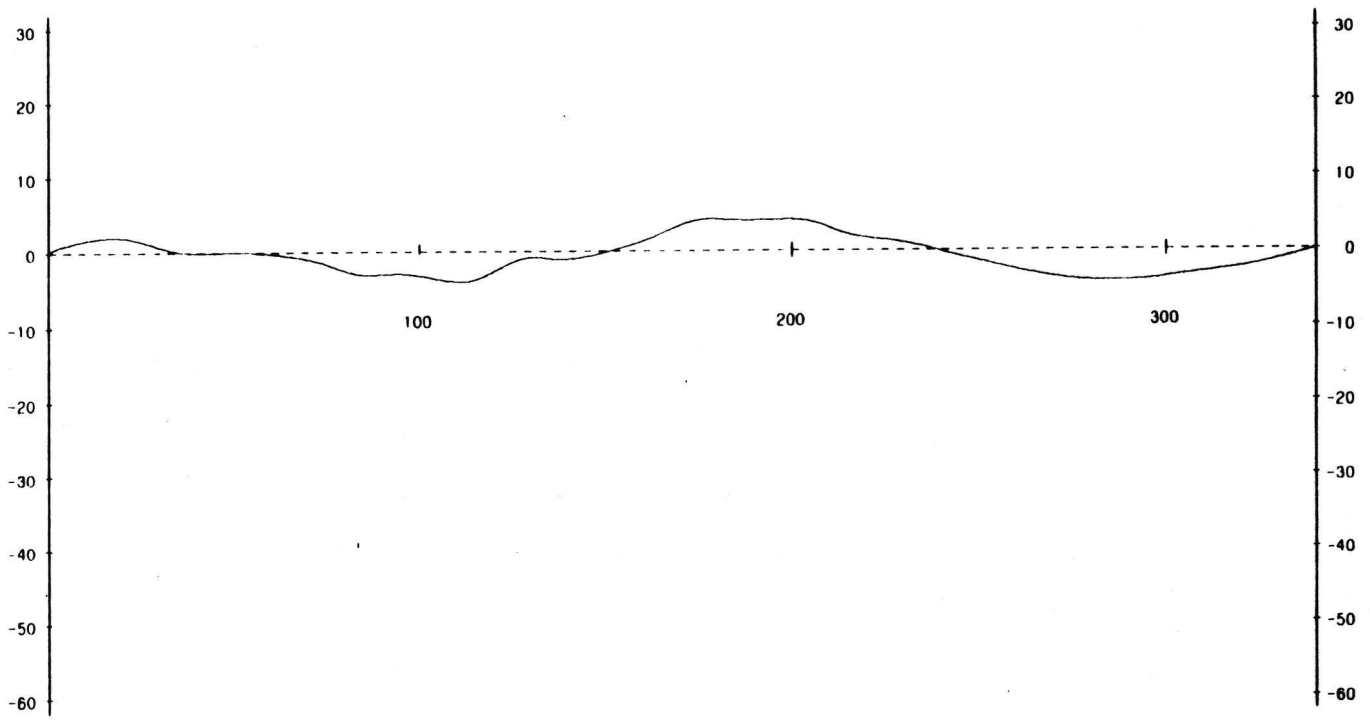

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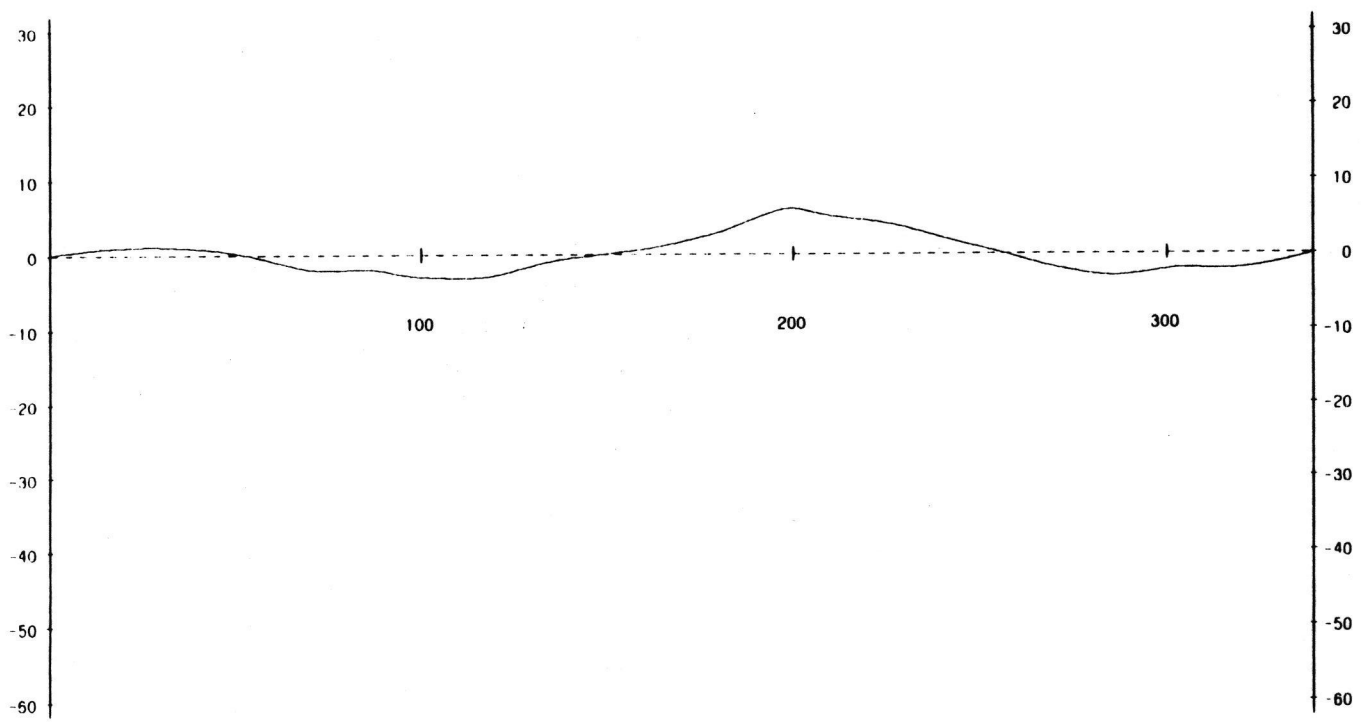

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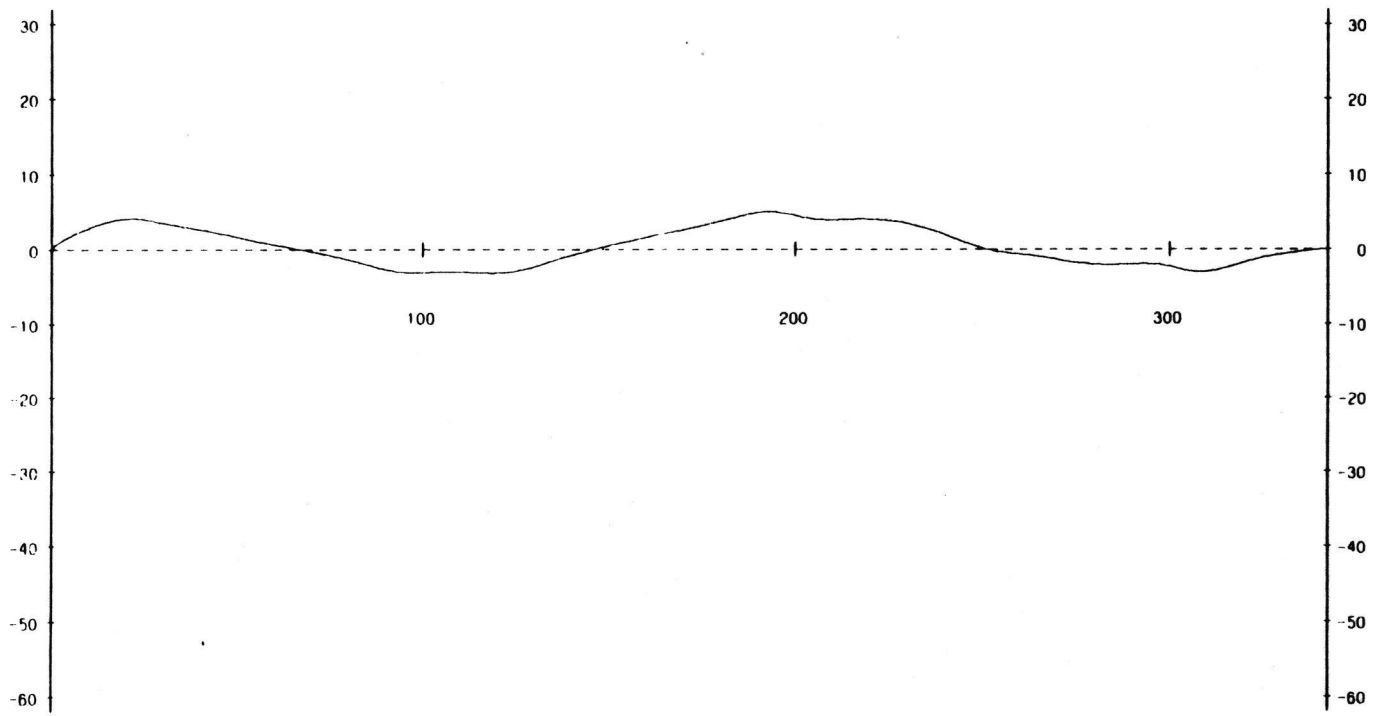

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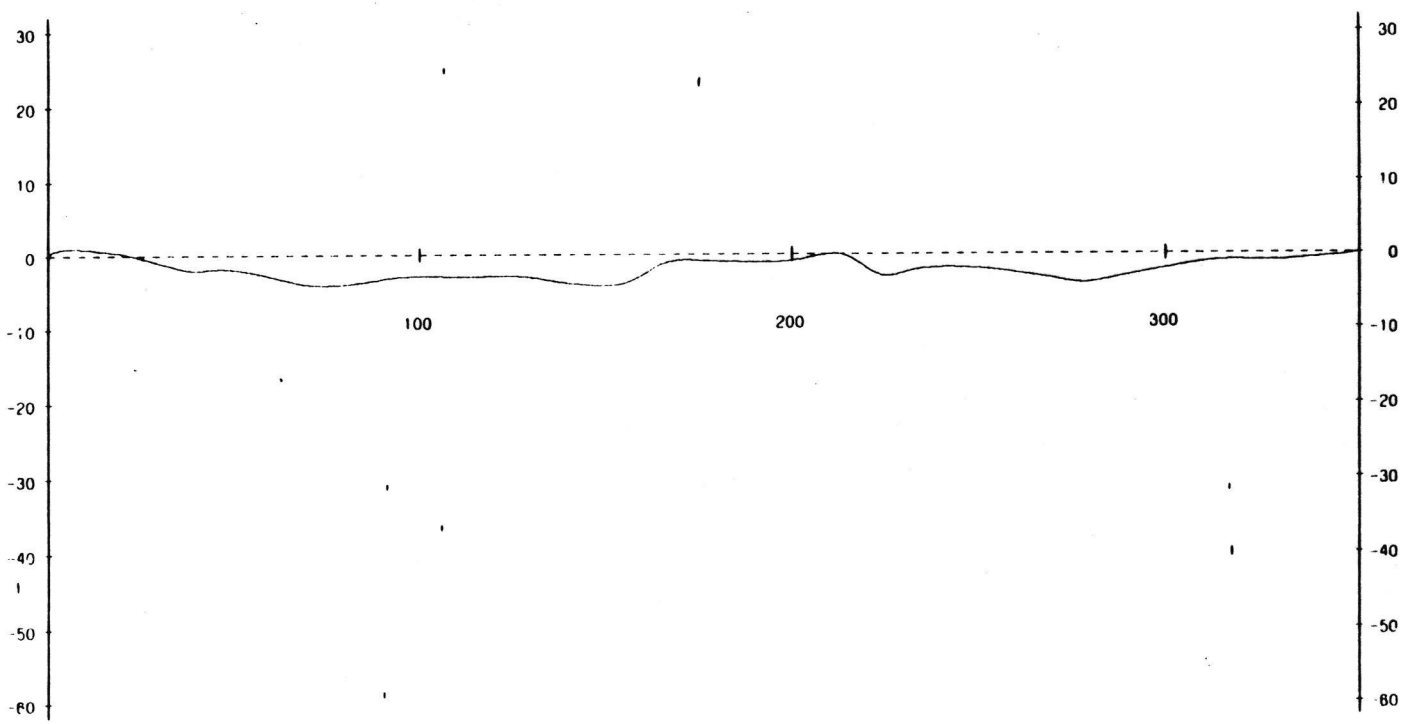

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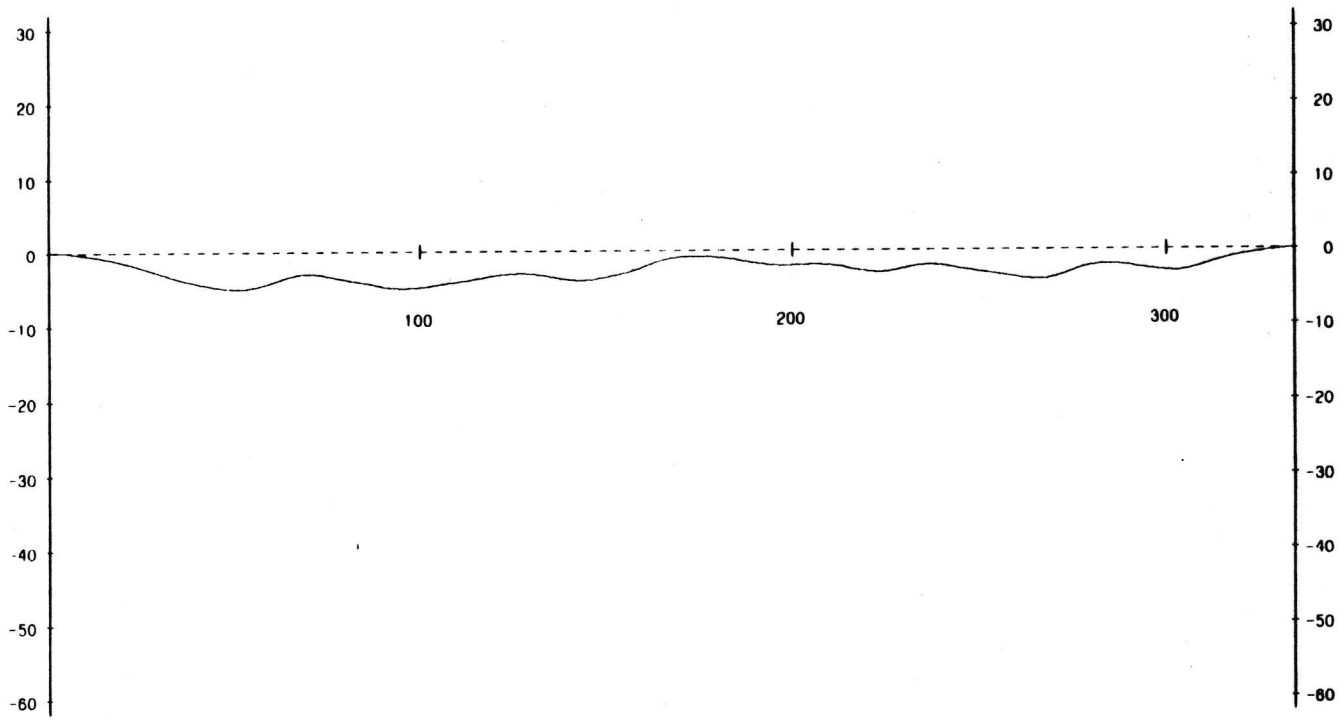

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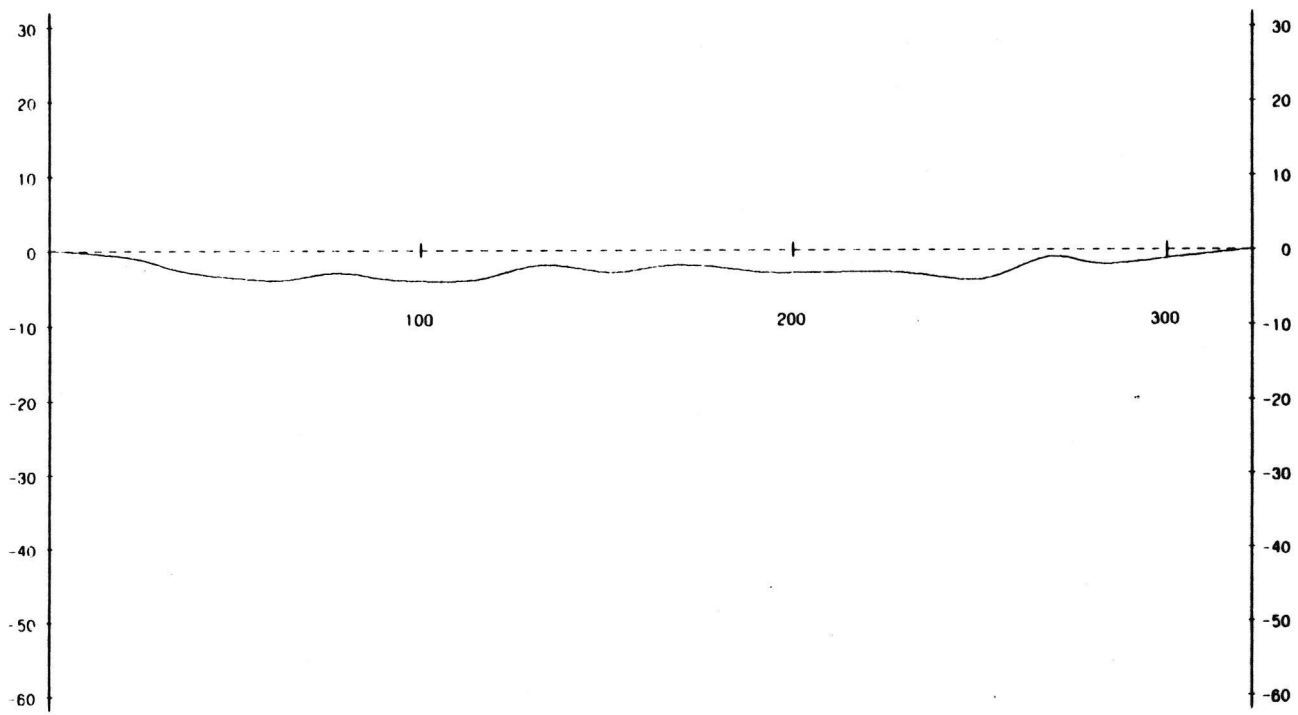

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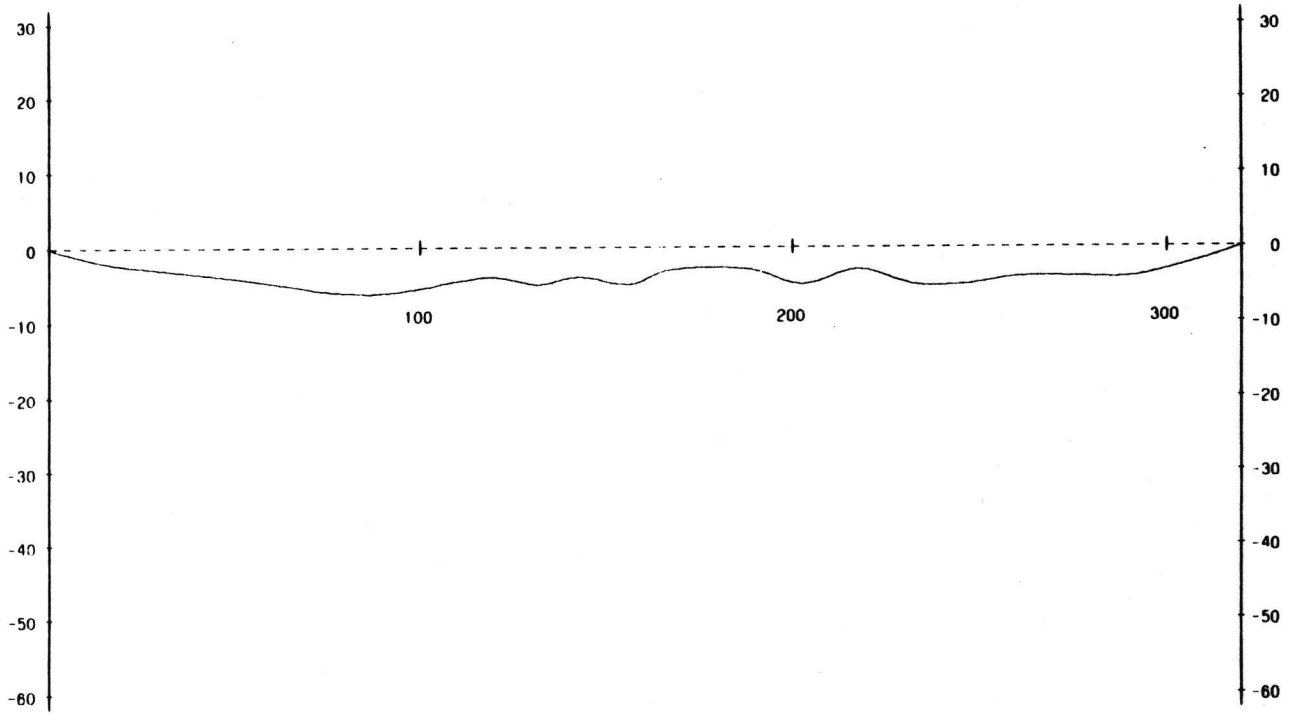

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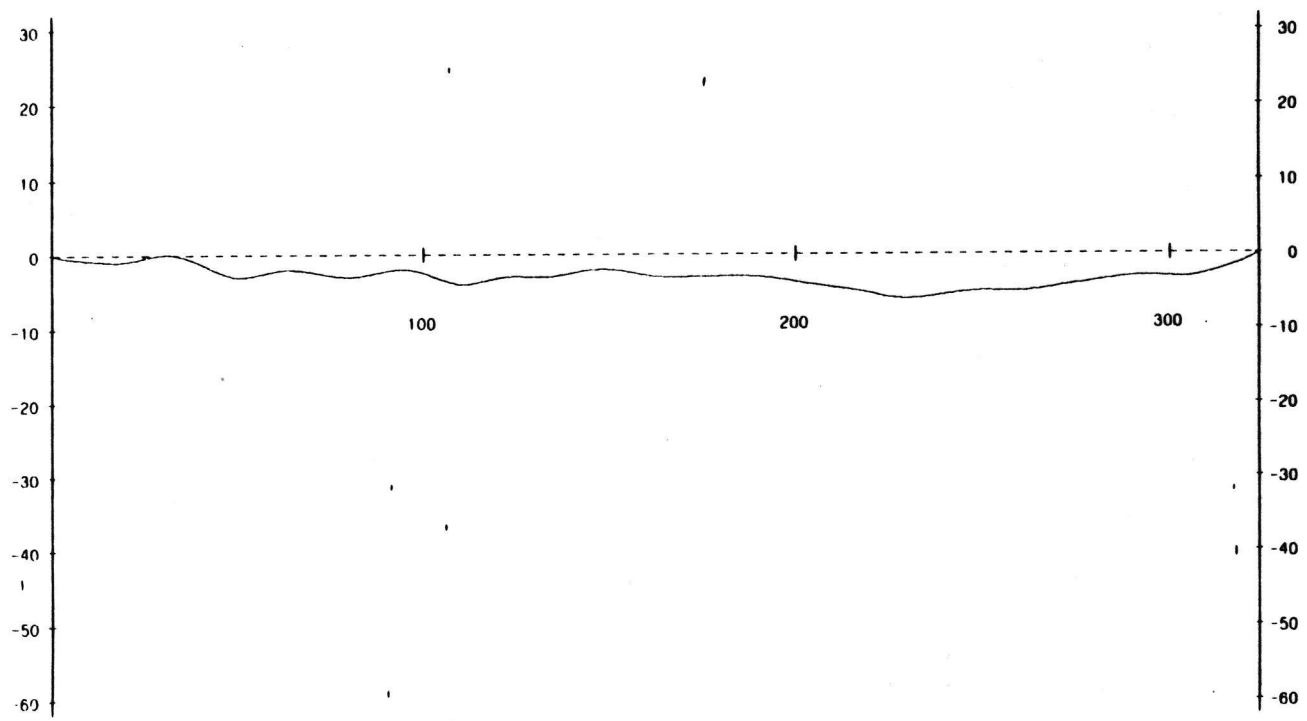

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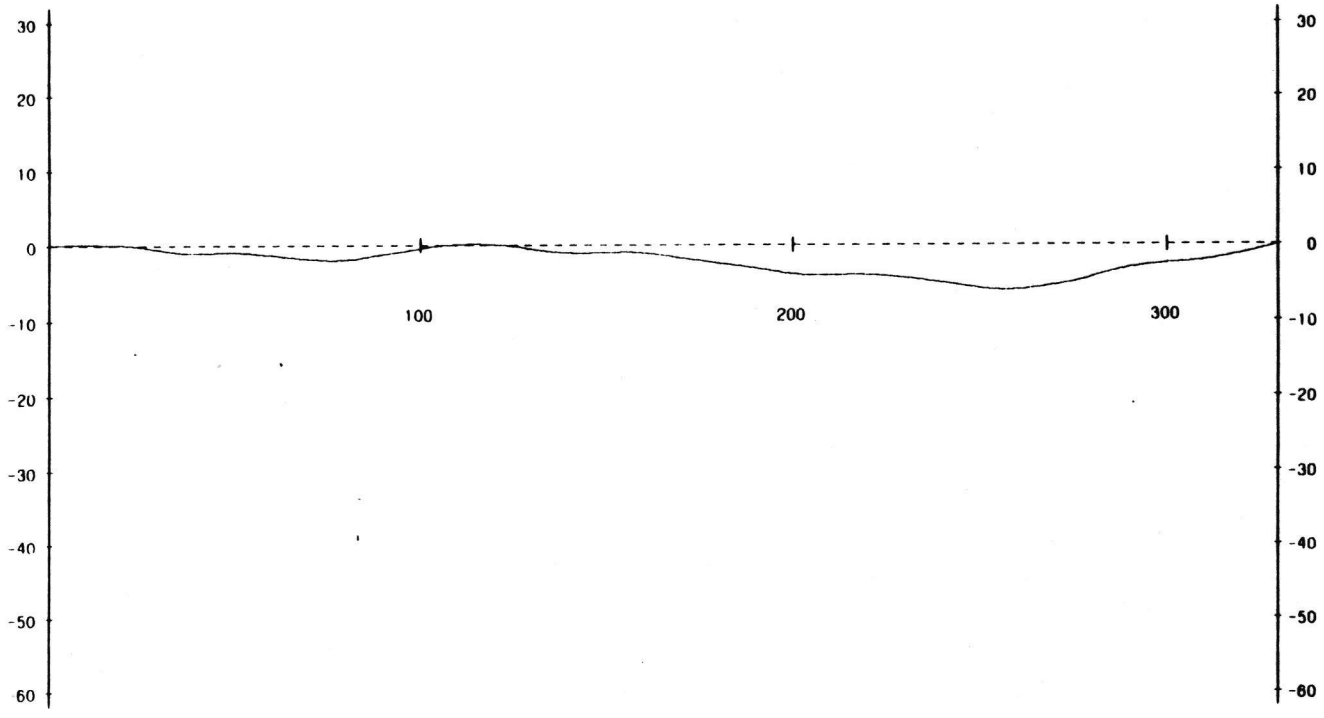

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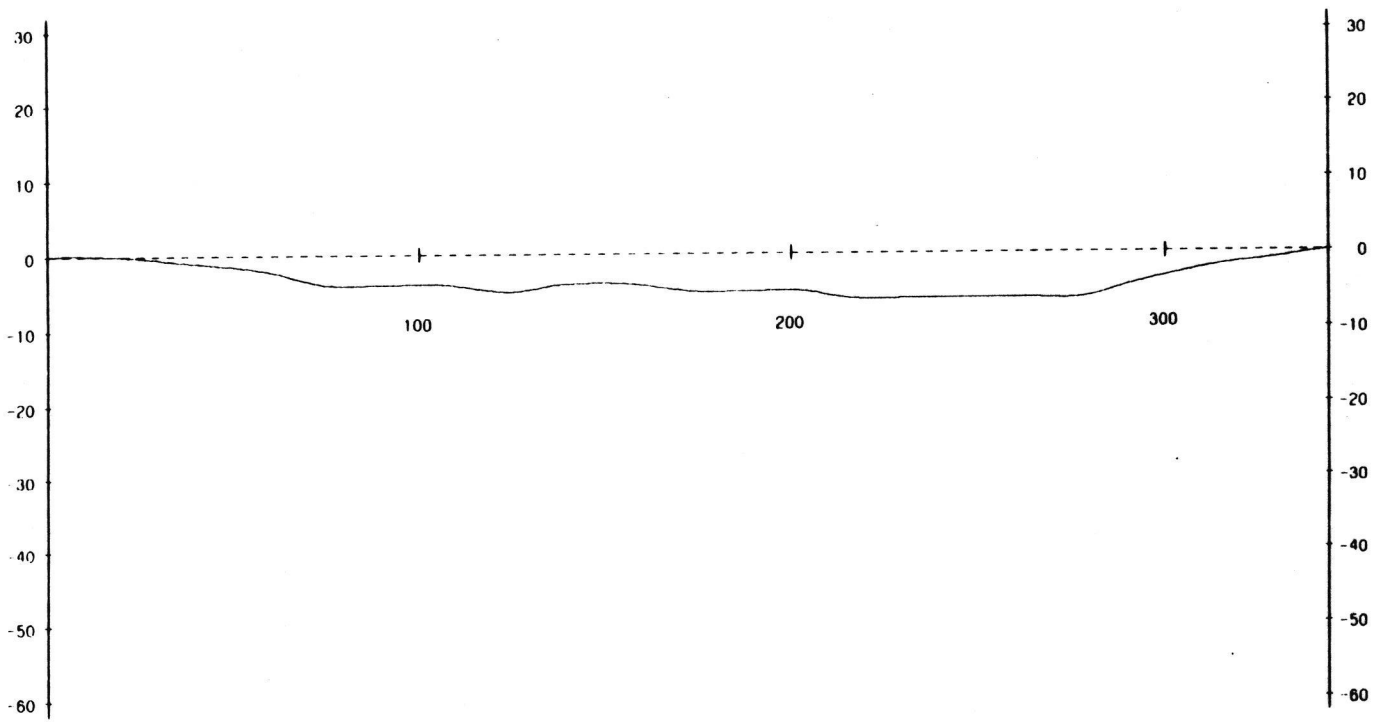

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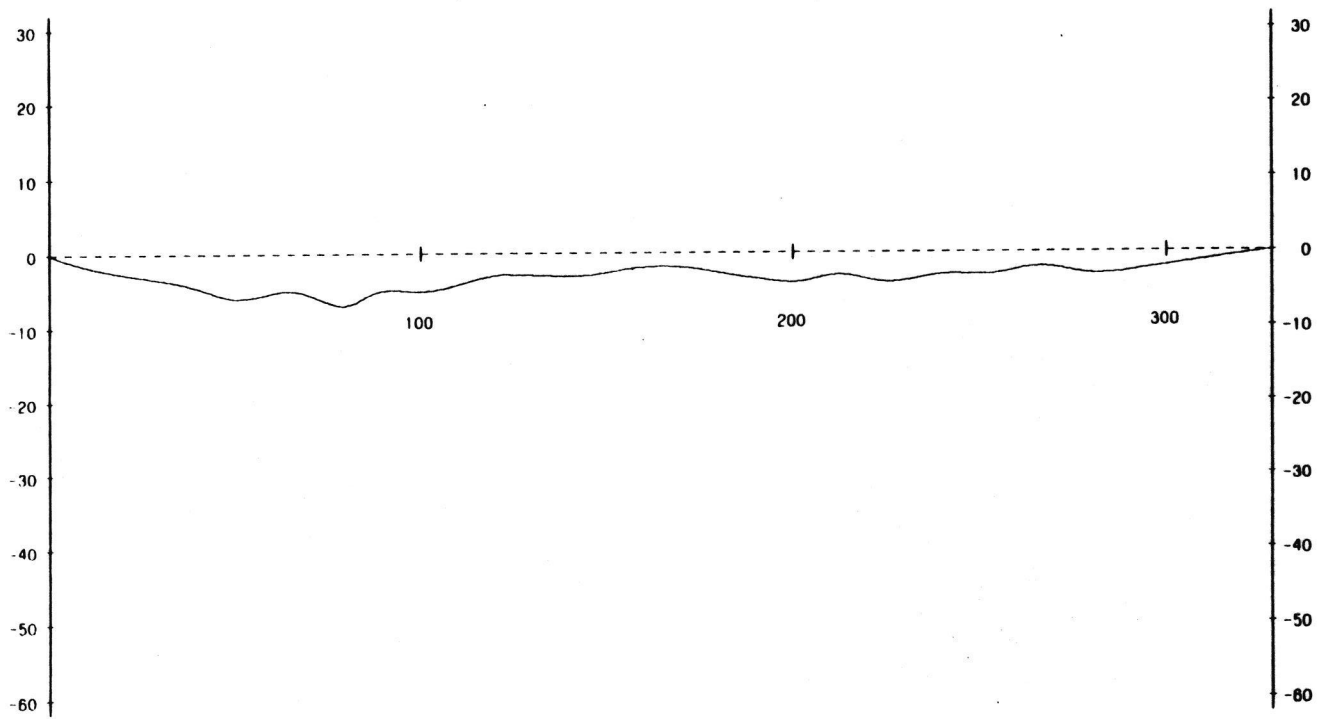

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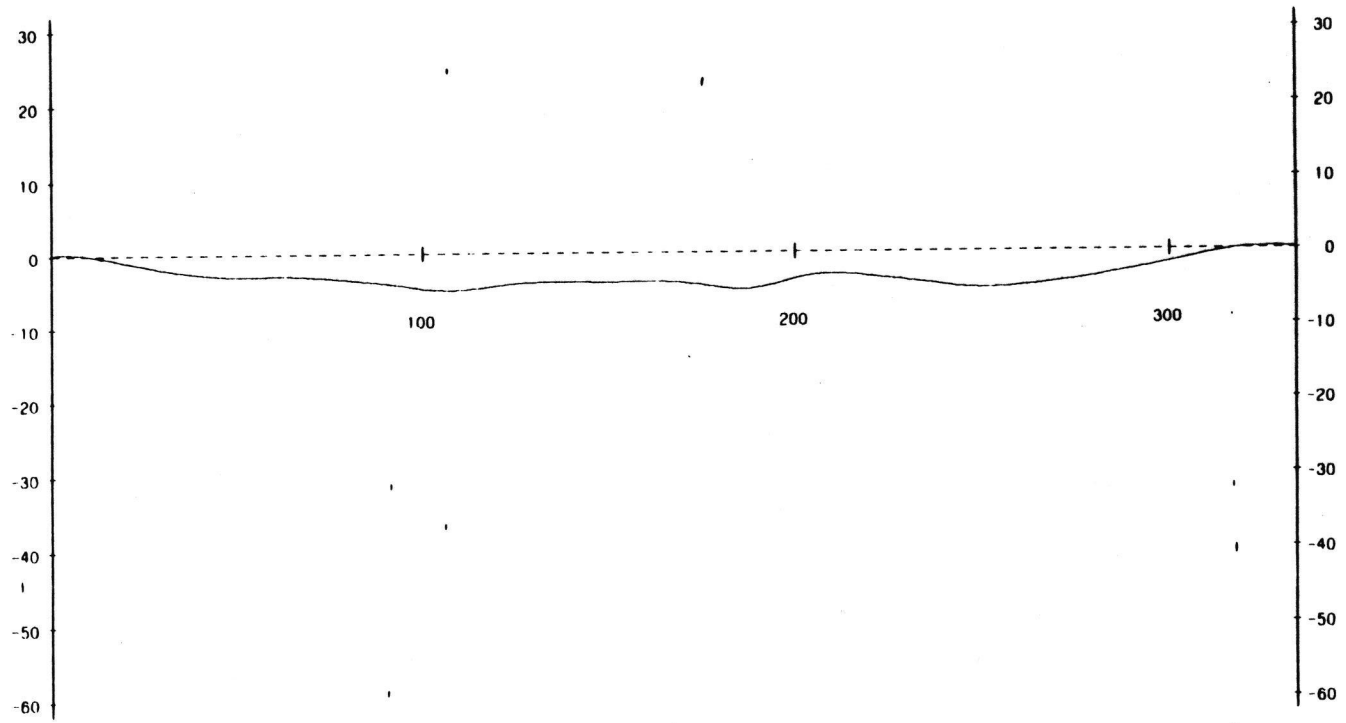

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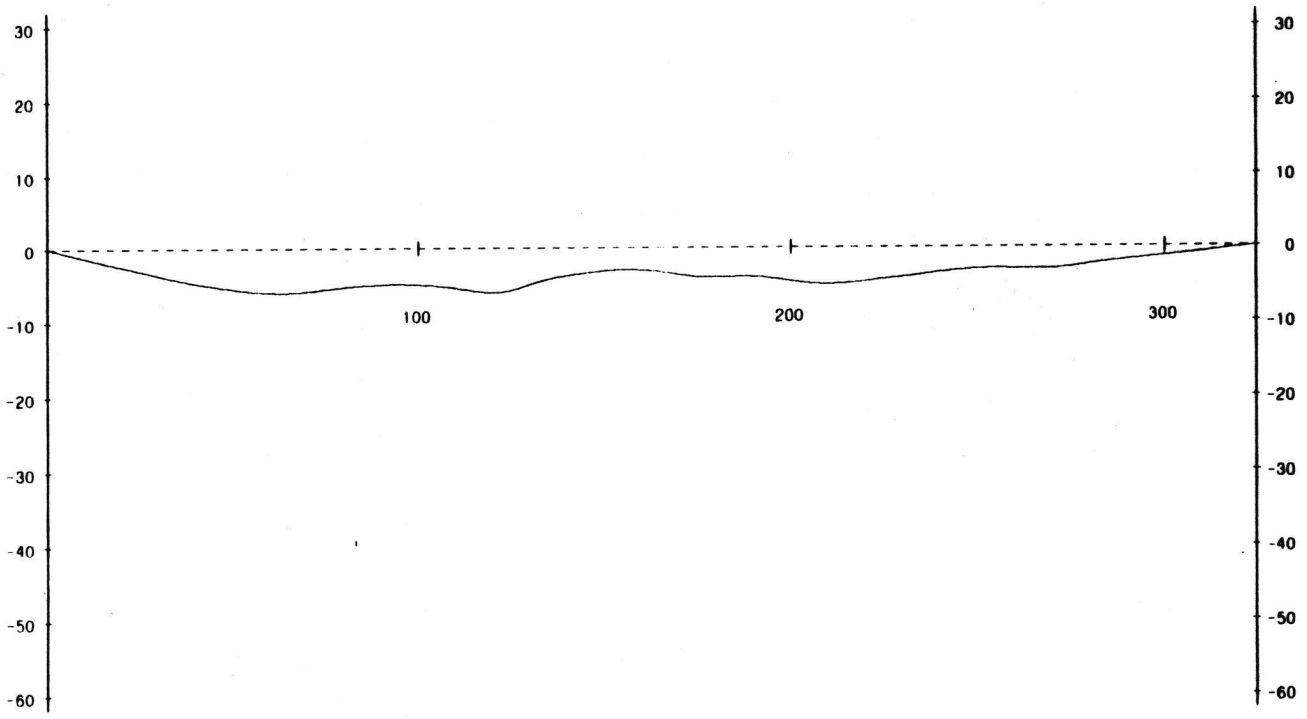

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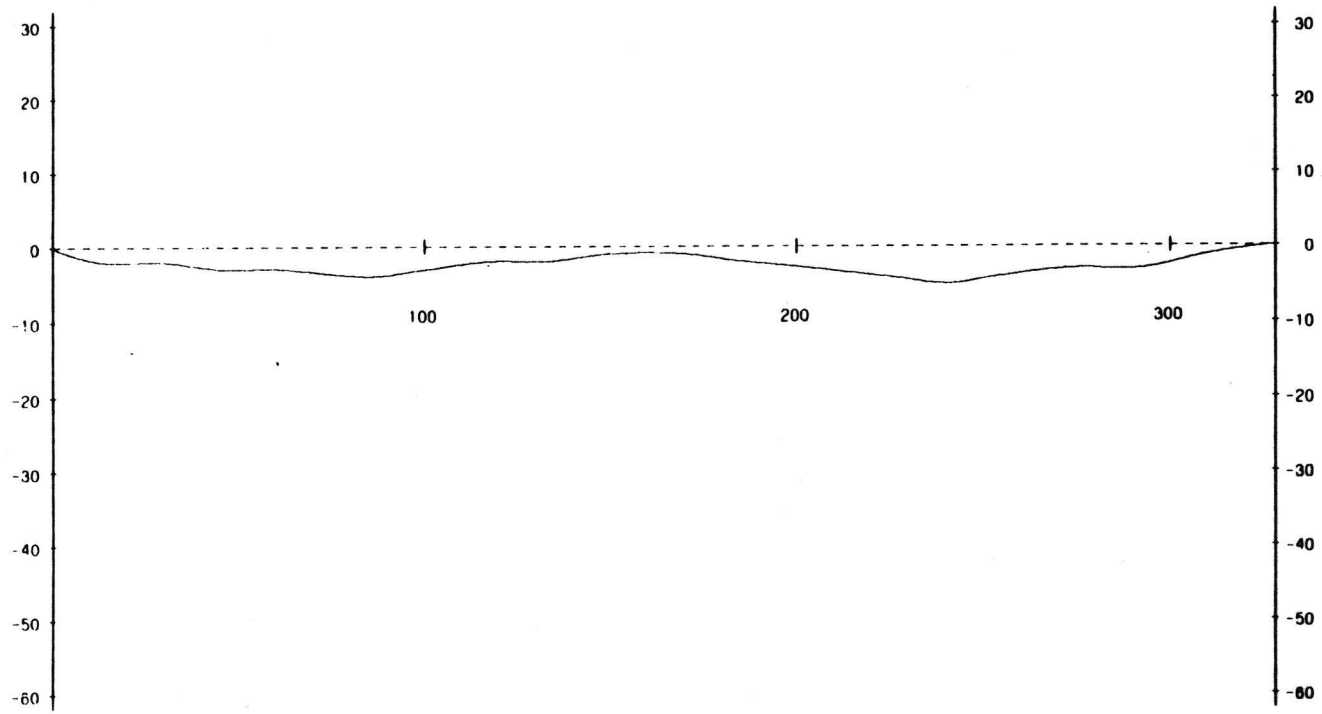

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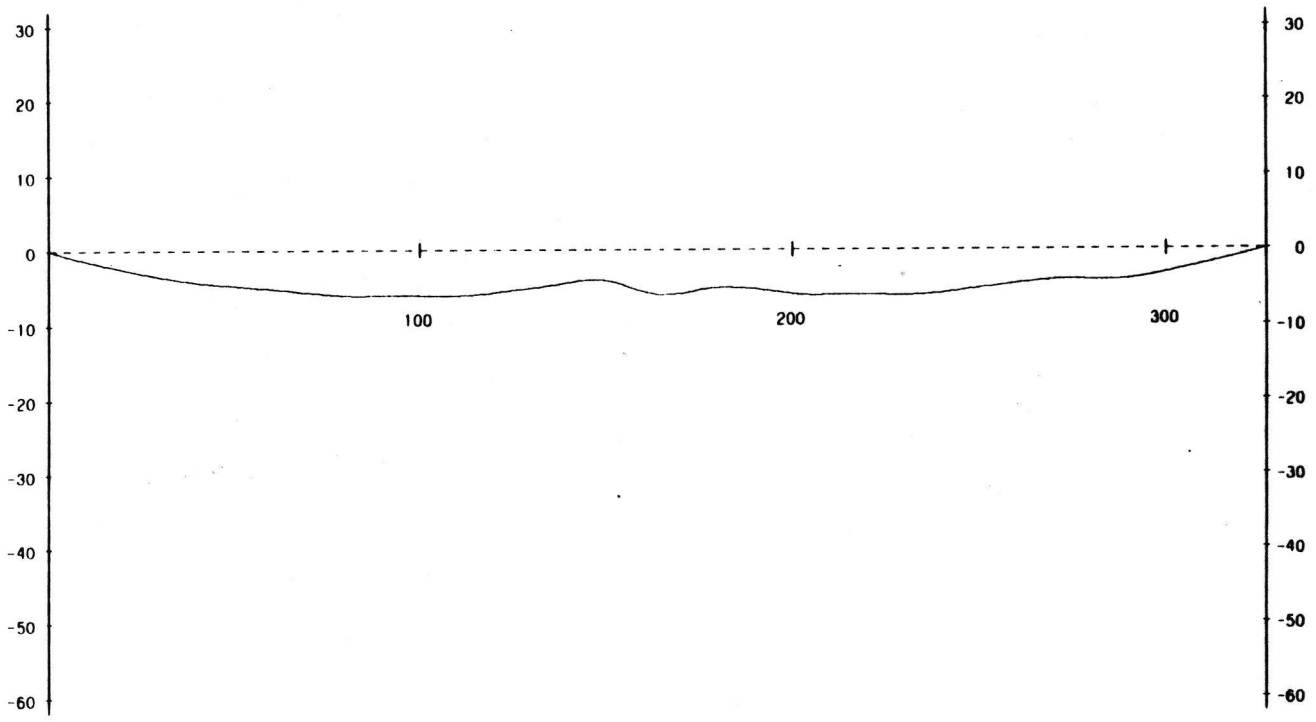

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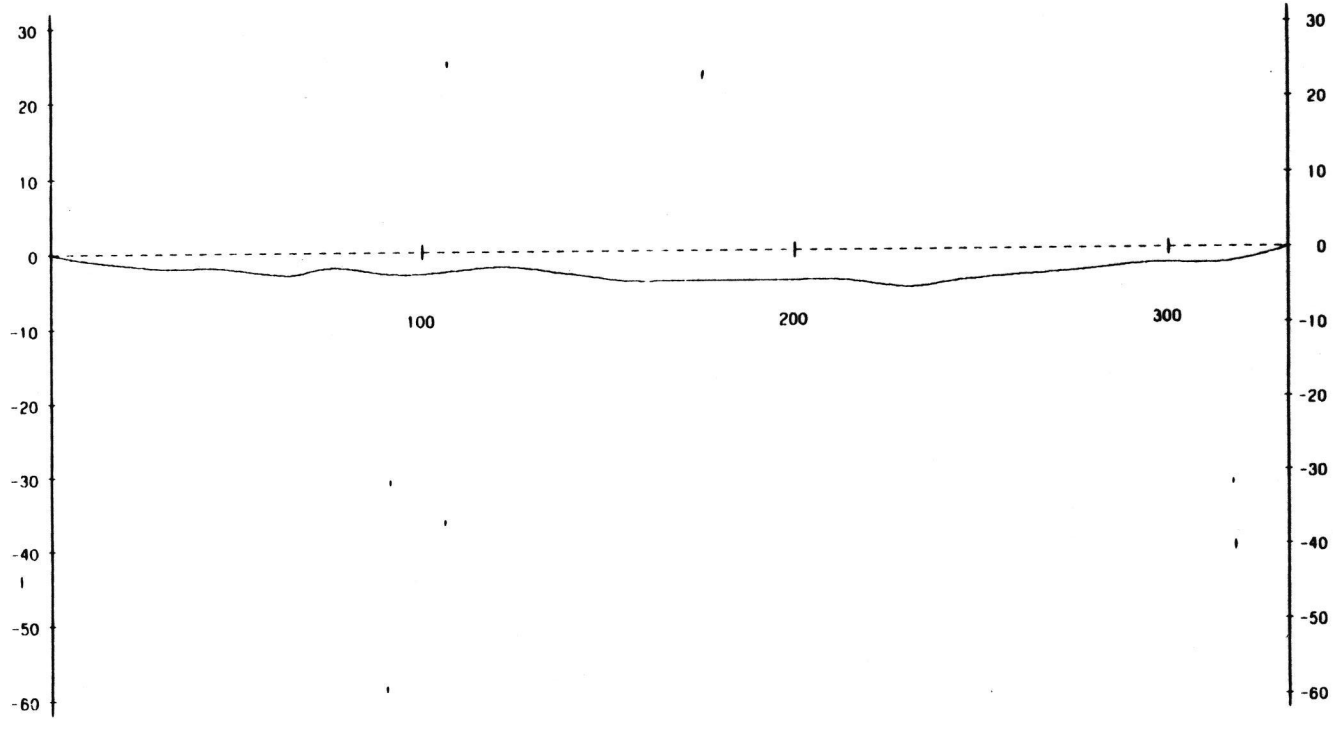

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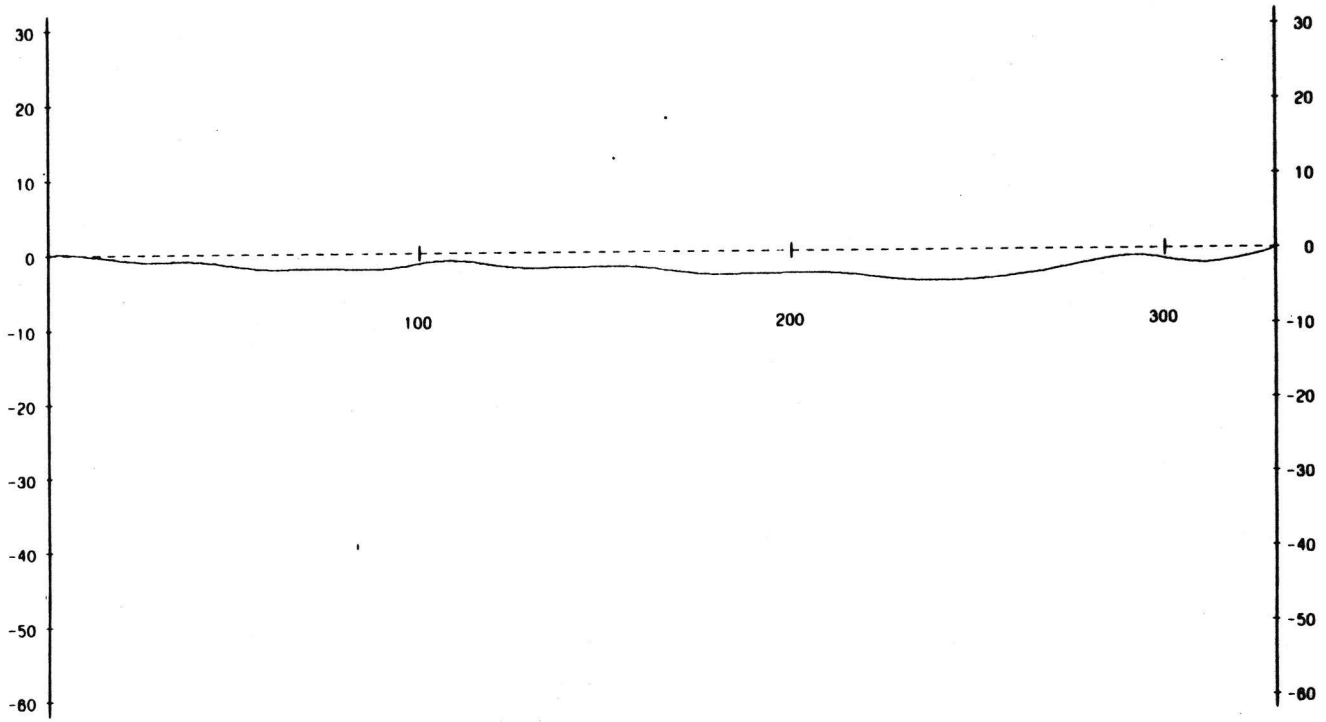

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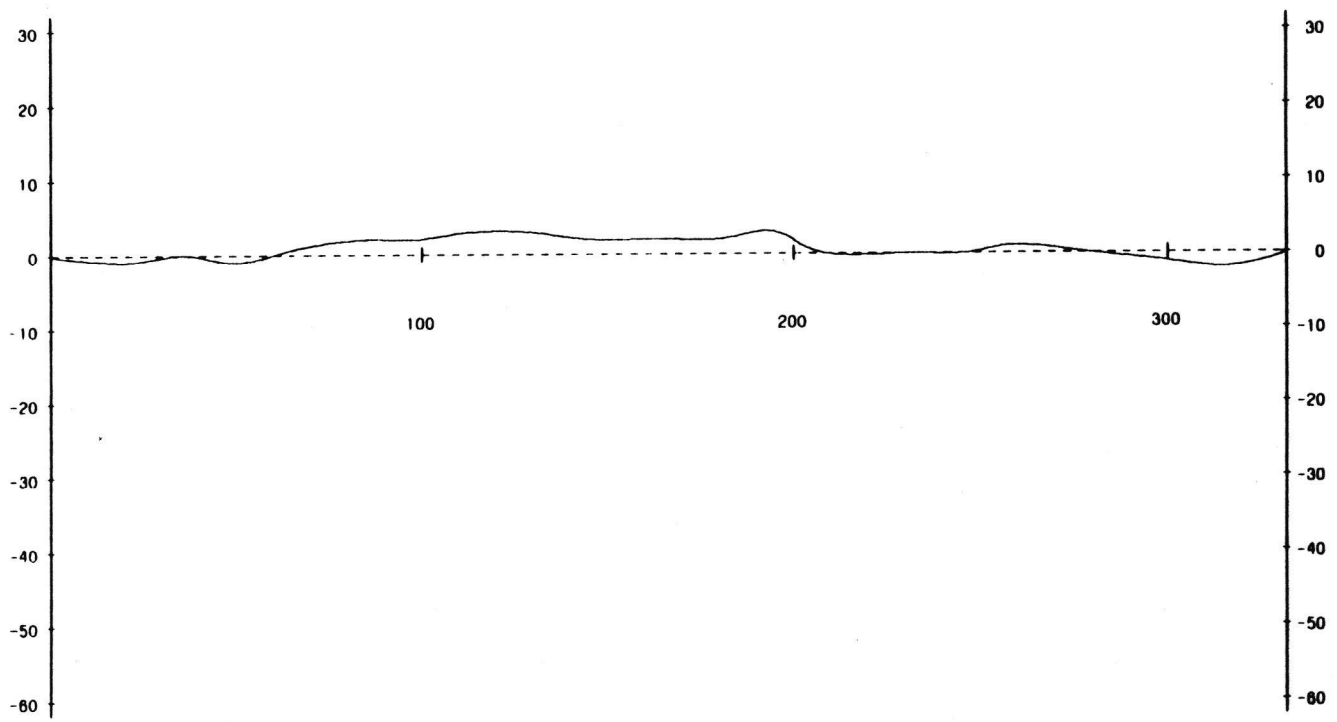

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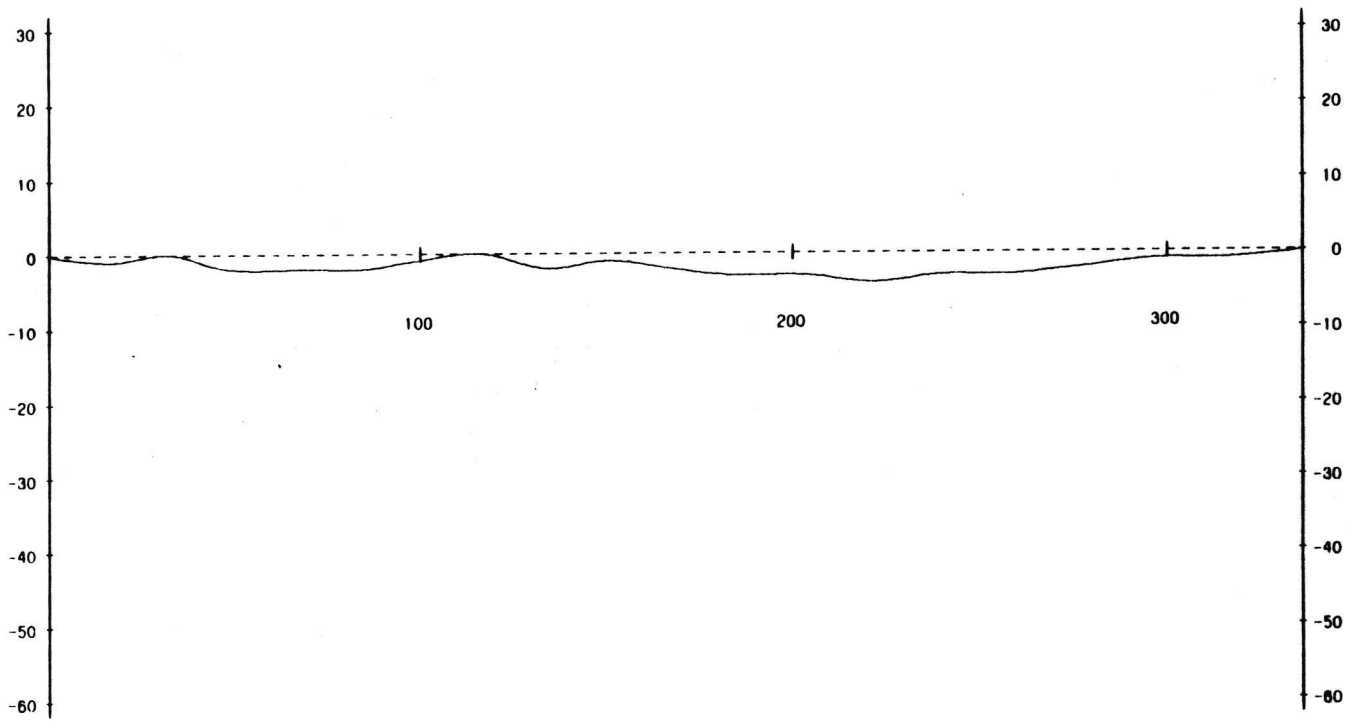

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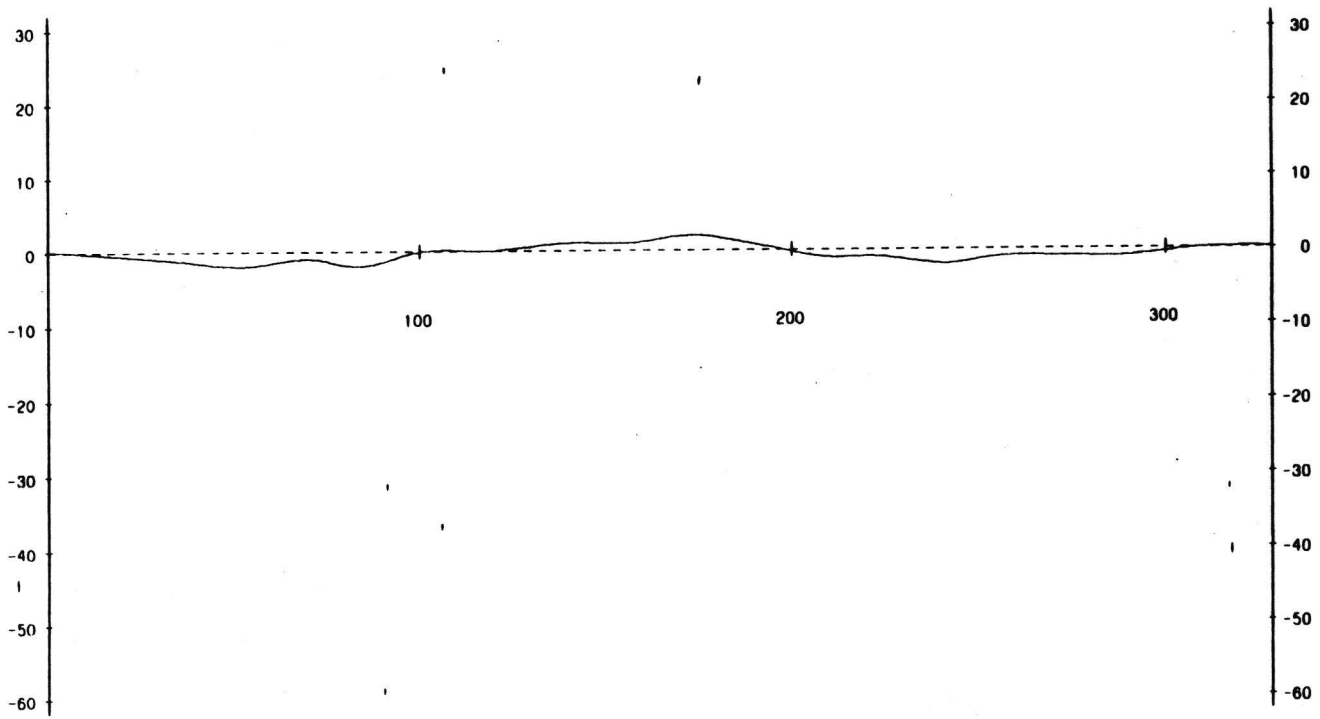

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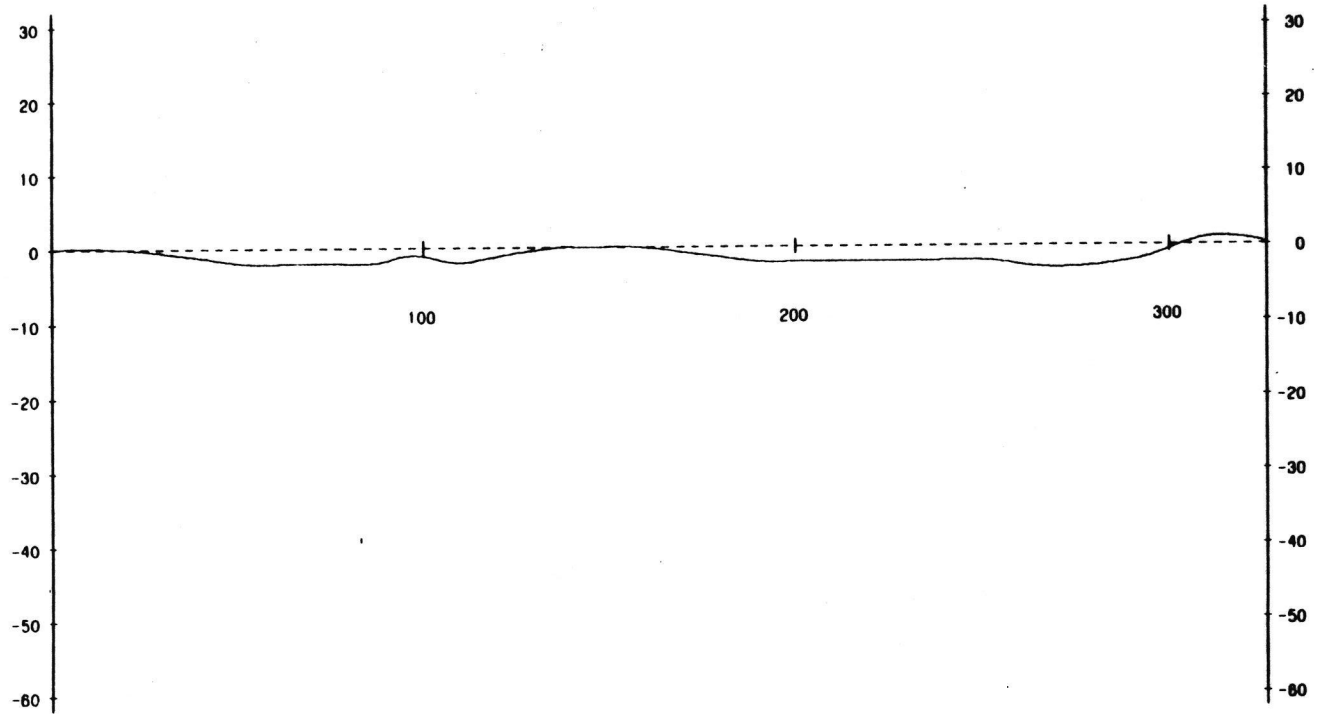

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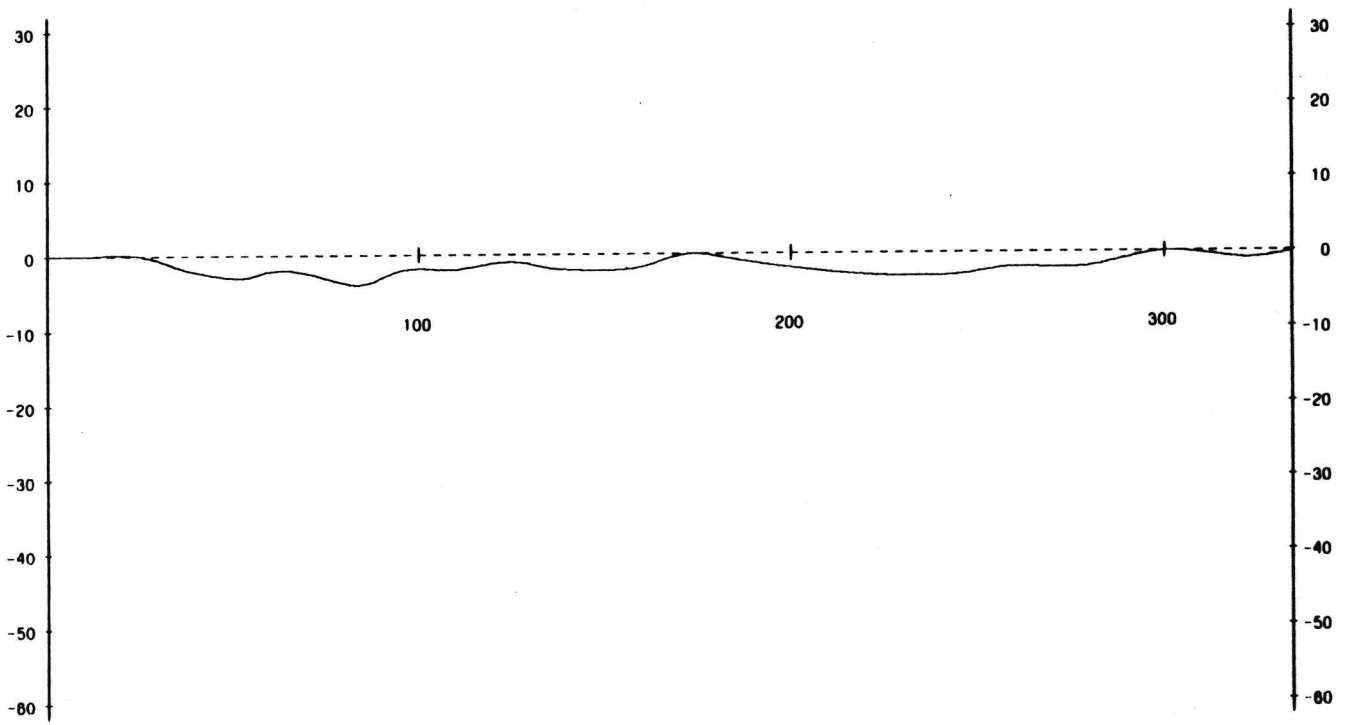

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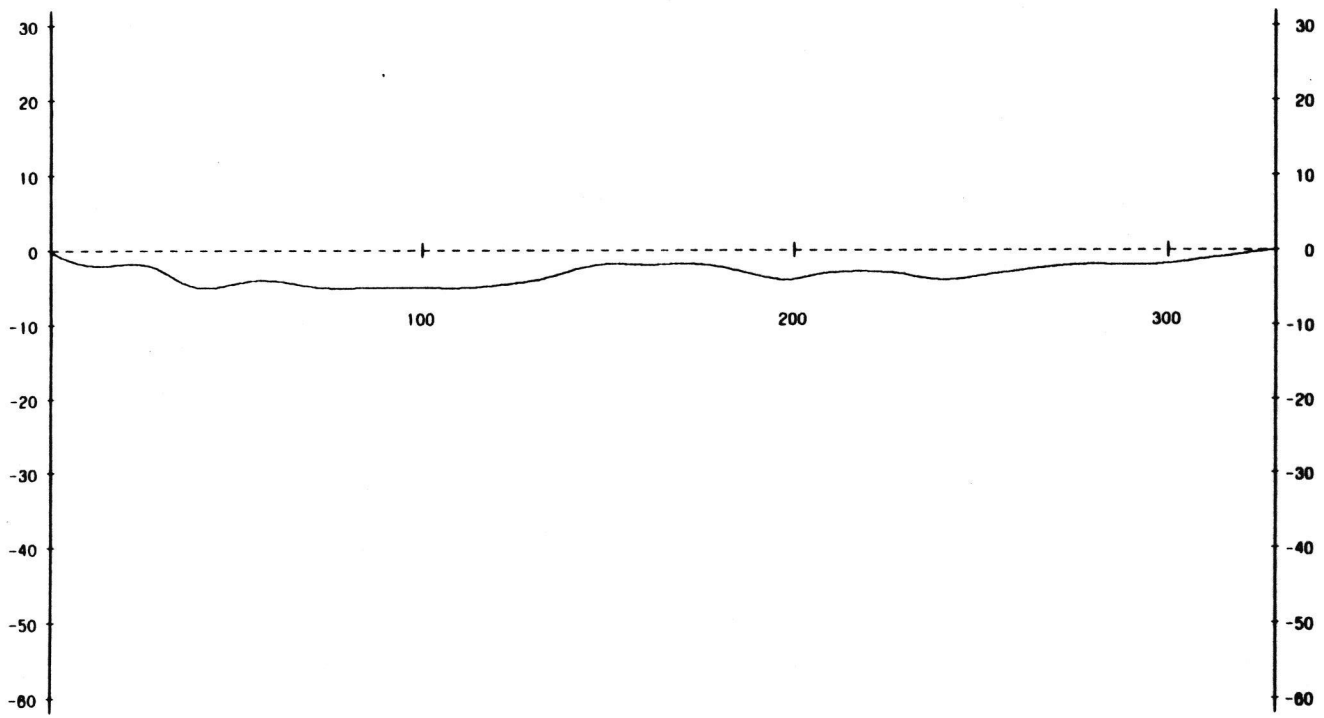

TRC 8802 C

PAVEMENT MANAGEMENT SURVEILLANCE SYSTEMS EVALUATION

APPENDIX C
TO
FINAL REPORT

TRANSPORTATION RESEARCH PROJECT NO. TRC8802

NOVEMBER 1988

PREPARED BY
ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT
MATERIALS AND RESEARCH DIVISION
RESEARCH SECTION
IN COOPERATION WITH
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

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The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the Arkansas State Highway and Transportation Department or the Federal Highway Administration.

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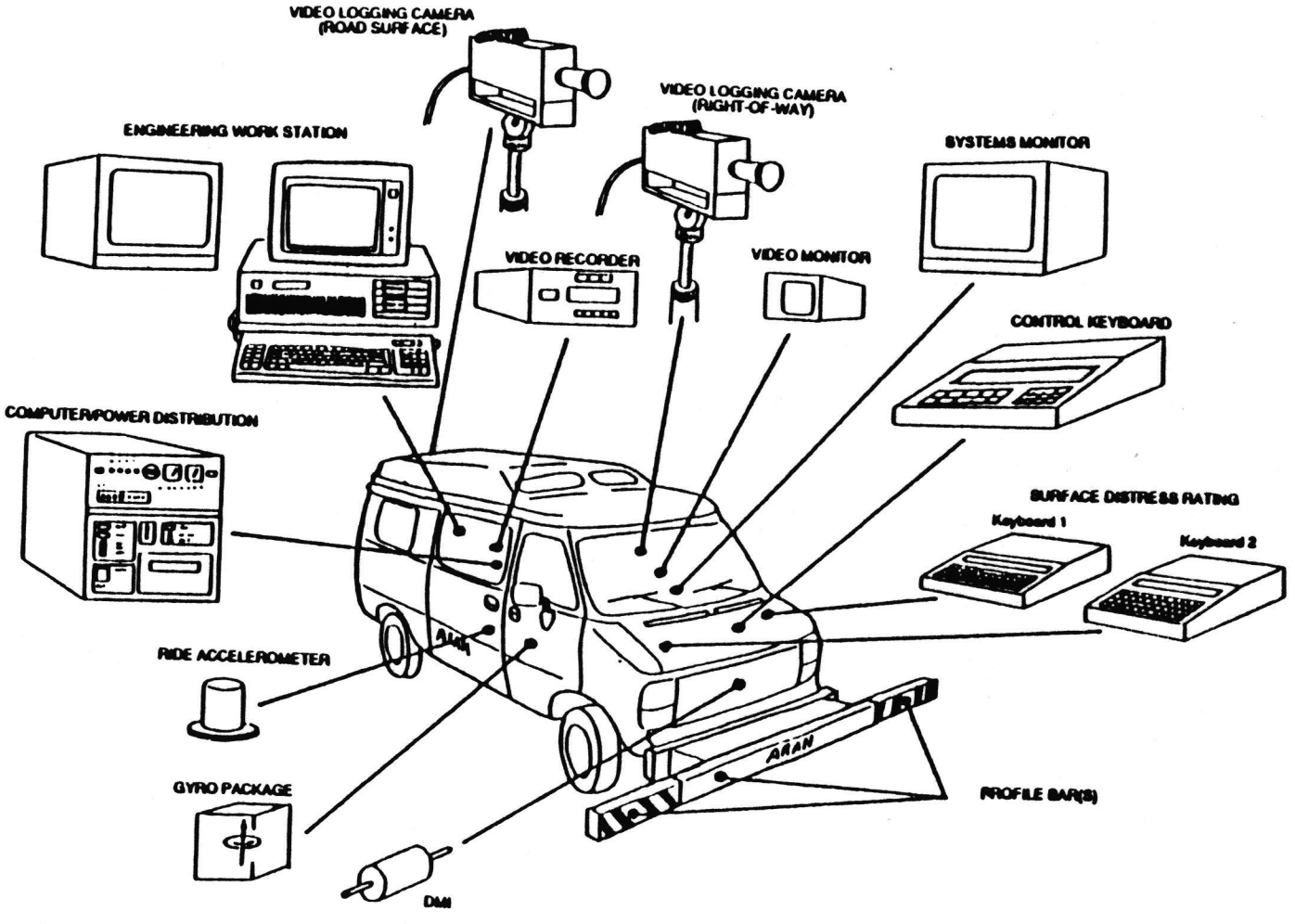

Figure 1. Schematic illustrating various components of HPI's automatic road analyzer (ARAN)

APWA TORONTO Sept 1988

New Technology For Pavement Management

Pavement Expenditure Planning (PEP) is a relatively new phenomenon. In the 1950's and 60's roadway activities centered on building more and bigger thruways by the many transportation authorities around the world. Meanwhile existing roads continued to age toward that point in their life cycle where the need for major maintenance activity would be required. In fact, many through neglect, passed the point of no return until major rehabilitation became necessary.

At the same time, costs of construction equipment, labour and materials (not the least of which is asphalt) sky rocketed. Economic slowdowns since the mid 1970's accelerated the problem, putting pressure on public funds available for roadway-related activity. Runaway inflation ate into already reduced rehabilitation dollars year after year until now we have smaller budgets in real dollars to do a far bigger job.

Today's watch-word has become "preserve what you have before it's to late" as opposed to the huge highway system expansions of a couple of decades ago. Authorities have recognized the billions of dollars already expended on roads and are now seeking to protect it like you would any other investment.

Even with the best records of "as-built" construction materials, methods, and structural design it is impossible to adequately manage a highway system without accurately measured current information on the status and physical condition of each individual part of the system.

The most basic system typically calls for a minimum set of performance data comprised of an assessment of existing surface distress manifestations and a measure of the surface roughness or riding comfort. There are, of course, other concerns as well, such as ruts, skid resistance, grade, crossfall, super elevation, etc. These represent specific problems perhaps unique to a local geographic area. They address specific safety aspects of the system, indicating where accident prevention measures are appropriate.

Many of these roadway parameters have, in past years, either been "eyeballed" or completely ignored. Thus an incomplete picture of the present condition of the total highway system has resulted in management programs that are sometimes inadequate.

Thus there is an obvious need to collect more objective roadway data of more types, in large quantities, quickly and economically. Highway Products International Inc. (HPI) foresaw this need some eight years ago and embarked on a hi-tech development program to produce a self-contained mobile device to do just that. By 1983 HPI had perfected two state-of-the-art devices which are being marketed world wide with some 23 units now in use. These are described briefly below along with their unique capabilities.

AUTOMATIC ROAD ANALYZER (ARAN®)

PRODUCT DESCRIPTION

The ARAN® is an electronic mobile data acquisition vehicle designed to measure and record a wide variety of pavement performance parameters. Self-contained in a standard or cube van, it is equipped with speed control, air conditioning, heavy duty suspension, heavy duty 12 volt electrical system, privacy glass, power steering and brakes and radial tires. Its exterior is painted school bus yellow for safety reasons.

MEASURING EQUIPMENT

On-board micro-processors and sensing devices permit the measurement and RAM drive recording of roadway characteristics while in motion. On-board software programs allow the unit to float with the traffic flow between 30 and 80 km/h and negotiate curves without adverse measurement effects. Either english or metric units can be operator-selected. At the end of the day, data is dumped to floppies and thereby transferred automatically to the in-house data base.

All systems are designed to collect roadway data in large quantities, quickly and economically. Applications at both network and project rehabilitation pre-engineering design levels are included. High-fidelity quality of data ensures its usefulness for years to come in spite of technological changes typical of the computer world.

.Roughness/Ride Quality

The ARAN® roughness system utilizes aerospace piezoresistive accelerometer technology to provide both longitudinal profile and reponse derived roughness measurements.

A differential-mounted accelerometer records vertical accelerations of the rear axle of the vehicle as it traverses the pavement surface, thus providing appropriately the average of the two wheel paths. Data displayed during operation includes RMSVA of all wavelengths between 1 ft. and 300 ft., a texture RMSVA considering only those wavelengths between 1 ft. and 2 ft. and a Mean Absolute Slope in mili-miles per mile or metres per kilometer.

A second, body-mounted accelerometer records simultaneous body absolute accelerations enabling post processing determination of longitudinal pavement profile using raw data from both accelerometers.

A unique but important aspect of the ARAN® Roughness system provides the capacity to compress and store raw data as collected. This data, if stored each year in a permanent data file can be recalled many years down the road to calculate any future roughness indices that may evolve. This enables the immediate production of life cycle performance curves for past years without extensive corelation studies.

Axle response roughness data displays utilize statistical as well as colour graphic formats to highlight problem areas requiring some form of rehabilitation.

Profile plots are produced from Longitudinal Profile Roughness data. These permit the determination of IRI and other roughness statistics of interest using their specific models.

.Surface Distress (Condition)

Detailed condition surveys have typically been conducted at the network level on a sampling basis either at selected mileposts or other arbitrarily selected locations.

The availability of the ARAN® condition rating keyboard system has enhanced the surveying process in two major ways:

a) It automates the recording of condition data as collected in the field as well as its transfer into the computer data base with dramatic labour savings over the traditional manual recording and transfer method.

b) Since the automated recording system (keyboards) facilitates surveying flexible pavements at speeds up to 30 miles per hour, it is possible to survey 100% of the network rather than only a small sample which may or may not be representative.

HPI's condition rating keyboards provide the capacity to record up to 20 individual pavement distresses each in 3 degrees of severity and up to 10 areal extent categories.

In addition, 8 separate keys are provided to anotate the precise location of landmarks such as railway crossings overpasses, bridge decks, etc.

The severity and areal extent recorded for all distresses observed are combined using a user-specified weighting formula to calculate a Pavement Condition Rating Index. This index is then plotted on a continuous chainage format using colour graphic software similar to roughness programs to "bubble-up" problem areas.

.Rut Depth

The ARAN® is equipped with a front-mounted rut bar extendable to a full 12 ft. lane width. 37 Ultrasonic transducers are mounted on 4" centres facing the pavement surface. Each transmits an impulse toward the pavement surface and subsequently receives the return signal. Computer tracking of the elapsed time interval enables the calculation of the distance travelled and hence the distance from each sensor to the pavement. Real time calculation of both right and left rut depth is accomplished utilizing the peripheral computer dedicated to operating and controlling the rut bar.

The effects of changes in air density are monitored using a separate transducer aimed at a fixed target. This sensor is fired each time the bar fires and compensation for air density changes is made in post processing software.

Sensor data analysis software identifies and quantifies both left and right ruts and can be displayed in a variety of colour-graphic formats including station by station depth calcualtions, averaging over longer distances and bar chart frequency distribution using a number of rut depth thresholds.

.ARAN Geometrics

The ARAN orientation system includes two precision ruggedized gryoscopes providing important pavement measurements as input to pavement management programs. The first, a pitch and roll gyroscope, provides accurate measurement of longitudinal slope as well as roll or cross slope measurements. While this is valuable network inventory information the cross slope measurements can also be combined with the transverse surface profile established by the Rut Bar. From the combined analysis comes an accurate evaluation of shim quantities i.e. the amount of asphalt required to fill both ruts and restore cross slope to design level. This calculation provides important input at the project pre-engineering level of activity in determing costs of rehabilitation alternatives.

The second is a precision directional gyroscope which measures change in direction continuously as a roadway curve is negotiated at highway speed. From this imput curve radii can be calculated with a range from 50 ft. to 6 miles (almost a straight line). These measurements provide important objective input into programs determing safe speed limits.

.Right of Way Videologging

HPI provides a through-the-windshield view of the total roadway using high quality cameras providing a continuous high resolution record of pavement as well as roadside appurtenances. Header data including chainage is recorded and displayed continuously on the video record for identification of any location along the road.

3/4" Umatic cartridges are used to record a total visual network inventory. Uses include in-house surveys of signs, bridges, culverts, curbs and any other roadway items of interest. Record of "before" and "after" rehabilitation conditions are often valuable as well as visual record of road conditions in defence of litigation resulting from traffic fatalities.

.Pavement Condition Rating Videologging

As a further step in automating condition surveys HPI has developed a videologging system which records a continuous high resolution record of the pavement surface as the vehicle travels along the pavement at traffic speeds. Header data including road identification and continous chainage is recorded on the video record. Video frame encoding facilitates computer controlled high speed search for specific chainage points in the condition rating work station provided as part of the ARAN$_R$ turnkey system.

This video record is then reviewed in a computerized engineering work station where still frame and frame-by-frame indexing video playback equipment enables detailed condition rating to be done. Rater keyboards identical to those used in the ARAN® for windshield surveys automate the recording of the distresses identified from the pavement images.

The videologging condition rating system has two major advantages:

a) It provides a safe, more relaxed atmosphere for the condition rating process.

b) It enables 100% detailed rating of heavily travelled highways and expressways which could never be observed even with a walking survey due to volume of traffic.

The development of pattern recognition software which will recognize the various types of surface distresses typically found on pavements will complete the automation of condition surveys using these high resolution video images.

PORTABLE UNIVERSAL ROUGHNESS DEVICE

A second device manufactured by HPI called the Portable Universal Roughness Device (PURD®) embodies identical technology to the ARAN®.

Designed for smaller agencies, it embodies the ARAN® roughness system including longitudinal profile and condition rating keyboards identical to those described for the ARAN®.

Configured in a two-wheeled trailer, it includes axle and body mounted accelerometers as well as compressed raw data storage capabilities.

The PURD® is towable by any vehicle having a heavy duty 12 volt electrical system. Compactly packaged computer and operator controls are carried in the towing vehicle with ready access by the operator.

USE OF NEW TECHNOLOGY IN PAVEMENT MANAGEMENT

It can be readily seen that the various ARAN® subsystems serve a dual purpose in pavement management programs.

a) All systems provide valuable objective input into evaluation of the total network, replacing the eyeball type of subjective data used in the past.

The measured data can be factored into equations that you have established to more accurately produce a ranking list of all sections in the network.

Those parameters more directly related to highway safety programs can now be more appropriately weighted into prioritization equations. This ensures that works program prioritization recognizes the high priority of those representing potential traffic safety concerns.

b) Several ARAN® subsystems have applications, as well, at the project level of activity. For example detailed pre-engineering evaluation of rehabilitation candidates typically should include close examination and quantification of rut depth, grade, cross slope, transverse profile and curve radius to ensure that rehabilitation restores the original design criteria and is safe for the prevailing speed limit and traffic flow. Shorter testing interval can be selected for these detailed surveys.

Shim quantity calculation based on these detailed measurements provides a better basis for the evaluation of the cost effectiveness of various rehabilitation options.

Videologging provides valuable before and after records of rehabilitation projects should property disputes arise as a result of pavement reconstruction or realignment.

Summary

Pavement Engineers need tools to do their job. In today's environment of high costs and reduced funding it is more important than ever that their tools be the best available. They must be accurate, reliable and repeatable with a practical ease of operation. Most important they must operate at traffic speeds for economic reasons as well as in the interest of safe operation.

The ARAN® addresses all of these needs and is fast becoming a world wide standard in its field.

Paper presented to TRB
by L.D. McDaniel,HPI

ARAN III

A NEW ROUGHNESS MEASURING SYSTEM

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January 15, 1987

ARAN III- A NEW ROUGHNESS MEASURING SYSTEM

ABSTRACT

A new pavement roughness measurement system is now available which offers the simplicity and low cost of Response Type Road Roughness Measurement Systems (RTRRMS) with the accuracy repeatability and flexibility of the Surface Dynamics Profilometer (SDP) measurements without the historical attendant problems of either. This memo presents the theory of the measurement and results of initial testing which show the advantages of this system. Any of the popular summary roughness statistics are available as output, and operator data validation checking is an integral part of this system.

ARAN III, A NEW ROAD ROUGHNESS MEASURING SYSTEM

Roughness may be defined as "the distortion of the road surface that imparts undesirable vertical accelerations and forces to the vehicle or to its riders and thus contributes to an undesirable, uneconomical, unsafe, or uncomfortable ride". (1) There has been a search for a device that can provide simple, direct, and relatively inexpensive roughness measurements that remain calibrated and stable day-to-day, year-to-year, and country-to-country.

In this regard, there have historically been two schools of thought- one using a vehicle response such as absolute body to axle movement in a Response Type Road Roughness Measurement System (RTRRMS). Several summary roughness statistics for this type system have been proposed amongst them Average Rectified Slope (ARS) and Average Rectified Velocity (ARV). (2) This approach has real appeal because of the simplicity and low cost, but has here-to-fore been plagued with variability of measure due to variation with time, temperature, suspension characteristics, and other parameters requiring frequent recalibration on a "standard surface". The second school trying to overcome these problems have resorted to measuring the road surface (profile) with a Surface Dynamic Profilometer (SDP) or a rod and level survey in each wheel track and then using a standard Quarter Car Simulation (QCS) to derive the response of a theoretical car to the averaged profiles at a given speed. (3) The problems with the profile approach have been multifaceted: high initial cost of equipment, high maintenance costs, lack of data validation means, lack of

sufficiently accurate models for complex vehicle suspension and tire responses. (4) " Now the profilometer is an expensive piece of equipment ; it costs $ 250,000 to purchase, and it might cost up to $ 100,000 to operate for one year, but you could pay for it in the first year." (7)

It has been suggested that a vehicle instrumented with accelerometers on both the rear axle and the body can overcome these problems. (5) By using this approach a profile which is independent of suspension parameters may be measured. Unlike the SDP, since tire envelopment is part of this measure no additional modeling is required for this function. Note that for the same reason, the problem of downward singularities (such as cracks and openings between joints) and upward singularities (such as patches and tar strips) being treated equally when roughness is calculated (4 p 169) is solved by this new system. Since the rear axle is used as the measure point, both wheel tracks are automatically averaged into the result.

Raw acceleration data is recorded so either RTRRM or profile is available to the user. in addition, any of the popular summary roughness statistics- ARS, ARV, RMSVA, Slope Variance, etc may be computed.

Part I presents the theory of the measurement, Part II presents the response of the axle and body of the vehicle to road stimuli, Part III gives the definitions of several popular summary roughness statistics, and Part IV presents some of the results of validation testing and analysis done in Canada, Texas, and Michigan.

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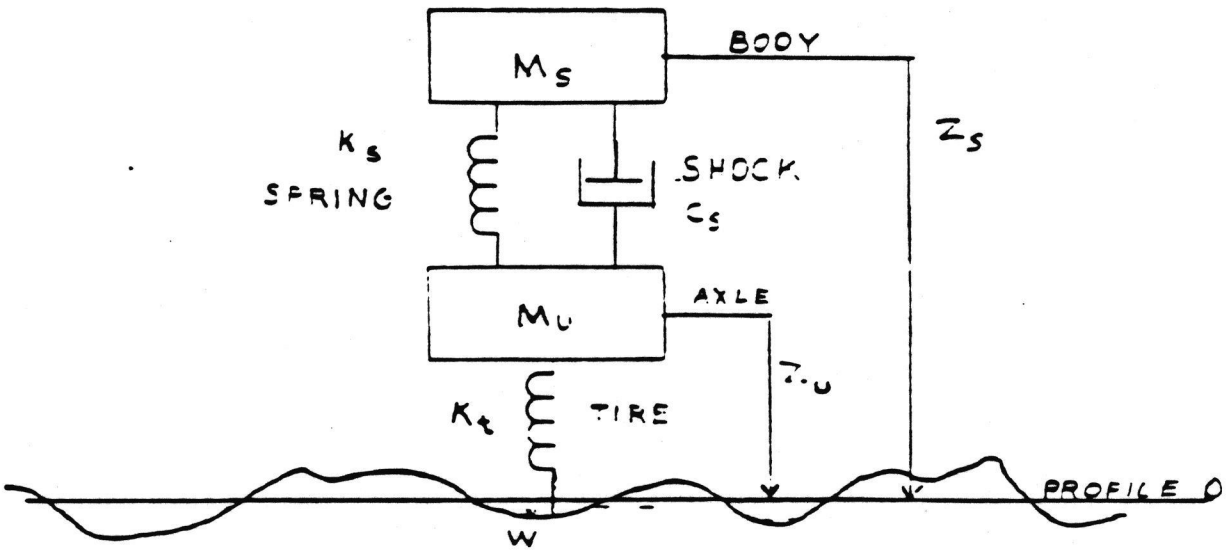
PART I

Theory Of Profile Measurement With Accelerometers

DEFINITIONS:



Summary Forces on the Sprung and Unsprung Masses

1. $M_s \ddot{Z}_s + C_s(\dot{Z}_s - \dot{Z}_u) + K_s(Z_s - Z_u) = 0$

2. $M_u \ddot{Z}_u - C_s(\dot{Z}_s - \dot{Z}_u) - K_s(Z_s - Z_u) = K_t(W - Z_u)$

Solving 1. for $M_s Z_s$ and substituting into 2. :

$$1/\ K_t(M_s\ddot{Z}_s + M_u\ddot{Z}_u) + Z_u = W$$

This expression relates the profile W to the measured accelerations $\ddot{Z}_u$ and $\ddot{Z}_s$ <u>independent of the suspension forces</u>.

Note that:

$$Z_u = \iint \ddot{Z}_u \, dt \, dt \quad .$$

Figure 2. Summary of forces on sprung and unsprung masses.

PART II

Axle and Body Mounted Accelerometer Response

Figures 3 and 4 show the response of the body mounted and the axle mounted accelerometers respectively to road stimuli. The attenuation of the response on the body of the vehicle makes it very difficult to measure profile from this response. The measurement in the GM type profilometer which carries the road roughness information is obviously the body to road surface distance measurement. This measurement is affected by extensive patching in the case of IR sensors, open texture pavements in the case of sonic sensors, and wheel bounce in the case of contact wheel sensors. In any of the cases, an approximation to the tire envelopment response must be made to the SDP data before the summary roughness statistic may be computed. (3) Since the tire is part of the measurement on the vehicle rear axle, no such step is required in the case proposed.

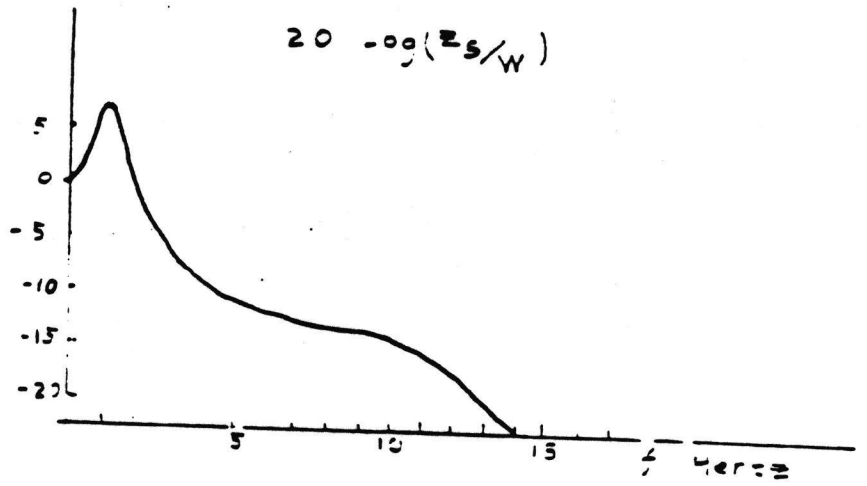


Figure 3. Plot of the response of body mounted accelerometers to road stimuli.

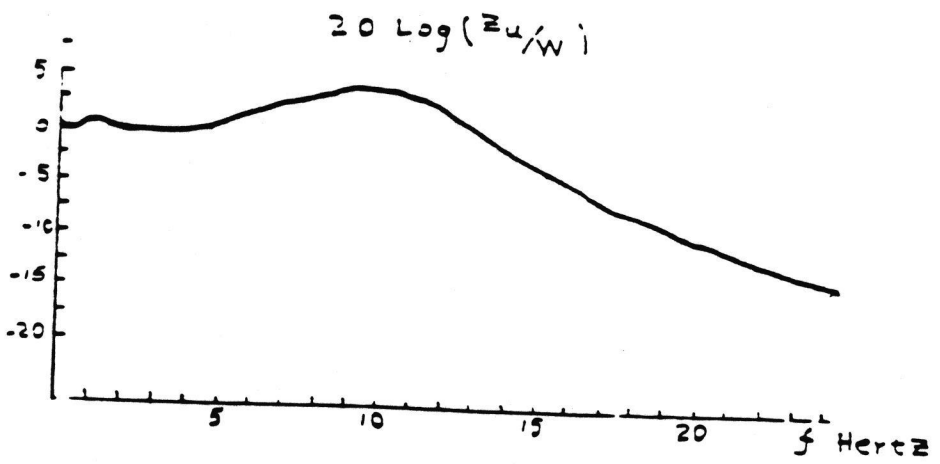


Figure 4. Plot of the response of axle mounted accelerometers to road stimuli.

PART III

SUMMARY ROUGHNESS STATISTICS

Average rectified Slope (ARS), Average Rectified Velocity (ARV), Root Mean Squared Vertical Acceleration (RMSVA), Slope Variance, and Quarter Car Responses are available from the proposed system. The following discussion defines each of the above summary roughness statistics given the raw acceleration data converted to profile as shown in Appendix I.

RARS and RARV are calculated from the Quarter Car Simulation given the profile as input. (3) RARS is computed from the QCS at a simulation speed of 80 kilometers per hour. It is the summation of the absolute value of the relative displacement (Z_s-Z_u) divided by the distance over which the summation is made. RARV is derived from RARS by multiplying RARS by the vehicle speed. (6)

RMSVA is calculated directly from the profile without using the QCS. (6) Given n sample points of elevation (profile) sampled at distance a apart, the RMSVA of base length b (a multiple of a i.e. b=ka) is calculated as follows. First the change in slope at point i (1<i<n) is estimated by:

$$[(Y_{i+k}-Y_i)/ka - (Y_i-Y_{i-k})/ka]/a$$

If the change in slope at point i is denoted by S_i then the mean squared value is found by summing the square of all S_i's from point k+1 to point n-k and getting the average by dividing this sum by the number of points summed (n-2k). The final two steps consist in taking the square root of this Mean Squared Sum and multiplying it by the speed of the vehicle squared to convert the spatial Root Mean Squared Sum to the temporal Root Mean Squared Sum which is by definition RMSVA. An advantage of this

summary statistic is its ease of calculation for different base lengths ka. Its disadvantage is that for anomalies of exactly that base length and multiples of it, there is no response (i.e. there are zeros in the spatial transfer function at those points). This behavior is exactly analogous to the response of a moving straight edge of length b. To overcome this problem, Hudson has suggested summing several base length RMSVA's to get another summary statistic.

In the case of the H.P.I. ARAN and PURD, samples of acceleration are taken every 1.2 inches, digitally filtered to correspond to responses from 2 feet to 300 feet, and recorded in a compact digital format. The root mean squared value of axle acceleration (not the same as RMSVA profile roughness as defined in Appendix IIIc is displayed in real time as an operator console summary roughness statistic. This summary roughness statistic is averaged over a length of three hundred feet but reported by station (approximately every 60 feet). Multiples of base length are thus out of the range of interest.

PART IV

ARAN PROFILOMETER TEST PROGRAM AND RESULTS

(As of Jan 12, 1987)

INTRODUCTION

A three phased test program designed to validate the ARAN profilometer by determining the accuracy, repeatibility, and parametric sensitivity of the measurement is presently being implemented. Analyses and measurements are being made in Canada at H. P. I., in Michigan at U. M. T. R. I., and in Texas.

The first phase consisted of a theoretical design and evaluation of the Digital Signal Processing system to record acceleration and derive profile. This simulation checked the digital filtering and accuracy of the algorithms used to derive profile. Both mathematical modeling and actual signal generator inputs were used to check the basic design.

The second phase consisted of testing a physical prototype system with a known roadway anomaly. Several half inch thick plywood sheets were used to approximate a profile pulse stimulus, and measured profiles were calculated from the raw data to check the physical prototype system. Also at this stage, FFT's were derived from the data and the spectral output examined for any spurious responses.

The third phase consisted of testing the prototype over real roadways with known profiles. With the cooperation of the staff of UMTRI, some 25 road sites were tested on the "Ann Arbor Profilometer Study" route. Multiple runs over a period of several days at varying speeds yielded a base of raw acceleration data from which Profile, IRI, and other summary statistics can be derived. Using this base, parametric ratios were varied systematically to determine the effect on the measurement of body loading, tire pressure, etc at least to a first order approximation. Comparisons with proven profilometers (those shown to yield as output true profile) were made. Additional filtered FFT studies were also undertaken to prove the validity of the measurement.

This appendix describes each of the phases and presents salient results of the testing.

PHASE I - SIMULATION

The peak amplitude and wavelength of the sinusoidal roadway profile is input. The transfer function Z / Z is solved from the quarter car model in the Laplace domain. The acceleration on the axle and body is solved exactly in the temporal domain. These analytic functions are then appropiately filtered, sampled and input to the Digital Signal Processing (DSP) system to yield a sampled profile output of the system. Mean square and RMS values are then calculated for the actual profile, the estimated profile, and the difference (or error) profile derived from a point by point comparison of the first two profiles.

This study found the RMS error profile to be greater than 40 dB below the RMS actual profile for all wavelengths between 0.3 meters and 100 meters. Since the actual profile and error profile were each sinusoidal having the same frequency, no distortion was introduced in the output profile.

The unit step profile was also used. Each Laplace transfer function was multiplied by the unit step 1 / S. Rather than go directly to the temporal response for the axle and body, the residues of the Laplace responses were evaluated numerically and the temporal response expressed as an analytic function of poles, zeros, and time. These functions are then appropriately sampled and input to the DSP system to gain an estimated sampled profile output. The same process was again repeated with a negative unit step profile in order to evaluate a unit rectangular pulse profile input. In each case the output profile yielded the correct step plus transient response.

PHASE II - PHYSICAL PROTOTYPE WITH PLYWOOD PULSE PROFILE

Several pieces of 4 ft X 8 ft X 1/2 inch plywood were placed on a smooth roadway to introduce a controlled anomaly and the test vehicle was driven over them at various speeds. Axle and body accelerations were sampled and recorded for further analysis. The vehicle used was a PURD trailer. The requisite parameters of sprung mass, unsprung mass, and tire spring constant were statically measured and used to analyze the data. Profile versus distance was derived and plotted. Appropriate system response was noted.

As mentioned in the introduction, unfiltered FFT's of 1024, 2048, 4096, and 8192 points were taken for both raw data and profile to check for any spurious system response. None was found.

PHASE III - ACTUAL ROADWAYS

Towards the end of April 1986, the ARAN prototype system was taken to Ann Arbor, Michigan for a week of testing on the profilometer circuit.(4) Eighteen months had elapsed since the initial experimental measurements had been made, but it was felt that this site offered the capability to validate the ARAN profilometry method. All sites (with the exception of sites 1 and 2 which had changed since the profilometer experiment) were run and raw acceleration data recorded. For each of the 25 sites, a representative run was chosen and profile calculated. The profile was presented in Engineering Research Division (ERD) format for convenience of transfer to UMTRI for further analysis. The study included comparison of specific site Power Spectral Density, International Roughness Index, and other summary roughness statistics as well as profile. Additional profiles were calculated from the data to determine the repeatibility and sensitivity of the measurement to variations of speed and other parameters. Some results are now available from this testing. Additional results will be made available to anyone who would like to receive them.

PROFILE

The UMTRI profilometer (now with the FHWA) with a Selcom laser height sensor was chosen as the unit of comparison. This unit was completely validated in the Ann Arbor Profilometer Meeting. Figures 5 and 6 show the profile measured by the UMTRI unit and the ARAN. The plots have been vertically offset for ease of viewing. Section 4 is a public roadway with medium and long waves.

PSD's

Although not as intuitively obvious as the profile, the Power Spectral Density of the profile slope is a better measure of the profilometer performance and indicative of the spatial content of the measurement. Figures 10, 12, and 13 show a comparison of the UMTRI and ARAN PSD for several different sites. Close agreement is found over the wave-bands of interest for any of the summary roughness statistics (1 meter to 100 meters). The peak above the 1 meter waveband seen in some of the plots is thought to be the first mode vibration of the rear axle. Steps are being taken to stiffen the axle and remove this response. At the present it will be removed by filtering. The agreement of the two systems in PSD imply the agreement in both profile and calculated summary roughness statistic.

REPEATIBILITY and SPEED VARIATION

Figure 7 shows the profile of a section at 50 miles per hour on the first day. Figure 8 shows another run on that section at 50 miles per hour on a different day. Figure 9 shows the same section profile at 30 miles per hour. The sample interval plotted is 0.0944 meters/ sample. The starting point on each of the plots is not exactly the same since only a portion of the site is used for this comparison. Note that all three overlay.

OTHER PARAMETRIC SENSITIVITY

The quarter car parameters appropriate for the trailer were used and a reference profile calculated. The parameters were then systematically varied and a second profile calculated. The error profile was then found by subtracting the second profile from the reference profile point for point. The mean square value of reference and error profiles were computed and the ratio formed in dB to give an estimate of the error introduced. The roughest roadways were the least sensitive to parametric variation and the smoothest were the most sensitive. The worst case was site 17,"a smooth bituminous overlay". This site has a 42 dB ratio for a 10 percent variation in the sprung mass.

SUMMARY ROUGHNESS STATISTICS- IRI

Figures 11,14,& 15 show a comparison of the IRI from the UMTRI and ARAN units. Figure 11 is site 10, good PCC with lateral grooves. The IRI is in close agreement. Figures 14 and 15 are included to show the range capability of the ARAN measurement. This site is the cowboy run. Any speed over 40 mph and you leave the ground! This is a very challenging site for all profilometers. The ARAN passes with flying (sic) colors.

CONCLUSION

The process of development of the ARAN profilometer has included many computations, simulations and tests. The salient results have been presented here to serve as an introduction to this new technology. The new profilometer has shown a capability of meeting its design goals of providing a reliable, accurate , and repeatible measure of roadway traveled surface characteristics.

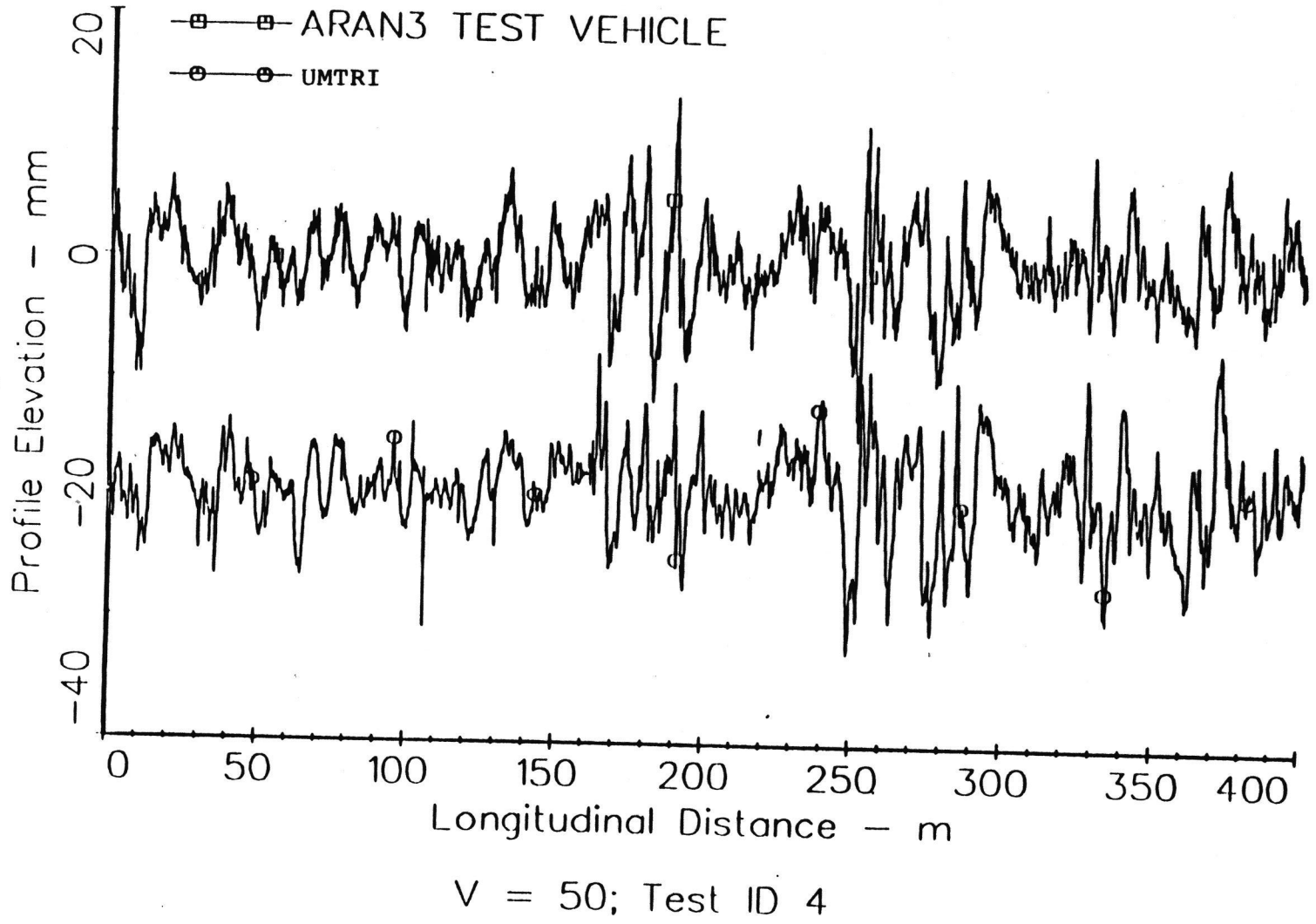


Figure 5. Profile of Section 4 by UMTRI and ARAN III run one.
(vertically displaced for comparison)

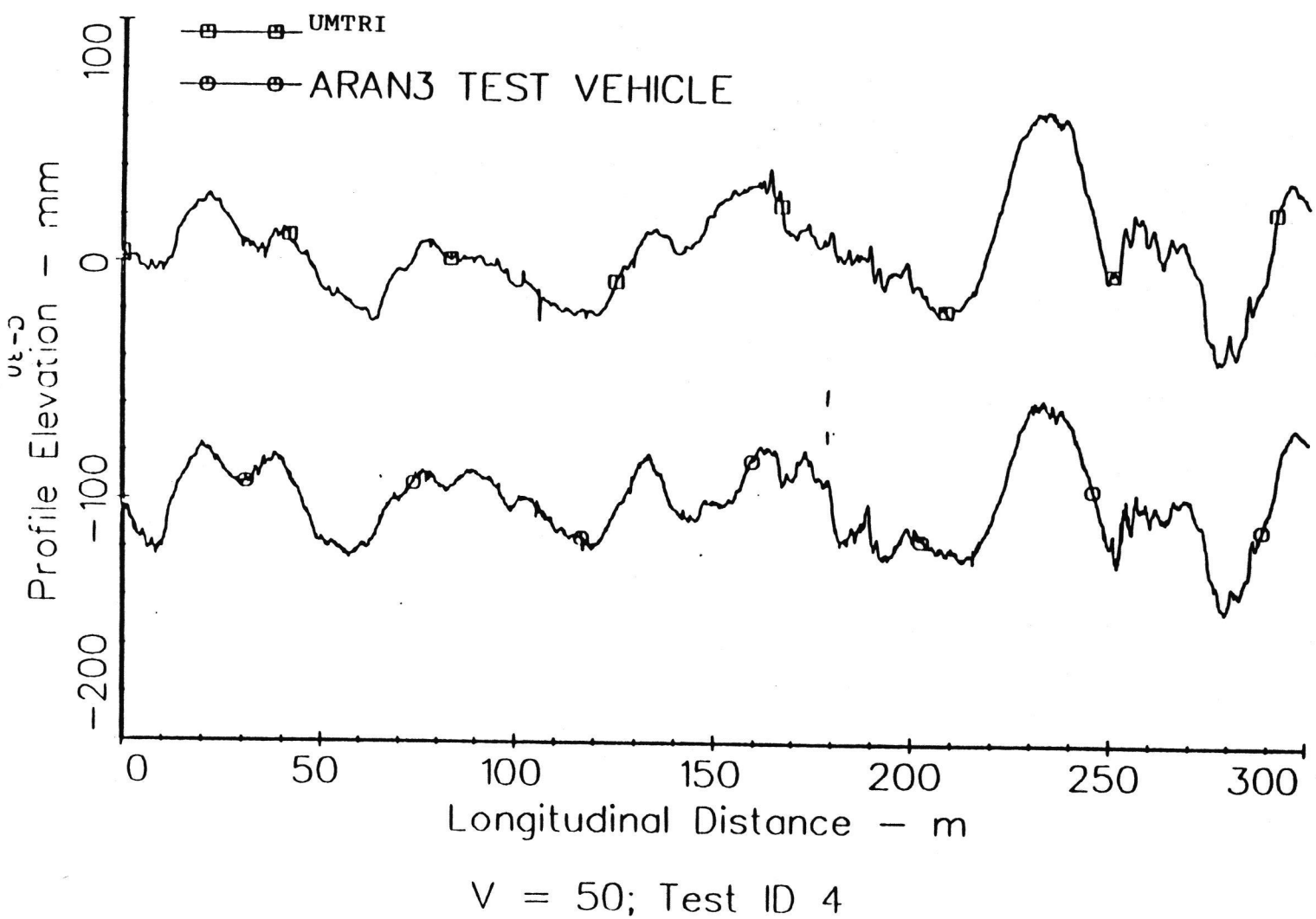


Figure 6. Profile of Section 4 by UMTRI and ARAN III run two.
(vertically displaced for comparison)

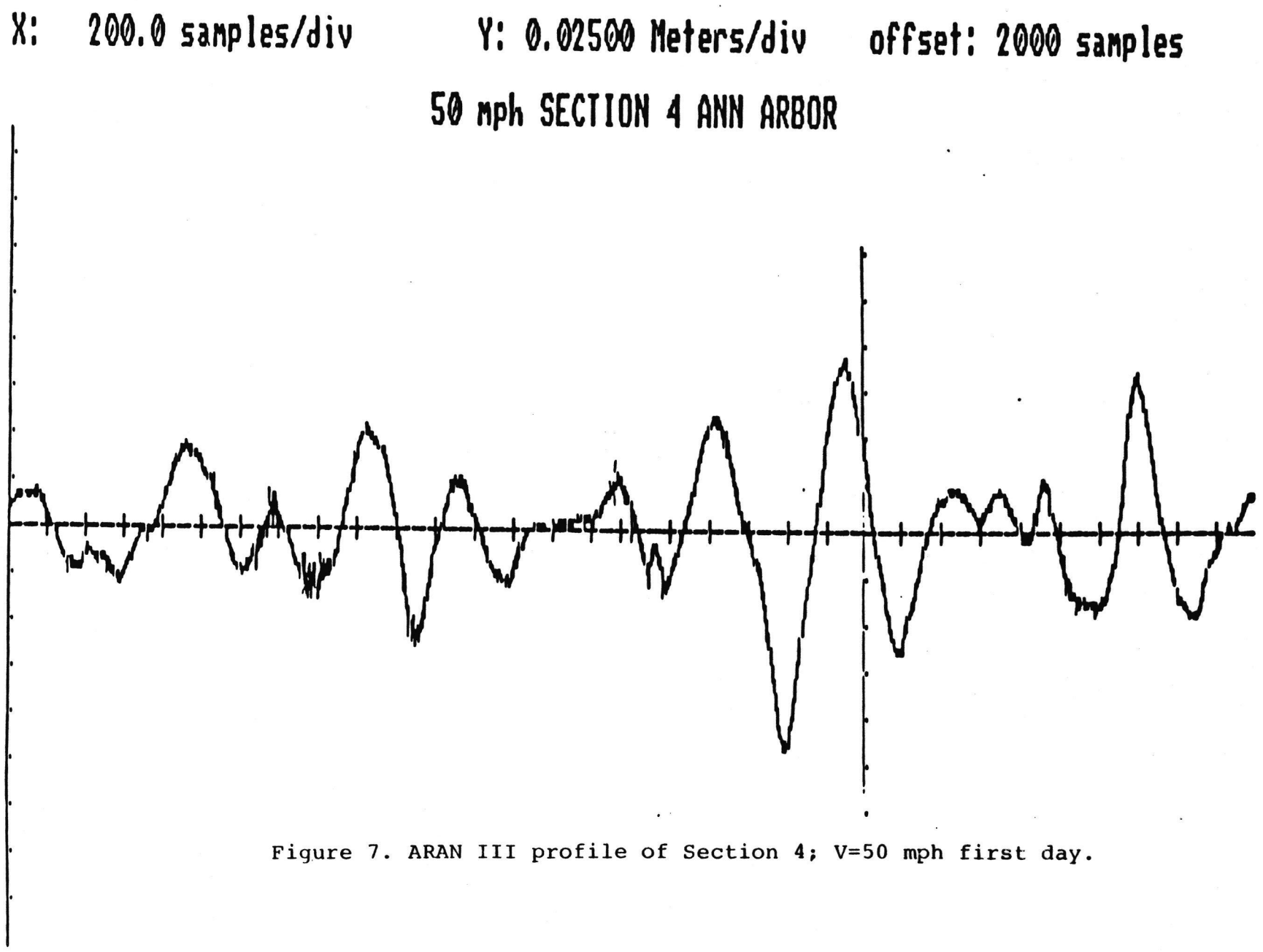


Figure 7. ARAN III profile of Section 4; V=50 mph first day.

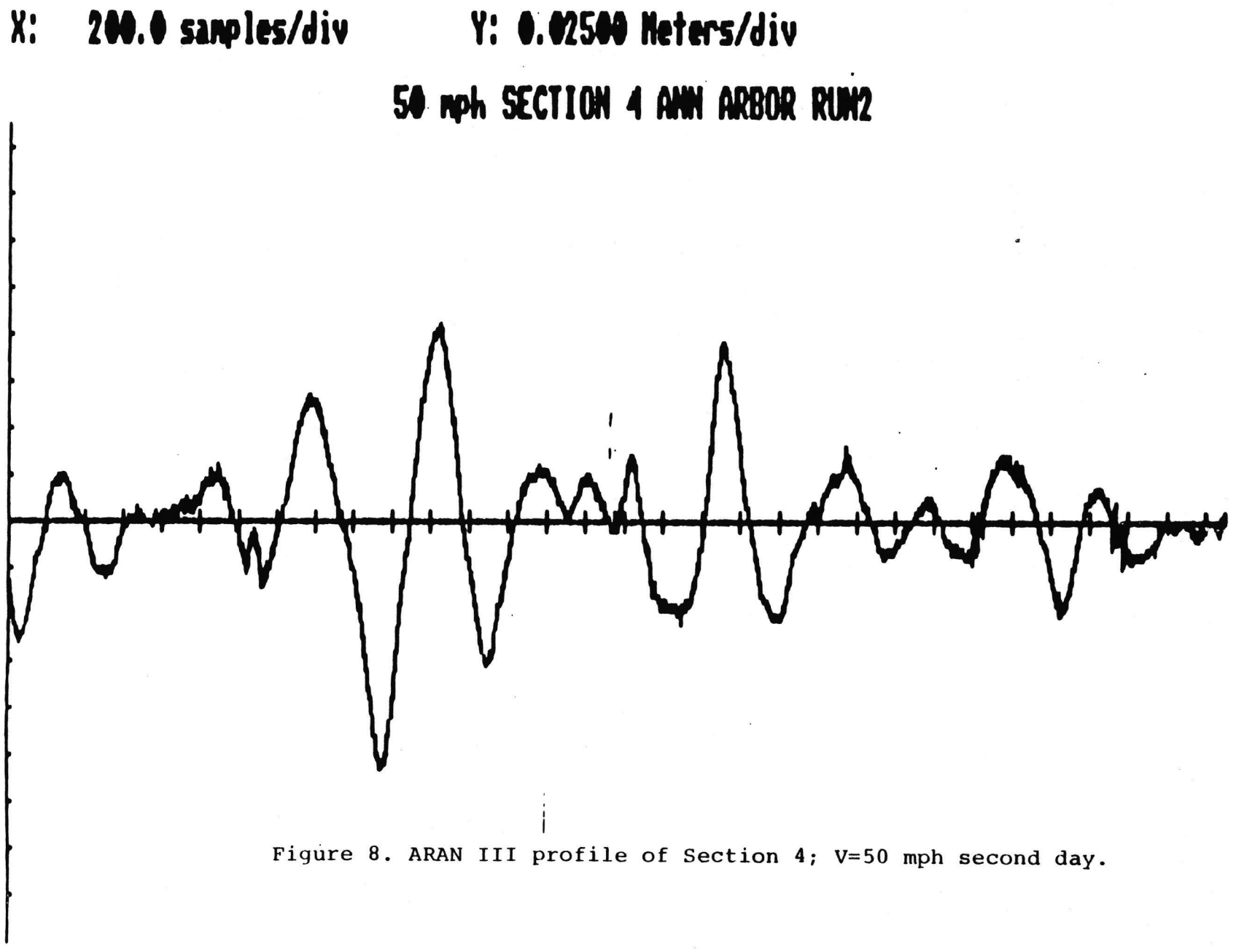


Figure 8. ARAN III profile of Section 4; V=50 mph second day.

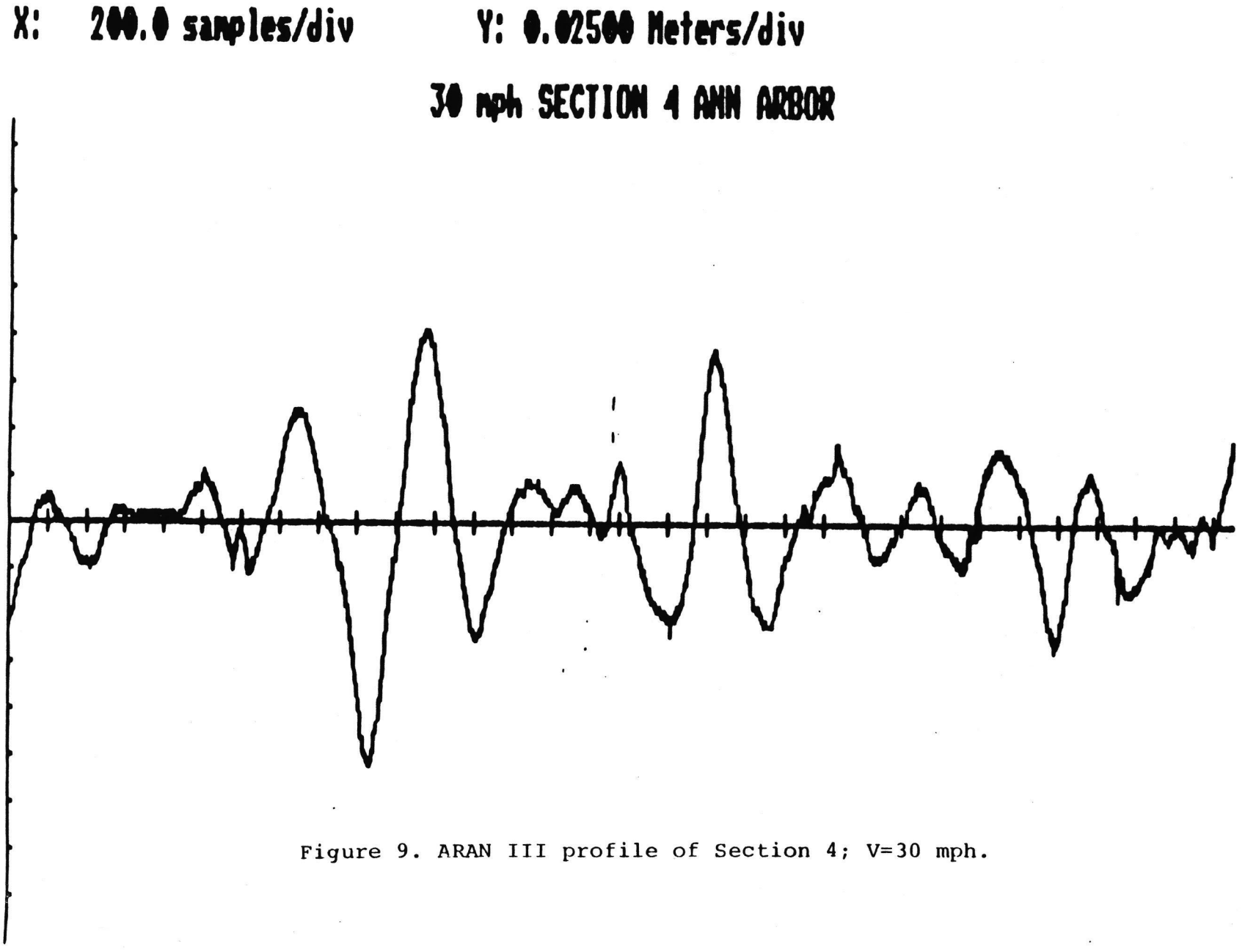


Figure 9. ARAN III profile of Section 4; V=30 mph.

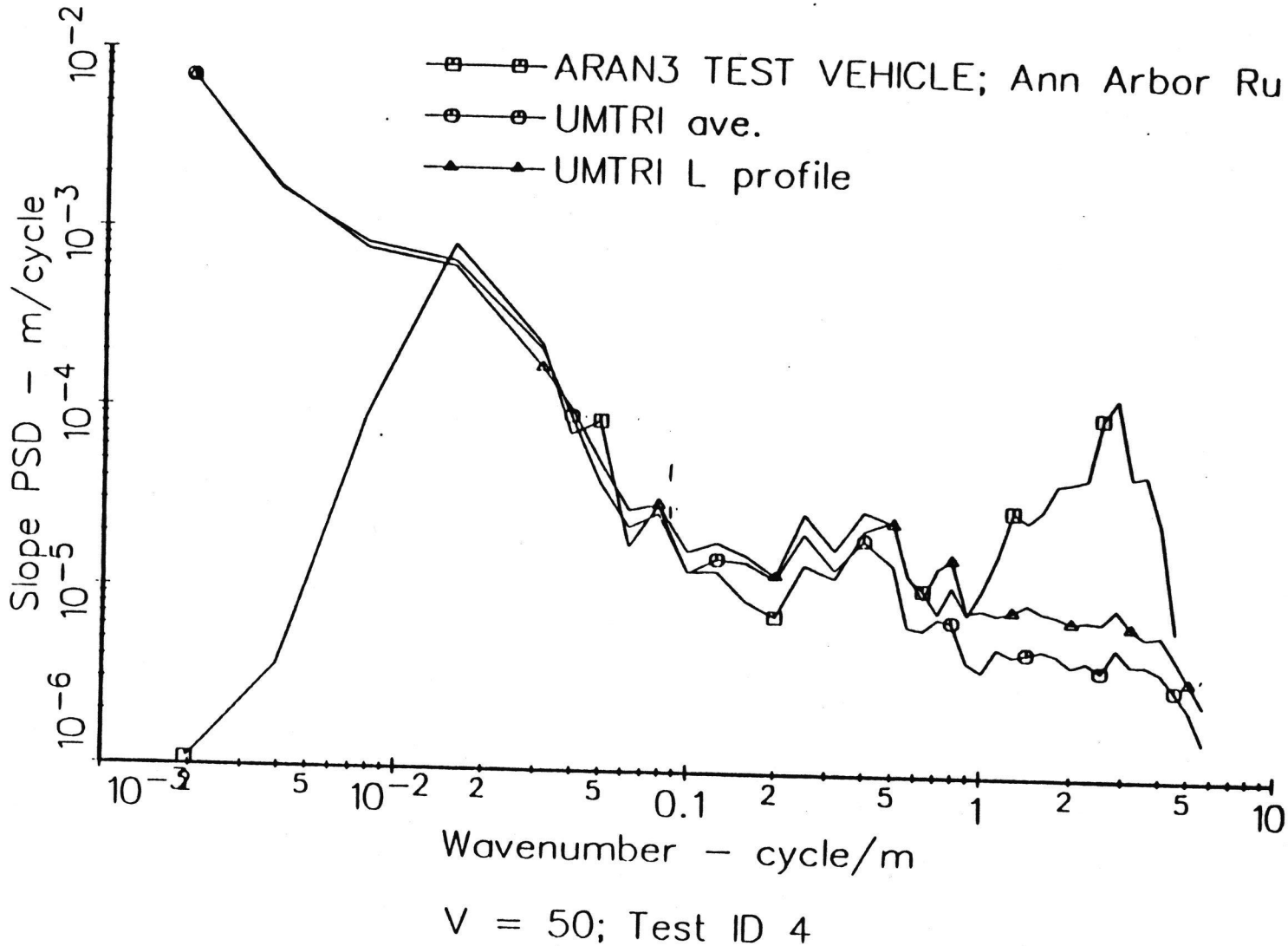
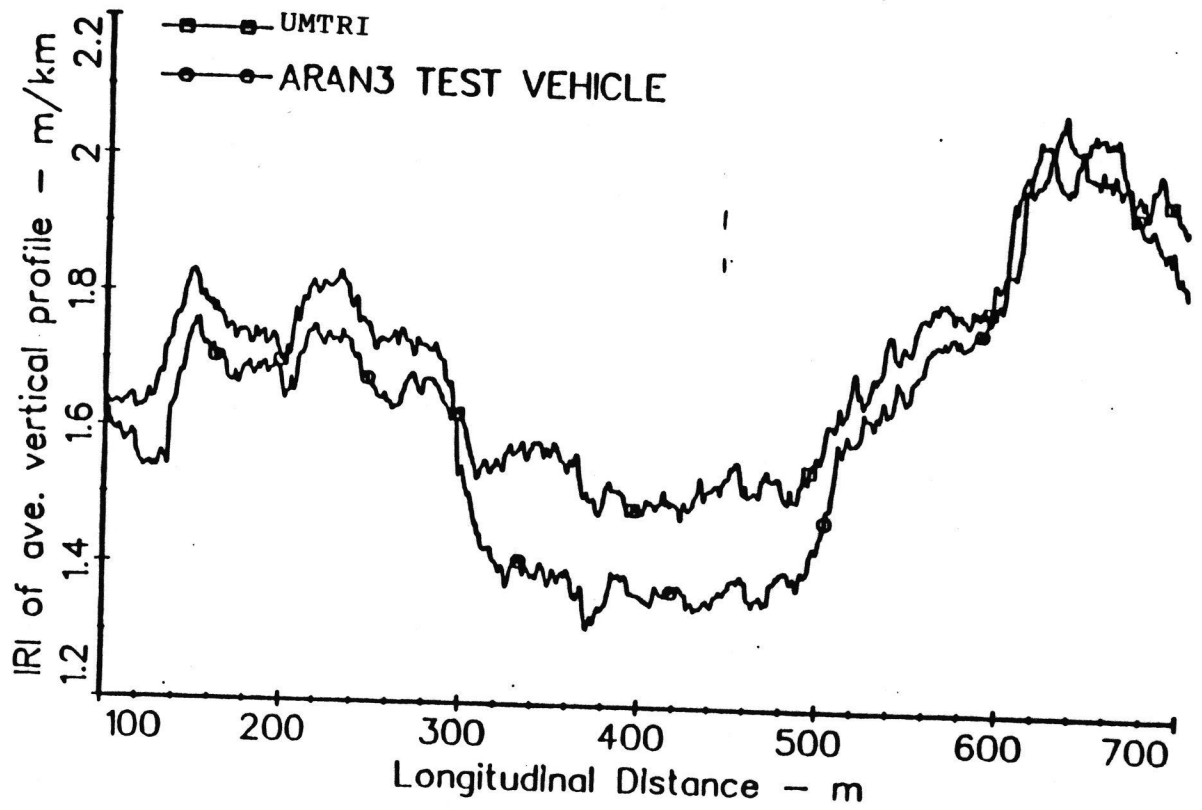


Figure 10. Power Spectral Density of the profile slope obtained by UMTRI and ARAN III from Section 4; V=50 mph.



Test ID 10; Vert IRI; Lopass = 161

Figure 11. Plot of IRI of average vertical profile obtained by UMTRI and ARAN III on Section 10.

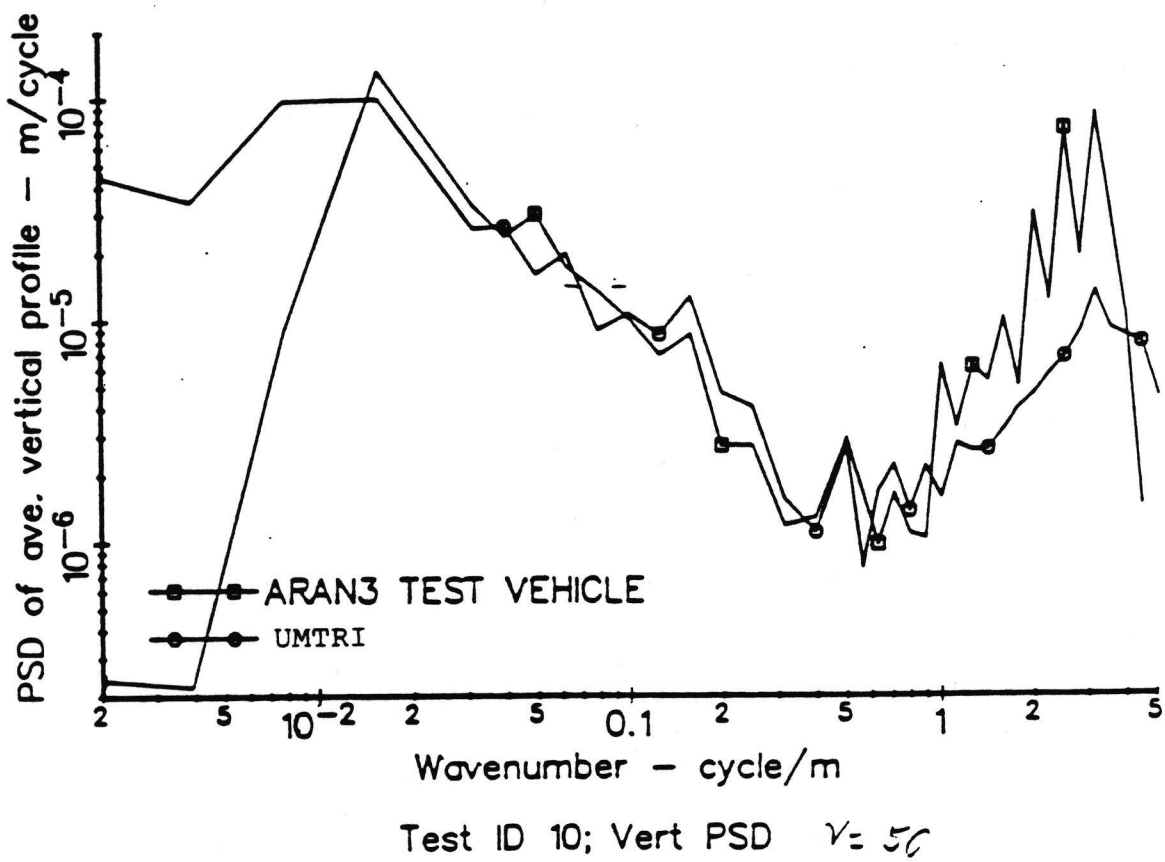
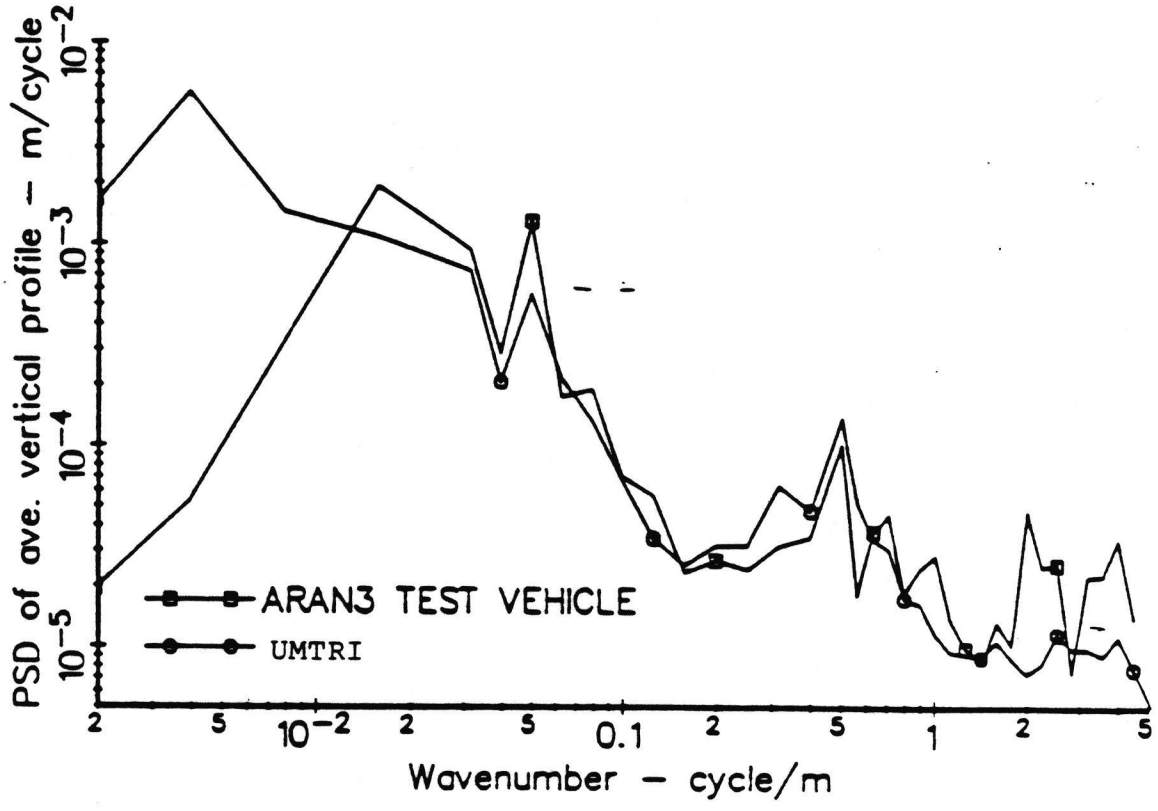


Figure 12. Power Spectral Density of the profile slope obtained by UMTRI and ARAN III from Section 10; V=50 mph.



Vert PSD

site 22 V=30

Figure 13. Power Spectral Density of the profile slope obtained by UMTRI and ARAN III from Section 22; V=30 mph.

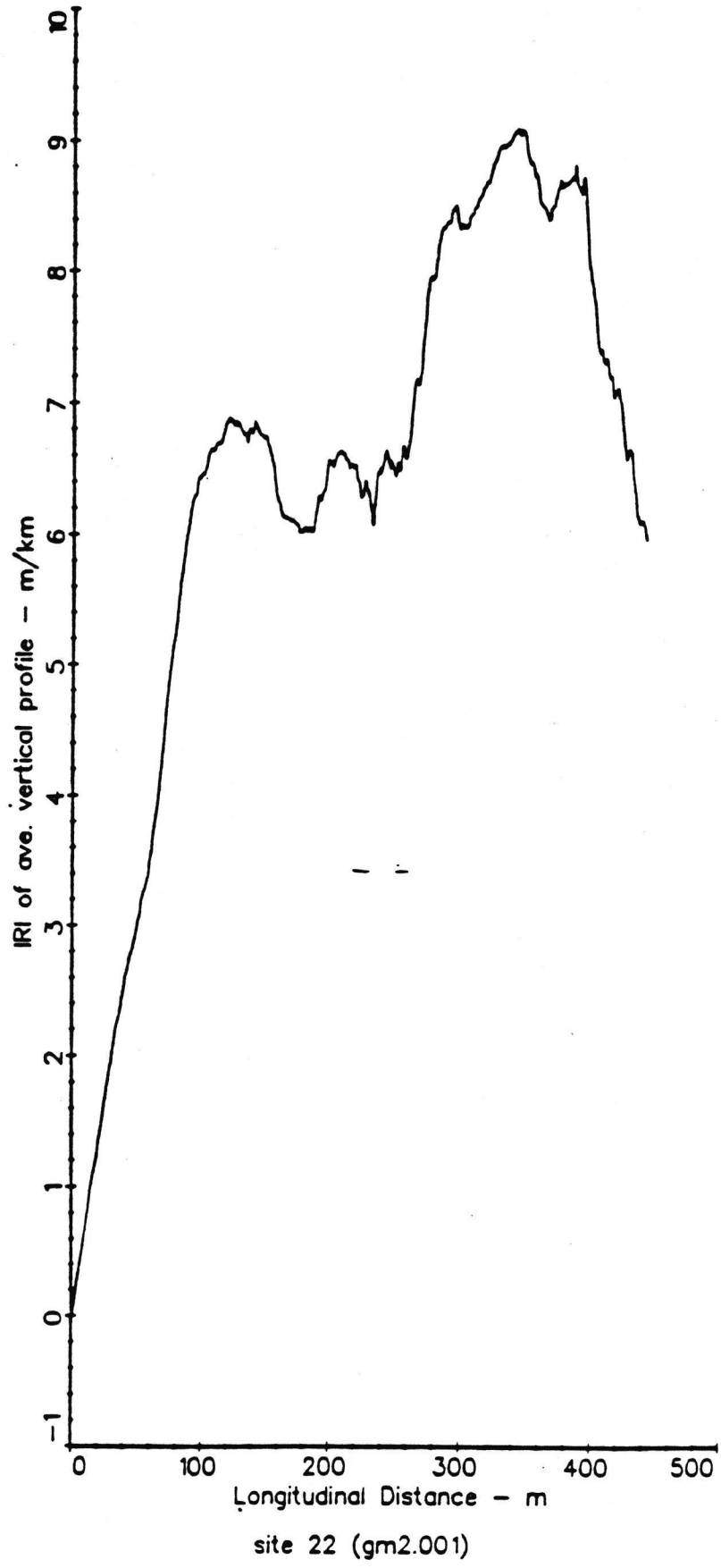


Figure 14. Plot of IRI obtained by ARAN III from Section 22.

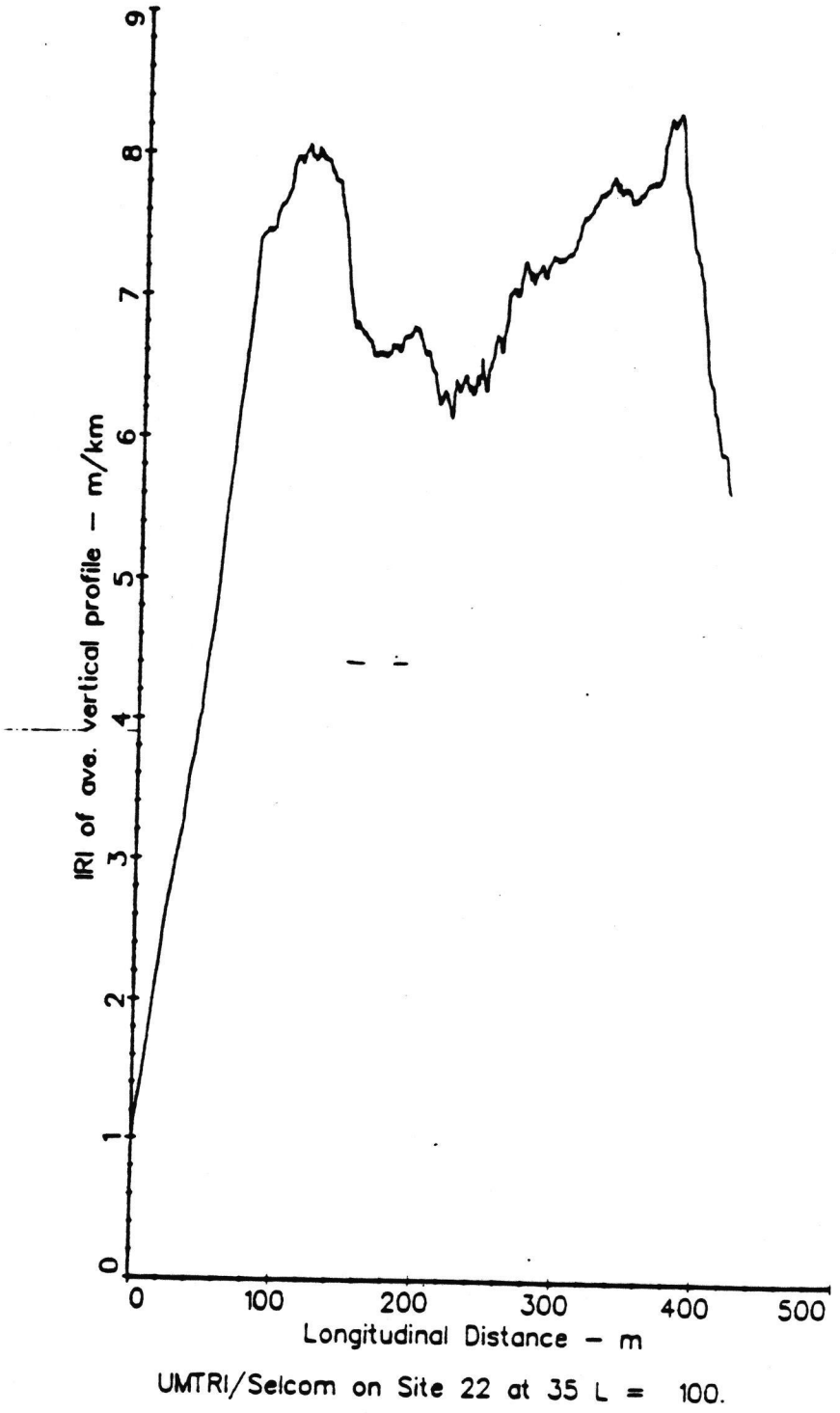


Figure 15. Plot of IRI obtained by UMTRI from Section 22.

NEW

PRODUCT INTRODUCTION

ARAN (TM)

PAVEMENT CONDITION RATING

VIDEO LOGGING SYSTEM

ARAN VIDEOLOG SYSTEM

1. Overview

The ARAN Videolog System provides continuous right-of-way and road surface images. The recorded picture can be utilized in an office environment for a multitude of inventory applications.(*) Figure 16 demonstrates the functional operation of the ARAN Videolog System.

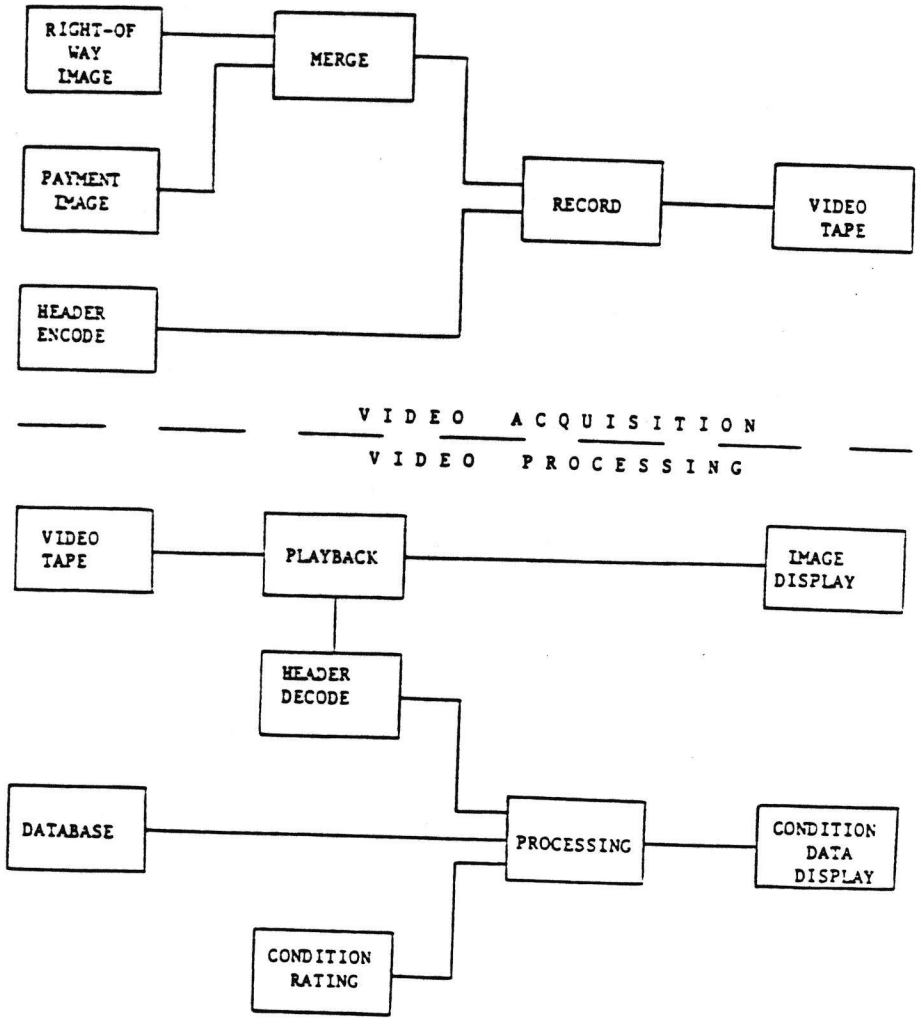


Figure 16. Functional operation of the ARAN VIDEOLOG System.

(*) The camera view has been termed "image", the recorded merged images have been termed "picture".

2. Video Acquisition

The ARAN Videolog Acquisition vehicle is shown in the attached Figure 17. The depicted vehicle also contains other measurement subsystems. Figure 18 is a block diagram of the vehicle components.

2.1 Image Capture

The video system includes 2 color cameras for image capture, as shown in Figure 17. The front facing camera is a standard high resolution tube camera with a zoom lens. This view captures the entire roadway right-of-way, including signs, road shoulders, overpasses, guard rails, pavement markings, etc.

The second camera, mounted at the rear and aimed downward at the pavement, is a new technology Shutter CCD camera with a fixed wide angle lens. This camera freezes highway speed (55 mph) road motion to less than 1/8 in. every video frame. The result is a sharp, clear and continuous view of one lane width of pavement surface.

The two camera images are merged, with the right-of-way image inserted into the top 1/3 of the road surface view. Figure 19 demonstrates the results.

2.2 Header Encoding

The Video picture must be recorded in the ARAN vehicle for later retrieval and analysis. Thus, the road name, section number, chainage, data, etc. must be recorded with the image. This can be accomplished by 2 methods.

The first method of recording Header and Chainage information is to superimpose the text over the cameras' image. This method has the disadvantage of covering potentially useful camera image information, so superimposition can be deselected by the user.

The second method is to digitially store the information with the picture using the Audio portion of the signal. The onboard Encoding system takes the Header and Chainage information from the ARAN computer and translates it into a coded format for storage and retrieval (3.2) purposes.

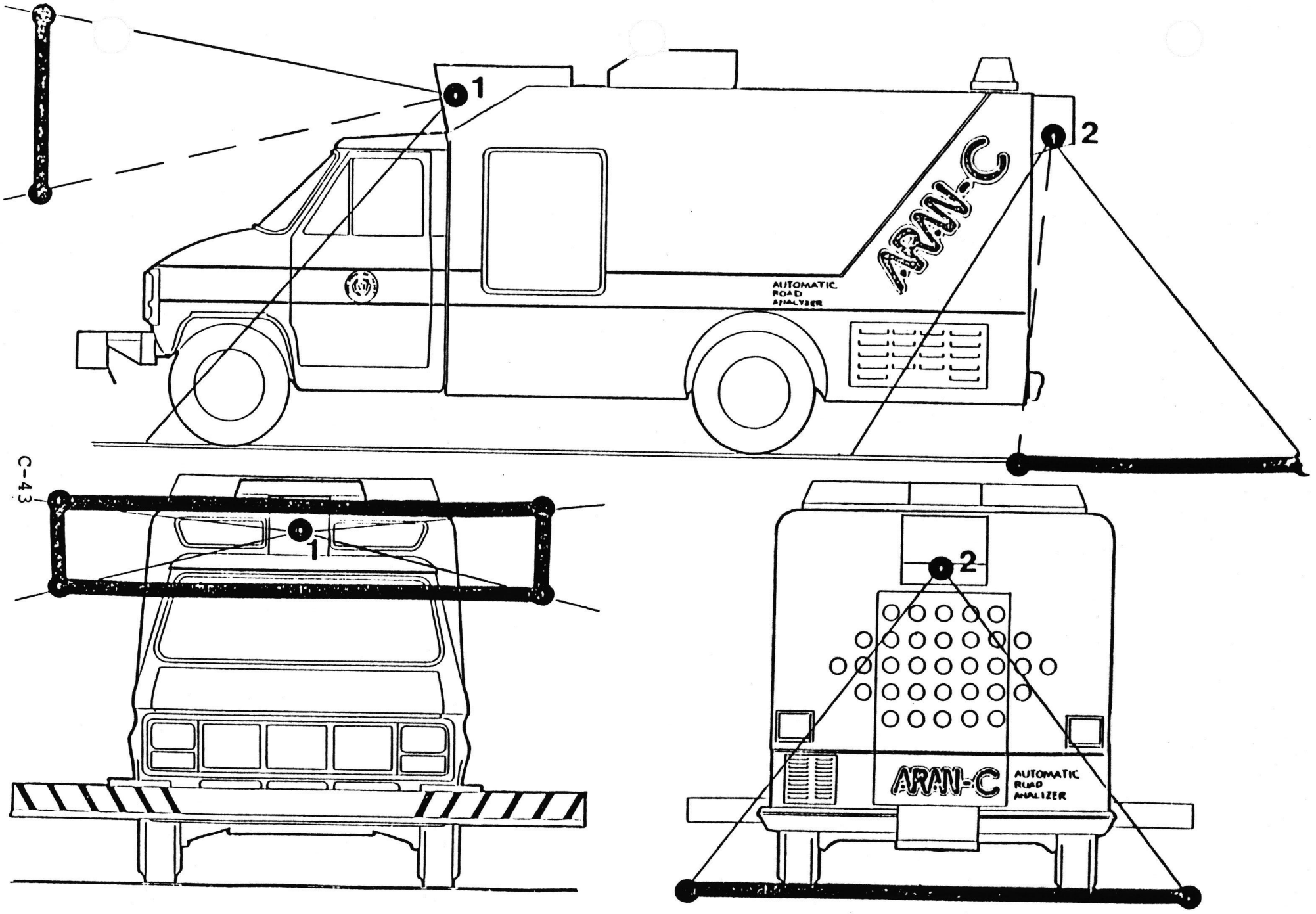


Figure 17. The ARAN Videolog Acquisition Vehicle showing camera placement.

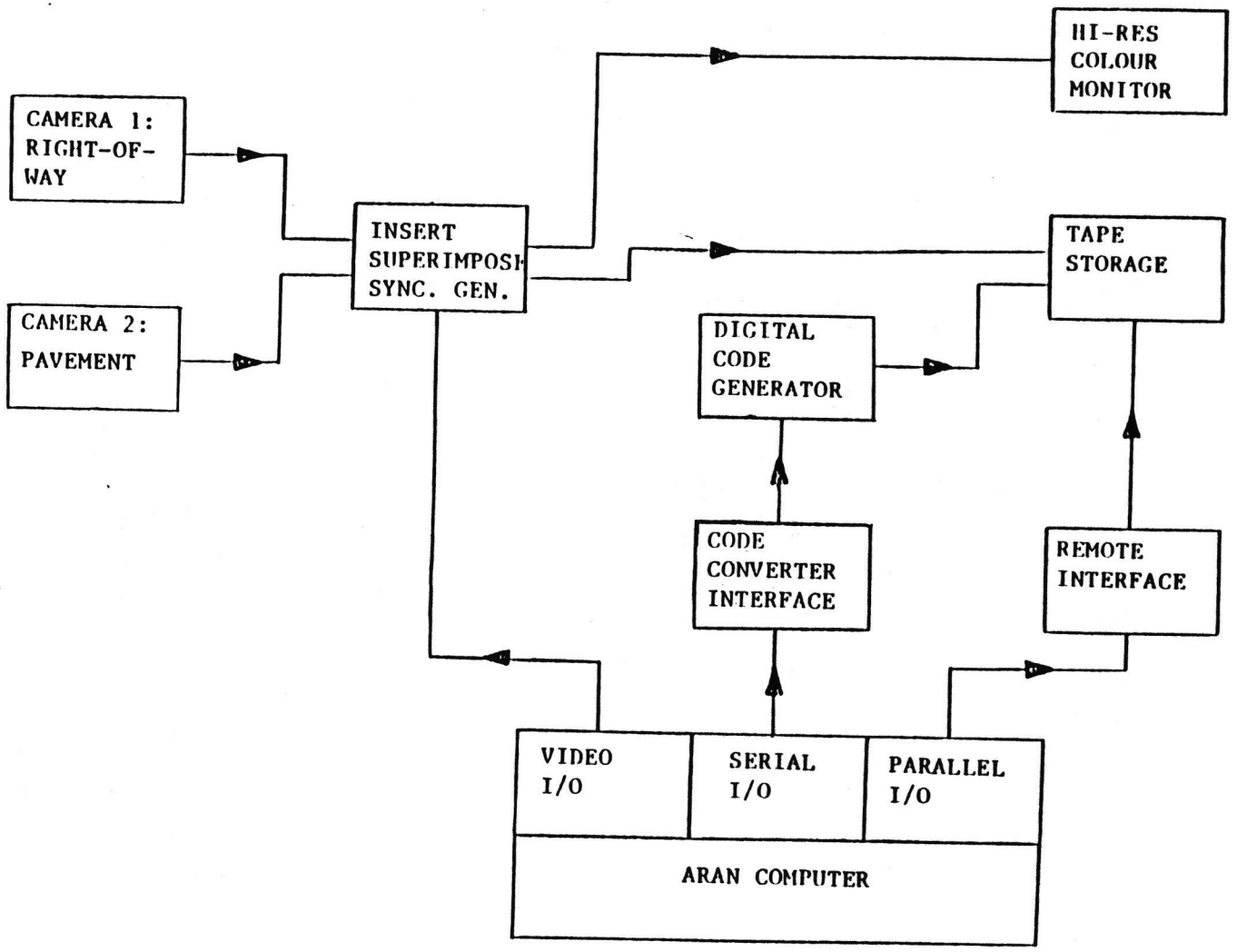


Figure 18. ARAN Videolog Acquisition System block diagram of the vehicle components.

2.3 Recording

The Video and Audio information are stored using industrial VHS recording equipment. The tape is controlled from the ARAN computer, recording only when the ARAN operator signals the start of a test section, and pausing at the end of a test section.

3. Video Processing

The ARAN Videolog Processing Center provides the capability of high speed video search, analysis, automated data entry, and interactive processing with the sensor data processing center. The Sensor data processing workstation performs data reduction, analysis and reporting functions on the other ARAN subsystems. Figures 20,21,and 22 describe the Video Processing Center.

3.1 Playback

The VHS Playback unit has noise free search/still capabilities, enabling detailed study of right-of-way and/or pavement surface conditions.

3.2 Header Decoding

The Audio encoded Header and Chainage information is read, translated and displayed by the Decoding system. The PC computer then uses this information to control the Tape Playback when searching for specific Roads, Sections, Chainages, etc. in the network. Additionally, the PC uses the Header/Chainage information to access the Sensor Data Base in the Master PC computer. This provides synchronization between the Video Image and the Sensor measurement results.

3.3 Condition Rating/Inventory Processing

The Videolog processing PC enables input from the Condition Rating/Inventory keyboards of the ARAN in the office. This permits Office Rating of the right-of-way and pavement surface at any time subsequent to Videolog/Data Acquisition. Rating data from field operation, located in the Master PC data base, can also be accessed for monitoring, editing, replacement, or supplementation.

3.4 Data Processing

The Videolog Processing system enables the synchronization of Video and the Sensor data base. Thus, it gives a means of annotating and subjectively Rating/Inventoring the Sensor Data Base Information in the Office. Additionally, the simultaneous study of both visual and quantitative measurements is a useful roadway analysis capability.

4. Options

Several alternatives are available to enhance the ARAN Videolog system.

4.1 Digitizing

The Videolog Processing center capabilities can be enhanced with the addition of a Video Digitizing system. The recorded Video signal can be captured inside the computer. The result can be displayed for analysis, annotation, and manipulation. The digital record can also be stored for later reference and use by evolving pattern recognition software.

4.2 Hardcopy Output

A still-frame result from the Playback unit can be captured with a Video compatible Image Recorder. The result is a high quality print or slide suitable for presentation or reporting.

4.3 Optical Disc Storage

A Video compatible Optical Disc recording is available for the vehicle, with a corresponding playback system for the office. This system, used as a supplement to Tape storage, provides a precise, high resolution frame-based storage of the cemeras' image. Image capture can be samples, continuous, or operator selected. Playback is achieved using random frame access. Maximum access time to any of 24000 frames per disc is a fraction of a second.

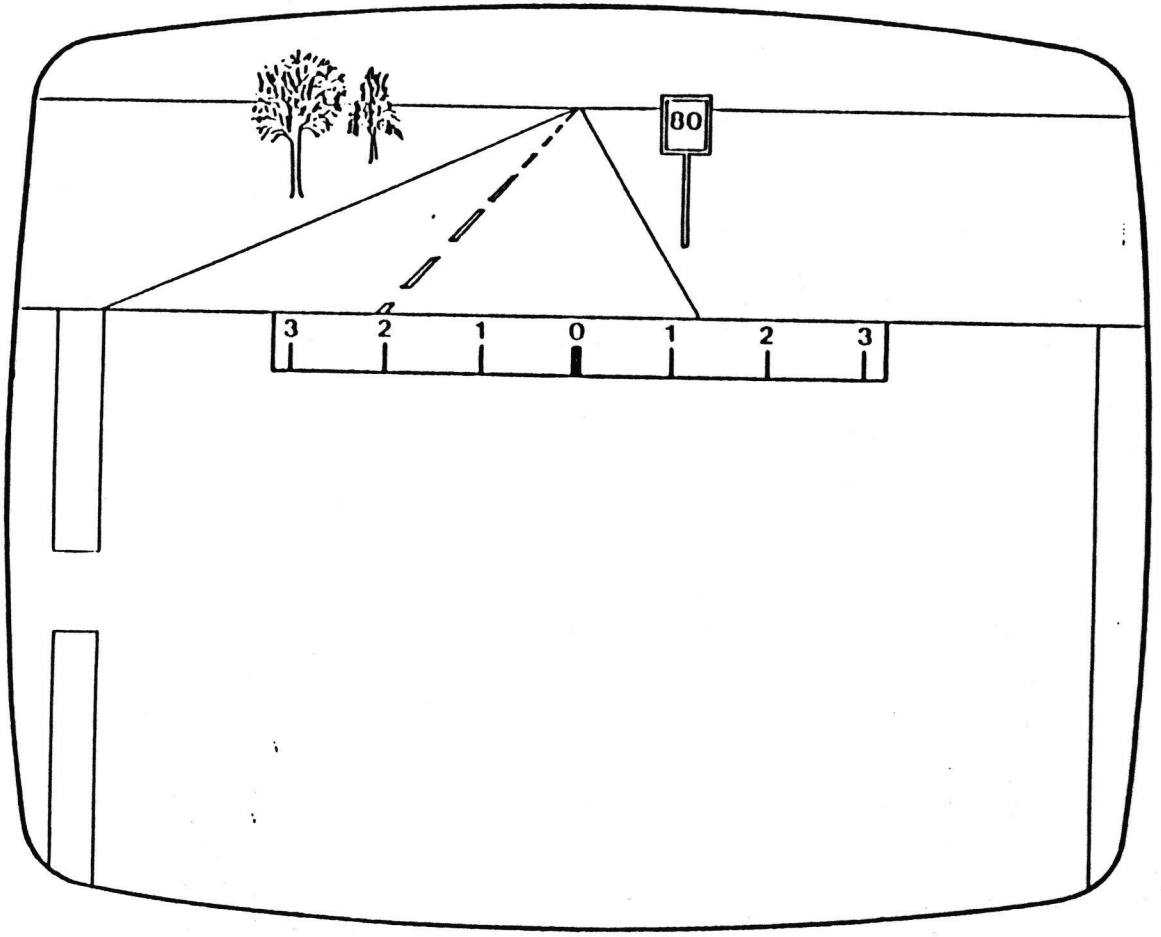


Figure 19. The two camera images are merged, with the right-of-way image inserted into the top 1/3 of the road surface view.

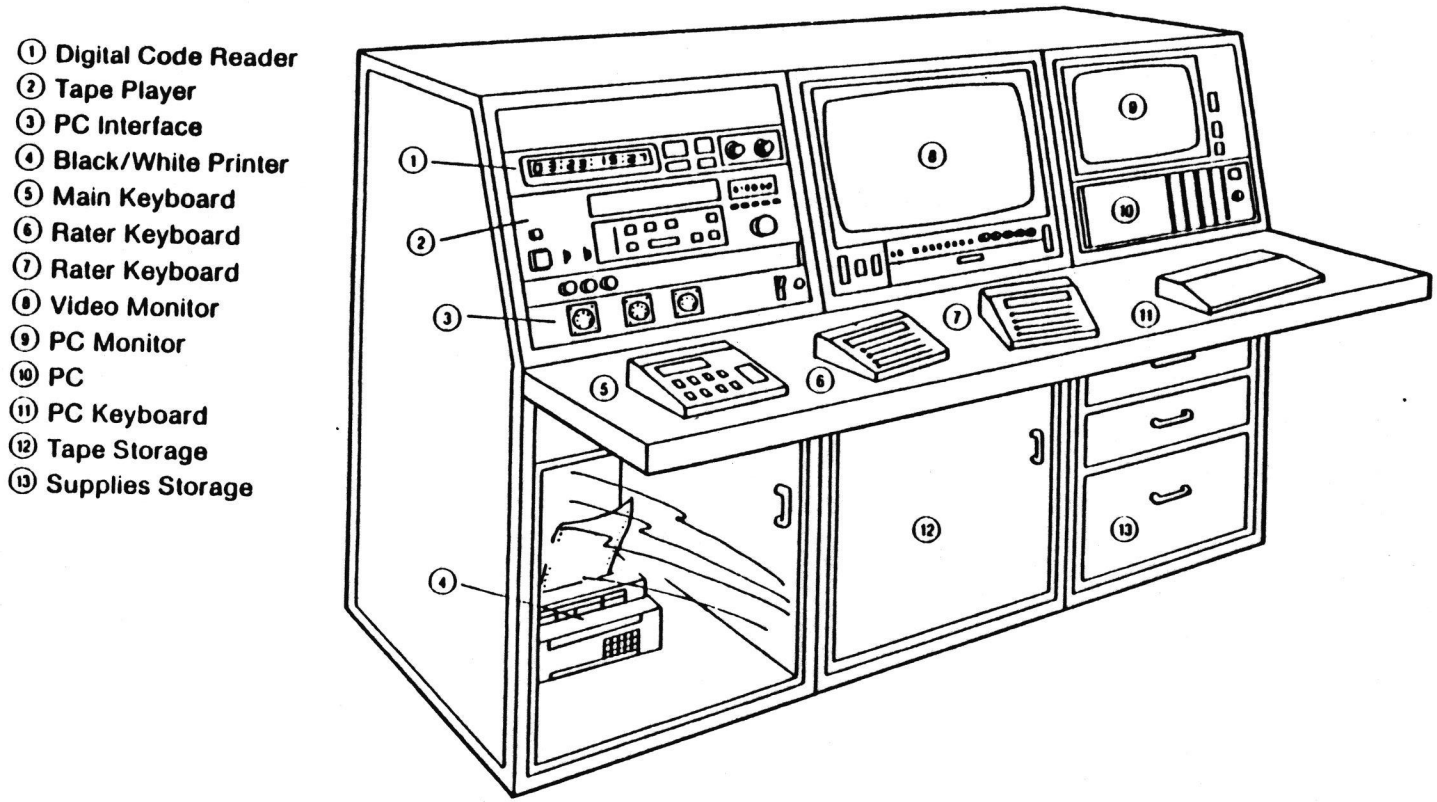


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Figure 20. The ARAN Video Processing and Training Center work station.

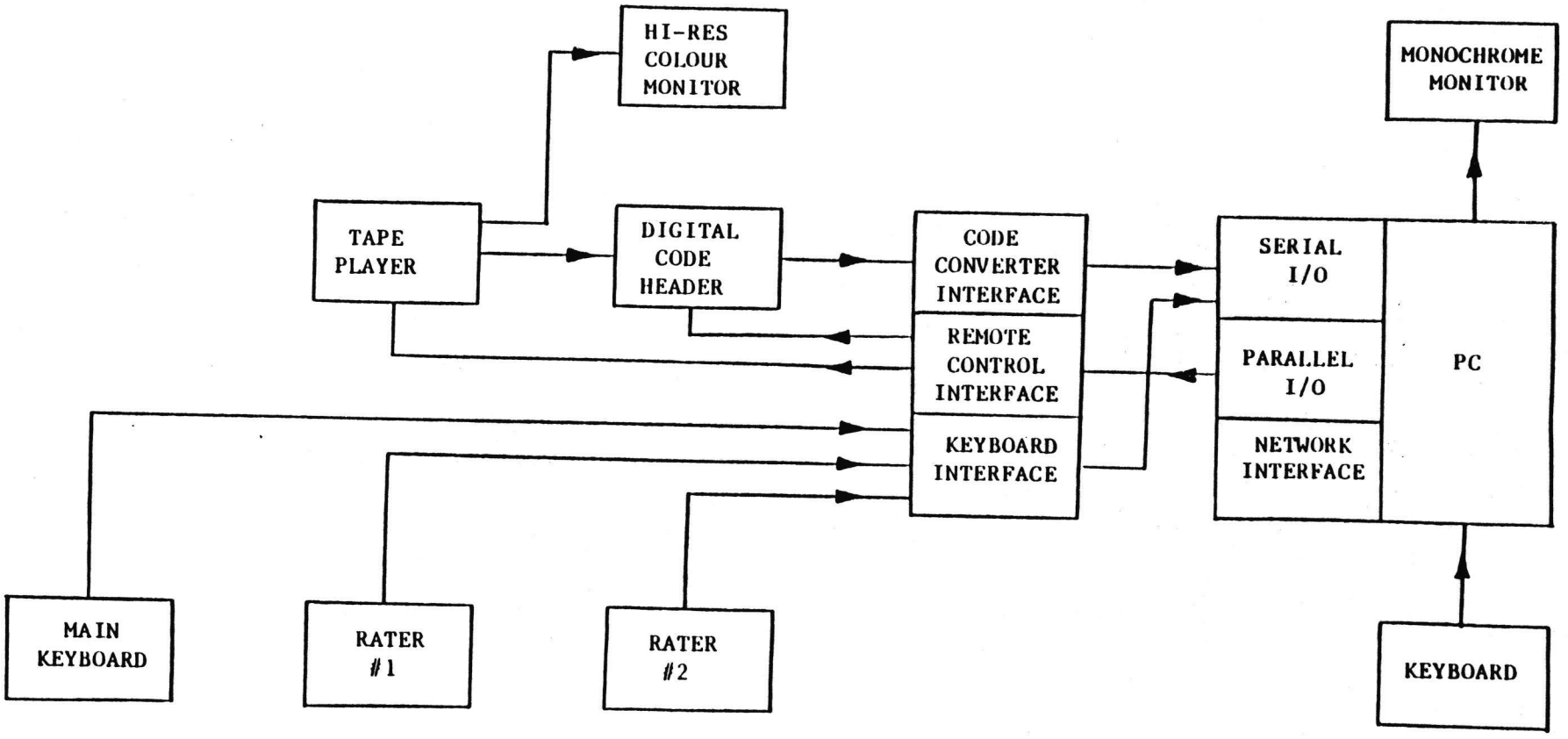

Figure 21. The ARAN Video Processing and Training work station block diagram.

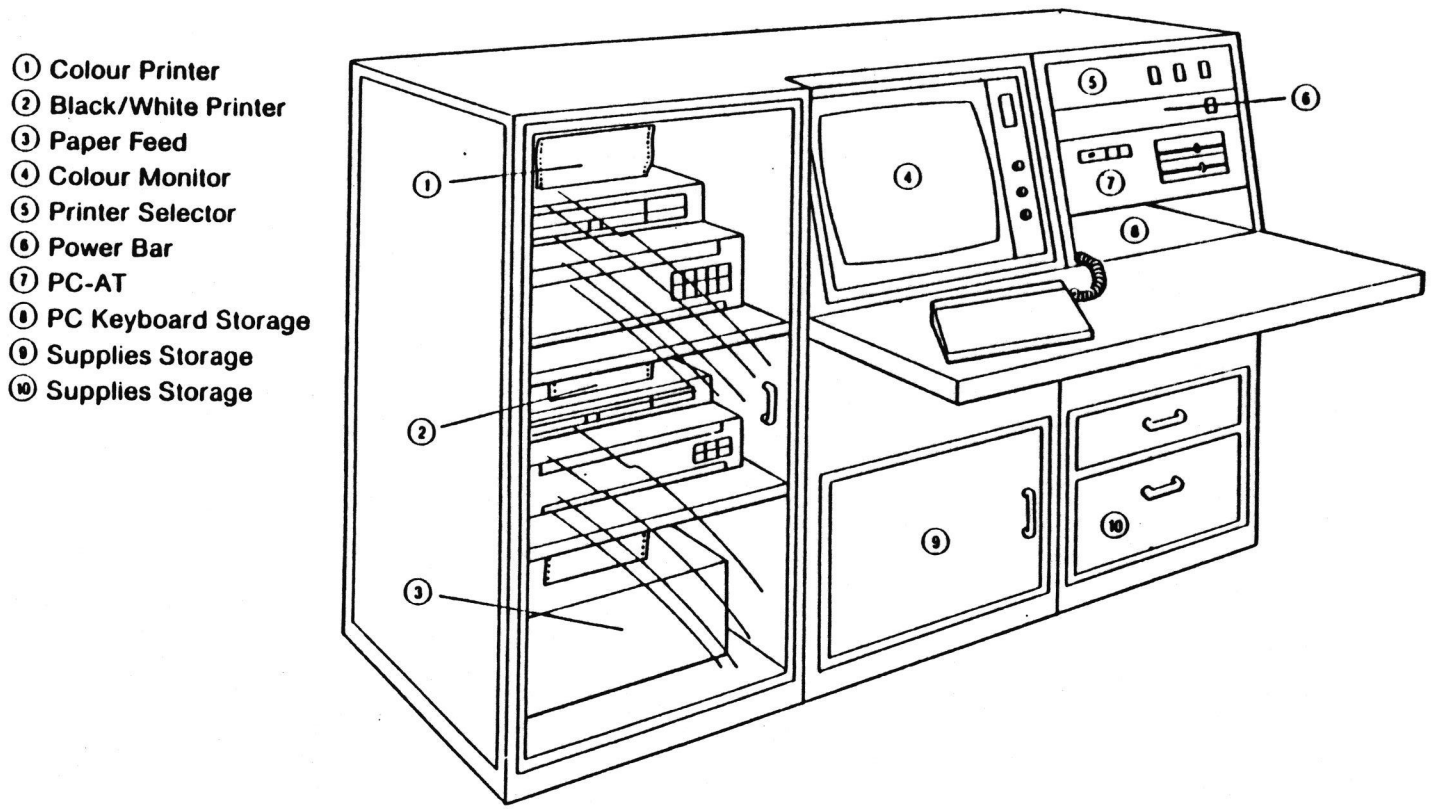

Figure 22. The HPI Data Reduction Console.

AUTOMATIC ROAD ANALIZER®

MOBILE

DATA ACQUISITION

VEHICLE

SUBSYSTEMS

HIGHWAY PRODUCTS INTERNATIONAL INC.

AUTOMATIC ROAD ANALYZER - ARAN®

The ARAN® design is firmly based on almost two decades of practical experience in the highway construction and maintenance fields. Backed, as well, by some eight years of intense development and testing, the ARAN® is soundly engineered to provide pavement engineers with state-of-the-art tools to do a first-rate job.

The ARAN® is a MOBILE DATA ACQUISITION VEHICLE capable of collecting and recording large quantities of roadway data quickly and economically. Truly unique in its wide ranging capabilities, ARAN® applications include both network inventory and project pre-engineering analysis.

It is the purpose of this booklet to introduce the ARAN® , its subsystems and unique functions and to indicate how they can help you achieve maximum results from your pavement expenditures. Further details are published in engineering technical papers and product brochures some of which are referenced.

We look forward to the opportunity to discuss with you how the ARAN® can fit into your pavement management activities.

Matching ARAN® to customer needs

	Traffic & Planning	Highway Needs	Constr.	Mtce.	ARAN Subsystem(s)
Horizontal curve length	✔				DMI, Directional Gyro
Deflection Angle/degree of curve	✔				Directional Gyro
Log mile curve location	✔				DMI
Vertical curve length	✔				DMI & Gyros
Beginning and end grades	✔				DMI & Gyros
Length of tangent sections	✔				DMI & Gyros
Grade of tangent sections	✔				DMI & Gyros
Log mile locations	✔				DMI
Pavement Roughness PSR	✔	✔	✔	✔	Axle Response/Long Profile Roughness
Surface Condition		✔		✔	Cond. Rtng.Videologging w/s Cond. Rtng.
Posted speed limit		✔			Right-of-way Videologging
Pavement condition		✔			Cond. Rtng.Videologging w/s Cond. Rtng.
Railroad crossings data 5 categories		✔			Right-of-way Videologging
Number of lanes		✔		✔	Right-of-way Videologging
Median type		✔			Right-of-way Videologging
Number of signalized intersections		✔			Right-of-way Videologging
Type of signalization		✔			Right-of-way Videologging
Prevailing type of area: residential, industrial, etc.		✔			Right-of-way Videologging
Surface type		✔		✔	Right-of-way Videologging
Shoulder type		✔		✔	Right-of-way Videologging
Number of structures (present)		✔			Right-of-way Videologging
Joint Faulting measurement			✔		Longitudinal Profile Roughness
Location of spalled joints requiring full depth patching			✔		Condition Rating Videologging
Location of minor spalled joints requiring partial depth patching			✔		Condition Rating Videologging
Location and size of pavement failures between joints requiring full depth patching of a full panel or partial panel			✔		Condition Rating Videologging
Rutting measurements			✔		Ultrasonic Rut Bar
Hot mix quantities to level and correct cross slope			✔		Ultrasonic Rut Bar & Gyros
Hot mix quantities to fill ruts			✔		Ultrasonic Rut Bar
Drainage condition				✔	ROW Videologging w/s Cond. Rating
Signs: condition, obscured				✔	Right-of-way Videologging
Sight clearance on horizontal curves				✔	ROW video and Directional Gyro
Bridge Decks: condition				✔	Condition Rating Videologging
Striping: condition				✔	Right-of-way Videologging
Bridge guardrail: condition				✔	Right-of-way Videologging
Cleanliness: litter, trash, debris				✔	Right-of-way Videologging
Vegetation: tree encroachment, undergrowth				✔	Right-of-way Videologging
Crash alternators: condition				✔	Right-of-way Videologging
Vertical curve line of sight				✔	Grade Gyro, Ultrasonics and S/W

Table 1. Matching ARAN to the customers needs.

ARAN· DIVERSIFIED APPLICATIONS

TYPE OF SURVEY	LEVEL OF ACTIVITY	
	NETWORK	PROJECT
• Roughness	+	
• Longitudinal Profile	+	
• Surface Distress	+	
• Rut Depth	+	+
• Grade	+	+
• Crossfall	+	+
• Transverse Profile	+	+
• Curve Radius	+	+
• Right-of-way Videologging	+	
• Pavement Condition Rating Videologging	+	
• Shim Quantities		+
• Mapping	+	

Table 2. ARAN's diversified applications.

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Figure 23. Two different styles of vehicles.

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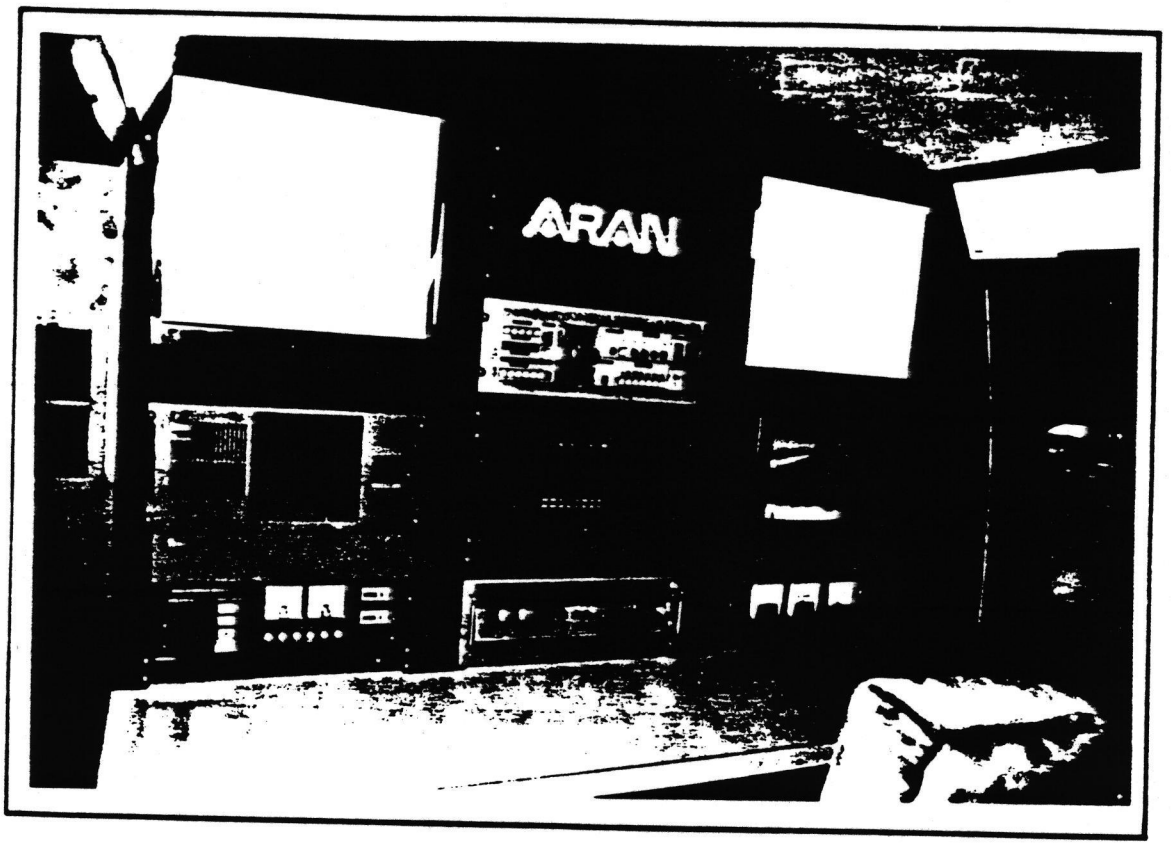

Figure 24. Interior views of equipment installed in the vehicle.

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ARAN

SUBSYSTEMS

- THEIR UNIQUE **FEATURES**
- HOW THEY **FUNCTION**
- THEIR **BENEFIT** TO YOU THE USER

FEATURE	FUNCTION	BENEFIT
• Axle-mounted time-stable Aerospace piezoresistive accelerometer sensor.	• Measures vertical accelerations of axle representing average roughness of two wheelpaths.	• RMSVA and MAS provided in real time. • Measurements repeatable over long time periods. • Accurate simulation of user roughness perception.
• Body-mounted time-stable aerospace piezoresistive accelerometer sensor.	• Measures vertical body accelerations which are stored in retrievable raw data form.	• Enables post collection calculation of longitudinal profile, Average Rectified Slope, Average Rectified Velocity and International Roughness Index.
• Snap-out accelerometer module.	• Variable orientation of accelerometer provides gravity-based total system calibration in minutes.	• Ensures system is functioning properly without frequent and extended calibration test runs.
• Digital computer with spatial filtering	• Filters out wavelengths of less than 1 foot and greater than 300 feet.	• Facilitates wide speed range of operation with consistent roughness wavelength sensitivity.

Table 3. Ride/Profile subsystem.

TRANSVERSE PROFILE SUBSYSTEM

FEATURE	FUNCTION	BENEFIT
• Front bumper-mounted ultrasonic bar.	• Up to 13 environmental sensors measure pavement surface profile of 6 to 12 feet lane width including wheel-track ruts.	• Identifies and quantifies pavement surface distortions including ruts. • Provides input for shim quantity calculations for rehabilitation projects.
• Ultrasonic bar fold-up wing extensions.	• Extend main bar by 2 to 6 feet in length.	• Provide flexibility of operation. • Provide easy bar length reduction for safe transit between job sites.
• Ultrasonic bar calibrating sensor.	• Monitors ultrasonic measurement sensitivity to temperature and humidity.	• Provides empirical basis to correct measurements for air density variations continuously and automatically.
• All-weather neoprene snap-on rubber sensor covers.	• Protect sensors from moisture and dust during transit. • Enables quick conversion to operational system status.	• Minimizes maintenance costs due to extended sensor life. • Saves time in preparing system for operation on site.

Table 4. Transverse profile subsystem.

ATTITUDE SENSING SUBSYSTEM

FEATURE	FUNCTION	BENEFIT
• Pitch and roll gyroscope.	• Measures pavement longitudinal grade and crossfall.	• Provides detailed measured inventory of grade and crossfall parameters. • Provides input along with ultrasonic bar profile data to calculate shim quantities for rehabilitation projects. • Enables longitudinal profile mapping of hills etc. that influence sight distance pavement marking.
• Precision directional gyroscope.	• Measures actual directional heading from 0 to 360° while negotiating roadway curves at traffic speed unaffected by lateral forces.	• Provides input for calculation of curve radii from 50 feet to 6 miles. • Facilitates **in-motion** management of grade and crossfall gyroscope during curve radius measurement (patent pending).

Table 5. Attitude sensing subsystem.

DISTANCE MEASURING SUBSYSTEM

FEATURE	FUNCTION	BENEFIT
• Transmission-driven distance measuring instrument.	• Measures average distance travelled by both rear wheels to .001 mile resolution by dividing wheel circumference into 1200 segments.	• Facilitates data referencing on a station-to-station basis for display and analysis.
• High resolution optical shaft encoder.	• Produces a pulsed signal that can be corelated with a known distance.	• Provides convenient and quick calibration for accuracy to compensate for tire wear.
• Custom on-board DMI control software.	• Produces accurate distance measurements in increasing or decreasing direction.	• Enables measurements to be made in opposing lane directions while maintaining common chainage reference for both lanes.
• Custom on-board calibration software.	• Single pass over a measured distance provides exact number of pulses per mile or kilometer.	• Provides simple, quick and accurate calibration check.

Table 6. Distance measuring subsystem.

FEATURE	FUNCTION	BENEFIT
• Pair of plug-in condition rating keyboards.	• Using special key matrix, surface distress data is entered onto magnetic recording medium while in motion.	• Surface distress data collection is automated and expedited with greatly reduced labour costs. • 100% of network can be surveyed at lower cost than limited sampling programs done manually on foot.
• Special event keys on condition rating keyboards.	• Data relative to landmarks and roadside appurtenances in 8 categories is entered onto magnetic recording medium adjacent to quantitative data.	• Provides precise location of railway crossings, bridges, overpasses, etc. for reference in editing and data analysis.
• Back-lit liquid crystal display on each condition rating keyboard.	• Displays most recent data entered by operator.	• Confirms data is being recorded as entered by operator.

Table 7. Condition rating subsystem.

FEATURE	FUNCTION	BENEFIT
• Main control keyboard.	• Permits entry of roadway section header data and controls all subsystems using special keypad and special function control keys.	• Facilitates systems start-up and in-motion control and updating of header data for continuous operation. • Keypad improves utility and durability versus conventional thumbwheel switches and general keyboard design.
• Back-lit liquid crystal display with viewer angle adjustment on main control keyboard.	• Displays header data identifying section being tested as data is being recorded.	• Assures operator that proper header information is used. • Enables operator to update header data for next section for instantaneous entry when entering next roadway section without stopping.
• CRT data display monitor.	• Displays series of operating menus and "prompt" instructions to help operator set up subsystem operation as well as selected diagnostic functions. • Displays data for all systems in operation as it is being collected.	• Simplifies the operating procedures and speeds up preparation for data collection mode. • Enables operator to monitor data continuously to ensure systems continue to function properly at all times.
• Time Drive software on-board.	• Provides simulated DMI output while vehicle is not in motion.	• Enables subsystem diagnostic and calibration procedures in a stationary mode.

Table 8. Operator main controls subsystem.

DATA RECORDING AND TRANSFER SUBSYSTEM

FEATURE	FUNCTION	BENEFIT
• On-board data storage	• Enables data to be recorded and stored on machine-readable floppy disks for automated transfer to home base engineering workstation data bank.	• Considerable reduction in manpower required to collect and transfer data. • Expedites availability of displayed data for analysis and post-collection use.
• On-board data verification software.	• Computer checks data files. • Computer checks detail in data files.	• Provides in-field check of data including detail level to confirm it was collected properly.

Table 9. Data recording and transfer subsystem.

ON-BOARD MICROCOMPUTER SUBSYSTEM

FEATURE	FUNCTION	BENEFIT
• Ruggedized Industrial IBM PC-AT	• Construction resists vibration, shock and temperature variations experienced in harsh operating environment.	• Minimized maintenance and down-time costs.
• High-speed sensor signal processing.	• Sophisticated digital filtering, data compression and processing are done simultaneously on all subsystems.	• Reduces data collection costs since all subsystems can be operated on a single pass of the ARAN®.
• Large mass storage capacity.	• Large quantities of raw data can be collected utilizing all subsystems simultaneously.	• Provides a comprehensive data base for home base processing using flexible software and upgraded analysis techniques.
• Wide variety of mass storage medium.	• User can specify mass storage medium to accommodate existing home base facilities.	• Reduces cost of integration with existing home base operations.
• Remote microcomputers.	• Selected subsystems have built-in microcomputers for subsystem control and data acquisition.	• Off-loads processing power of main computer freeing capacity for simultaneous operation of all subsystem sensors.

Table 10. On-board microcomputer subsystem.

ON-BOARD SOFTWARE SUBSYSTEM

FEATURE	FUNCTION	BENEFIT
• Speed compensating software provided on-board.	• Provides compensation for variations from reference speed during data collection functions.	• Allows driver to float with varying traffic speeds, minimizing need for restarts due to traffic slowdowns and backups.
• Diagnostic software provided on-board for specific subsystems.	• Permits operator to simulate data collection mode to verify that a specific subsystem is functioning properly.	• Speeds up trouble shooting for source of apparent malfunction.
• Calibration software provided on-board for specific subsystems.	• Enables ARAN* major systems checks for operational status.	• Enables operator to do "before" and "after" calibration checks to ensure all data collected is good before leaving jobsite.

Table 11. On-board software subsystem.

FEATURE	FUNCTION	BENEFIT
• Rear van interior working area including spacious desk top area, drawer space, good lighting, airconditioning and swivel chair.	• Operator can perform data checks editing, video verification etc. in comfortable work space.	• Field verification ensures all data is useable before returning to home base. If reruns are necessary they can be done on the same trip, saving costs of returning to field.

Table 12. Field office subsystem.

FEATURE	FUNCTION	BENEFITS
• High resolution industrial video camera and recorder equipment.	• Produces continuous through-the-windshield industrial quality video recording of the total roadway including roadside appurtenances.	• Enables agency personnel to play back video tapes in home base engineering work station without taking the time to physically drive the roads. • Provides visual documentation of roadway conditions to support rehabilitation budget needs to management for approval. • Provides documented evidence in defence of accident litigation.
• High resolution pavement camera mounted at top rear and aimed at pavement surface.	• Produces sharp, clear continuous view of one full lane width of pavement surface while travelling at highway speeds.	• Enables playback on unit with noise-free search with still capabilities to facilitate detailed study for surface condition rating purposes.
• Machine-readable video tapes.	• Road section header data is cross referenced on audio track of video tape.	• Permits high speed search on playback and enables software synchronizing of video and digital records by location.
• See-through header information superimposed on video frames.	• Header data can be displayed continuously identifying each location by chainage on video record. (Can be de-selected for unobstructed view).	• Identifies each location by road number, direction, chainage etc. for playback location referencing.
• High resolution video monitor on-board.	• Displays video pictures (as recorded) in rear van work area. • Enables remote monitoring of cameras.	• Enables operator to set up cameras and monitor quality of video recording during system operation.
• VTR computer control card	• Automatically starts and stops VTR equipment.	• Reduces routine operating work load of crew.

Table 13. Pavement condition rating videologging subsystem.

FEATURE	FUNCTION	BENEFIT
• High resolution industrial video camera and recorder equipment.	• Produces through-the windshield-industrial quality video recording of the total roadway including roadside appurtenances at highway speeds.	• Enables agency personnel to play back video tapes in home base engineering work station without taking the time to physically drive the roads. • Provides visual documentation of roadway conditions to support rehabilitation budget needs to management for approval. • Provides documented evidence in defence of accident litigation.
• Machine-readable video tapes.	• Road section header data is cross referenced on audio track of video tape.	• Permits high speed search on playback and enables software synchronizing of video and digital records by location.
• See-through header information superimposed on video frames.	• Header data can be displayed continuously identifying each location by chainage on video record. (can be de-selected for unobstructed view)	• Identifies each location by road number, direction, chainage etc. for playback location referencing.
• High resolution video monitor on-board.	• Displays video pictures (as recorded) in rear van work area. • Enables remote monitoring of camera.	• Enables operator to set up camera and monitor quality of video recording during system operating.
• VTR computer control card.	• Automatically starts and stops VTR equipment.	• Reduces routine operating work load of crew.

Table 14. Right-of-way videologging subsystem.

FEATURE	FUNCTION	BENEFIT
• Video processing / training centre.	• Facilities monitoring and automated control of video records to enable condition surveys to be conducted using condition rating keyboards. • Facilitates training of personnel to perform surface distress evaluation.	• Condition surveys can be done more leisurely and therefore more thoroughly. • Reduced cost of training versus on-the-road manual surveys. • Provides expansion facilities for automatic digitizing and pattern recognition analysis.
• Data reduction console.	• Facilitates transfer of data from field magnetic medium to fixed disk of PC, editing and displaying data in tabular and colour graphic formats, and producing summary reports.	• Automates data transfer process saving labour and expediting report availability. • Colour graphics reduce analysis time by using colour thresholds to highlight unacceptable pavement conditions for various parameters.

Table 15. Home base workstation subsystem.

FEATURE	FUNCTION	BENEFIT
• Colour graphic data display software.	• Pavement parameters including Pavement Condition Rating (PCR), Pavement Servicability Index (PSI), ruts, grade, crossfall and curve radius are plotted in a continuous station by station format. Colour thresholds are used to differentiate between levels of acceptability with highly-visible red being unacceptable.	• Saves time in reviewing network status since unacceptable road sections are highlighted quickly as candidates for rehabilitation. Balance of data requires only monitoring in future years for progression toward unacceptable levels.
• Shim Quantity Calculation Software.	• Permits computer calculation of quantity of paving material required to fill ruts, correct other surface distortions and restore design crossfall.	• Permits quick calculation of paving material costs. • Saves high costs of manual pavement surveys. • Enables high-speed highways to be surveyed without traffic interruptions and lane closures.

Table 16. Data display tools subsystem.

COMPLEMENTARY PAVEMENT MANAGEMENT SOFTWARE SUBSYSTEM

FEATURE	FUNCTION	BENEFIT
• Complete software package covering all aspects of planning for pavement expenditures including network ranking, performance prediction, prioritization, works programming and budget level prediction.	• Programs are designed to be easily tailored to agency's unique policies, and practices including geo-political budget splits. • Colour graphic formats are utilized for data display and analysis as well as reporting functions.	• Provides user agency with load-and-go pavement management capability. • Provides an integrated system capability from data collection to processing, storage, recall and analysis use for both network and project rehabilitation predesign activities. • Provides user with a stand-alone PC-based in-house pavement management decision analysis facility.

Table 17. Pavement management software subsystem.

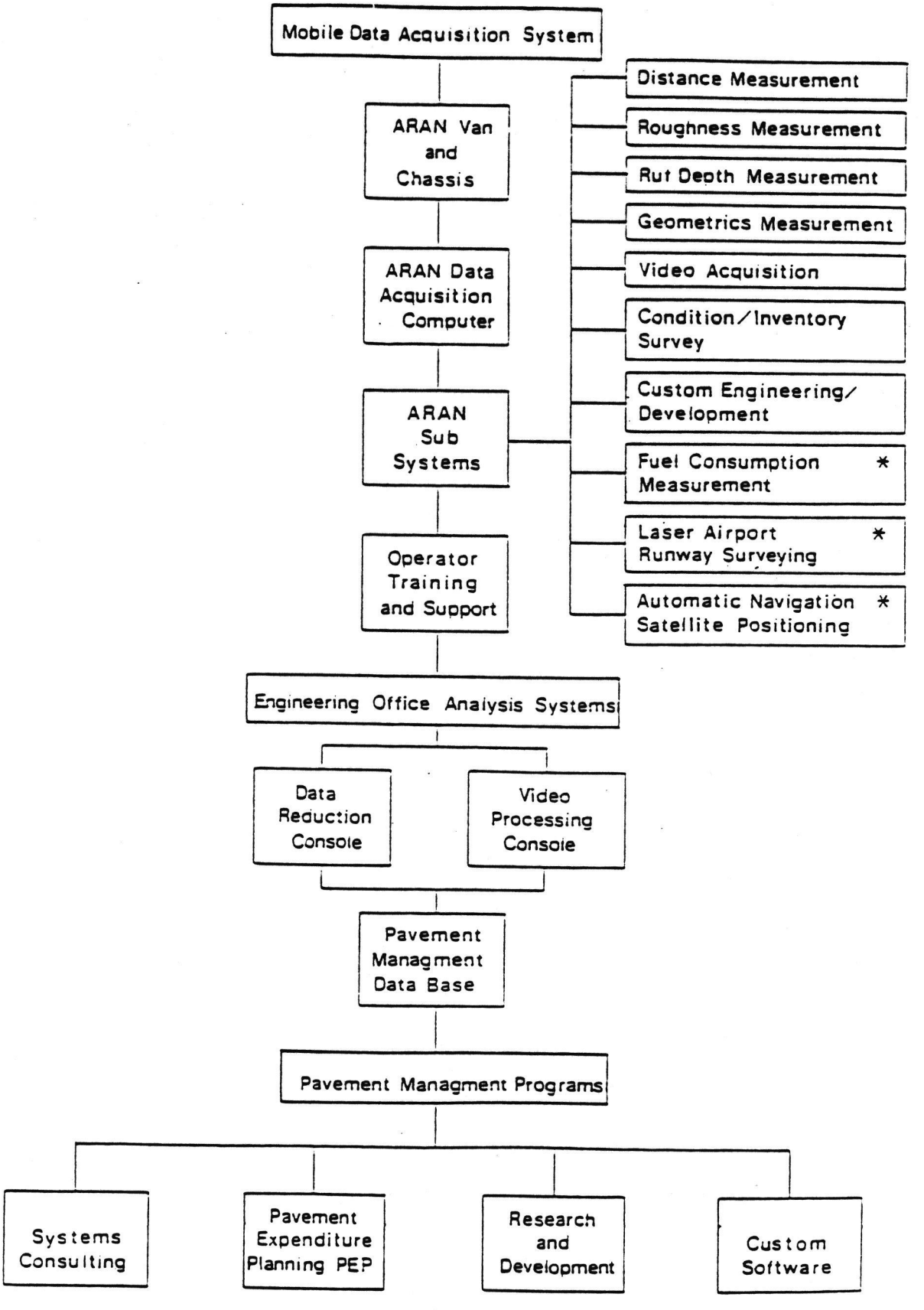

Figure 25. Data flow chart for ARAN System.

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HIGHWAY PRODUCTS INTERNATIONAL INC. ARAN$_R$ REFERENCES

COMPLETED ARAN$_R$ DELIVERIES

1) Autostrade S.p.A.
Mr. Gabriele Camomilla
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Telephone: 39-6-4977-4542
(Mr. Piercarlo Moretti will answer. He speaks English)

2) Tennessee Department of Transportation
Mr. Willard Newton
Suite 1000, James K. Polk Building
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Telephone: (615) 741-0977

3) State of New Hampshire
Public Works & Highways
Concord, New Hampshire, U.S.A.

Attn: Mr. Robert Lyford
Telephone: (603) 271-3344

4) New Jersey Department of Transportation
1035 Parkway Ave.
Trenton, New Jersey, U.S.A.

Attention : Mr. A. A. Jumikis
Telephone : (609) 292-3560

5) State of Texas
Dept. of Highways & Public Transp.
D-18 Pavements & Permits
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6) Ontario Ministry of Transportation
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9) Ministerie van Verkeer en Waterstaat
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2600 GA, Delft, Netherlands

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Telephone: 15-699319

10) Commonwealth of Massachusetts
Dept. of Public Works, Research & Materials
99 Worcester Street
Wellesley Hills, Massachusetts, 02818

Attn: Mr. Matt Turo
Telephone: (617) 727-4690

RIDING COMFORT INDEX
DETAILED INVENTORY REPORT

FOR 00000 Road: 0024 District: 0160

SECTION : 999999 : Inner Westbound Lane

Station	Interval Roughness	Riding Comfort Index RCI	Remarks
0+050	48.21	4.3	
0+100	13.22	7.7	
0+150	13.45	7.7	
0+200	30.92	5.4	
0+250	58.50	3.8	Catch Basin
0+300	54.96	3.9	
0+350	82.09	2.9	
0+400	71.11	3.2	
0+450	47.83	4.3	Service Cut
0+500	82.36	2.8	
0+550	17.64	6.9	
0+600	36.90	5.0	
0+650	57.58	3.8	
0+700	12.60	7.8	
0+750	4.17	10.0	
0+800	7.87	9.1	Service Cut
0+850	74.64	3.1	
0+900	68.72	3.3	
0+950	71.84	3.2	M.H.Cracking
1+000	17.87	6.9	
1+050	76.40	3.0	
1+100	32.59	5.3	
1+150	85.13	2.7	
1+200	87.12	2.6	
1+250	87.64	2.7	
1+300	6.37	9.7	Catch Basin
1+350	19.10	6.7	
1+400	59.40	3.7	
1+450	41.43	4.7	
1+500	8.46	8.9	
1+550	45.11	4.5	
1+600	70.82	3.2	
1+650	66.57	3.4	Service Cut
1+700	96.91	2.4	
1+750	13.24	7.7	
1+800	28.82	5.6	
1+850	65.27	3.4	
1+900	88.72	2.6	
1+950	55.11	3.9	M.H. Sinkage
2+000	50.20	4.2	
2+050	53.48	4.0	
2+100	25.19	6.0	
2+150	51.18	4.1	
2+200	66.59	3.4	
2+250	91.35	2.5	

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RIDING COMFORT INDEX
DETAILED INVENTORY REPORT

FOR 00000 Road: 0024 District: 0160

SECTION : 999999 : Inner Westbound Lane

Station	Interval Roughness	Riding Comfort Index RCI	Remarks
2+300	89.19	2.6	
2+350	96.84	2.3	
2+400	42.96	4.5	
2+450	94.59	2.4	
2+500	63.83	3.5	
2+550	58.21	3.8	
2+600	23.22	6.2	
2+650	63.35	3.5	
2+700	29.95	5.5	
2+750	79.95	2.9	
2+800	49.82	4.2	
2+850	56.32	3.8	
Mean :	52.51	4.6	
Standard Deviation:	27.22	2.0	
Minimum RCI :		2.3	
Maximum RCI :		10.0	

Survey Date : Sept 01 1984 Weather : Sunny & Clear
No. Of Tests : 57 Interval : 50 m Length Of Lane : 2850 m

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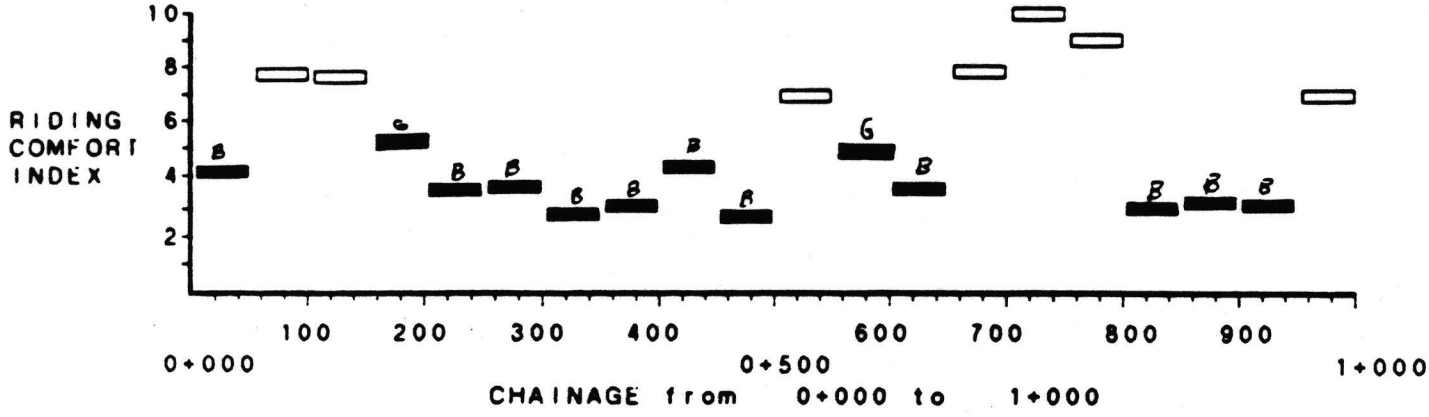
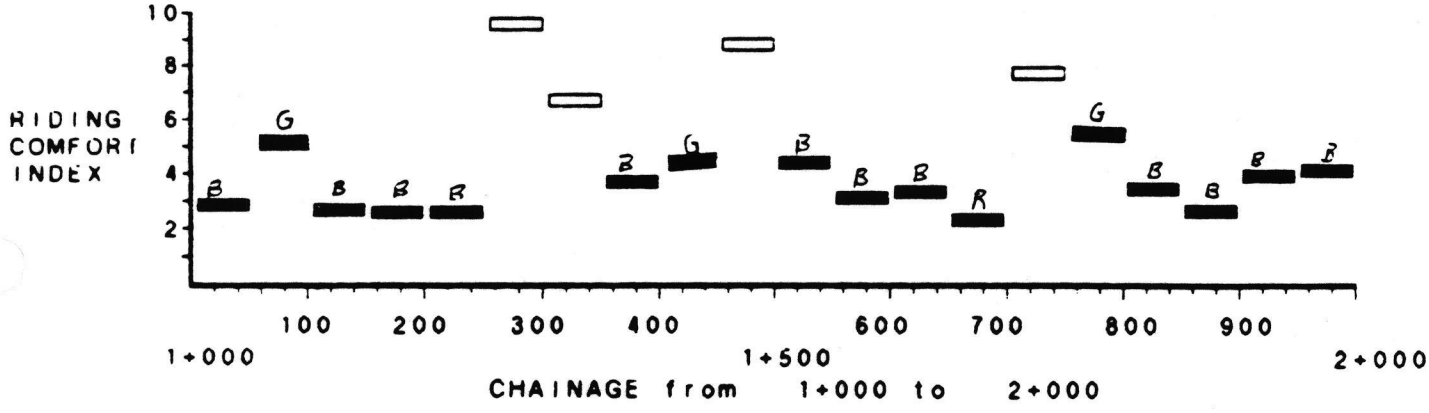
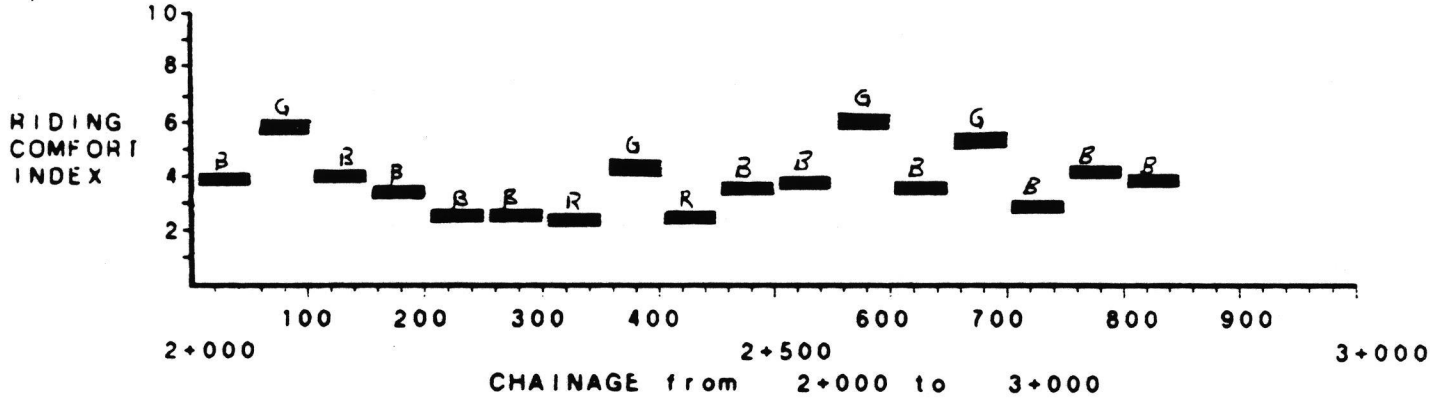
FOR 00000 Road: 0024 District: 0160

SECTION : 999999 : Inner Westbound Lane







SECTION SUMMARY

Mean RCI : 4.6
Std.Deviation: 2.0

Minimum RCI : 2.3 At 2+350
Maximum RCI : 10.0 At 0+750

Survey Date : Sept 01 1984
No. Of Tests : 57 Interval : 50 m

Weather : Sunny & Clear
Length Of Lane : 2850 m

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SURFACE DISTRESS INDEX
DETAILED INVENTORY REPORT

FOR 00000 Road: 0024 District: 0160

ECTION : 999999 : Inner Westbound Lane

STATION	RIP/ SHOV	RAV/ STRK	FLUS H/BL	DIST ORTN	EX C ROWN	EDGE CRAK	ALLI GATR	POT HOLE	MAP CRAK	LONG CRAK	RUTT ING	TRAN CRAK	SDI
0+050	1-3	0-5	0-2	0-5	1-3	1-3	0-2	2-5	1-4	0-4	0-3	1-4	3.3
0+100	2-1	0-5	0-2	1-1	1-1	2-4	0-3	2-4	1-5	2-1	2-1	0-1	5.2
0+150	0-1	2-2	0-5	0-1	0-3	0-1	1-1	1-5	0-4	0-3	2-3	1-2	5.2
0+200	1-5	2-4	1-4	0-2	0-3	2-4	2-4	1-2	1-4	1-1	1-3	0-4	4.0
0+250	2-1	2-5	0-2	1-2	1-2	2-4	2-3	1-1	1-2	1-3	2-4	1-2	3.9
0+300	2-2	2-3	2-5	0-3	1-3	2-5	2-5	1-1	1-1	1-1	2-2	0-1	4.3
0+350	1-4	2-1	2-1	0-3	2-3	2-2	2-3	1-2	2-2	2-3	0-4	1-4	4.4
0+400	1-1	0-3	0-3	1-4	1-1	1-3	1-3	0-4	0-5	2-2	0-5	2-5	3.9
0+450	1-5	0-3	1-2	2-4	2-2	1-1	1-5	0-4	2-1	2-4	1-5	0-5	3.0
0+500	1-3	2-3	2-3	2-1	1-1	1-2	0-2	2-4	2-2	1-3	2-4	1-2	4.4
0+550	2-4	0-1	2-2	0-1	2-4	2-5	2-5	0-1	2-2	0-5	1-2	1-4	5.1
0+600	1-3	2-3	2-2	2-3	0-4	2-1	2-3	2-3	0-2	1-4	2-3	2-2	3.4
0+650	1-5	0-4	0-5	1-3	1-4	0-4	2-3	0-3	1-1	2-1	2-3	2-5	3.8
0+700	1-1	0-4	0-3	0-5	2-1	1-5	0-3	0-3	0-5	2-5	1-2	2-5	3.8
0+750	0-4	1-2	0-5	1-1	2-2	1-3	2-4	2-5	0-3	2-3	0-5	2-4	3.4
0+800	2-2	1-5	2-2	1-3	0-5	1-5	1-5	2-3	0-1	0-2	0-1	2-5	3.5
0+850	2-1	1-1	2-3	1-4	0-2	0-3	0-3	1-3	1-3	2-5	0-3	2-1	4.8
0+900	1-5	1-2	2-4	1-1	1-1	2-5	1-5	2-3	2-5	0-4	0-1	2-4	4.6
0+950	0-1	1-5	1-4	0-2	1-5	0-3	2-4	2-1	2-5	1-2	0-5	1-1	3.8
1+000	1-2	2-5	2-4	1-4	1-1	2-5	2-5	2-4	2-5	0-1	1-2	0-5	2.8
1+050	1-4	2-5	2-3	2-5	1-1	2-5	2-5	0-4	2-5	0-4	2-3	2-3	2.1
1+100	2-1	0-5	2-5	2-3	1-3	2-5	2-5	2-5	2-5	2-4	2-2	2-4	1.9
1+150	0-4	2-4	0-4	2-4	0-5	2-5	2-5	2-3	1-3	1-2	1-1	0-4	3.0
1+200	1-3	0-2	1-2	1-2	0-3	2-2	0-2	1-1	0-2	1-2	2-3	2-5	5.1
1+250	0-3	1-4	0-4	1-3	2-1	0-1	1-5	0-2	0-4	2-5	1-5	0-2	3.6
1+300	0-2	0-5	2-5	1-1	1-1	1-3	1-3	2-3	0-2	2-5	0-4	2-5	4.0
1+350	2-4	2-4	2-1	0-3	0-1	0-2	2-3	1-1	1-3	1-4	0-4	0-3	4.7
1+400	2-5	2-3	0-2	0-5	2-2	0-5	1-2	0-5	2-5	0-4	2-1	2-2	3.6
1+450	0-3	1-4	1-1	0-2	0-3	2-4	2-4	0-1	2-5	2-3	2-3	0-1	4.6
1+500	0-5	1-1	0-5	2-5	2-1	1-2	1-4	0-2	1-5	2-3	1-3	1-3	4.2
1+550	0-5	1-5	0-3	1-2	0-3	1-1	1-2	0-1	2-4	0-2	2-2	1-3	4.9
1+600	0-3	1-5	0-2	2-1	2-2	2-4	0-4	0-5	2-3	2-2	2-5	2-1	3.2
1+650	0-4	2-1	1-4	0-3	0-1	2-3	0-3	1-1	1-1	2-1	0-2	2-3	6.1
1+700	0-4	0-3	2-2	2-1	1-2	2-1	1-2	2-3	0-4	0-1	1-2	0-1	5.5
1+750	0-2	0-3	1-2	0-3	1-2	0-1	1-2	0-2	0-1	2-1	2-2	0-5	5.3
1+800	2-3	2-3	0-4	1-2	0-4	2-4	2-2	1-1	0-3	2-1	0-5	0-5	4.3
1+850	2-2	0-5	1-4	0-4	0-5	0-4	2-4	2-3	2-4	0-1	2-3	0-5	3.2
1+900	1-5	2-2	1-4	1-3	1-4	1-2	0-5	2-4	0-5	2-1	0-3	0-2	3.7
1+950	0-5	1-2	0-3	2-5	1-1	0-2	2-3	0-4	0-4	2-1	0-3	2-3	4.1
2+000	2-4	0-2	2-2	2-4	1-1	0-1	0-1	0-3	2-4	0-2	2-1	2-1	6.0
2+050	1-1	2-4	2-4	2-2	1-1	2-1	1-1	2-5	0-3	2-2	2-4	1-3	3.9
2+100	0-1	2-2	2-3	0-1	1-2	0-5	2-5	2-2	1-2	2-3	1-5	1-3	3.8

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SURFACE DISTRESS INDEX
DETAILED INVENTORY REPORT

FOR 00000 Road: 0024 District: 0160

CTION : 999999 : Inner Westbound Lane

STATION	RIP/ SHOV	RAV/ STRK	FLUS H/BL	DIST ORTN	EX C ROWN	EDGE CRAK	ALLI GATR	POT HOLE	MAP CRAK	LONG CRAK	RUTT ING	TRAN CRAK	SDI
2+150	1-4	2-2	0-4	2-4	0-3	1-5	0-1	2-2	0-4	0-3	1-1	2-2	5.0
2+200	0-1	2-2	1-1	0-3	0-5	1-4	1-1	2-2	2-2	2-4	1-4	2-3	4.4
2+250	1-1	2-5	0-2	1-1	2-2	2-5	2-5	2-4	2-3	1-4	2-2	0-3	3.1
2+300	2-4	2-5	0-3	1-5	2-1	2-5	2-5	0-2	2-5	0-5	2-3	2-5	2.2
2+350	2-5	0-3	0-2	0-4	1-5	2-4	2-5	2-2	2-5	2-5	2-4	2-2	2.6
2+400	1-5	2-4	1-2	2-3	0-5	1-3	2-3	2-2	2-1	1-2	1-3	2-1	3.5
2+450	2-2	2-2	0-5	1-1	2-5	1-3	0-3	0-4	2-4	2-2	0-1	0-4	5.0
2+500	2-3	1-5	1-4	1-1	1-2	2-3	2-3	2-2	1-4	1-4	1-3	1-4	3.8
2+550	0-2	0-1	1-1	2-4	2-3	1-4	2-5	0-2	2-2	0-5	1-4	2-4	3.8
2+600	0-5	2-2	1-4	2-4	1-2	1-3	2-1	0-3	0-1	1-1	2-3	0-5	4.4
2+650	0-5	1-5	0-5	2-3	2-4	2-4	1-4	2-1	2-2	0-2	2-2	1-1	3.7
2+700	0-4	1-4	1-1	0-3	1-4	0-4	0-2	2-4	1-5	0-4	1-3	1-4	3.9
2+750	0-5	0-5	0-1	2-2	1-3	1-5	0-1	1-4	1-5	0-5	1-5	1-2	3.6
2+800	0-1	0-1	0-2	2-2	2-4	1-5	2-5	1-5	2-2	2-2	1-4	2-1	3.6
2+850	0-3	0-5	0-5	0-1	0-5	0-1	1-1	1-3	0-1	2-3	2-4	2-5	4.6

Survey Date : Sept 01 1984 Weather : Sunny & Clear
No. Of Tests : 57 Interval : 50 m Length Of Lane : 2850 m

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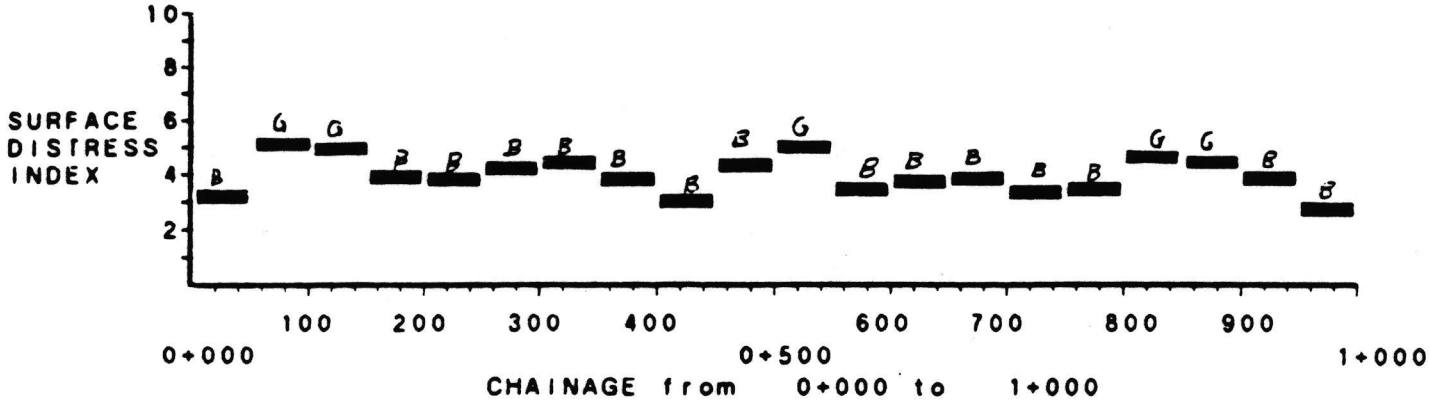
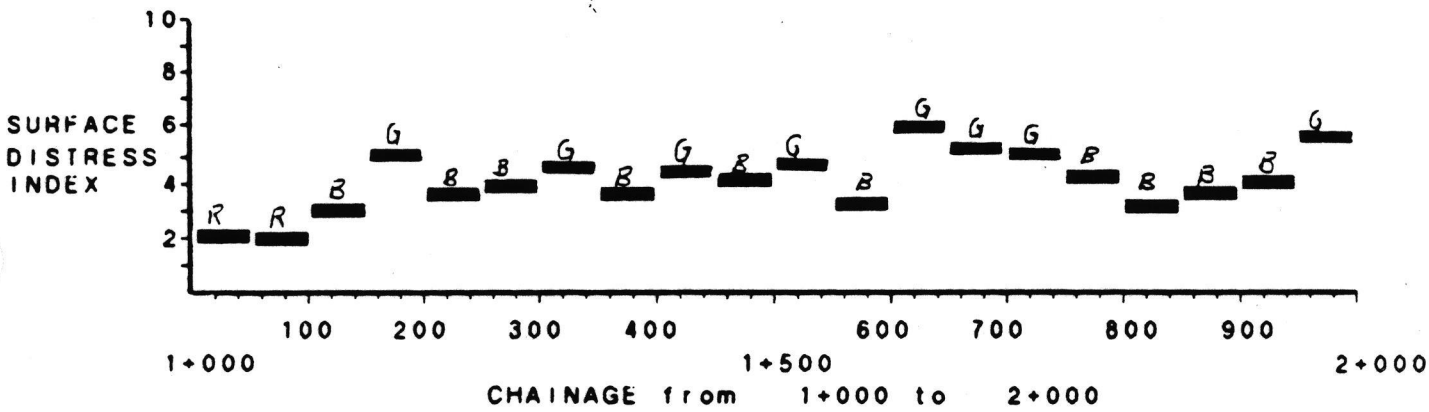
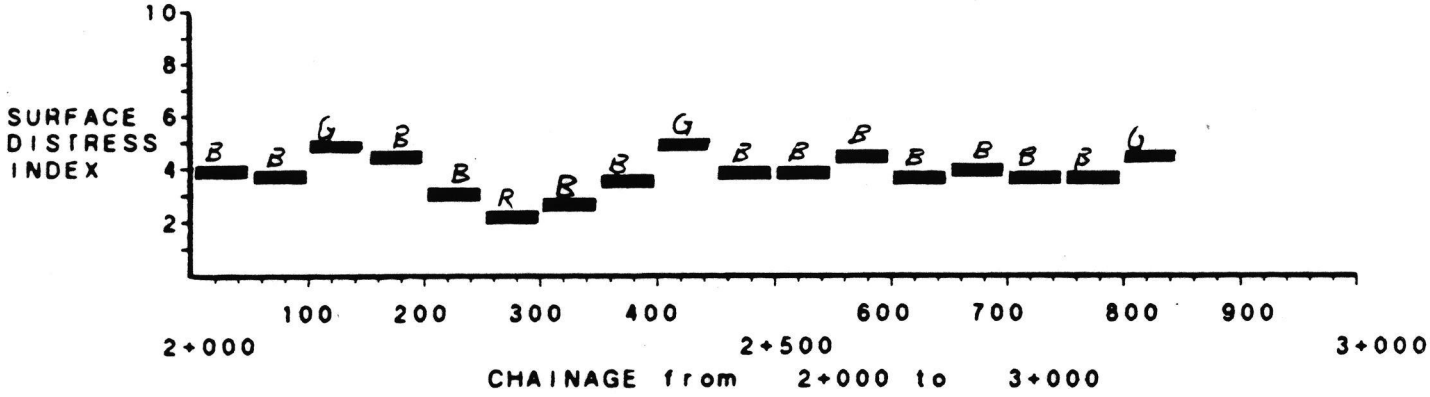
SURFACE DISTRESS INDEX
SECTION SUMMARY REPORT

FOR 00000 Road: 0024 District: 0160

ECTION : 999999 : Inner Westbound Lane







SECTION SUMMARY

Mean SDI	: 4.0		Minimum SDI	: 2	At 1+10
Std.Deviation	: 0.9		Maximum SDI	: 6	At 1+65

Survey Date	: Sept 01 1984	Weather	: Sunny & Clear
No. Of Tests	: 57 Interval : 50 m	Length Of Lane	: 2850 m

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RUT DEPTH ANALYSIS
DETAILED INVENTORY REPORT

FOR 00000 Road: 0024 District: 0160

SECTION: 999999 : Inner Westbound Lane

-- STATION --		------ RUT INFORMATION ------				--------- REMARKS ---------		
start	finish	No.	mean rut	%>12.5	%>25.0	ruts	curves	Xfall
0+020	0+200	10	41.0	40	0	Right	Straight	Slight
0+220	0+400	10	10.6	30	0	Right	Straight	Moderate
0+420	0+600	10	36.0	0	0	Right	Straight	Slight
0+620	0+800	10	12.4	40	0	Right	Straight	Moderate
0+820	1+000	10	11.0	40	0	Right	Left	Slight
1+020	1+200	10	21.0	50	0	Right	Left	Severe
1+220	1+400	10	12.1	50	0	Left	Right	Severe
1+420	1+600	10	45.0	40	0	Left	Right	Slight
1+620	1+800	10	11.0	50	0	Left	Right	Slight
1+820	2+000	10	9.8	20	0	Left	Right	Slight
2+020	2+200	10	25.0	60	0	Left	Right	Slight
2+220	2+400	10	19.0	50	0	Left	Right	Moderate
2+420	2+560	8	13.0	63	0	Left	Right	Severe

Survey Date : Sept 01 1984 Weather : Sunny & Clear
No. Of Tests : 128 Interval : 20 m Length Of Lane : 2560 m

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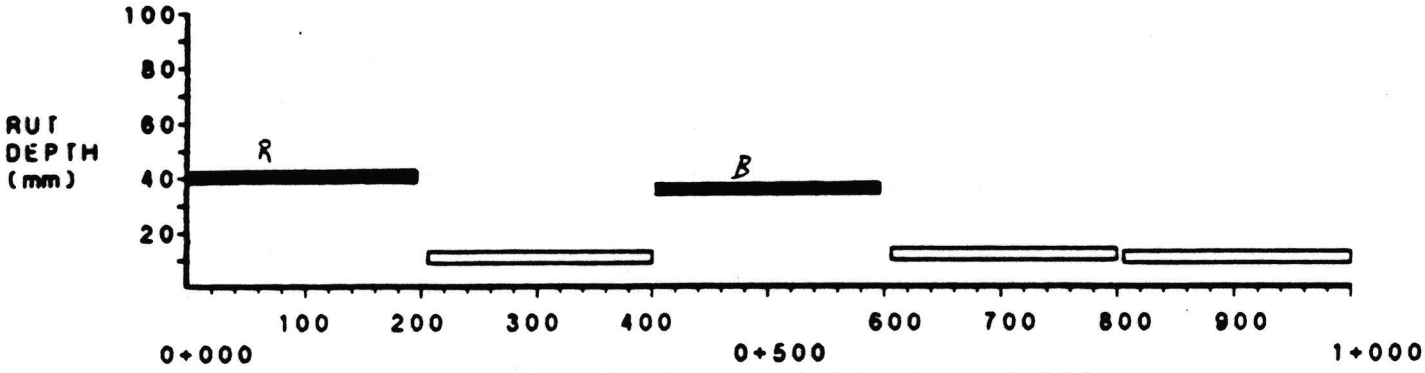
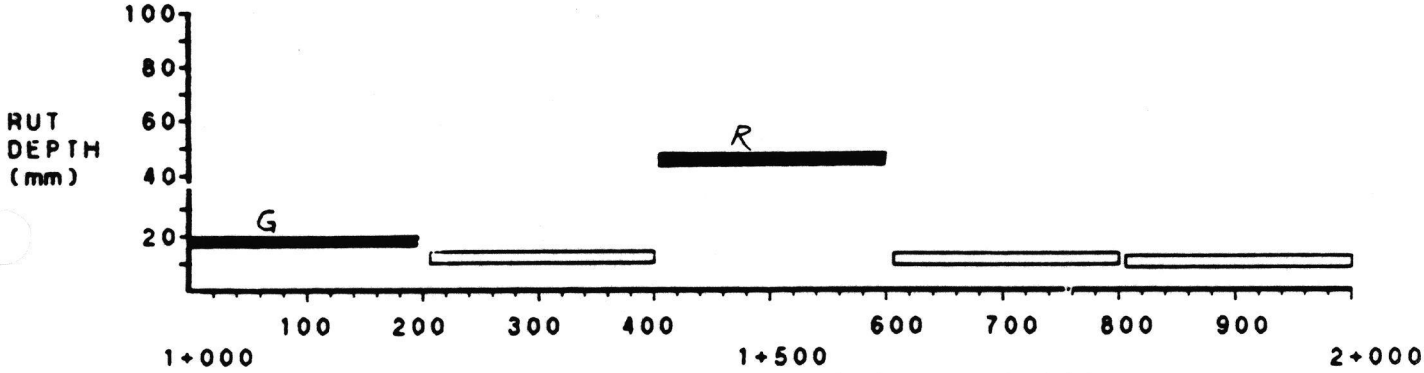
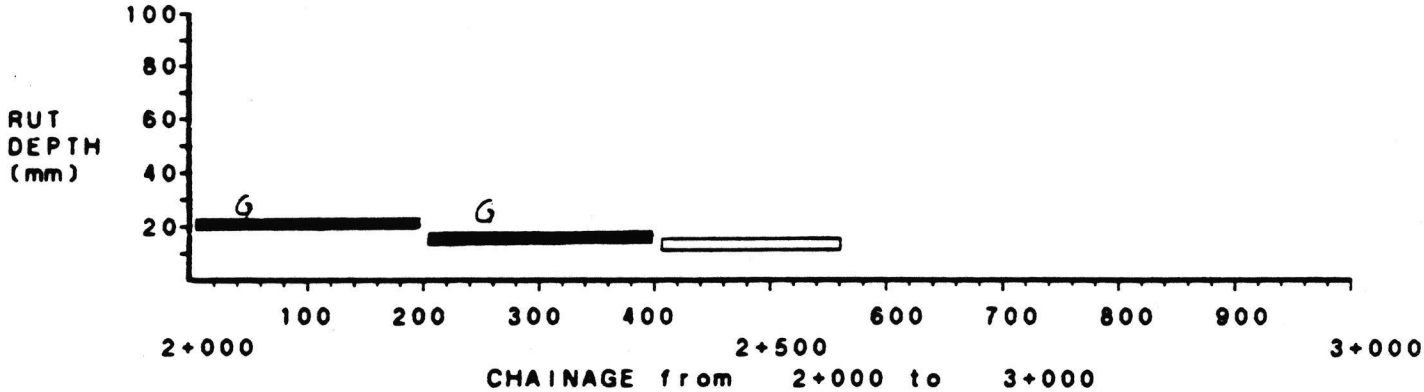
FOR 00000 Road: 0024 District: 0160

SECTION: 999999 : Inner Westbound Lane







SECTION SUMMARY

Mean	: 11.0	Minimum	: 9.8 At 1+820
Std.Deviation	: 1.4	Maximum	: 45.0 At 1+420

Survey Date : Sept 01 1984 Weather : Sunny & Clear
No. Of Tests : 128 Interval : 20 m Length Of Lane : 2560 m

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SITUATION DIAGRAM
PROBLEM EVALUATION

Section: 222222 Road: 4444 Inner Northbound Lane

SITUATION 1 - STATIONS 0.920 TO 0.980

OBSERVATIONS
- RIGHT RUT 1.1 TO 1.3" DEEP
- X-FALL IS HIGH DUE TO SUPER ELEVATION IN CURVE
- CURVE RADIUS 1345 TO 1592 FEET TO THE RIGHT

SAMPLE ANALYSIS BASED ON LOCAL EXPERIENCE AND POLICIES IT MIGHT BE CONCLUDED THAT THE SUPER ELEVATION WILL EFFECTIVELY DRAIN ANY WATER THAT WOULD OTHERWISE COLLECT IN 1.2" RUTS (AND FREEZE IN WINTER). THIS WOULD MINIMIZE THE SAFETY HAZZARD ON THE CURVE. THE LOCAL RUTTING CONDITION WOULD BE NOTED TO MONITOR FURTHER PROGRESSION OF ITS SEVERITY.

SITUATION 2 - STATIONS 0.680 TO 0.740

OBSERVATIONS
- RUTS IN BOTH WHEELPATHS FROM 1.2 TO 1.8" DEEP
- X-FALL IS LESS THAN 2% DESIGN
- GRADE IS APPROACHING 2%
- ROADWAY SECTION IS STRAIGHT

SAMPLE ANALYSIS AS IN SITUATION 1 THE RUTS WILL NOT POND AND FREEZE OVER DUE TO 2% GRADE WHICH WILL PROVIDE NATURAL DRAINAGE. REPAIRS MAY BE DELAYED IN FAVOUR OF MORE DEMANDING SITUATIONS.

SITUATION 3 - STATIONS 0.320 TO 0.380

OBSERVATIONS
- RUTS IN BOTH WHEELPATHS FROM 1.1 TO 2" DEEP
- X-FALL IS WELL BELOW 2% DESIGN
- GRADE IS FLAT
- ROADWAY CURVES SHARPLY TO RIGHT

SAMPLE ANALYSIS THIS SITUATION REPRESENTS A PONDING/FREEZING SAFETY HAZZARD SINCE THERE IS NO NATURAL DRAINAGE FOR THE RUTS. THE CURVE HAS NO SUPER ELEVATION AND THEREFORE, EVEN AT REDUCED SPEEDS, THE PROBABILITY OF "SKID-OUTS" IS HIGH. THIS SITUATION SHOULD BE A HIGH PRIORITY PROJECT FOR MAINTENANCE REHABILIATION.

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SITUATION DIAGRAM

Section:222222 Road: 4444 Inner Northbound Lane Report Date Jan 17 1986

Station	LeftRut	RightRut	Xfall	Shim-Q	Grade	CurveRad
.080	0.1	0.2	B 0.6	2.2	G 1.0	STR 0
1.060	G 0.3	0.2	B 0.5	1.8	G 1.2	STR 0
1.040	0.0	0.0	B 0.9	1.5	0.0	STR 0
1.020	G 0.5	G 0.5	B 1.3	G 4.6	G 1.8	STR 0
1.000	0.0	G 0.3	G 4.4	G 9.4	G 1.8	STR 0
0.980	G 0.3	R 1.2	R 7.8	B 14.7	-0.1	TRN 0
0.960	0.0	R 1.3	R 9.5	B 15.8	G 0.7	G -1592
0.940	0.0	R 1.1	R 9.4	B 16.8	G -0.6	G -1559
0.920	0.2	R 1.2	R 7.8	B 14.9	-0.1	G -1345
0.900	0.0	0.0	R 7.0	B 14.1	0.3	G -1345
0.880	G 0.3	0.1	R 5.4	B 11.0	0.1	G -1345
0.860	G 0.3	0.0	G 4.1	G 9.6	-0.3	STR 0
0.840	B 0.9	0.0	B 0.9	2.0	G -1.0	STR 0
0.820	0.1	G 0.3	B 0.8	1.4	G 0.6	STR 0
0.800	0.2	0.0	G 2.8	1.7	0.0	STR 0
0.780	G 0.4	0.0	B 1.8	1.1	0.3	STR 0
0.760	0.1	G 0.4	B 1.2	1.1	G 1.1	STR 0
0.740	R 1.3	G 0.4	B 1.7	1.4	G 1.8	STR 0
0.720	R 1.8	R 1.2	B 1.4	1.4	G 1.2	STR 0
0.700	R 1.8	R 1.5	B 1.4	1.4	G 1.3	STR 0
0.680	R 1.2	B 1.0	B 1.9	1.2	G 1.9	STR 0
0.660	B 1.0	0.0	B 1.7	0.8	G 1.8	STR 0
0.640	0.0	0.0	G 2.5	1.6	G 0.8	STR 0
0.620	0.1	G 0.3	G 3.2	1.3	G 0.9	STR 0
0.600	0.0	0.0	G 3.5	2.0	G 2.2	STR 0
0.580	0.2	G 0.4	G 2.1	1.2	G 0.6	STR 0
0.560	0.0	0.2	B 1.8	1.5	G -0.6	STR 0
0.540	0.0	0.0	G 3.1	1.6	G 1.1	STR 0
0.520	0.1	0.0	G 3.5	1.8	-0.3	STR 0
0.500	G 0.4	0.0	G 2.6	1.5	G 1.7	STR 0
0.480	0.2	0.0	G 3.6	1.9	-0.4	STR 0
0.460	0.0	0.0	G 4.7	2.8	G 0.7	STR 0
0.440	0.0	0.1	G 4.6	2.7	G 0.8	STR 0
0.420	0.0	G 0.4	G 3.4	1.8	G 1.3	STR 0
0.400	G 0.4	0.2	G 2.3	1.5	G 0.8	TRN 0
0.380	R 1.2	0.1	B 0.0	G 9.0	0.5	B -855
0.360	R 1.3	R 1.5	B 0.7	3.1	0.0	B -855
0.340	R 1.3	R 1.1	B 0.5	1.8	0.0	B -855
0.320	R 2.0	R 1.1	B 0.5	1.8	0.0	B -855
0.300	G 0.5	G 0.3	B 0.0	G 6.3	0.0	TRN 0
0.280	G 0.3	0.2	B 1.5	1.4	G 0.6	STR 0
0.260	0.0	0.0	G 2.4	1.6	G 1.3	STR 0
0.240	0.1	0.0	G 2.7	1.3	G 1.7	6807
0.220	0.0	0.0	G 3.0	1.7	G 2.1	6807
0.200	0.2	B 0.8	G 2.9	1.6	B 2.9	6807
0.180	0.0	B 0.6	G 2.1	1.3	G 2.5	6807
0.160	0.0	G 0.5	G 2.7	0.9	G 2.0	TRN 0
0.140	0.0	B 0.6	R 5.1	G 4.3	G 1.6	STR 0
0.120	0.0	G 0.3	G 4.5	2.9	G 1.2	STR 0
0.100	0.0	0.2	G 2.7	1.3	G 2.7	STR 0
0.080	0.0	0.2	G 2.2	0.2	B 6.3	STR 0
0.060	B 0.7	0.1	B 1.2	1.0	B 1.2	TRN 0
0.040	0.1	G 0.3	B 1.1	1.1	G 2.5	3981

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