ROAD PROFILE STUDY

FINAL REPORT

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ABSTRACT

Rough pavements are objectionable to the public and detrimental to the long term performance of the highway. In an effort to obtain smooth highways, states attempt to limit as built roughness. Roughness is measured with a variety of devices ranging in sophistication from relatively simple straightedges to complex electronic instruments. This report documents the evaluation of a moderately complex but non-electronic roughness measuring device; the Rainhart model profilograph.

The evaluation was accomplished by comparison testing the profilograph, the 10-foot rolling straightedge, and the Mays Ride Meter on several hot-mix asphalt concrete (HMAC) and portland cement concrete (PCC) pavements. In addition, the surface profiling ability of the profilograph was evaluated by testing it over an induced "artificial" road surface of known horizontal and vertical dimensions. Ease of transport operation and degree of maintenance was also considered.

The Rainhart profilograph graphical trace of the roadway surface profile was found to be repeatable and was found to be representative of the actual surface profile. The profilograph's digital roughness indicators were found to be unuseable. The measured graphical output correlated well with the 10-foot long rolling straightedge and Mays Ride Meter. The profilograph while not needing calibration, was found to have numerous operational and maintenance problems.

The results of this evaluation indicates that a profilograph type device can be a useable quality control and acceptance tool, especially suited for PCC pavements.

Recommendations are made to develop profilograph oriented specifications for use of this type of device for quality control and acceptance of PCC pavements.

METRIC CONVERSION FACTORS*

To Convert from	To	Multiply by
Length		
foot	meter (m)	0.3048
inch	millimeter (mm)	25.4
yard	meter (m)	0.9144
mile (statute)	kilometer (km)	1.609
Area		
square foot	square meter (m^2)	0.0929
square inch	square centimeter (cm^2)	6.451
square yard	square meter (m^2)	0.8361
Volume (Capacity)		
cubic foot	cubic meter (m^3)	0.02832
gallon (U.S. liquid)**	cubic meter (m^3)	0.003785
gallon (Can. liquid)**	cubic meter (m^3)	0.004546
ounce (U.S. liquid)	cubic centimeter (cm^3)	29.57
Mass		
ounce-mass (avdp)	gram (g)	28.35
pound-mass (avdp)	kilogram (kg)	0.4536
ton (metric)	kilogram (kg)	1000
ton (short, 2000 lbs)	kilogram (kg)	907.2
Mass per Volume		
pound-mass/cubic foot	kilogram/cubic meter (kg/m^3)	16.02
pound-mass/cubic yard	kilogram/cubic meter (kg/m^3)	0.5933
pound-mass/gallon (U.S.)**	kilogram/cubic meter (kg/m^3)	119.8
pound-mass/gallon (Can.)**	kilogram/cubic meter (kg/m^3)	99.78
Temperature		
deg Celsius (C)	kelvin (K)	$t_K=(t_C+273.15)$
deg Fahrenheit (F)	kelvin (K)	$t_K=(t_F+459.67)/1.8$
deg Fahrenheit (F)	deg Celsius (C)	$t_C=(t_F-32)/1.8$

*The reference source for information on SI units and more exact conversion factors is "Metric Practice Guide" ASTM E 380.

**One U.S. gallon equals 0.8327 Canadian gallon.

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INTRODUCTION

A rough pavement is uncomfortable to those occupying a vehicle as it travels the highway and in addition increases the cost of travel through increased fuel consumption and wear and tear on the vehicle. The motoring public judges the success of a new paving project, to a large extent, by the smoothness or ride quality of the roadway.

The ride quality of the roadway not only affects the motorists senses and pocketbook, but also affects the life of the pavement. According to the AASHTO design equasions a pavement built with a rough surface will have a shorter service life than that of the same pavement built with a smooth surface. A rough pavement is subject to increased detrimental stresses and strains by the action (impact loads) of vehicles "bouncing" across the pavement surface.

Louisiana specifies that pavements are to be constructed smooth by setting limits on allowable roughness. If a roadway is constructed and its degree of roughness is outside the specified limits then the contractor must take corrective actions. In some instances adjustments in the contracted unit price are also specified, as a disincentive mechanism.

All states want roads that are constructed smooth. To obtain smooth roads they used various devices to determine roughness during construction (quality control) and for project acceptance. Each state, based upon the degree of smoothness that they desire, specify limits of roughness suited for measurement by a particular device. Each type device "feels" and records roughness in a different manner. Therefore roughness data obtained in one state with one type of device is not necessarily useful to anyone outside that state. If all states measured roughness with the same device, use in the same manner, then many "universal" questions concerning how best to construct smooth roadways could possibly be answered. The rolling profilograph (such as the Rainhart model) has been suggested as a candidate for this universal device due to its graphical output format and purported accuracy and repeatability.

Louisiana currently uses the 10' rolling stredge to determine the degree of compliance to surface tolerance specifications. This equipment is relatively inexpensive and simple to operate and maintain, but requires frequent calibration. The straightedge roughness output is relatable to highway ride quality but does not measure the actual surface profile of the roadway.

The Rainhart profilograph is a more sophisticated roughness measuring device that the 10-foot rolling straightedge. The profilograph is purported to not need calibration and to produce a graphical trace which closely resembles the actual surface profile of the road, and of being more reflective of highway ride quality.

This study was undertaken to evaluate the overall usefulness of the Rainhart profilograph as a roughness measuring device.

OBJECTIVE

The objective of this study was to evaluate the Rainhart profilographs overall usefulness to the La. DOTD as a pavement roughness measuring device, as outlined by the following specific aims :

1. Ease of transport, maintenance and operation.

2. Repeatability of graphical and digital output.

3. Comparison of roughness measure to currently used (La. DOTD) measuring devices.

4. Surface profiling (mapping) ability.

5. Applicability of profilograph as a quality control and acceptance tool for new pavements.

SCOPE

This evaluation was accomplished through testing several newly constructed rigid and flexible paving projects with the Rainhart profilograph.

The general useability of the device was evaluated under field conditions during transport and project testing. Repeatability of the profilograph's digital and graphical outputs was determined by repeative testing of projects over various time periods and with using several operators. On each project tested with the profilograph, comparison testing was conducted with other roughness measuring devices currently in use by the La. DOTD. The data generated during comparison testing was evaluated in an effort to establish recommended roughness tolerances (profilograph) for possible use by the Department.

The ability of the graphical output of the profilograph to map the actual longitudinal surface profile of a roadway was investigated by testing on a surface with varied but known (induced) profile.

To add additional range to the degree of roughness encounted on new construction, several older projects were also tested.

METHOD OF PROCEDURE

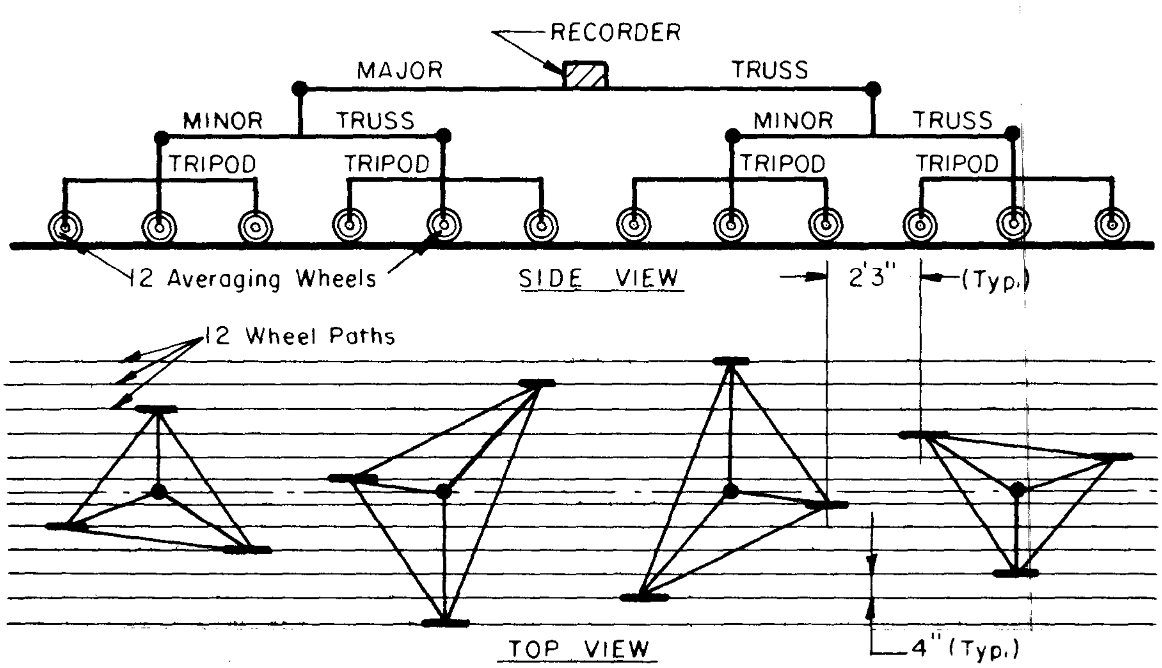
Equipment

The Rainhart Profilograph

The Rainhart profilograph is a 26 ft. long device composed of a major truss which is supported at each end by two minor trusses. The minor trusses are supported at each end by a tripod, each supported by 3 small wheels. The instrument that records roughness is centered on the device and is located at the top center of the main truss. The minor trusses are pinned to the main truss and the tripods are connected to the minor trusses with a ball and socket arrangement allowing partially independent movement of each major component of the device. The 12 small wheels that support the device are called averaging wheels, and each traverses a different path as the profilograph is pushed longitudinally along the roadway. Due to the geometrics of the profilograph, 1/12th of the vertical movement of an individual averaging wheel is transmitted mechanically to the center of the main truss where the recording instrument is located. A schematic diagram of the Rainhart profilograph is presented in Figure 1 on page 6 .

The roughness recording instrument is actuated mechanically during vertical distance changes between the recorder and a 5 ft. circumference recording wheel which rides on the pavement surface below the recorder. The recorder is a strip chart recorder which is also equipped with a digital longitudinal distance counter and two vertical roughness counters. As the 5 ft. recording wheel moves longitudinally and vertically along the pavement surface it mechanically drives the chart paper, pen carriage and counters.

The profilograph truss and averaging wheels are designed to provide a relatively consistant vertical frame of reference to the recorder



Schematic of the Rainhart Profilograph

FIGURE 1

band was used to discount small irregularities of the pavement surface, such as tining on concrete and the macrotexture of hot-mix, which do not contribute to a rough ride. This discounting of small surface irregularities is also a feature on one of the digital counters in that it discounts or "filters" the first 1/10 of an inch of movement of the measuring wheel, after it passes from a downstroke and starts an upstroke.

Rolling Straightedge

The 10-foot long rolling straightedge was used for comparison testing with the profilograph on the same projects and same testing paths. The La. DOTD specifies the rolling straightedge as its project quality control tool for both rigid and flexible pavements. The straightedge is also used to assess pay penalties and/or designate areas requiring corrective action.

The straightedge consists of a rigid metal beam (approximately 10 ft. long) that is supported at either end by two wheels. The wheel base is 10 ft. long. At the center of the beam is the roughness indicator. The roughness indicator, essentially consists of a scale wheel which is free to move vertically as it travels across the pavement, and a pointer/scale and miscroswitches that are activated by the movement of the scale wheel. As the straightedge is pulled along the pavement, vertical movement of the scale wheel in relation to the beam is indicated by the pointer. The scale and the microswitches can be set to activate a dye release mechanism at a pre-set degree of vertical movement. The microswitches and dye release mechanism, when activated spray a dye onto the pavement marking those areas outside the pre-set tolerance. These dye marks are measured and when divided by the total length tested, gives a roughness measurement that is expressed as the % of the tested length that exceeds the pre-set tolerance. Additional infomation as to the Department calibration and use of the rolling straightedge as well as pictures of the device may be found in the current addition of La. DOTD Testing Procedures Manual, Volume 2, designations TR 603-84 and TR 618-84.

One drawback to the rolling straightedge is that it requires frequent calibration. Another drawback is that it does not actually "map" or indicate the true surface profile. This is because 1/2 of the relative vertical movement of the front and/or the back wheels is transmitted to the roughness indicator. As an example, consider a straightedge being pulled along a planar surface which contains a 1 in. high bump. As the front wheels ride over this 1 in. bump, the indicator, located at the center of the beam, will rise 1/2 in. The device will react by indicating a 1/2 in. depression which does not actually exist located at the scale wheel.

The Mays Ride Meter

The Department uses the Mays Ride Meter to evaluate the roughness of existing pavements. The ride meter measures roughness response by recording the mechanical displacement created by the relative motion between the rear axle and frame of a test vehicle. This mechanical movement is converted into an electrical impulse through a photo-electric cell. The electrical signal is transmitted back into a mechanical movement which is recorded on graph paper. The Mays Ride Meter when installed in a passenger vehicle and operated at traffic velocities supplies a permanent graphical log of roughness summation. All roughness measurements are expressed in units of inches of roughness per mile. Additional information on the Departments calibration and use of the ride meter may be found in a report entitle "The Mays Ride Meter" preparted by the La. Department of Highways, Research and Development Section, Training Unit; 1975.

The ride meter was comparison tested with the profilograph and straightedge on each project.

Site Selection

Sites were selected, based upon availability, to provide a wide range of roughness. New construction did not provide the range of roughness needed, so some older, rougher, projects were included for testing. Both rigid and flexible projects were selected for testing, with an emphasis placed upon rigid pavements due to the semmingly shorter (less than 10 feet) wavelength of as built surface deviations usually encountered. The site selected for the testing of the profilograph mapping ability was chosen for its relative smoothness, its lack of traffic, and its closeness to the research facilities. Testing was accomplished by rolling the profilograph over boards of varied dimensions and spacing to simulate various degrees and types of roughness.

DISCUSSION OF RESULTS

Ease of Transport, Maintenance and Operation

The Rainhart profilograph is easily transported to the test site by trailering on its retractable trailer wheels. Due to its 26 ft. overall length some problems can be expected when towing in tight quarters. The length of the device may also be a problem when manually turning the instrument on roadways that are open to traffic. Caution must be used when turning the profilograph around to keep the end from extending into the lane adjoining the lane being tested.

Maintenance of the profilograph to date has been considerable. Under normal circumstances the only component that should require replacement is the recorder drive string, if it is broken, stretched or loosened. On two occasions, the rear tripod and wheel of the profilograph broke off while being towed to a test site. On one of these occasions the tripod was destroyed when run over by the vehicles following behind. This incident could have, but did not, cause a serious accident in the very heavy interstate traffic. Upon inspection, it was found that the bolt securing the tripod to the minor truss, had fatigued and broken, due to vibration while being towed. The tripod and averaging wheels were replaced by the manufacturer and a safety line is now used between the truss and tripod while the profilograph is being towed. Another maintenance problem that occurred often is that the steering wheel tended to slip on its shaft. This problem was solved by placing a pin through the steering wheels hub and the shaft.

Operating the profilograph has proved to be somewhat difficult. Because of its length and steering mechanism, the profilograph is not very easy to steer. It is difficult to hold a consistent line with the profilograph and it is necessary to make continual steering adjustments. The turning response time is very slow which makes oversteering a continuing problem. The steering is complicated by the relatively short walking space afforded the operator. The operator must take short strides to keep the back of their foot from being struck by the averaging wheel located approximately 3 ft. behind the steering wheel. Because of this, it is difficult for the operator to steer and help push at the same time, necessitating one or two other persons for efficient operation.

Another frequent and annoying problem encountered with the profilograph, involved the recorders chart paper feed and storage mechanisms. The sprockets, which pull the perforated chart paper past the recording pen, failed to release the paper causing it to become fouled between the stripper rod and sprocket. This problem persisted throughout the entire range of feed/tension adjustments and was not solved during this study. Other, less serious problems encountered were, tearing between chart paper perforations by the drive sprockets and failure of the recorder to fold the chart paper after release by the drive sprockets. The Rainhart profilograph utilizes a "Z - fold" chart paper which has a greater potential for feed problems than a rolled chart paper.

When compared to the rolling straightedge, the profilograph is harder to transport and handle during testing, but requires no calibration. If the persistent problems encountered with the recorder can be eliminated, the overall "ease" of maintaining and using the two devices could be considered comparable.

Since the profilograph and the Mays Ride Meter are two entirely different devices, no objective comparison was attempted with the respect to ease of transport, maintenance, etc.

Repeatibility

Selected projects were tested several times. To determine the repeatability of the profilograph roughness measuring system (graphical and digital). Repeat testing was conducted across time periods ranging from several minutes to several months, and using both single and multiple operators.

The graphical output was found to be very repeatable. When graphs of the same project and wheel paths were superimposed and laid on a light table, very little, if any difference between traces could be found. Variation in measuring the roughness (by the Georgia method, Appendix A) has been observed. Repeat measurements by an individual, or between individuals was observed to vary by as much as 3 or 4 inches of roughness per mile. This aspect of repeatability was not evaluated during this study. It is assumed that with practice and experience this variation can be reduced to acceptable levels. Different, less arbitrary methods of interpreting the graphical trace may also be developed. Because of this variation in measuring or interpreting the graphical output no statistical value could be assigned to the repeatability of the trace itself. Only visual observations could be made. Both of the digital roughness counters (1/10 in. filtered and unfiltered) were found to be very unrepeatable. Table 1 on page 15, presents the data obtained during repeatability testing of the profilographs digital counters, along with test section averages and ranges. The range in roughness data produced by the counters was found to be as much as 29.0 inches of roughness per 0.2 mile. The digital roughness counters were considered to be too variable for further use or evaluation during the remainder of this study. This variability is believed to be caused by design/mechanical problems in the counter system.

Other studies (1,2)* conducted in Louisiana found that both the 10 - foot rolling straightedge and Mays Ride Meter have repeatabilities on (on HMAC) within useable limits, if maintained, calibrated and operated properly.

Towards the end of this study the profilograph was taken to Arkansas and tested along with Arkansas' Rainhart profilograph, on one test

*Underlined numbers in parentheses refer to list of references.

TABLE 1

SUMMARY OF DIGITAL COUNTER DATA

SECTION NUMBER	DATE	OUTSIDE WHEEL PATH INCHES / 0.2 MILE		INSIDE WHEEL PATH INCHES / 0.2 MILE	
		FILTERED	UNFILTERED	FILTERED	UNFILTERED
01	04/26/83	18.3 19.5 20.4	51.7 61.0 65.0	15.3 16.6 17.3	45.4 51.4 53.7
	01/03/84	18.1 17.8	36.0 36.2	13.7 14.2	31.1 31.1
	AVERAGE RANGE	18.8 2.6	50.0 29.0	15.4 3.6	42.5 22.6
03	04/08/83	6.5 9.8 10.8	17.1 33.7 37.8	9.8 9.4	27.9 36.3
	04/19/83	10.9 11.8 12.3 14.0		11.7 13.7 14.9 14.0	
	04/25/83	11.6 12.0 13.7		12.9 13.0 13.4	
	08/23/83	5.5	16.1	6.1	16.2
	01/03/84	9.1 9.6	24.4 27.2	11.0 10.4	31.6 30.8
	AVERAGE RANGE	10.6 8.5	26.0 21.7	10.8 8.8	28.6 20.1
09	03/15/83	5.5 4.0 3.3 4.8 2.0	14.7 11.1 12.4 13.5 5.7	9.8 10.0 7.3 7.0 7.8	26.3 26.1 19.2 15.0 16.4
	AVERAGE RANGE	3.9 3.5	11.5 9.0	8.4 3.0	20.6 11.3
12	06/02/83	19.7 17.8 25.8	74.3 70.7 93.7	13.6 14.1 14.7	46.7 47.2 54.1
	AVERAGE RANGE	21.1 8.0	79.6 23.0	14.1 1.1	49.3 7.4
13	04/25/83	11.0 11.4 12.1	43.3 45.8 47.7	11.1 11.9 11.6	39.3 37.7 38.4
	AVERAGE RANGE	11.5 1.1	45.6 4.4	11.5 0.8	38.5 1.6

section. The traces obtained from the two profilographs, when overlaid on a light table, matched almost exactly.

Comparison of Roughness Measure :

A direct numeric relationship between the devices was not expected or achieved because the devices "feel" and measure roughness in different manners. The following is a summary of some of the major differences that affect the roughness measure of the straightedge and profilograph.

1. Wheel Base : The wheel base of the measuring device to some extent determines which wavelengths of roughness (bumps and/or depressions) the device can measure. All normal ranges of wheelbases should be able to measure short, choppy surface deviations above that which is considered macro-texture, but neither type device can measure a deviation whose wavelength exceeds its wheelbase.

The wheelbase of the straightedge is 10 feet. The wheelbase of the profilograph is unknown due to the varied spacing of its 12 averaging wheels.

2. Unit of Measure : The two devices measure different "quantities" of roughness. The straightedge measures the linear footage of tested surface which exceeds a pre-set tolerance level. The profilograph graphically records the vertical deviation and length of each individual bump or depression within the tested length. When the graphical trace is evaluated using the 1/10 in. filter band then the unit of measure is the cumulative vertical inches of deviation of each individual bump or depression that exceed the height of the filter band per mile of surface tested. For example, if both devices were run over a 100 foot long planar surface with two surface deviations, one of which is 1 in. high x 4 ft. long and the other is 1 in. high x 2 ft. long, the following would be measured : The

straightedge (pre-set to 1/8 in. tolerance) theoretically would indicate 4 + 2 feet out of 100 feet or 6 % of the tested surface exceeded the 1/8 in. tolerance. The profilograph, run over the same bumps would theoretically indicate that the 100 foot long test length had 1 and 8/10 inches (1 in. minus 1/10 in. + 1 in. minus 1/10 in.) of roughness.

3. Diameter of Measuring Wheels : The diameter of the wheel which activates the indicator or recorder affects the degree to which the device measures very small surface deviations. A large wheel will tend to "ride over" small depressions while a smaller wheel will tend to "fall in" and measure these same depressions. The measuring wheel of the profilograph is 19 inches in diameter, while the measuring (scale) wheel of the straightedge is 4 inches in diameter.

4. Geometrics : The geometry of the measuring devices has a great influence on the "quantity" of roughness measured. The degree to which the indicator or recorder is shielded from the vertical movement of the traveling wheels is reflected in its roughness measure. For example, when the leading traveling wheels of a 10 ft. rolling straightedge first encounter a 1/2 in. high bump, the pointer on the indicator, which is located 5 ft. behind the front wheels will register the beginning of a 1/4 in. non-existent depression located 5 ft. away from the bump. This is because a 1/2 in. vertical rise of the traveling wheel will cause a 1/4 in. vertical rise of the indicator, creating a false 1/4 in. differential between the recorder and scale wheel. The geometry of the profilograph reduces the tendency of this type of equipment to falsify the location of surface deviation. When the leading traveling (averaging) wheel of the profilograph first encounters the same 1/2 in. bump, the recorder will theoretically registered a non-existent 1/12 of 1/2 in. depression located approximately 12 ft. before the bump. As each of the 12 averaging wheels pass over the bump, a non-existant depression is recorded and located at the various lateral positions of the recorder in relation to bump as measuring wheel/recorder approaches and then leaves to the bump.

This also holds true, but in the opposite sense, when a depression is encountered by either the straightedge or profilograph.

The above discussion does not include the differences in ability to "feel" and measure the pavement surface roughness between the Mays Ride Meter and the two devices which are manually operated, due to the ride meters vastly different design and operational characteristics.

Table 2 on page 19 presents the test results obtained during comparison testing of flexible and rigid pavements with the straightedge, ride meter and profilograph.

Regression techniques by a SAS (Statistical Analysis System) procedure were utilized to correlate the data obtained during this study. Table 3 on page 20 presents the results of this regression.

TABLE 2

COMPARISON TESTING DATA

HMAC TEST SECTIONS

TEST SECTION NUMBER	STRAIGHTEDGE % OVER 1/8" TOLERANCE	RIDE METER SI	PROFILOGRAPH IN / MILE
34	0.00	4.7	2.25
35	0.70	4.6	2.50
28	0.00	4.4	8.12
27	0.10	4.3	8.25
30	1.70	4.0	9.75
29	1.20	3.9	11.12
32	2.50	3.6	13.62
33	3.60	3.4	16.75
31	4.50	3.1	17.50

PCCP TEST SECTIONS

TEST SECTION NUMBER	STRAIGHTEDGE % OVER 1/8" TOLERANCE	RIDE METER SI	PROFILOGRAPH IN / MILE
17	0.55	4.6	13.50
18	0.50	4.5	15.60
26	0.60	4.4	13.75
40	1.20	4.2	**
41	1.30	4.2	**
38	1.60	4.2	**
37	1.90	4.2	**
39	1.20	4.0	**
12	3.80	4.0	*
23	2.00	4.0	29.50
24	2.80	4.0	38.13
25	2.60	4.0	29.25
03	1.70	3.9	23.50
08	4.50	3.9	*
13	1.00	3.9	*
43	1.20	3.8	**
09	2.20	3.7	*
21	7.20	3.6	39.87
19	7.40	3.5	51.87
20	6.00	3.5	43.50
36	4.50	3.5	**
06	7.70	3.4	*
22	7.40	3.4	46.63
04	7.00	3.2	*
07	8.90	3.2	*
42	6.80	3.1	**
05	7.60	3.0	*
10	11.20	2.8	61.00
01	17.33	2.6	60.50
16	12.90	2.6	66.50
14	30.00	2.3	*
15	16.40	2.2	85.00
02	23.20	2.0	78.37
11	44.00	2.0	*

** - NO PROFILOGRAPH RUN
 * - NO GRAPHICAL OUTPUT OBTAINED

TABLE 3

Summary of Regression Analysis

Devices Compared	Surface Type	Equation of Best Fit Curve
Straightedge vs. Mays	JCP	$In. = 440.4 \times e^{(-1.311 \times SI)}$ R squared = 0.83, C.V. = 49.04
	HMAC	$In. = 145.7 \times e^{(-1.152 \times SI)}$ R squared = 0.99, C.V. = 14.92
Straightedge vs. Profilograph	JCP	$\% = 10^{(-2.27 + 1.852 \times \text{Log } In.)}$ R squared = 0.89, C.V. = 27.90
	HMAC	$\% = 202.70 \times e^{(-6.133 + 0.117 \times In.)}$ R squared = 0.99, C.V. = 14.92
Profilograph vs. Mays	JCP	In. = 136.93 - 26.895 x SI. R squared = 0.95, C.V. = 11.95
	HMAC	In. = 49.47 - 9.866 x SI. R squared = 0.98, C.V. = 9.80

SI. = Serviceability index (ride meter)

% = lineal % exceeding 1/8 in. tolerance (straightedge)

In. = inches/mile (profilograph)

Table 4 , on page 22, is a listing of the relative rankings (from smoothest to roughest) of the HMAC and PCCP test sections as determined by the three devices. For the HMAC test sections, the ride meter and the profilograph both rank all sections equally. The straightedge does not rank the sections in the same order as do the two devices, but does maintain the same relative ranking of smooth to rough sections. For the PCCP sections there are no two devices that consistantly rank the test sections equally, but as with the straightedge on the HMAC sections, a relativity of roughness ranking does exist between all three devices. In other words, all devices equally rank the same test sections as being relatively smooth, moderate or rough.

Surface Profiling (Mapping) Ability :

An evaluation of the ability of the profilograph to actually "map" the pavement surface profile was included to compare measured and known profiles. This portion of the study was conducted by Department personnel in cooperation with a study for a Masters Thesis by Cox, D.O.(3). The portion of this thesis concerning the mapping ability of the profilograph is reproduced in this report in Appendix B. Appendix B can be found beginning on page 41 of this report.

The surface profiling or mapping ability of the Rainhart profilograph was evaluated by testing the profilograph on a pavement surface containing induced roughness. A HMAC shoulder on a newly con-constructed roadway was selected as a test section. This test section was selected for its relative smoothness, lack of traffic and convenient locale. Roughness on this test section was induced by using full sheets of plywood laid upon the shoulder surface in various configurations. A baseline graphical trace of the HMAC shoulder was obtained by operating the profilograph over the 500 ft. test section without induced roughness. Graphs were obtained for the ten separate induced roughness test patterns which were set-up within the 500 ft. test section. The physical location and

TABLE 4

RELATIVE RANKINGS OF TEST SECTIONS

HMAC TEST SECTIONS

RANKING (SMOOTH TO ROUGH)	TEST SECTIONS STRAIGHTEDGE	RIDE METER	PROFILOGRAPH
1	34	34	34
2	28	35	35
3	35	27	27
4	35	27	27
5	29	30	30
6	30	29	29
7	32	32	32
8	33	33	33
9	31	31	31

PCCP TEST SECTIONS

RANKING (SMOOTH TO ROUGH)	TEST SECTIONS STRAIGHTEDGE	RIDE METER	PROFILOGRAPH
1	18	17	17
2	17	18	26
3	26	26	18
4	03	23	03
5	23	24	25
6	25	25	23
7	24	03	24
8	20	21	21
9	21	19	20
10	22	20	22
11	19	22	19
12	10	10	01
13	16	01	10
14	15	16	16
15	01	15	02
16	02	02	15

dimensions of the induced roughness was documented to enable accurate comparison to the graphical trace.

The results obtained during this portion of the study can be summarized as follows :

1. The profilograph accurately located the longitudinal position of the induced roughness where the wavelength of the roughness was less than the wheel base of the profilograph.

2. The profilograph does not accurately locate the longitudinal position of the induced roughness when the wavelength of the roughness approaches or exceeds the wheelbase length of the profilograph.

3. The profilograph closely approximates the actual vertical dimensions of the induced roughness, when the wavelength of the roughness is less than the wheelbase of the profilograph.

4. When the graphical trace is evaluated using the 0.1 inch filter band, the additional inches of roughness indicated above that of the baseline graph, closely approximates the inches of roughness actually added (induced).

5. The filter band tends to discount the majority of the "false" portion of the graphical trace. The false portions of the trace were expected due to the geometrics of the device.

As stated above the profilograph was able to graph the position and vertical dimension of the induced roughness. This is true only to the extent of the users ability to interpret the trace. In the induced roughness testing and evaluation, the interpretation of the trace was greatly enhanced by having a baseline trace, knowing the locations and dimensions of the boards and knowing where the profilograph first encountered and then left the artificial roughness.

Without this additional information, the profilograph mapping ability or rather the degree to which the user can interpret or use its mapping ability is reduced. As indicated earlier in this report, the geometrics of the profilograph somewhat inhibits a "true" mapping ability. The graphical trace output of the profilograph does not present the actual surface profile of the roadway but can be used to accurately identify the position and vertical magnitude of the intermediate and large bumps or depressions which cause the major decrease in ride quality. Small bumps intermixed within larger undulations may or may not be identifiable.

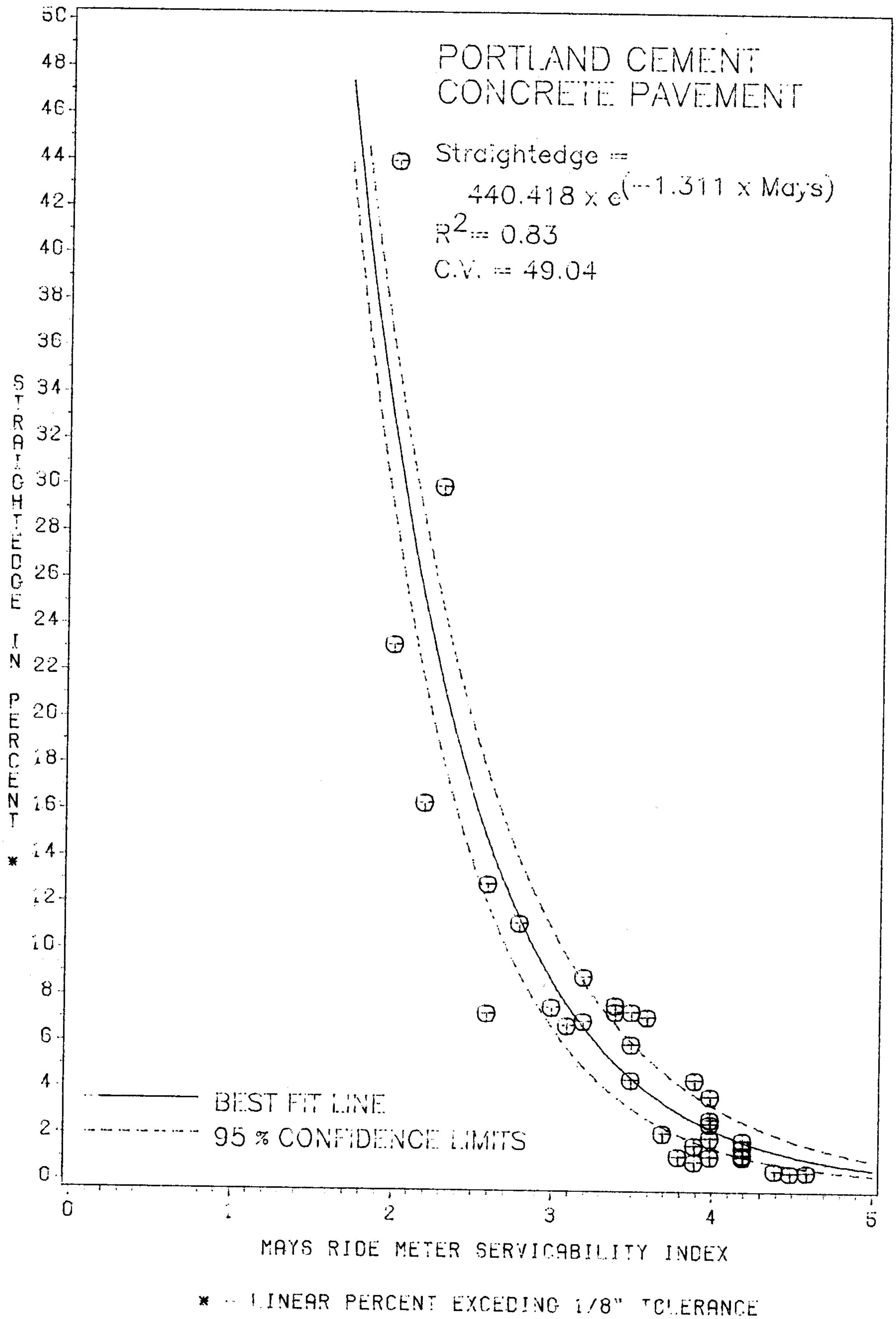
Applicability of Profilograph as a Quality Control and Acceptance Tool :

Louisiana currently specifies the 10-foot rolling straightedge as its quality control and acceptance tool. At the time this study was conducted requirements for mainline concrete pavements were that no more than 6 % of each lot tested could exceed the 1/8 in. high/low tolerance. Lots that exceeded this 6 % limit or had any vertical deviation in excess of 1/4 in. were subject to pay penalties and/or corrective measures. Current requirements for mainline PCC pavements are that 0.0% of each lot can exceed the 1/8 in. tolerance. Current reuirements for mainline HMAC pavements are that no more than 1% of each lot tested can exceed the 1/8 in. high/low tolerance. Lots that exceed this 1% limit or have any vertical deviation in excess of 1/4 in. are subject to pay penalties and/or corrective measures. The straightedge is run in each wheelpath in each lane for concrete and along a single longitudinal path in each lane for HMAC pavements.

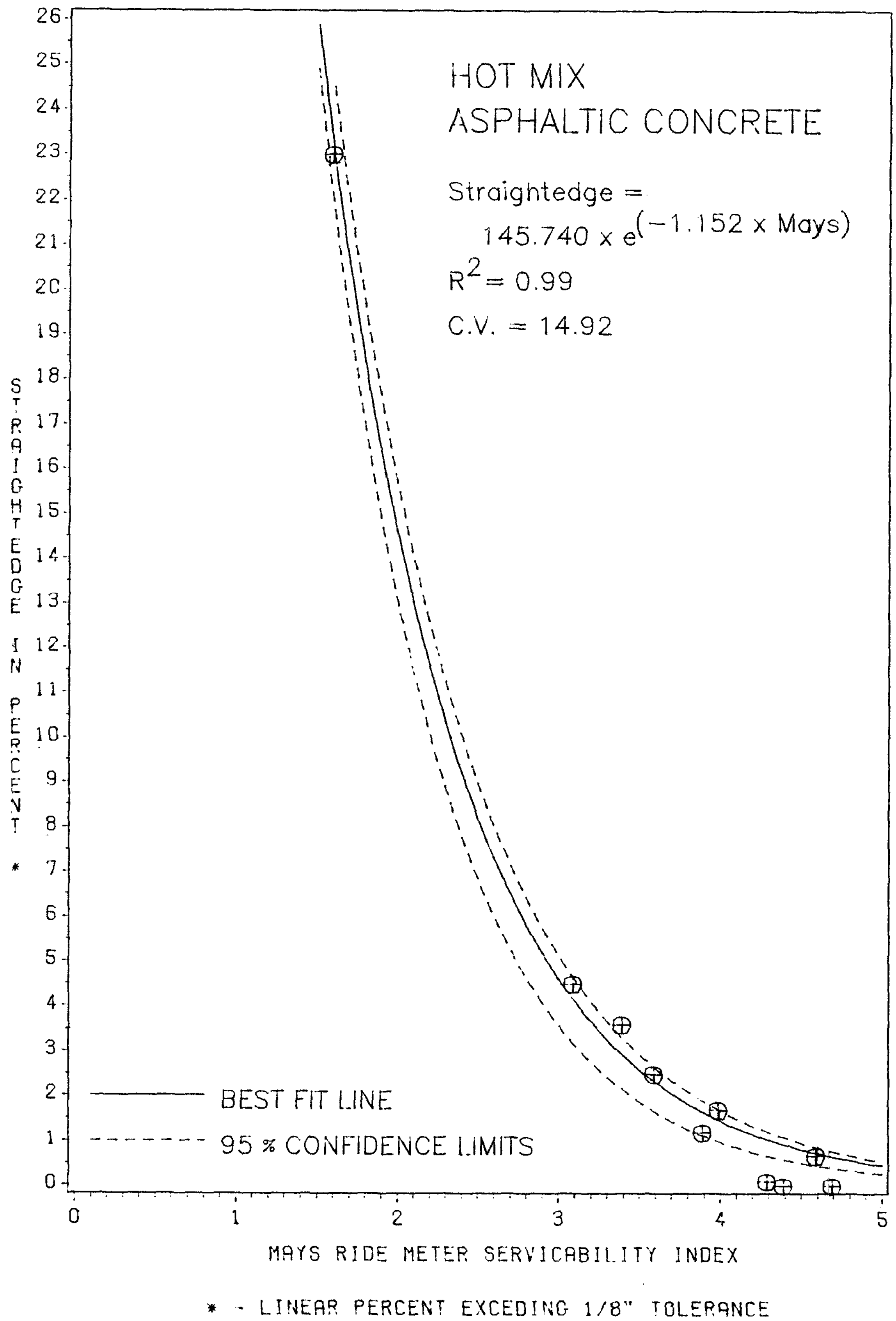
The Mays Ride Meter, being housed in a vehicle, cannot be used for timely quality control on green concrete. Louisiana uses the ride meter for survey and management purposes.

Figures 4,5,6,7,8, and 9 on pages 26 through 31, are plots of the data obtained from comparison testing of the three roughness measuring devices. Included in these plots is the best fit curve, as determined by the SAS procedures for regression analysis, for each pavement type. From a comparison of these plots, for concrete pavements, it can be seen that the 6% (allowable straightedge) limit is approximately equal to 44 in/mile (profilograph) which is approximately equal to a SI of 3.4 (ride meter). By updating tolerance requirements to 0.0% of the lot allowed to exceed 1/8 in. SI levels of 4.5 may be achieved. For the HMAC surfaces, the same comparison, indicates that the 1% (allowable straightedge) limit is approximately equal to 6 in/mile (profilograph), which is approximately equal to a SI of 4.4.

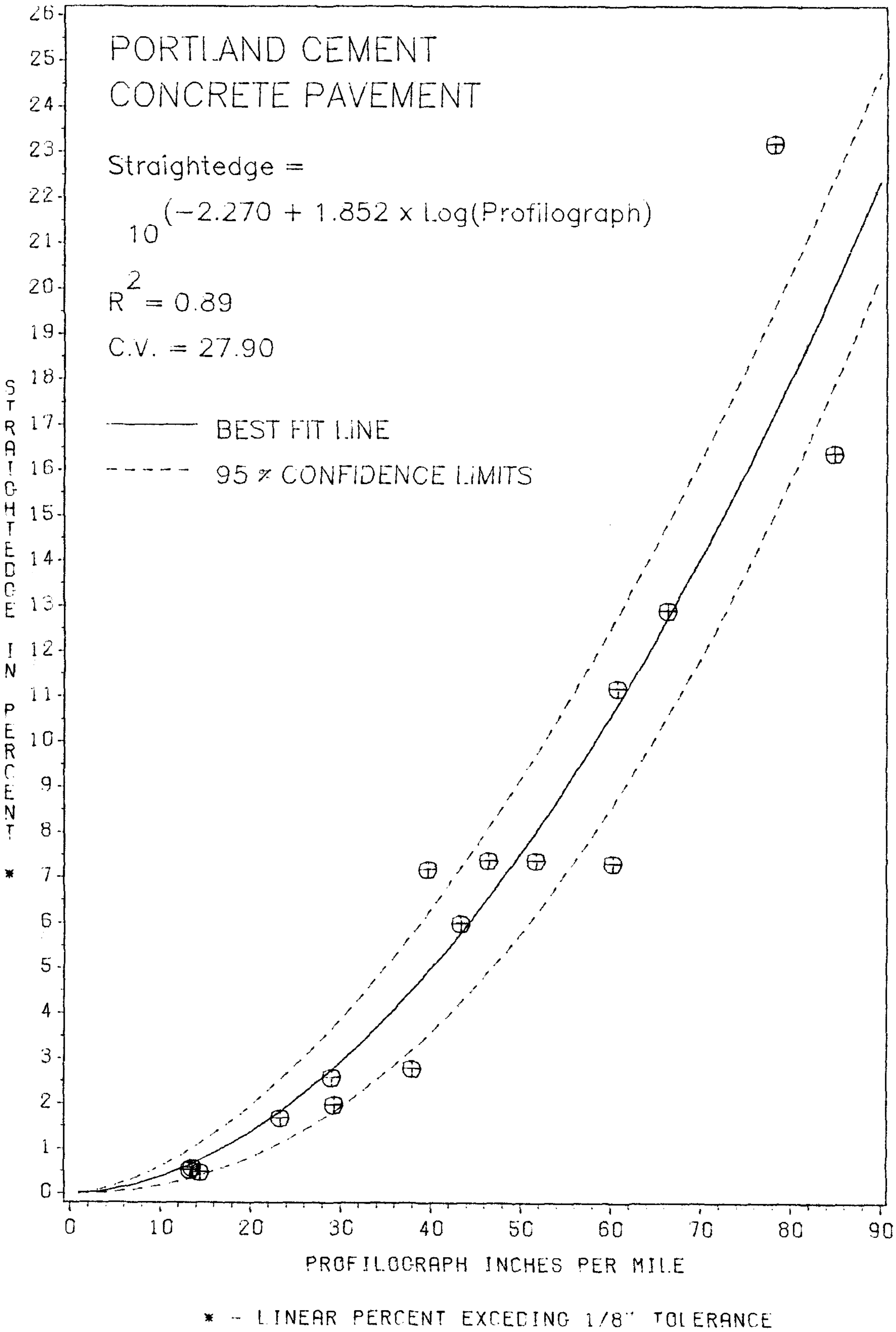
As indicated previously both the straightedge and profilograph tend to distort the accurate measurement of roughness. As long as this distortion is realized and accounted for, the profilograph, as is the straightedge, is suitable for quality control and acceptance of newly constructed pavements.



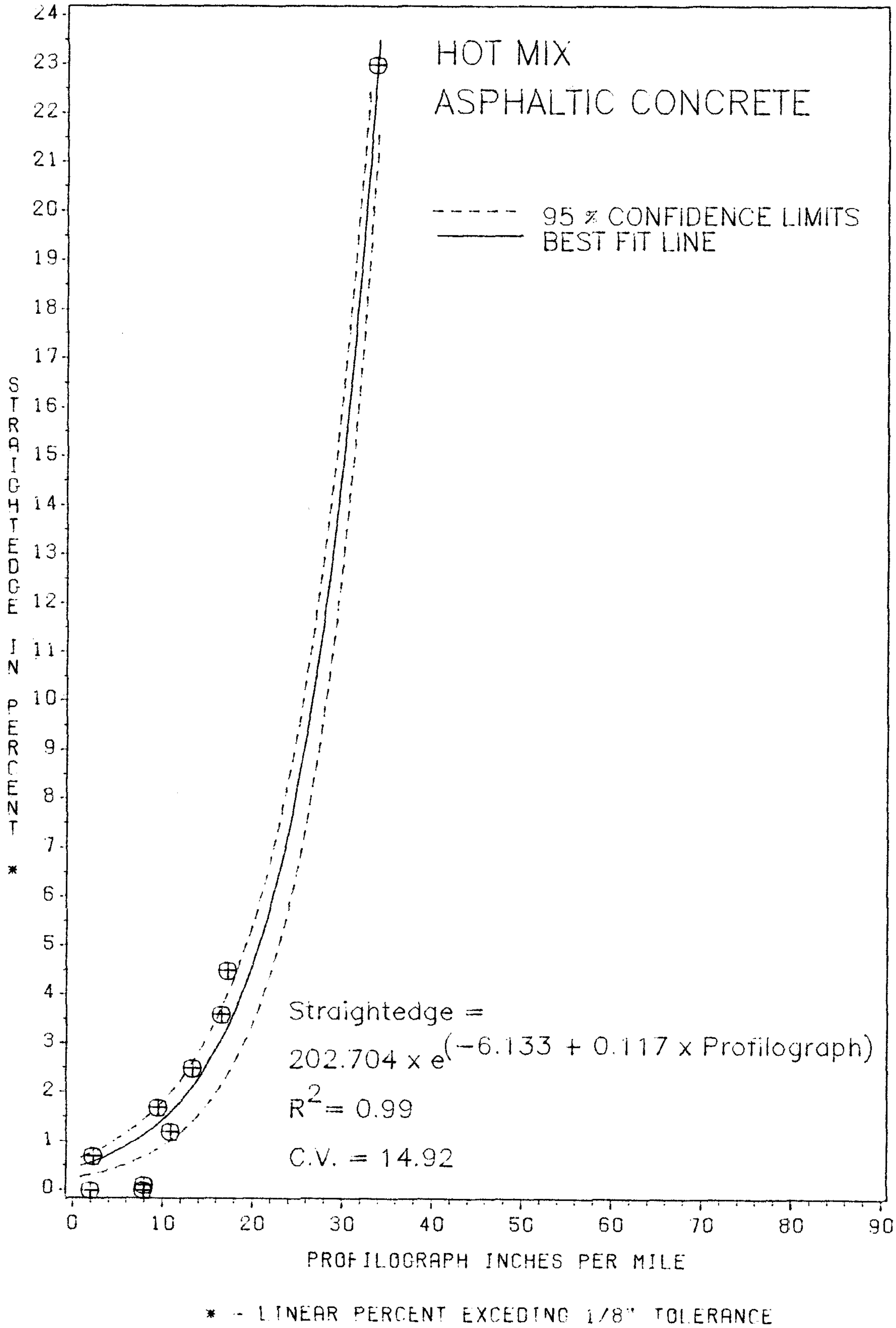
Graph of Best Fit Curve
(Straightedge vs. Mays Ride Meter) PCC
FIGURE 4



Graph of Best Fit Curve
(Straightedge vs. Mays Ride Meter) HMAC
FIGURE 5

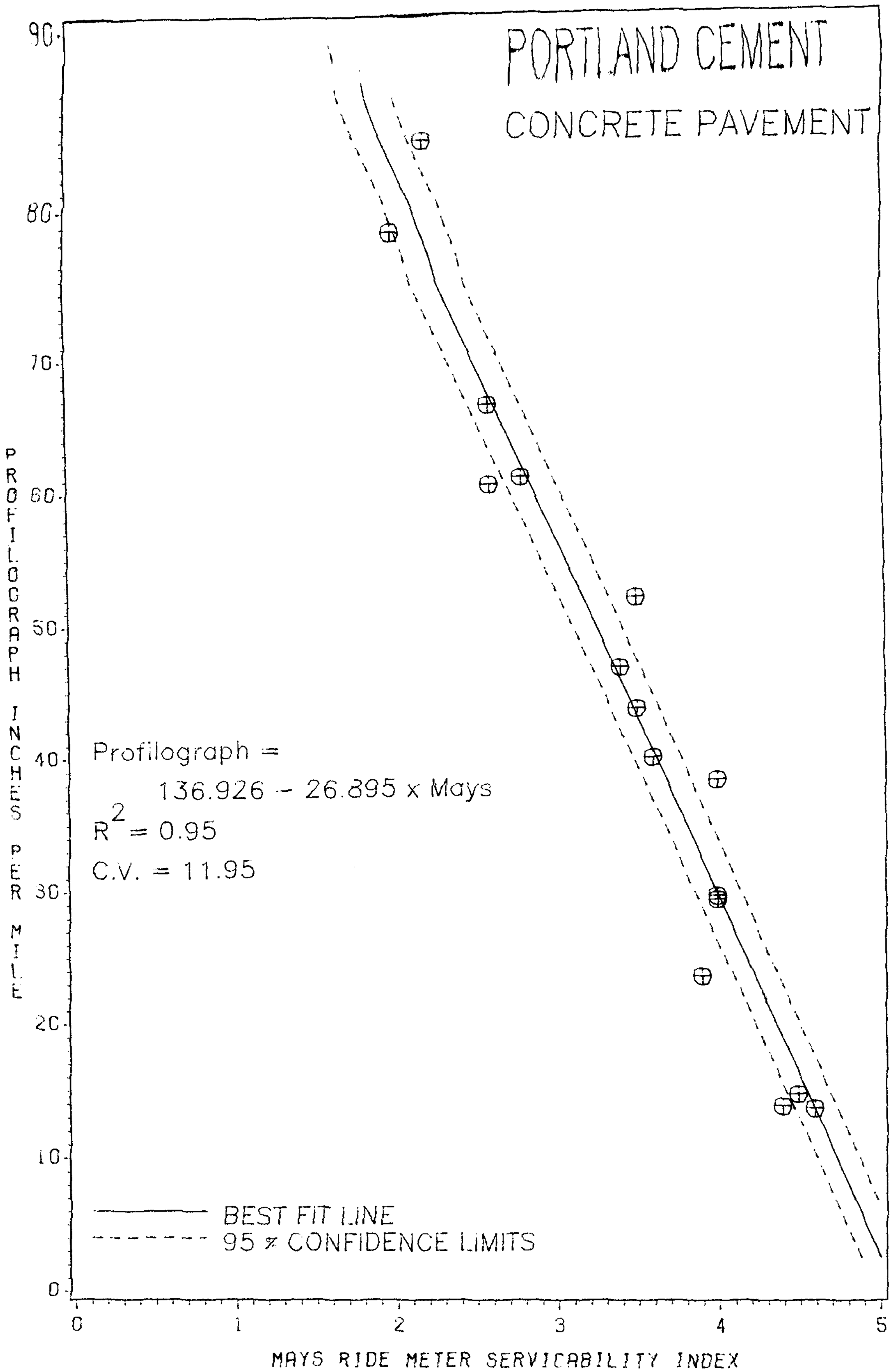


Graph of Best Fit Curve
(Straightedge vs. Profilograph) PCC
FIGURE 6



Graph of Best Fit Curve
(Straightedge vs. Profilograph) HMAC

FIGURE 7



Graph of Best Fit Curve
(Profilograph vs. Mays Ride Meter) PCC

FIGURE 8

CONCLUSIONS

The following conclusions are based upon the observations made and data obtained during the course of this study :

1. The profilograph can be considered unwieldy during testing and requires frequent maintenance but is easily transported and needs no calibration.

2. The strip chart recorder did not feed or store the chart paper properly during testing. Improvement in this area could be obtained by replacing the "Z fold" paper with rolled paper, as utilized by the California style profilograph.

3. The profilograph digital recording of roughness is not repeatable. The graphical trace of roughness is very repeatable but the interpretation (measure) of this trace is not as repeatable.

4. The graphical trace of the surface profile as indicated by two Rainhart profilographs matched each other during very limited testing.

5. The profilograph does not accurately "map" the pavement surface profile. It does however properly identify the location and magnitude of intermediate and large bumps/depressions when their wavelengths are less than the wheelbase length of the profilograph. Mapping and identification of large wavelength and/or small vertical dimension roughness is restricted due to the geometrics of the profilograph.

6. On PCC pavements, the profilograph may be better suited to enable more accurate measurement of roughness than the straightedge.

7. On HMAC pavements, no particular advantage in ability to measure the as built (long wavelength) roughness, was indicated by the profilograph, straightedge or ride meter.

8. The profilograph, with some minor modifications (steering, paper feed), could be a useful quality control and acceptance tool.

RECOMMENDATIONS

Although the profilograph may be better suited to enable more accurate measurement of roughness that the straightedge, consideration should not be given at this time to replacing the straightedge with a profilograph as LA.DOTD acceptance tool for PCC pavements. Consideration to replacing the straightedge with a profilograph type device should only be given at such a time that problems experienced with the interpretation and measurement of the graphical trace are remedied.

LIST OF REFERENCES

1. Law S.M., Rolling Straightedge Correlation Study, Louisiana Department of Highways, Research Report No. , June 1967.

2. Shah S.C., Correlation of Various Smoothness Measuring Systems for Asphaltic Concrete Surfaces, Louisiana Department of Highways, Research Report No. , June 1974

3. Cox, D.O., Applicability of the Rainhart Profilograph as a Specification Tool for Louisiana Pavements, Louisiana State University, Master's Thesis, December 1984.

APPENDIX A

GEORGIA HIGHWAY DEPARTMENT TEST METHOD G.H.D. 78

GHD-78

METHOD OF TEST FOR

DETERMINING PROFILE INDEX VALUE

A. SCOPE: This method describes the procedure used for determining the Profile Index from profilograms of pavements made with the Rainhart type profilograph.

The profilogram is recorded on a scale of one-inch equal to 25 feet longitudinally and full scale vertically. The determination of the Profile Index involves measuring "scallops" that appear outside a "blanking" band.

B. EQUIPMENT:

The only special equipment needed to determine the Profile Index is a clear plastic scale 1.50 inches wide and 11.0 inches long. Near the center of the scale is an opaque band 0.1 inch wide extending the entire length of 11.0 inches. On either side of this band are scribed lines 0.1 inch apart, parrallel to the opaque band. These lines serve as a convenient scale to measure deviations of the graph above or below the blanking band. These are called "scallops."

C. PROCEDURES:

Place the plastic scale over the profile in such a way as to "blank out" as much of the profile as possible. When this is done, scallops above and below the blanking band will be approximately balanced. See Figure I.

The profile trace will move from a generally horizontal position when going around super-elevated curves, making it impossible to blank out the central portion of the trace without shifting the scale. When such conditions occur the profile should be broken into short sections and the blanking band repositioned on each section. See Figure II.

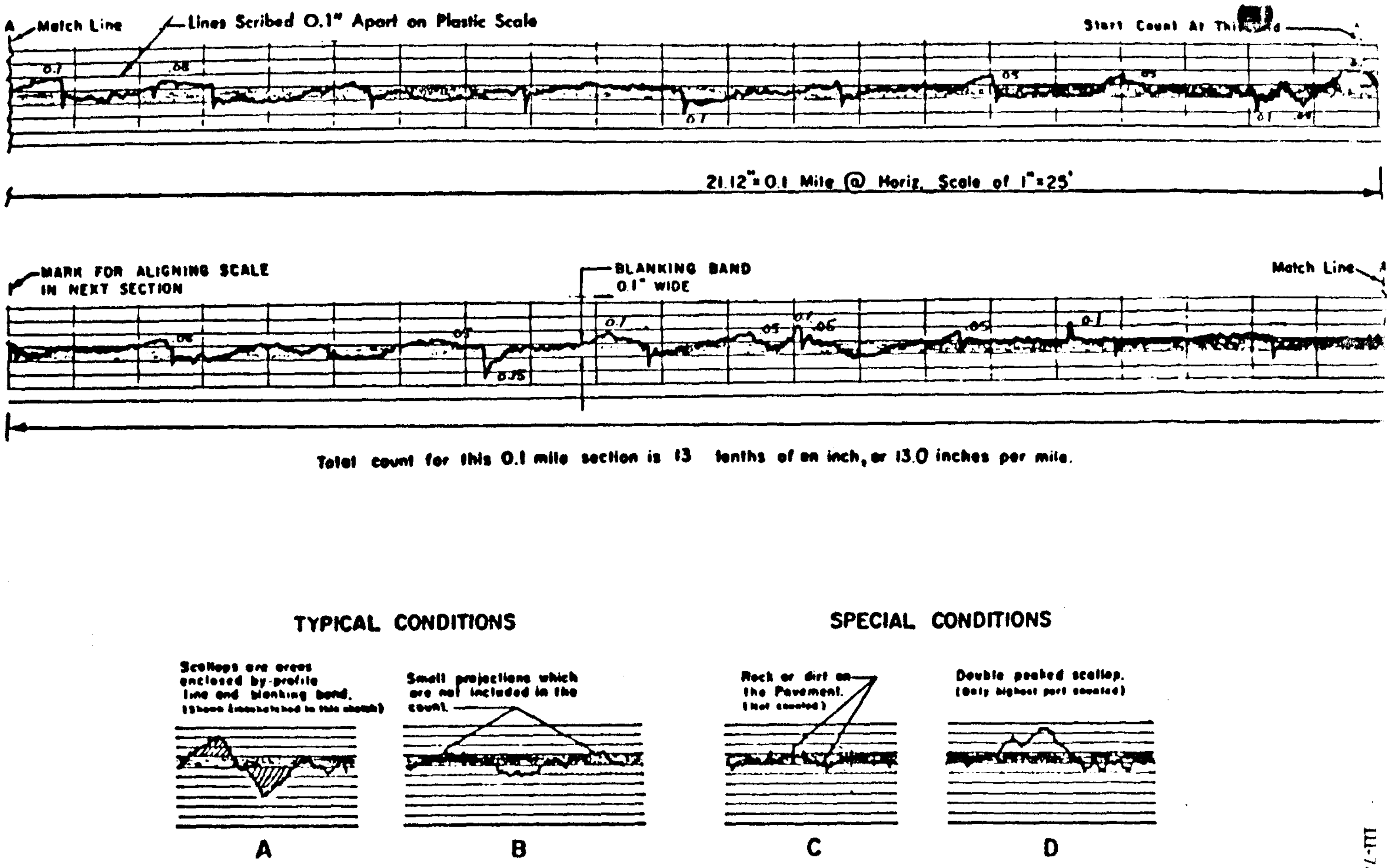
Beginning at the right end of the scale, measure and total the height of all the scallops appearing both above and below the blanking band. Each scallop is to be measured to the nearest 0.05 inch (half a tenth.) Short portions of the profile line may be visible outside the blanking band, but unless they project 0.03 inch or more and extend longitudinally for two feet (0.08 inch on the profilogram) or more, they are not included in the count. See Figure I for special conditions.

When scallops occuring in the first scale length are totaled, slide the scale to the left aligning the right end of the scale with a small mark made at the end of the first scale length.

D. CALCULATIONS:

The Profile Index is determined as "inches per mile in excess of the 0.1 inch blanking band." The formula for calculating Profile Index is as follows:

$$\text{Profile Index} = \frac{1 \text{ mile}}{\text{length of section in miles}} \times \text{total count in inches}$$



EXAMPLE SHOWING METHOD OF DERIVING PROFILE INDEX FROM PROFILOGRAMS

FIGURE 1

METHOD OF COUNTING WHEN POSITION OF PROFILE SHIFTS AS IT MAY WHEN ROUNDING SHORT RADIUS CURVES WITH SUPERELEVATION

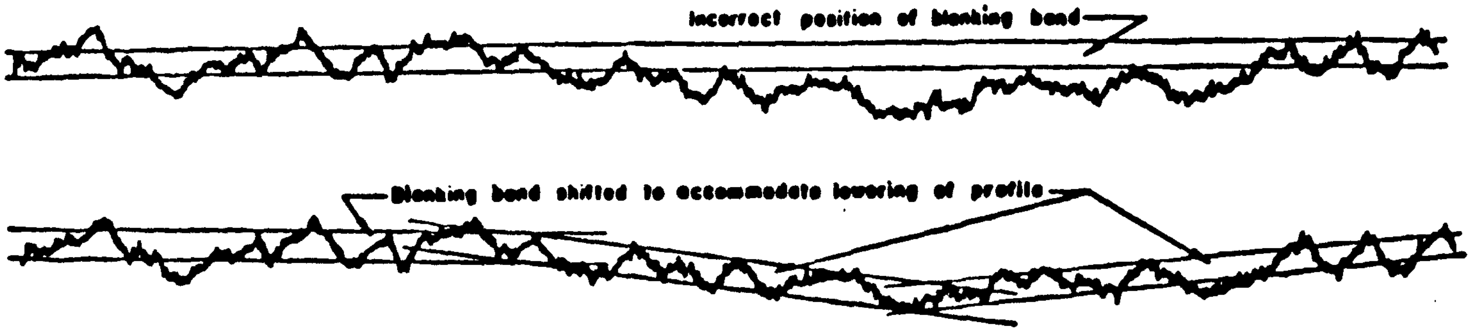


FIGURE 2